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Radiological assessment of periapical status using the periapical index: comparison of periapical radiography and digital panoramic radiography

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Abstract

Ridao-Sacie C, Segura-Egea JJ, Fernández-Palacín A, Bullón-Fernández P, Ríos-Santos JV. Radiological assessment of periapical status using the periapical index (PAI): comparison of periapical radiography and digital panoramic radiography. *International Endodontic Journal*, **40**, 433–440, 2007.

Aim To compare the use of periapical radiographs and digital panoramic images displayed on monitor and glossy paper in the assessment of the periapical status of the teeth using the periapical index (PAI).

Methodology A total of 86 subjects were examined. All participants underwent a full-mouth radiographic survey (14 periapical radiographs) and a panoramic radiography. The periapical status, using the PAI score, of all appraised teeth was assessed.

Results Periapical radiographs allowed the assessment of the periapical status of 87% of teeth using the PAI. On the contrary, digital radiography had a significantly reduced potential to allow assessment of the periapical status ($P < 0.01$). Only 57.6% and 34.1% of teeth could be appraised using digital panoramic images displayed on monitor and glossy paper respectively ($P < 0.01$). The total percentage of teeth with periapical pathosis was five fold higher when assessed with digital panoramic images displayed on glossy paper compared with periapical radiographs ($P < 0.01$).

Conclusions Teeth were best viewed on periapical radiographs except maxillary second and third molars, which were better viewed in orthopantomograms. Orthopantomograms on screen were scorable more often than when on printed images. Apical periodontitis was scored more often on paper than on screen, and more often on screen than in periapical radiographs.

Keywords: apical periodontitis, endodontics, epidemiology, periapical index, radiology.

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Introduction

Apical periodontitis (AP) is primarily an inflammatory sequela to dental caries caused by infection of the root canal system. The assessment of periapical status, determining the incidence and prevalence of AP in different populations, is important because it may help to define treatment needs and to relate treatment outcome to various technical and clinical factors of endodontic intervention (Huumonen & Ørstavik 2002). In the evaluation of the apical periodontium, bone density changes present in radiographs are the most consistent feature of the presence, progression or resolution of periapical inflammation. Although there seemed to be no standard criteria for the registration of AP in epidemiological surveys, either for periapical radiographs or panoramic radiographs, recently the 'periapical index' (PAI) scoring system has been modified and applied to epidemiological (Kirkevang *et al.* 2000, Jiménez-Pinzón *et al.* 2004) and clinical comparative studies of treatment outcome (Kirkevang *et al.* 2001, Segura-Egea *et al.* 2005). The possibility of

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comparisons amongst studies carried out with calibrated observers makes this system attractive (Huumonen & Ørstavik 2002). PAI provides an ordinal scale of five scores ranging from 'healthy' to 'severe periodontitis with exacerbating features'. The PAI is based on reference radiographs with verified histological diagnoses published originally by Brynolf (1967). PAI was first described for periapical radiographs (Ørstavik *et al.* 1986), but some epidemiological studies have used PAI for panoramic radiographs (De Cleen *et al.* 1993, Marques *et al.* 1998, De Moor *et al.* 2000, Lupi-Pegurier *et al.* 2002), or a combination of panoramic radiographs and periapical radiographs (Eriksen & Bjertness 1991, Weiger *et al.* 1997, Eriksen *et al.* 1998, Sidaravicius *et al.* 1999, Dugas *et al.* 2003).

Recent improvements in electronic radiographic imaging systems, such as digital panoramic radiography, have introduced many potential benefits to clinical dentistry. The use of digital panoramic radiography in the assessment of periapical status could be one of these benefits. But there is a need amongst dentists, to be able to print the digital images on a hard copy medium with a diagnostic accuracy matching that of the monitor displayed images. There are, however, some problems to be considered. First, not all dentists possess a computer or have access to e-mail and Internet facilities. Secondly, producers of digital systems have not accepted the need for storing images in standard formats facilitating communication between systems. Thirdly, a good quality image in one system can deteriorate when opened in another system's software because some software producers perform routine enhancement before storing the image (Benediktsdóttir & Wenzel 2004). Also, even if the receiver is able to display the image, a lack of enhancement possibilities at the recipient's site may impair their use. Fourthly, communicating digital radiographs between dental clinics electronically may raise questions on the security of patient-related data. Although it may be argued that only the native medium should be used for primary diagnosis of digital images, the above-listed concerns may necessitate the use of printed hard copies to communicate digital images between dental clinics. Such prints should fulfill the same demands for image quality as the primary medium for the particular diagnostic task.

Few studies have evaluated the diagnostic accuracy of digital images printed on hard copy media compared with that of the monitor-displayed image. In an early study on caries detection, sensitivity was lower in paper prints of digitally captured images than in bitewing films (Russell & Pitts 1993). Another study evaluated subjective image quality and conspicuity of anatomical structures in thermal prints and monitor-displayed digital panoramic images (Guerrant *et al.* 2001). Recently, Pecoraro *et al.* (2005) have compared intra-examiner and interexaminer reproducibility in assessing alveolar bone height on direct digital and conventional radiographs, and Akdeniz & Sogur (2005) compared the subjective image clarity of two different speed films and the Digora - phosphor plate images with respect to the length and homogeneity of root fillings. However, no studies have evaluated the diagnostic accuracy of digital images printed on hard copy media compared with that of the monitor-displayed images in assessing periapical status.

The purpose of this study was to compare the use of periapical radiographs and digital panoramic images displayed on monitor and glossy paper in the assessment of the periapical status of the teeth using the PAI.

Materials and methods

Patient selection

The sample consisted of 86 subjects, 38 males (44%) and 48 females (56%), aged 30–79 years, presenting as new patients seeking routine dental care (not emergency care) at the University of Seville, Faculty of Dentistry, between the years 2003 and 2004. The criteria for inclusion in the study were as follows: (i) patients should be attending for the first time; (ii) patients must be over 18 years old; (iii) patients having <10 remaining teeth were excluded; (iv) patients having a community periodontal index scoring ≥3 at least in two posterior sextants, who needed a full mouth radiographic survey; (v) patients requiring a panoramic radiograph because of third molar surgery, cysts or tumours. The Ethics Committee of the Dental Faculty approved the study and all the patients gave written informed consent.

Radiographic examination

All participants underwent a full-mouth radiographic survey consisting of 14 periapical radiographs and a panoramic radiograph. All periapical radiographs were taken with a Trophy IRIS 70 CCX Digital model CEI 601–2-7, class 1, type B X-ray unit, (Trophy Radiologie – 94300, Vincennes, France). Two experienced radiographers using the long-cone paralleling technique of XCP devices (Rinn Co., Elgin, IL, USA), setting of 70 kV,

8 mA, a film-focus distance of 28 cm, and Kodak Ultra Speed DF-57 film (Eastman Kodak, Rochester, NY, USA), took all periapical radiographs. The panoramic radiographs were taken by two trained radiology assistants using a digital ortho-pantomograph machine (Promax, Planmeca, class 1, type B, 80 KHz, Planmeca, Helsinki, Finland). Images were obtained using the Dimaxis Pro 3.1.1 program (Planmeca Group) and printed in photographic paper (HP, 175 g m^{-2}, A4) using the HPDeskjet 1220C printer (Hewlett Packard, Palo Alto, CA, USA).

Radiographic evaluation

From the full-mouth radiographic survey, as well as from the panoramic radiography, all teeth were recorded according to the FDI nomenclature. The periapical status was assessed using the PAI score (Ørstavik *et al.* 1986). Each of the roots was categorized as: (1) Normal periapical structure; (2) small changes in bone structure; (3) changes in bone structure with some mineral loss; (4) periodontitis with well-defined radiolucent area; and (5) severe periodontitis with exacerbating features. Each category used in the PAI represents a step on an ordinal scale of registration of periapical infection. The worst score of all roots was taken to represent the PAI score for multirooted teeth.

The method of viewing the periapical radiographs was standardized; films were examined in a darkened room using an illuminated viewer box with magnification (3.5×) whilst mounted in a cardboard slit to block off ambient light emanating from the viewer. The viewing conditions for the digital panoramic images were also standardized. Digital panoramic images were displayed in a 17' Plug and Plag model monitor using a NVIDIA Riva TNT 2 model 64 graphic card with 32 bit quality colour and 1280 × 1024 pixels resolution (120 ppp) in a room with subdued light and the printed images in reflected light.

The interpretation of radiographs was performed independently by two examiners with extensive clinical experience in endodontics. Before evaluation, the observer participated in a calibration course for the PAI system, which consisted of 100 radiographic images of teeth (kindly provided by Dr Ørstavik), as described previously (Jiménez-Pinzón *et al.* 2004). The examiner variability was determined by calculating Kappa. Intraexaminer and interexaminer reproducibility were evaluated by the repeat scoring of 10 patients 2 months after the first examination. The consensus radiographic standard was the simultaneous interpretation by the two examiners of all radiographs for each subject (Flint *et al.* 1998, Rushton *et al.* 2002). When both examiners agreed on the impossibility of assessing the periapical status of a tooth, this one was scored as 'nonappraised tooth'.

Statistical analysis

A score >2 (PAI > 2) was considered to be a sign of periapical pathology (Ørstavik *et al.* 1986). Thus, a PAI score of 3, 4 or 5 defined AP including periapical cysts and periapical granulomas (Kirkevang *et al.* 2001). The periapical status on all appraised teeth was assessed.

Raw data were entered into Access® (Microsoft Corporation, Redmond, WA, USA). The Chi-squared test (with the Yates' correction if indicated) and the Cochran test were used to determine the significance of differences using the SPSS program 12.0 for Windows (SPSS, Inc., Chicago, IL, USA) .

Results

Inter- and intra-observer kappa values were above 0.6, ensuring adequate reproducibility. The average number of teeth per patient was 24 ± 4 teeth. No significant differences between males and females were found for number of teeth.

A total of 2088 teeth were examined. The percentage of nonappraised teeth is shown in Table 1. Periapical radiographs allowed the assessment of a higher percentage of teeth. However, maxillary second molar teeth as well as both maxillary and mandibular third molar teeth shown were more difficult to evaluate using periapical radiographs ($P < 0.01$). Digital panoramic images did not show a significantly higher percentage of appraised third molar teeth ($P > 0.05$). Digital panoramic images displayed on a monitor resulted in a higher percentage of appraised teeth compared with digital images displayed on glossy paper in all cases ($P < 0.05$).

Table 2 shows teeth, grouped by type, that could not be appraised in periapical or panoramic radiographs. Periapical radiographs allowed the assessment of the periapical status of 87.3% of teeth using the PAI (12.7% teeth could not be evaluated). On the contrary, digital radiography had a significantly lower potency in the assessment of periapical status ($P < 0.01$). Only 57.6% and 34.1% of teeth could be appraised using digital panoramic images displayed on monitor and glossy paper respectively ($P < 0.01$). Digital panoramic images displayed on monitor allowed the assessment of

Table 1 Percentage of nonappraised teeth using periapical index in periapical and digital panoramic radiographs. Periap: periapical radiograph; Ortho paper: panoramic radiograph printed in paper; Ortho screen: panoramic radiograph viewed in the screen

Tooth (FDI)	18	17*	16	15	14	13	12	11	21	22	23	24	25	26	27**	28
Periap	91.7	42.4	5.7	0	0	12.8	3.9	2.5	1.3	3.8	16.5	8.3	3.6	15.4	56.5	82.4
Ortho screen	36.1	32.3	53.8	48.3	47.7	39.0	38.7	53.2	48.1	42.9	47.4	72.9	34.5	60.8	39.3	73.5
Ortho paper	58.3	53.0	75.5	67.8	84.8	74.4	69.7	77.5	70.0	75.6	69.6	81.7	69.6	90.4	69.4	88.2
Tooth (FDI)	48	47**	46	45	44	43	42	41	31	32	33	34	35	36**	37	38
Periap	40.0	7.0	2.3	2.8	4.9	12.8	6.2	0	1.3	3.7	7.3	3.8	4.1	0	22.4	55.3
Ortho screen	42.5	16.1	9.3	20.0	43.2	54.1	60.0	60.3	63.6	55.6	53.1	27.8	13.7	2.5	1.7	53.3
Ortho paper	55.0	33.3	36.4	39.4	59.8	70.9	76.5	86.1	87.2	75.6	68.3	61.3	43.2	14.6	24.8	55.3

Cochran test $P < 0.0005$; *$P \leq 0.05$; **$P \leq 0.01$.

Table 2 Percentage of nonappraised teeth using periapical index in periapical and digital panoramic radiographs. Maxillary teeth (top value), mandibular teeth (centre value) and total teeth (bottom value)

%	Periapical radiography	Panoramic radiography (screen)	Panoramic radiography (paper)	*P*
Incisors and canines	6.8	44.9	72.8	<0.01
	5.3	57.7	77.3	
	6.0	51.4	75.1	
Bicuspids	2.1	51.1	76.3	<0.01
	3.9	26.7	51.5	
	3.1	37.4	62.4	
Molars	44.6	47.5*	71.3	<0.01
	19.8	15.3*	35.3	
	32.7	32.1*	54.0	
All teeth	16.9	47.2	73.2	<0.01
	8.7	37.9	59.0	
	12.7	42.4	65.9	

*$P > 0.05$ periapical versus screen.

the periapical status of both maxillary and mandibular molar teeth as well as periapical radiographs ($P > 0.05$). However, the assessment of the periapical status of maxillary molar teeth was more difficult in all cases: approximately a half of molar teeth could not be evaluated.

Table 3 shows the percentage of teeth with PAI scoring ≥3 as determined with the three radiographic techniques. The radiographic technique influenced significantly the percentage of diseased teeth. In all cases, digital panoramic images displayed on glossy paper had the higher percentage of teeth with AP. Moreover, the total percentage of periapically diseased teeth was five fold higher when assessed with digital panoramic images displayed on glossy paper (14.7%) compared with periapical radiographs (3.1%) ($P < 0.01$). Digital panoramic images displayed on the screen also had a three fold higher total percentage

Table 3 Percentage of appraised teeth with apical periodontitis (PAI scoring 3, 4 or 5) in periapical and digital panoramic radiographs. Maxillary teeth (top value), mandibular teeth (centre value) and total teeth (bottom value). Cochran test was used to calculate the *P*-value

%	Periapical radiography	Panoramic radiography (screen)	Panoramic radiography (paper)		*P*
Incisors and canines	1.6	3.9**	9.4††	Maxillary	<0.05
	3.0	3.4*	9.9††	Mandibular	>0.05
	2.3	3.7*	9.6††	All teeth	<0.05
Bicuspids	5.0	1.2**	28.1††	Maxillary	<0.05
	2.3	5.9**	10.1†	Mandibular	>0.05
	3.6	7.7**	15.0†	All teeth	<0.01
Molars	2.0	12.1**	17.2†	Maxillary	<0.05
	4.0	19.8**	20.0	Mandibular	<0.01
	4.3	16.7**	19.1	All teeth	<0.01
All teeth	3.0	7.9**	15.8†	Maxillary	<0.01
	3.3	10.0**	14.1†	Mandibular	<0.01
	3.1	9.1**	14.7†	All teeth	<0.01

*$P < 0.05$ periapical versus screen; **$P < 0.01$ periapical versus screen.
†$P < 0.05$ screen versus paper; ††$P < 0.01$ screen versus paper.

of diseased teeth compared with periapical radiographs ($P < 0.01$). Comparing the two digital panoramic images, the glossy paper images had a significantly higher percentage of diseased teeth (14.7%) than images displayed on the screen (9.1%) ($P < 0.05$). However, significant differences between the two digital images in molar teeth were not found.

Discussion

This study was carried out to compare the use of periapical radiographs and digital panoramic images displayed on monitor and glossy paper in the assessment of the periapical status of the teeth using the PAI. The subjects included in this study were adult patients attending for the first time the dental service of the Faculty of Dentistry of Seville (Spain). The recruitment of subjects included the criteria of having a community periodontal index scoring ≥3 at least in two sextants, justifying the full-mouth radiographic survey. This fact could explain the relatively high prevalence of periapical lesions found in this investigation. The frequency of teeth with AP in other studies varies from 0.6% (Eriksen *et al.* 1995) to 9.8% (Allard & Palmqvist 1986). The range is large, probably due to the variation amongst populations examined.

Radiographic examination was carried out by two experienced radiographers using the long-cone paralleling technique. The technique of placing the film parallel to the root axis is frequently recommended, and it often gives images of good quality. In follow-up studies of individual cases, identical or at least similar conditions for exposure are essential (Huumonen & Ørstavik 2002). The paralleling technique provides images with a minimum of geometric distortion, but with some enlargement of structures. The bisecting angle technique introduces some image distortion, particularly in the bucco-lingual direction. Differences were not found between the two techniques in assessment of periapical lesion size, but paralleling technique had better reproducibility of repeated exposures (Forsberg & Halse 1997). Panoramic radiographs used in this study were taken by two trained radiology assistants using a digital ortho-pantomograph machine.

The periapical status was assessed using the PAI score (Ørstavik *et al.* 1986). The reproducibility of the observer (Cohen's $\kappa = 0.75$) was acceptable, probably because of prior calibration. Criteria for AP vary amongst studies (Ödesjö *et al.* 1990, Buckley & Spangberg 1995, Saunders *et al.* 1997, De Moor *et al.* 2000, Lupi-Pegurier *et al.* 2002), but in recent years studies have increasingly used the PAI index scoring to assess periapical status.

The results of this study showed that periapical radiographs allowed higher percentage of apices, with the exception of maxillary second and third molars, that were better viewed in orthopantomograms. The superposition of anatomical structures such as zygomatic bone, malar process, maxillary sinus and sinus septa, and even the coronoid process, interfered with the evaluation of maxillary molars in periapical radiographs. Maxillary premolars and mandibulary incisors were more difficult to appraise. These results are in good agreement with those of Gijbels *et al.* (2004).

The percentage of nonappraised teeth in periapical radiographs was higher in the maxilla compared with the mandible. Amongst the causes that could justify this finding are two: (i) the difficulty of using correctly paralleling technique in the maxilla when the patient has a low palate, and (ii) that the anterior wall of the maxillary sinus extends over the premolar teeth (White & Pharoah 1999).

In the present study, the total percentage of periapically diseased teeth was five fold higher assessed with digital panoramic images displayed on glossy paper (14.7%) compared with periapical radiographs (3.1%) ($P < 0.01$). The frequency of teeth with AP in other studies varies from 0.6% (Eriksen *et al.* 1995) to 9.8% (Allard & Palmqvist 1986). The range is large, probably due to the variation amongst populations examined.

Periapical index was first described for periapical radiographs (Ørstavik *et al.* 1986, Petersson *et al.* 1989, Ödesjö *et al.* 1990, Imfeld 1991, Buckley & Spangberg 1995, Saunders *et al.* 1997, Kirkevang *et al.* 2001, Boucher *et al.* 2002, Segura-Egea *et al.* 2004). However, several studies have used panoramic radiographs (De Cleen *et al.* 1993, Marques *et al.* 1998, De Moor *et al.* 2000, Lupi-Pegurier *et al.* 2002), or a combination of panoramic radiographs and periapical radiographs (Eriksen & Bjertness 1991, Weiger *et al.* 1997, Eriksen *et al.* 1998, Sidaravicius *et al.* 1999, Dugas *et al.* 2003). The results reported in the present study demonstrated that digital images displayed both on monitor or glossy paper achieve significantly higher percentages of teeth with PAI scoring ≥3. Nishikawa *et al.* (2000) found similar results. On the contrary, other investigators have found that an underestimation of lesions occurred when panoramic radiography was used (Rohlin *et al.* 1989, Eriksen & Bjertness 1991, Huumonen & Ørstavik 2002). Moreover, Valachovic

et al. (1986) found that panoramic radiography recognized less lesions that periapical radiography. However, some authors did not find statistically significant differences between panoramic and periapical radiographs (Muhammed & Manson-Hing 1982, Ahlqwist *et al.* 1986, Molander *et al.* 1992), and others even maintained that panoramic radiography was superior diagnosing AP (Ohba & Katayama 1972). The prevalence of AP in connection with molar teeth was higher than for premolar teeth and anterior teeth. These results are in agreement with those of Segura-Egea *et al.* (2004) and Jimenez-Pinzón *et al.* (2004).

Because of their improved quality, low radiation dose and ease of use panoramic radiographs have become popular in dental diagnosis. As an extraoral method it may be more comfortable for the patient and may allow a more vertical alignment of the structures than do periapical intraoral radiographs (Huumonen & Ørstavik 2002). However, panoramic radiography may underestimate periapical lesions compared with periapical radiography (Rohlin *et al.* 1989, Huumonen & Ørstavik 2002). On the other hand, the overall accuracy of these two techniques has been shown to be similar (Muhammed & Manson-Hing 1982, Ahlqwist *et al.* 1986, Molander *et al.* 1992). Molander *et al.* (1995) compared sensitivity and specificity of panoramic X-rays with respect to periapical lesions and to the type of teeth. In panoramic radiographs, lesions were detected in 60–83% of cases found with periapical film for most tooth types, but for mandibular incisors and canines this sensitivity was only 29%. A false positive diagnosis was seldom made with panoramic radiographs; the specificity was over 95% for all types of teeth.

Recent improvements in electronic radiographic imaging systems, such as digital panoramic radiography, have introduced many potential benefits to clinical dentistry. Digital panoramic radiography systems include a 50–80% reduction in radiation exposure, wider exposure latitude, immediate image generation and manipulation and elimination of chemical processing of radiographs. Disadvantages include the size, shape and stiffness of the sensor and lower image resolution (Huumonen & Ørstavik 2002). Conventional intraoral films have a spatial resolution exceeding 20 line pairs per millimetre (Czajka *et al.* 1996), whilst the corresponding resolution for photostimulable phosphors is <7 line pairs per millimetre (Stamatakis *et al.* 2000), and that of the newest charge-coupled devices up to 20 line pairs per millimetre (Farman & Farman 1999). This difference in resolution of details may have an effect on subtle features such as thin trabeculae, the lamina dura and the periodontal ligament.

The identification and assessment of lesion size appear to be influenced by the technology employed. Bohay (2000) compared digital and conventional radiography in periapical diagnosis of posterior teeth and reported that conventional imaging was consistently the less effective method, although its performance was acceptable for clinical applications.

Benediktsdóttir & Wenzel (2004) have compared the accuracy of three modalities of digital panoramic radiographs (monitor displayed images and printed copies on glossy paper and on blue transparent film) for assessment of position and morphology of mandibular third molars. This author concluded that no systematic differences in diagnostic accuracy for assessment of position and morphology of mandibular third molars were found amongst three modalities for digital panoramic radiographs, monitor-displayed images and printed images on glossy paper and transparent film.

Akdeniz & Sogur (2005) compared the subjective image clarity of two different speed films and the Digora - phosphor plate images with respect to the length and homogeneity of root canal fillings founding that enhanced digital images were rated as significantly superior followed by E- and F-speed films and then the original digital images for the evaluation of both homogeneity and length of root canal fillings. Agreement amongst endodontists' and radiologists' measurements was high in all of the imaging methods ($\kappa = 0.87$).

Conclusions

Teeth were best viewed by periapical radiographs except maxillary second and third molars, which were better viewed in orthopantomograms. Orthopantomograms on screen were more often scorable than printed images. AP was scored more often on paper than on screen, and more often on screen than in periapical radiographs.

References

Ahlqwist JR, Halling A, Hollender L (1986) Rotational panoramic radiography in epidemiological studies on dental health. *Swedish Dental Journal* **10**, 79–84.

Akdeniz BG, Sogur E (2005) An ex vivo comparison of conventional and digital radiography for perceived image quality of root fillings. *International Endodontic Journal* **38**, 397–401.

Allard U, Palmqvist S (1986) A radiographic survey of periapical conditions in elderly people in a Swedish country population. *Endodontics and Dental Traumatology* **2**, 103–8.

Benediktsdóttir IS, Wenzel A (2004) Accuracy of digital panoramic images displayed on monitor, glossy paper, and film for assessment of mandibular third molars. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* **98**, 217–22.

Bohay RN (2000) The sensitivity, specificity, and reliability of radiographic periapical diagnosis of posterior teeth. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* **89**, 639–42.

Boucher Y, Matossian L, Rilliard F, Machtou P (2002) Radiographic evaluation of the prevalence and technical quality of root canal treatment in a French subpopulation. *International Endodontic Journal* **35**, 229–38.

Brynolf I (1967) A histological and roentgenological study of the periapical region of human upper incisors. *Odontologisk Revy* **18**(Suppl. 11) 1–176.

Buckley M, Spangberg LSW (1995) The prevalence and technical quality of endodontic treatment in an American subpopulation. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* **79**, 92–100.

Czajka J, Rushton VE, Shearer AC, Horner K (1996) Sensitometric and image quality performance of 'rapid' intraoral film processing techniques. *British Journal of Radiology* **69**, 49–58.

De Cleen MJ, Schuurs AH, Wesselink PR, Wu MK (1993) Periapical status and prevalence of endodontic treatment in an adult Dutch population. *International Endodontic Journal* **26**, 112–9.

De Moor RJ, Hommez GM, De Boever JG, Delme KI, Martens GE (2000) Periapical health related to the quality of root canal treatment in a Belgian population. *International Endodontic Journal* **33**, 113–20.

Dugas NN, Lawrence HP, Teplitsky PE, Pharoah MJ, Friedman S (2003) Periapical health and treatment quality assessment of root-filled teeth in two Canadian populations. *International Endodontic Journal* **36**, 181–92.

Eriksen HM, Bjertness E (1991) Prevalence of apical periodontitis and results of endodontic treatment in middle-aged adults in Norway. *Endodontics and Dental Traumatology* **7**, 1–4.

Eriksen HM, Berset GP, Hansen BF, Bjertness E (1995) Changes in endodontic status 1973–93 among 35-year-olds in Oslo, Norway. *International Endodontic Journal* **28**, 129–32.

Eriksen HM, Bjertness E, Ørstavik D (1998) Prevalence and quality of endodontic treatment in an urban adult population in Norway. *Endodontics and Dental Traumatology* **4**, 122–6.

Farman AG, Farman TT (1999) RVG-ui: a sensor to rival detect exposure intra-oral x-ray film. *International Journal of Computerized Dentistry* **2**, 183–96.

Flint DJ, Paunovich E, Moore WS, Wofford DT, Hermesch CB (1998) A diagnostic comparison of panoramic and intraoral radiographs. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **85**, 31–35.

Forsberg J, Halse A (1997) Periapical radiolucencies as evaluated by bisecting angle and paralleling radiographic techniques. *International Endodontic Journal* **30**, 115–23.

Gijbels F, Sanderink G, Pauwels H, Jacobs R (2004) Subjective image quality of digital panoramic radiography displayed on monitor and printed on various hardcopy media. *Clinical Oral Investigation* **8**, 25–29.

Guerrant GH, Moore WS, Murchison DF (2001) Diagnostic utility of thermal printed panographs compared with corresponding computer monitor images. *General Dentistry* **49**, 190–6.

Huumonen S, Ørstavik S (2002) Radiological aspects of apical periodontitis. *Endodontic Topics* **1**, 3–25.

Imfeld TN (1991) Prevalence and quality of endodontic treatment in an elderly urban population of Switzerland. *Journal of Endodontics* **17**, 604–7.

Jiménez-Pinzón A, Segura-Egea JJ, Poyato-Ferrera M, Velasco-Ortega E, Ríos-Santos JV (2004) Prevalence of apical periodontitis and frequency of root filled teeth in an adult Spanish population. *International Endodontic Journal* **37**, 167–73.

Kirkevang LL, Ørstavik D, Hörsted-Bindslev P, Wenzel A (2000) Periapical status and quality of root fillings and coronal restorations in a Danish population. *International Endodontic Journal* **33**, 509–15.

Kirkevang LL, Hörsted-Bindslev P, Ørstavik D, Wenzel A (2001) Frequency and distribution of endodontically treated teeth and apical periodontitis in an urban Danish population. *International Endodontic Journal* **34**, 198–205.

Lupi-Pegurier L, Bertrand M-F, Muller-Bolla M, Rocca JP, Bolla M (2002) Periapical status, prevalence and quality of endodontic treatment in an adult French population. *International Endodontic Journal* **35**, 690–7.

Marques MD, Moreira B, Eriksen HM (1998) Prevalence of apical periodontitis and results of endodontic treatment in an adult, Portuguese population. *International Endodontic Journal* **31**, 161–5.

Molander B, Ahlqwist M, Gröhndal HG, Hollender L (1992) Comparison of panoramic and intraoral radiography for the diagnosis of caries and periapical pathology. *Dentomaxillofacial Radiology* **22**, 28–32.

Molander B, Ahlqwist M, Gröndal H-G (1995) Panoramic and restrictive intraoral radiography in comprehensive oral radiographic diagnosis. *European Journal of Oral Sciences* **103**, 191–8.

Muhammed AH, Manson-Hing LR (1982) A comparison of panoramic and intraoral radiographic surveys in evaluating a dental clinic population. *Oral Surgery, Oral Medicine, and Oral Pathology* **54**, 108–17.

Nishikawa K, Wakoh M, Kuroyanagi K (2000). Suitability of the general-purpose graphic printer as an image output

device for digital dental x-ray images. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* **89**, 382–7.

Ödesjö B, Hellden L, Salonen L, Langeland K (1990) Prevalence of previous endodontic treatment, technical standard and occurrence of periapical lesions in a randomly selected adult, general population. *Endodontics and Dental Traumatology* **6**, 265–72.

Ohba T, Katayama H (1972) Comparison of orthopantomography with conventional periapical dental radiography. *Oral Surgery, Oral Medicine, Oral Pathology* **34**, 524–30.

Ørstavik D, Kerekes K, Eriksen HM (1986) The periapical index: a scoring system for radiographic assessment of apical periodontitis. *Endodontics and Dental Traumatology* **2**, 20–34.

Pecoraro M, Azadivatan-le N, Janal M, Khocht A (2005) Comparison of observer reliability in assessing alveolar bone height on direct digital and conventional radiographs. *Dentomaxillofacial Radiology* **34**, 279–84.

Petersson K, Lewin B, Hakansson J, Olsson B, Wennberg A (1989) Endodontic status and suggested treatment in a population requiring substantial dental care. *Endodontics and Dental Traumatology* **5**, 153–8.

Rohlin M, Kullendorff B, Ahlqwist M, Henrikson CO, Hollender L, Stenström B (1989) Comparison between panoramic and periapical radiography in the diagnosis of periapical bone lesions. *Dentomaxillofacial Radiology* **18**, 151–5.

Rushton VE, Horner K, Worthington HV (2002) Screening panoramic radiography of new adult patients: diagnostic yield when combined with bitewing radiography and identification of selection criteria. *British Dental Journal* **9**, 275–9.

Russell M, Pitts NB (1993) Radiovisiographic diagnosis of dental caries: initial comparison of basic mode videoprints with bitewing radiography. *Caries Research* **27**, 65–70.

Saunders WP, Saunders EM, Sadiq J, Cruickshank E (1997) Technical standard of root canal treatment in an adult Scottish subpopulation. *British Dental Journal* **182**, 382–6.

Segura-Egea JJ, Jiménez-Pinzón A, Poyato-Ferrera MM, Velasco-Ortega E, Ríos-Santos JV (2004) Periapical status and quality of root fillings and coronal restorations in an adult Spanish population. *International Endodontic Journal* **37**, 524–30.

Segura-Egea JJ, Jiménez-Pinzón A, Ríos-Santos JV, Velasco-Ortega E, Cisneros-Cabello R, Poyato-Ferrera MM (2005) High prevalence of apical periodontitis amongst type 2 diabetic patients. *International Endodontic Journal* **38**, 564–9.

Sidaravicius B, Aleksejuniene J, Eriksen HM (1999) Endodontic treatment and prevalence of apical periodontitis in an adult population of Vilnius, Lithuania. *Endodontics and Dental Traumatology* **15**, 210–5.

Stamatakis HC, Welander U, McDavid WD (2000) Physical properties of a photostimulable phosphor system for intraoral radiography. *Dentomaxillofacial Radiology* **29**, 28–34.

Valachovic RW, Douglass CW, Reiskin AB, Chauncey HH, McNeil BJ (1986) The use of panoramic radiography in the evaluation of asymptomatic adult dental patients. *Oral Surgery, Oral Medicine, Oral Pathology* **61**, 289–96.

Weiger R, Hitzler S, Hermle G, Löst C (1997) Periapical status, quality of root canal fillings and estimated endodontic treatment needs in an urban German population. *Endodontics and Dental Traumatology* **13**, 69–74.

White SC, Pharoah MJ (1999) *Oral radiology: Principles and Interpretation, 4th edn.* St Louis, MO: Mosby (Harcour Health Sciences).

