Subtraction radiography of interradicular bone lesions

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Subtraction and conventional radiography were evaluated for their diagnostic potential to assess interradicular bone lesions in the mandibular premolar region. Both conventional radiographs and subtraction images were interpreted by 10 observers. The receiver-operating characteristic (ROC) technique was used to compare the two techniques. The diagnostic validity was higher for the subtraction technique, both for lesions confined to cancellous bone and for lesions including the cortical bone, than for the conventional technique. For bone defects confined to cancellous bone the diagnostic accuracy was lower than those reported from periapical bone lesions irrespective of whether subtraction or conventional radiography was used. We conclude that subtraction radiography improves the detectability of bone lesions, shallow ones in particular. Lesions in the interradicular bone are more difficult to detect than those in the periapical bone. □ *Apical periodontitis; dental radiography; subtraction radiography*

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Radiography plays a central role in the diagnosis of diseases affecting the jaw bone. However, the effects of these diseases are not radiographically detectable until some time after their initiation. Depending on such factors as disease activity, location of the lesion, and radiographic technique, a short or long period of time may elapse during which radiographic examination will give a falsely negative result.

On the basis of results of previous experimental studies, it has been claimed that bone lesions in the mandible can only be detected when the cortical bone tissue has become involved (1–5). In a study on sections of long bones with a structure basically the same as that of the mandible, van der Stelt (6) showed that the density of the cancellous bone influenced the visibility of a lesion reaching the junction area. However, lesions completely situated in cancellous bone were mostly not radiographically visible. The bone lesions in some of the cited studies (1, 4, 6) were created in bone tissue not including the periapical regions. The structure of the periradicular bone tissue is unique because of the presence of the lamina dura. Conclusions drawn from the results of studies of bone lesions in other regions might therefore not be valid with regard to periapical lesions. Another factor of importance for the diagnostic accuracy not discussed in these investigations is the observer. In a study by Duinkerke et al. (7) the borders of artificial periapical bone lesions were outlined with tracing by different observers, some of whom also detected lesions in cancellous bone. Their observations showed a great variability, especially when only the cancellous bone had been removed. The above-mentioned studies demonstrate the existence of important limitations of the radiographic diagnosis of diseases occurring within the jaw bone. These limitations seriously compromise the results of the radiographic examinations and, consequently, the outcome of the subsequent clinical management.

Radiography is also used at subsequent examinations to evaluate the effect of treatment. The purpose of the follow-up examination is to show changes that may have occurred over an interval of time. Computer-assisted subtraction of serially obtained standardized radiographs has been shown to give a higher diagnostic accuracy and precision than conventional radiography for periapical lesions (8, 9). The difference in diagnostic performance between the two radiographic techniques was higher for lesions confined to the cancellous bone than for lesions including the cortical bone. The availability of the digital subtraction technique has in recent years increased with the introduction of inexpensive personal computers, which have been shown to yield a diagnostic accuracy similar to that of the 'high-cost' equipment (10).

The aim of this investigation was to compare the diagnostic performance in the detection of small interradicular lesions in dry human mandibles when using conventional radiographs and images obtained with a computer-assisted subtraction technique.

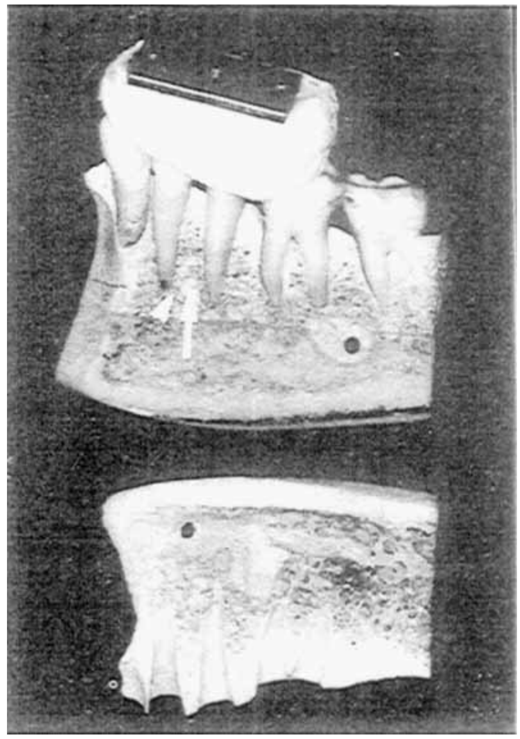

Fig. 1. Mandibular block section containing one buccal and one lingual part. Plastic pins were used as a steering device to ensure identical repositioning of the two parts. The arrow indicates the interradicular bone lesion. The arrowhead indicates a periapical bone lesion (see Kullendorff et al.(8)).

Materials and methods

Bone lesions

From each of six human mandibles, differing with regard to trabecular bone pattern, a section was taken from the canine region to distally of the molars. All mandibles appeared radiographically to be free of periapical and interradicular lesions. After removal of the teeth the block section was divided into a buccal and a lingual part. The teeth were then replaced and glued to the lingual part. Two plastic pins in the lingual part with corresponding steering grooves in the buccal part (Fig. 1) ensured identical repositioning of the buccal part.

After removal of the buccal part, one lesion with a diameter of 1 mm was made with a round diamond bur in the bone tissue between the apices of the two premolars on each specimen (Fig. 1). (At the same time, a periapical lesion was also made in one of the premolars, as described in a previous study (8).) Lesions of incrementally increasing depth were then prepared in the six mandibles. The depth of the lesion was approximately 0.5 mm in each step and gradually extended in the lingual direction. The diameter, approximately 1 mm, was kept as constant as possible.

After each preparation the lesion was evaluated as being confined to the cancellous bone or also including the cortical bone. Lesions located in the junction area were classified as including the cortical bone. Altogether there were 28 interradicular lesions, of which 14 were confined to the cancellous bone and 14 also involved the cortical bone.

Radiographic examination

Each mandibular block was mounted on a mechanical device by means of plaster surrounding the base of the mandibular bone section to ensure a reproducible relationship

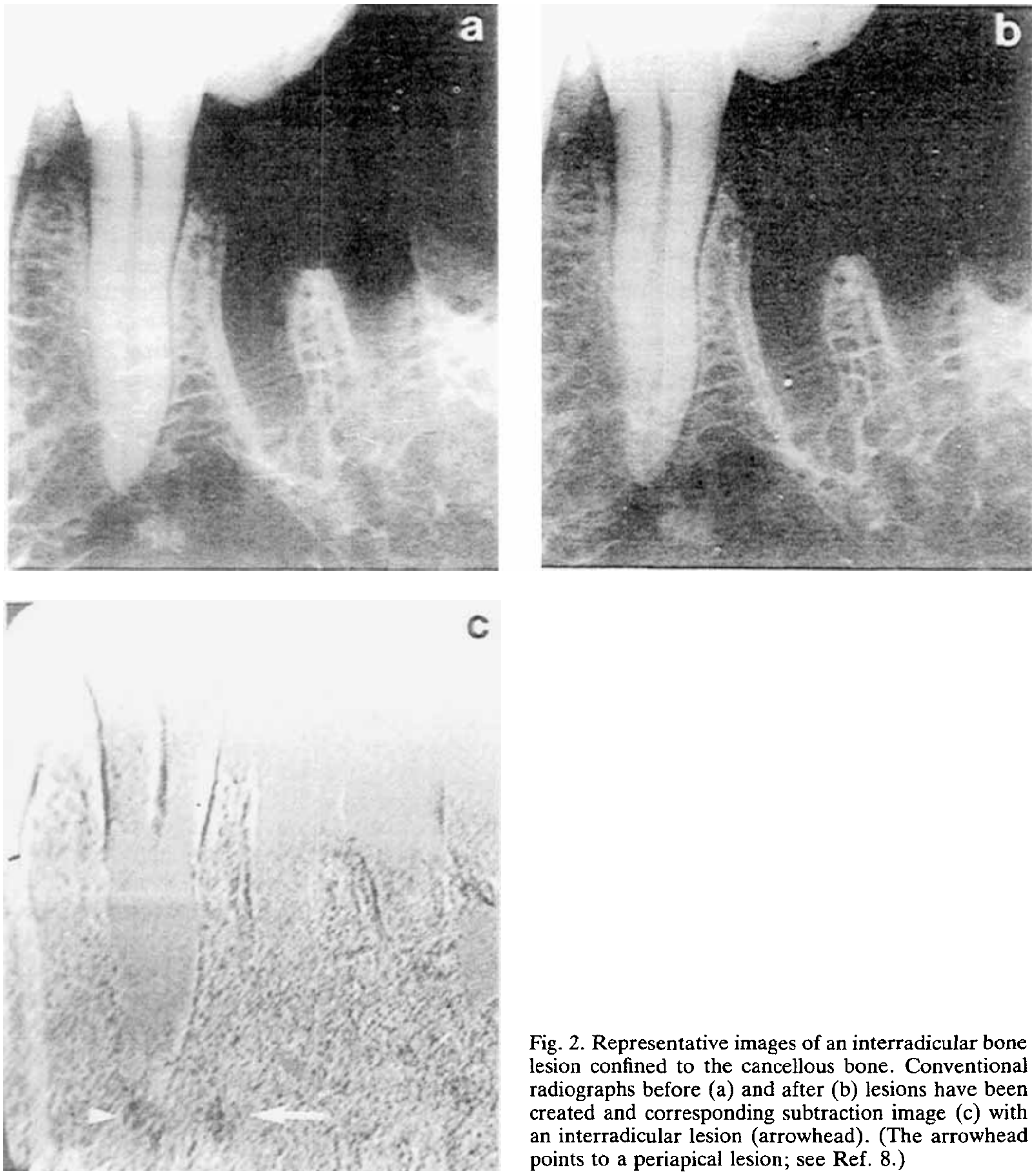

Fig. 2. Representative images of an interradicular bone lesion confined to the cancellous bone. Conventional radiographs before (a) and after (b) lesions have been created and corresponding subtraction image (c) with an interradicular lesion (arrowhead). (The arrowhead points to a periapical lesion; see Ref. 8.)

among the X-ray machine, object, and film. The device was attached to the X-ray machine (Siemens Nanodor II, 60 kV, 20 mA) and a film-holder. The focus–object and object–film distances were kept constant at 40 cm and 1 cm, respectively. Reference radiographs were taken before the lesion was made with the film (Kodak DF 57 Eastman-Kodak, Rochester, N.Y., USA) parallel to the long axis of the premolars and with the central beam perpendicular to the film plane. After each preparation step the mandibular section with the buccal part replaced was remounted on the device, and a new radiograph obtained. All films of each block were processed at the same time.

Subtraction technique

The conventional radiographs were converted into video signals, which were digitized (Digitix 300, Bildsystem AB, Malmö) into a 512 × 512 matrix with a depth of 8 bits (256 gray levels). The reference radiographs were digitally subtracted from the radiographs taken after stepwise deepening of the lesions. The resultant subtraction images were displayed on a TV screen and photographed.

Interpretation of radiographic images

The conventional radiographs, obtained before (Fig. 2a) and after (Fig. 2b) the creation of the lesions, were mounted in pairs. The left radiograph was always a reference image without a lesion, and the right one a radiograph in which a lesion was present in 70% of the images and not present (identical image) in 30%. The subtraction images (Fig. 2c) were presented separately as photographs. Ten observers, five oral radiologists and five endodontists, who 2 months previously had participated in a similar study on periapical lesions (8), were asked to report the condition of the interradicular bone tissue.

The observers were informed of what area to examine, the a priori probability of lesion presence, and the approximate diameter of the lesions. They were asked to indicate for each area the certainty with which a lesion could be detected or not. A five-point rating scale was used. All conventional and subtraction images were interpreted a second time after 6 months.

Analysis of observations

The diagnostic accuracy of the two radiographic methods was tested using the receiver-operating characteristic (ROC) technique (11, 12). Both the index P(A) (11) and the index A_z (12) were calculated. A_z is the area under a straight ROC graph plotted on a binormal graph, whereas the P(A) area is the result of connecting empirical ROC points on linear probability scales. P(A) was calculated for each imaging technique and for the different lesion depths separately for each observer, whereas A_z could only be calculated as a mean value for all observers for each technique and lesion depth.

The lesions were classified into those confined to cancellous bone and those also involving the cortical bone (Fig. 3). The mean value of the two reading occasions was calculated and used in the results. Student's *t* test for paired samples was used for significance testing.

Results

The results of interpretation of interradicular bone lesions comparing the conventional and subtraction technique are presented as mean P(A) and A_z values in Table 1. The P(A) values were higher for the subtraction technique both for lesions confined to cancellous bone ($p < 0.001$) and for lesions including

Table 1. Diagnostic accuracy measured as area beneath the receiver-operating characteristic curve, A_z and P(A), for the subtraction and conventional technique for different depths of interradicular bone lesions. Mean differences (D) between the P(A) areas, standard deviations (SD), and significance levels using Student's *t* test

	Mean area						
	Subtraction technique		Conventional technique		Mean difference P(A), subtractional/conventional		
Lesion depth	A_z	P(A)	A_z	P(A)	D	SD	Significance level
Cancellous bone	0.798	0.768	0.569	0.582	0.186	0.073	***
Cancellous and cortical bone	0.933	0.905	0.794	0.811	0.094	0.103	*

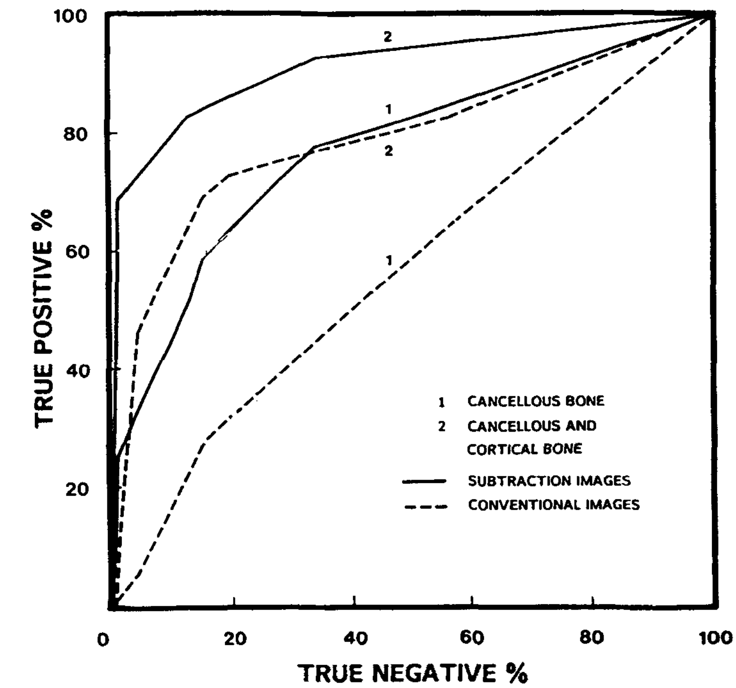

Fig. 3. Mean receiver-operating characteristic curves from interpretation by 10 observers of subtraction and conventional radiographs of interradicular bone lesions confined to cancellous bone and to cancellous and cortical bone.

the cortical bone ($p < 0.05$). The diagnostic accuracy expressed as A_z presented a somewhat higher mean difference between the conventional and subtraction technique than the P(A).

The diagnostic accuracy of the individual observers is presented in Table 2. The range for the areas, P(A), under the ROC curves was approximately the same for the two techniques. When utilizing the conventional technique for lesions confined to the cancellous bone, 4 of the 10 observers approached the pure chance level of diagnostic performance. Two of the observers (observers 1 and 3) obtained a lower P(A) value for the subtraction technique than for the conventional technique for lesions including cortical bone. The low P(A) value of observer 1 resulted in a high standard deviation of the subtraction technique for lesions including cortical bone.

Discussion

The results indicated that for the detection

Table 2. Area, P(A), under the receiver-operating characteristic curve by technique and depth of interradicular bone lesion for each of 10 observers

Lesion depth	Technique	Observer 1	2	3	4	5	6	7	8	9	10	Mean	SD	Range
Cancellous bone	Conventional	0.571	0.535	0.572	0.531	0.610	0.535	0.518	0.692	0.620	0.640	0.582	0.057	0.531–0.692
	Subtraction	0.644	0.794	0.777	0.710	0.728	0.809	0.783	0.790	0.770	0.875	0.768	0.062	0.644–0.875
Cancellous + cortical bone	Conventional	0.771	0.802	0.929	0.695	0.801	0.781	0.804	0.881	0.702	0.944	0.811	0.085	0.695–0.944
	Subtraction	0.701	0.954	0.869	0.747	0.915	0.958	0.981	0.970	0.953	1.0	0.905	0.102	0.701–1.000

of small osseous lesions in the interradicular area of alveolar bone, digital subtraction radiography was significantly better than the conventional technique. As could be expected, the difference in diagnostic accuracy was more pronounced for the lesions confined to cancellous bone than for lesions including the cortical bone. In a previous study (8) we examined the diagnostic accuracy of periapical bone lesions. For periapical lesions confined to cancellous bone the P(A) values for subtraction technique and conventional technique were 0.899 and 0.672, respectively, which are higher than the corresponding values for interradicular lesions examined in the present study. The differences in detectability may be due to the fact that the observers were informed about the location of a probable lesion—that is, periapically or interradicularly. The area to scan is smaller with regard to periapical lesions if there is a slight misalignment which reveals the outline of the teeth. Another reason might be that more bone mineral was removed when the lamina dura was involved in the lesion.

The diagnostic accuracy can be given both as A_z value and P(A) value. Compared with P(A), the A_z value is considered to give more precise information on the diagnostic accuracy, as A_z is less affected by the location and spread of the points that define the ROC curve (12). To facilitate comparison with the results of previous studies (8, 10, 13), in which the diagnostic accuracy has been expressed as P(A) for the comparison between conventional and subtraction technique, the P(A) was also analyzed in the present study.

The bone defects were artificially created by cutting the bone trabeculae with a bur. As Farman (14) pointed out, such bone defects are not identical to inflammatory lesions, as reactive bone formation most often occurs clinically, surrounding the area of resorption. Thus, for periapical lesions, which most frequently have an inflammatory nature, one part of the radiographic signal, the reactive bone apposition, is missing in artificial defects. Interradicular lesions, on the other hand, are often non-odontogenic and appear most frequently as bone destructions. The discrepancy between the experimental and clinical situations, particularly for the periapical lesions, must be considered a methodologic deficiency in this and in earlier investigations based on artificial bone lesions. There are, however, ethical objections to obtaining clinical material with bone defects of incrementally increasing bone loss.

Classification of bone defects has previously been done by describing the defects by size, by amount of bone removed, or by the kinds of bone at the lesion site. With regard to the cancellous bone of the jaws, it is difficult to measure the size of the lesion, as the trabeculae, particularly in the mandible, are very sparse and unequally distributed. Methods for determining the amount of bone loss in the jaws by means of densitometric analysis of radiographs (15–17) or isotope absorptiometry (18) are also available. These methods were, however, developed for the cortical bone tissue and have mostly been applied to estimate changes in the mineral content of marginal bone over time. In previous studies (8, 13) we found that when the lesions include both cancellous and cortical bone, calculation of the bone loss by means of isotope absorptiometry with radioactive iodine was complicated. Consequently, a simple separation between the bone lesions confined to cancellous bone and those also involving the cortical bone was preferred in this study.

It has earlier been stated that most of the cancellous bone can be removed without any visible signs in the radiograph. However, it was evident that the diagnostic accuracy was influenced not only by the lesion depth but also by the observer. These results are in accordance with previous comparisons of the conventional and subtraction technique (8, 10, 13) and of xeroradiography and the conventional technique (19). In the latter study a greater range between the 10 observers than between the 2 imaging systems was noted, which is in accordance with the present study. The interobserver variability was equally high for the subtraction and the conventional technique, in contrast to our results on periapical lesions (8) and the observations made by Gröndahl et al.

(20) and Möystad et al. (10). One of the observers showed markedly lower accuracy than the others for the subtraction technique, thereby contributing to the somewhat unexpectedly high variability.

Subtraction radiography showed higher accuracy for detection of interradicular lesions confined to the cancellous bone than conventional radiography. Similar results were obtained by Kullendorff et al. (8) and Möystad et al. (10) for periapical lesions and by Tyndall et al. (9) for artificial periapical and interradicular lesions, although not presented with the ROC technique. The observers obtained higher accuracy for both conventional and subtraction radiography when studying lesions including cortical bone compared with cancellous bone lesions. The increase in accuracy between cancellous lesions and those including cortical bone was more pronounced for conventional than for subtraction radiography. This indicates that subtraction radiography, as expected, has a greater potential for improving detectability at lower signal-to-noise ratios. Such a tendency was also reported by Gröndahl et al. (13) for marginal bone lesions, by Kullendorff et al. (8) for periapical lesions, and by Tyndall et al. (9) and Rethman et al.(21) for periapical and interradicular lesions. The higher diagnostic accuracy reported by Rethman et al. (21) was probably due to their way of producing the artificial lesions. In their study the lesions were made from the outside through the buccal cortical bone plate, whereas the lesions in the present study were produced on the inside of the split bone specimen.

As the detectability of the interradicular lesions was lower than that of comparable periapical lesions confined to the cancellous bone, it might be that the results of some previous studies in which the bone defects were produced outside the periapical bone tissue cannot be applied unconditionally to the detectability of periapcal lesions. For the detectability of periapical lesions the ability to perceive fine details such as the lamina dura is of utmost importance. Kaffe & Gratt (22) showed that the highest diagnostic accuracy was obtained for the imaging of the lamina dura as compared with other radiographic features. They found that 'even less effective observers do interpret discontinuity in the lamina dura and notice its abnormal configuration'. The lamina dura, evidently an important indicator of abnormality (22–24), will, however, not be present when artificial bone defects are produced outside the periapical region.

One very important factor for the usefulness of the subtraction technique in dentistry is the reproducibility of the projection geometry. An experimental study on small periodontal bone lesions (25) demonstrated that subtraction images obtained from conventional radiographs with an angulation of 3° between reference and subsequent image were still significantly better than conventional radiographs obtained with optimal projection. Our experience from clinical trials, however, is that it is more difficult to obtain reproducible radiographs presenting the periapical bone than the marginal bone. More elaborate equipment is generally needed. Although the cephalometric approach, as presented for experimental use by Jeffcoat et al. (26) and for clinical use by Proestakis et al. (27), promises well, the clinical problems with the reproducibility of the periapical film placement have yet to be solved. A minor displacement of the film might produce artefacts simulating bone changes. To reduce false-positive assessments, Janssen (28) proposed a training program for observers to make them familiar with the technical aspects of the subtraction technique. It should also be mentioned that Webber et al. (29) have presented a mathematical model for computer correction of projective distortions (29). This so-called warping transformation was applicable for distortions caused by bending of one film relative to another. A difference in the position of the X-ray source between two radiographs could, however, not be corrected for. This problem was dealt with by Wenzel (30), who presented a method to improve the positioning of non-identical images to be subtracted. If there is a difference in vertical angulation between the two images, the subtraction process is facilitated by computerized superpositioning of reference points. Still, the problem of obtaining periodicidentical images might be a serious drawback of the clinical availability of the subtraction technique for the diagnosis of interradicular and periapical bone lesions. It might therefore be advisable to evaluate other digital imaging techniques and compare them with the subtraction technique for improvement of the diagnosis of interradicular and periapical bone.

We conclude that the digital subtraction technique significantly increases the detectability of small interradicular lesions, particularly those confined to cancellous bone. Compared with lesions in the periapical area, the detectability is somewhat lower. This implies that the location of lesions can be an important factor when studies of bone lesions are compared. Another important factor is the selection of observers and what kind of information they receive about the diagnostic task.

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