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Assessment of simulated internal resorption cavities using digital and digital subtraction radiography: a comparative study

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Abstract – *Aim:* To compare the diagnostic accuracy of digital radiography with that of digital subtraction radiography in the detection of simulated internal resorption cavities. *Materials and Methods:* Simulated internal resorption cavities of varying sizes were created using round burs in 18 single-rooted teeth with visible pulp chamber, which had been extracted from dentate dry mandibles and split into two halves in a mesio-distal direction. Resorption cavities were created in the buccal half of the root in the cervical, middle, and apical third. Digital radiographs were taken from three different horizontal view angles before and after the creation of the cavities. This process was followed by digital subtraction radiography to evaluate their detection. Seven experienced observers and all specialists in endodontics were asked to examine the digital and digital subtraction images for the presence of the cavities. The data were analyzed using SPSS 14. *Results:* The overall sensitivity of digital subtraction radiography was superior to digital radiography and with statistically better results for all cavities regardless of their location (cervical, middle, apical third) ($P < 0.05$). The detection of the cavities was affected by the root third in which they were located. Cavities in the apical third were more easily detected compared with those in the middle or cervical third of the root. Small-sized lesions (0.5 mm, 0.6 mm) in the middle and apical third were more frequent and more easily detected using subtraction imaging. *Conclusion:* Digital subtraction radiography is superior to digital radiography for the detection and monitoring of the progress of internal root resorption.

Internal inflammatory root resorption is a relatively rare resorption in permanent teeth, which begins in the root canal and destroys surrounding dental hard tissues (1). Odontoclastic multinuclear cells are responsible for the resorption adjacent to granulation tissue in the pulp. The prevalence, etiology, and natural history are uncertain (2). It has been suggested that the process is initiated by a variety of stimuli such as trauma, pulpotomy, extreme heat produced during cutting of dentin without an adequate water spray etc. and is perpetuated mainly by bacterial factors (3, 4).

Clinical characteristics of internal root resorption vary depending on the development and location of the resorption. Teeth presenting internal resorption are usually asymptomatic. Pain may be a symptom if perforation of the crown occurs and the granulation tissue is exposed to oral fluids.

Radiographic imaging is the main diagnostic tool after a traumatic injury of a tooth, and it is of great importance for the early detection of an internal root resorption, so that it can be endodontically treated, before an uncontrolled expansion occurs.

Digital radiography could have comparable or even better results than conventional radiography, when it is used for the diagnosis of simulated external resorption cavities (5–9).

The use of digital subtraction radiography, which results in the elimination of identical image regions in a series of radiographs obtained at different time intervals, could improve lesion detectability through a reduction in background complexity (10). Two studies have shown the superiority of digital subtraction radiography in the detection of simulated external (11) or internal resorption cavities (2).

The purpose of this study was to compare the diagnostic accuracy of digital and digital subtraction radiography in the detection of simulated internal resorption cavities in cadavers. Digital subtraction radiography was performed using the Eikona Subtraction Radiography software (12). The effect of the location and size of the internal root resorptions on the diagnostic accuracy of the above methods was evaluated as well.

Materials and methods

Three dentate dry mandibles were used in this study, obtained from the Department of Anatomy, Medical School, Aristotle University of Thessaloniki. All procedures were performed according to the rules of Ethical Issues Committee in Greece and EU. After a preliminary radiographic and visual examination, 18 single-rooted teeth (eight incisors, six canines, four premolars) were selected for our experiment using the criteria listed below:

1 radiographically visible pulp chambers
2 no restorations or root canal fillings
3 no periapical pathosis, no anatomic deviations of the root canal system
4 no fractures

The experiment was based on a sequence of digital radiographs that were taken using a modified beam aiming device.

The selected teeth were gently extracted, replaced in the sockets, and again radiographed to ensure the absence of any bone or root fractures.

Soft tissue simulation was obtained by covering the bone with bovine muscle in strips (7).

The teeth were removed again from the sockets, split into two parts (buccal and lingual) at a mesiodistal direction using a diamond disk (4″ Dia, Buehler, IL, USA). Artificial internal root resorptions were simulated using round burs with increasing diameter (ISO 0.5, 0.6, 0.8, 1.00 and 1.20 mm), by drilling to the full depth under an operating microscope (Kaps, Asslar/Wetzlar, Germany) at the cervical, middle, and apical third of the buccal wall of each tooth. The number and location of the internal root resorptions to each mandible according to their size and root third is shown in Table 1. The two parts (buccal, lingual) of each tooth were relocated with superglue (Loctite® Super Glue ULTRA Gel Control™, Westlake, OH, USA) and repositioned in its socket after each procedure.

Each mandible was placed into polyvinylsyloxane putty impression material and mounted on a wooden platform fixed to the X-ray machine. An experimental rotator device was used which enabled accurate changes in the horizontal angle under fully reproducible conditions. The radiographic sensor was held in place with the appropriate holder (XCP-DS®, Dentsply, York, NY, USA) during exposures. The structure of the whole experimental system is shown by diagram in Fig. 1. Teeth were radiographed in an orthoradial, mesioradial, and distoradial views with a 15° horizontal angle change for the mesial and distal exposures. Digital radiographs were taken before and after internal root resorptions drilling. Teeth were exposed at 65 kV and 7.5 mA (ORALIX DC, GENDEX Dental Systems, Milan Italy) using a CCD receptor (size 1, 312000 points, resolution 8–10 lp/mm, 44 μm pixel size, active area 604 mm^2). Exposure time was set at 0.16 s. For the process of digital subtraction radiography, the software Eikona Subtraction Radiography was used (12). The software runs on a Pentium PC under Windows 2000 or newer operating system. To register the input digital radiographic images acquired in two different time instances using the parallel technique, i.e., to correct the geometrical distortions (rotation, scaling, translation) prior to their subtraction, several pairs of user-defined landmark points were selected on them. The pairs of the selected landmark points must correspond to identical anatomical elements on the two digital radiographs. The selection of each landmark point is made by clicking with the mouse on the desired point of the corresponding digital radiographic image. A magnification window helps the user to accurately select the desired points on the two digital radiographs. The registration procedure is based both on those landmark points as well as on a refinement step that aims at improving the initial results using image intensity information. Registration is accompanied by a normalization step that eliminates brightness and contrast differences between the two images. Finally, the two images are superimposed and subtracted (13, 14).

The total number of images resulted using this methodology was 135 (90 digital radiographs and 45 digital subtractive images). Seven experienced observers (all endodontists) were asked to examine the series of images (digital radiographs and results of digital subtraction) that resulted for each mandible, for the presence of resorption cavities, after they were given written instructions regarding the study. Each observer

Table 1. Distribution and size of the simulated internal root resorptions for each tooth of each mandible

	Tooth number							
1st Jaw	45	44	43	41	31	32	33	34
Location	Resorption diameter (mm)							
Cervical third	1	0.8	1.2	0.5	1		0.6	
Middle third	1.2	1.2	0.6	1	0.8	0.8	0.5	1.2
Apical third				0.5	0.6	1	1.2	0.5

	Tooth number						
2nd Jaw	43	42	41	31	32	33	34
Location	Resorption diameter (mm)						
Cervical third	0.5	0.8	0.5	1.2		0.8	1
Middle third	0.6	0.8		1	0.5		
Apical third	1	0.6	0.8	0.5	0.6	1.2	1.2

	Tooth number		
3rd Jaw	43	42	34
Location	Resorption diameter (mm)		
Cervical third	1.2	0.6	0.6
Middle third	0.5	1	0.6
Apical third	0.8	0.8	1

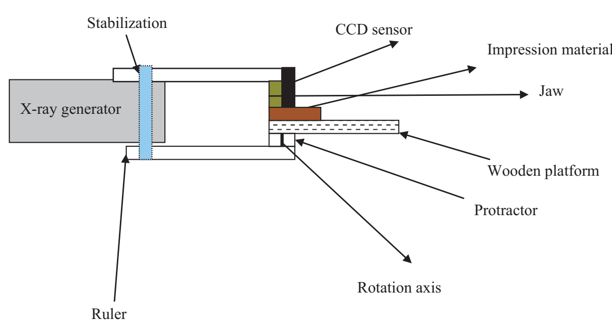

Fig. 1. The experimental device as it is shown in diagram.

was asked to examine the same radiographs on his own. The radiographs were provided to the observers in the same order. Viewing was performed in a darkened room. The digital images were opened with Photoshop 8, and the observers were asked not to manipulate the images or use the brightness and contrast tools of the program. After the examination of each set of radiographs for each mandible, resting periods of 15 min were allowed to the observers. The observers were asked to record the presence and location of resorption cavities of the teeth according to a questionnaire that was prepared for each mandible for this reason. The questionnaire was made according to the exist/does not exist model (8, 9). So, each observer was asked to record 0: for the absence or 1: for the presence of resorption at each third of each tooth. The examination of the digital subtraction radiography images was performed by each observer 4 weeks later, following an extensive explanation of the subtraction process. A data set of pre-operative and post-operative digital radiographs taken under disto, ortho, and mesioradial exposures and their subtraction radiography images is shown in Fig. 2.

Statistical analysis of the data was performed in the Department of Informatics, Aristotle University of Thessaloniki, Greece, using SPSS14 for Windows XP statistical software (BrotherSoft, www.brothersoft.com).

Results

The total number of correct answers (true positive and true negative) for internal resorption cavities using the two methods (digital radiography and digital subtraction radiography) independently regarding their size can be seen in Table 2. The results showed a higher number of cavities observed by the examiners when using the digital subtraction radiographs ($P = 0.000 < 0.05$). The total number and percentage of the correct answers of all the observers and for all the locations, in consideration of the variable diameter of the simulated internal root resorptions using digital radiography and digital subtraction radiography, are shown in Table 3 (SD: standard deviation). It can be concluded from Table 3 that for all sizes of internal root resorptions the percentage of correct answers using digital subtraction radiography was higher. Figure 3 shows diagrammatically the total percentage of correct diagnoses using the two methods without any consideration of the size of the resorptions. On the same table, standard deviation is shown as well.

The values for accuracy measurements such as specificity, sensitivity, positive predictive value, and negative predictive value are shown in Table 4, while the exact number of true positive, true negative, false positive, false negative responses for all observers can be seen in detail in Table 5.

The percentage of correct readings for digital radiography was 54% for the cervical, 67.6% for midroot, and 67.9% for the apical locations. The percentage of total correct readings for digital subtraction radiography was 72.1% for the cervical, 81% for midroot, and 84.8% for the apical locations (Table 6).

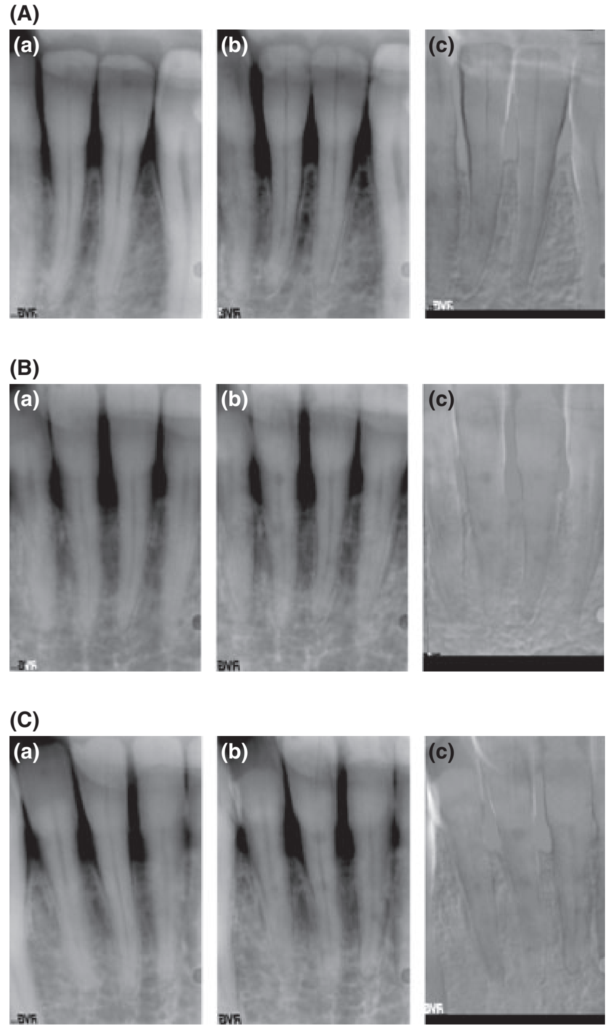

Fig. 2. Images of jaw No 2 from inferior tooth region. (a) Mesioradial exposure. (A) Pre-operative radiograph. (B) Post-operative. (C) Result of digital subtraction of (B) from (A). (b) Orthoradial exposure. (A) Pre-operative radiograph. (B) Post-operative. (C) Result of digital subtraction of (B) from (A). (c) Distoradial exposure. (A) Pre-operative radiograph. (B) Post-operative. (C) Result of digital subtraction of (B) from (A).

Table 2. Total numbers and proportions of correct answers, for all sizes of internal root resorptions given from all observers with the two methods (SD: standard deviation)

	Digital radiography	Digital subtraction radiography	*P*-value
Diagnosis	597 (63.2%, SD: 1.56)	749 (79.3%, SD: 1.31)	0.000 < 0.05

Discussion

Radiography is the main diagnostic tool for detecting dental and maxillofacial lesions. The validity of a diagnostic test is generally determined by two parameters such as sensitivity and specificity. Radiography is characterized by a low degree of sensitivity, because it can give false-positive results. There are many reasons

Table 3. Total numbers and proportions of correct answers of all observers and for all locations, in consideration of the variable diameter of the simulated internal root resorptions using digital radiography and digital subtraction radiography (SD: standard deviation)

Resorption diameter (mm)	Digital radiography	Digital subtraction radiography	*P*-value
0.5	77 (40.7%, SD: 3.57)	118 (62.4%, SD: 3.52)	0.000 < 0.05
0.6	74 (39.1%, SD: 3.54)	121 (64%, SD: 3.49)	0.000 < 0.05
0.8	118 (62.4%, SD: 3.52)	145 (76.7%, SD: 3.07)	0.001 < 0.05
1.00	158 (83.5%, SD: 2.69)	178 (94.2%, SD: 1.70)	0.001 < 0.05
1.20	170 (89.9%,SD: 3.70)	187 (98.9%, SD: 0.75)	0.001 < 0.05

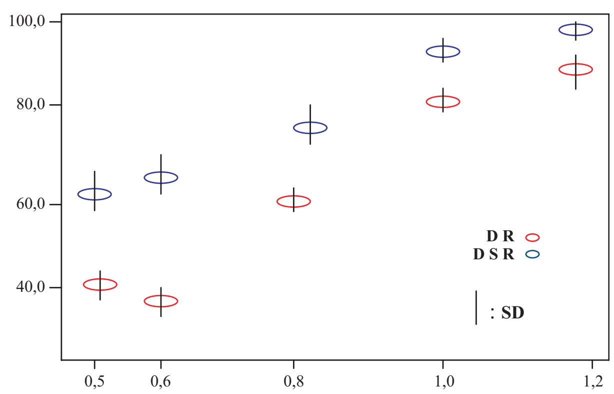

Fig. 3. Graphic illustration of the data in Table 3. (DR, digital radiography, DSR, digital subtraction radiography, SD, standard deviation). It is clearly shown that digital subtraction radiography is superior to digital radiography.

Table 4. Values of selected accuracy measurements like sensitivity, specificity, positive predictive value, and negative predictive value for both radiographic methods

Accuracy measurements	Digital radiography (%)	Digital subtraction radiography (%)
(Sensitivity)	63.2	79.3
(Specificity)	87.3	86.2
Positive predictive value	96.1	94.9
Negative predictive value	30.7	45.40

that yield this result, such as operator bias when interpreting radiographs, as well as anatomical and technical factors. It has been reported that lack of agreement in radiographic interpretation exists between different evaluators (inter-observer variability) (15). There are even large discrepancies in the analysis of a single evaluator with himself at different time periods (intra-observer variability) (16). Another factor that complicates 2D radiographic interpretation relates to

Table 5. Total numbers of true positives and false negatives for each one of the observers.

	True Positive (TP)/False negative (FN)	
Observers (No)	Digital radiography	Digital subtraction radiography
1	86/49	107/28
2	88/47	115/20
3	89/46	112/23
4	65/70	103/32
5	102/33	102/33
6	74/61	112/23
7	93/42	98/37
	True positive (TP)/False Negative (FN)	
Observers (No)	**Digital radiography**	**Digital subtraction radiography**
1	24/3	25/2
2	24/3	15/12
3	21/6	25/2
4	22/5	24/3
5	27/0	27/0
6	24/3	24/3
7	23/4	23/4

the fact that conventional radiographic images display two dimensions of the three-dimensional reality; hence, the images of different anatomical structures are superimposed on each other and thus, make it difficult to detect the lesions. The advantage of digital subtraction radiography is that it cancels out the complex anatomic background, against which the subtle changes occur. As a result, the changes become substantially more evident. Subtraction images are well suited for acquiring quantitative information such as linear, area, and density measurements.

The results of this study showed that the number of cavities detected was higher when the observers examined digital subtraction images in comparison with the digital radiography using a CCD receptor and the difference between the two methods was statistically significant ($P < 0.05$).

Holmes et al. (2) in human cadavers showed that digital subtraction radiography was better than conventional radiography in the detection of simulated internal resorption cavities. These results are in agreement with those of Kravitz et al. (11) and Heo et al. (17), this time in simulated external root resorptions.

Recent studies (2, 8, 9) strongly dispute, for various reasons, the value of the five-point scale ROC curve in providing cues regarding the sensitivity and the specificity of the diagnostic means in such studies (with many artificial lesions). Thus, to reach safe conclusions using the ROC curve, one should create only one lesion in each tooth and not one in each third or, even worse, from 20 to 54 lesions as is usually performed in studies that deal with artificial external resorptions (5, 9, 16, 18). Furthermore, in some other studies that utilized the five-point scale, a strong inclination toward the wrong diagnosis was observed. The latter was found to be preferable to no diagnosis (2, 19). For the above reasons,

Table 6. Distribution of readings according to the location of the simulated resorption cavities and the imaging method that was followed. The corresponding proportions are shown in this table and the standard deviation (SD) as well

Location	Digital radiography	Digital subtraction radiography
Cervical third		
Yes		
Count %	170	227
within correct	(54.0%, SD: 2.80)	(72.1%, SD: 2.52)
NO		
Count %	145	88
within correct	(46.0%, SD: 2.80)	(27.9%, SD: 2.52)
Total		
Count %	315	315
within correct	100.0%	100.0%
Middle third		
Yes		
Count %	213	255
within correct	(67.6%, SD: 2.63)	(81.0%, SD: 2.21)
NO		
Count %	102	60
within correct	(32.4%, SD: 2.63)	(19.0%, SD: 2.21)
Total		
Count %	315	315
within correct	100.0%	100.0%
Apical third		
Yes		
Count %	214	267
within correct	(67.9%, SD: 2.63)	(84.8%, SD: 2.02)
NO		
Count %	101	48
within correct	(32.1%, SD: 2.63)	(15.2%, SD: 2.02)
Total		
Count %	315	315
within correct	100.0%	100.0%

the exist/does not exist model (8, 9) was selected for the observers in this study.

The size of a lesion had a strong influence on its detection rates no matter the method used as seen in Table 3. Using the digital radiography, the detections rates for the different lesion sizes were lower than the rates for digital subtraction radiography (Fig. 3). In the study of Holmes et al. (2), the smallest size of lesion that could be detected was 0.8 mm in diameter. In our study, lesions as little as 0.5 mm could be detected with the use of digital subtraction technique. Probably, the main reason for this difference is that the former study used only maxillary central incisors that have larger root canals compared with mandibular central and lateral incisors or premolars that were used in our study.

The root third that a lesion is located in many studies has been shown as another strong parameter that influenced its detection. In other studies where simulated external resorption cavities were followed, did not the root thirds where the lesions were located affect their results (9, 11). In our study, all lesions were more easily detected when they were located at the apical third, while those located in a more cervical position were more difficult to detect. A reason for this might be the mask effect (especially for the smallest lesions) exerted by the root canal shadow, which projects over the artificial lesion. This mask effect was of a lesser impact in the digital subtraction images in which the background, against which a lesion must be discerned, is less complicated. On the contrary, Holmes et al. (2) using maxillary incisors found that apical lesions were more difficult to detect as compared with coronal.

Finally, in what regards the effect of the horizontal angulation during the radiographs acquisition on the correct diagnosis, our results are in agreement with those reported in Chapnick (20), i.e. that the change in the horizontal angulation does not affect the correct diagnosis of lesions in either the digital or the digital subtraction images.

Conclusively, digital subtraction radiography is superior to digital radiography for the detection and monitoring of the progress of internal root resorption.

Finally, we should mention that the absence of totally 'blind teeth' (=without cavities) comprises a shortcoming in with our study. Also, it would be probably better to involve fewer observers to avoid more inter-observer bias and also use as many teeth as possible. But the current study was a first attempt to compare the diagnostic accuracy of digital and digital subtraction radiography in the detection of simulated internal resorption cavities in cadavers. Future work will focus on including more teeth in this type of studies. We think subtraction can be a useful technique for internal resorption assessment.

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