RESEARCH

The effect of horizontal X-ray beam angulation on the detection of furcation defects of mandibular first molars in intraoral radiography

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Objectives: The aim was to investigate the effect of changes in horizontal X-ray beam angulation in intraoral radiography on the detection accuracy of furcation defects in the mandibular first molar, and to examine the anatomical relationship between the roots and furcation area as a possible cause of changes in detectability.

Methods: Simulated furcation defects with various depths were created in five mandibular first molars. Intraoral radiographs were taken at various horizontal angulations of the projection beams. The diagnostic accuracies were determined based on receiver operating characteristic analysis. The geometric relationship that might influence the accuracy was investigated through use of a compact cone beam CT in 59 first molar areas.

Results: Although the horizontal angulations showing the highest accuracies were shifted mesially, no differences were found between the angles of -10° and 20° . The relationship between the roots and the furcation area was relevant to the range of angulations showing high detectabilities.

Conclusions: The angulations traditionally used for detecting proximal caries are also suitable for detecting furcation defects.

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Introduction

As furcation involvement in molars is one of the major problems in periodontal treatment¹ and is directly related to the survival of the teeth,² it should be detected accurately at an early stage. Usually, it is assessed by using a probing procedure, but the anatomical complexity in this region often reduces its accuracy.^{3,4} Although radiographic diagnosis is likely to underestimate the furcation bone loss in comparison with the probing procedure,^{4,5} intraoral radiography plays an adjunctive role in the diagnosis.^{4,6} It is recommended that intraoral radiographs should be

taken at different X-ray beam angles to reduce the risk of missing furcation involvement.⁶ However, there are no recommendations for suitable angulations to detect furcation involvement. Moreover, the influence of change in angulation has not been investigated in the detection of bifurcation involvement of the mandibular molars.

Even for furcation disease, the horizontal angle of the X-ray beam is recommended to be tangential to the interproximal surface of the contact point.⁶ Several studies confirm that this traditional horizontal angulation shows the best detectability in the evaluation of proximal caries. However, there have been no studies verifying that the best angulation for proximal caries is also suitable for detecting bifurcation involvement in the mandibular first molar.

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Diagnostic accuracies are generally determined with receiver operating characteristic (ROC) analysis, which requires a gold standard, but only a few studies have addressed the furcation involvement in intraoral radiography.^{7,8} This may be partially attributed to the difficulty of verifying the actual size of bony defects. A recently available compact cone beam CT (CBCT) apparatus enables measurement of the actual size⁹ and can provide a sufficient gold standard.

On the other hand, the configuration of the furcation area^{10–12} shows wide variations, and the geometrical relationship between the mesial and distal roots differs among subjects.^{13,14} This relationship may influence the detectability of a furcation defect. CBCT can also clearly depict this relationship.⁹

The purposes of the present study were to find the effective horizontal X-ray beam angulation of intraoral radiography for the detection of artificially created furcation defects of the mandibular first molar and to examine the geometric relationship between the roots and furcation area based on an investigation with compact CBCT.

Materials and methods

Furcation disease model

Three adult dried mandibles (age and gender unknown) with bilateral first molars were used. No periodontal bone loss was found around the first molars. These molars were extracted carefully to preserve the periodontal bony structures. Five of them were successfully extracted without any fractures and were used in the following experiments. They could be easily reinserted into the extraction socket. One molar was excluded because of irrecoverable damage.

The present study was carried out according to the method described by Grgan *et al*,⁸ which is the only previous study based on artificially created mandibular furcation defects. Simulated furcation defects were created step-by-step from the buccal side in the

interradicular bone of the first molars with a 1 mm round burr, to mimic the clinical progression of plaque-induced periodontal bone defect^{12,15} (Figure 1). Initially, the buccal bony structure, including the cortical plate, was shaved vertically until the buccolingual width of the remaining plate reached approximately 2 mm (Figure 1). However, it was stopped at the highest level where the furcation entrance could be seen from the horizontal plane regardless of the plate thickness. The interradicular bone was then cut horizontally from the buccal furcation entrance to the lingual cortical plate with a vertical depth of 2 mm (Figure 1). Whenever new cutting with an approximately 1 mm reduction of bone was performed, intraoral radiographs were taken in various directions with a special device, described below. The number of radiographs obtained differed among the five molar areas used for this experiment because of the difference in the buccolingual width of the five areas. To measure the actual size and shape of the bone defects, three-dimensional images were obtained simultaneously using a compact CBCT unit (3DX multi-image micro CT, Morita, Kyoto Japan) with exposure conditions of 80 kV and 1.2 mA. The imaging area had a cylindrical volume, with radius 20 mm and height 30 mm. The spatial resolution was set to 0.125 mm. A dried mandible was set on a specially fabricated table and the first molar was positioned at the centre of the imaging area.

Acquisition of intraoral radiographs

Radiographs were taken using an MTX-90 dental radiograph machine (Asahi Roentgen Ind. Co., Ltd., Kyoto, Japan) at 60 kV and 5.25 mAs, and with a 1.5 mm Al filter. The films used were Insight IP-22 (Eastman Kodak Co., Rochester, NY). All radiographs were processed immediately after exposure with an automatic processor (Excel, DENT-X Corporation, Elmsford, NY). All the processing chemicals and machines were properly managed by radiological technicians.

Figure 1 Preparation of furcation defects and a typical image obtained by compact cone beam CT

A device was fabricated to standardize the projection angle, and consisted of a wooden base, two rings for fixing the cone and a rotation table (Figure 2). The projection angle was determined using the rotation table with reference to a protractor. The mandible, a soft tissue equivalent material and a film-fixing device made of acrylic resin were mounted on the rotation table by adhesive tape. The mandibular occlusal plane was adjusted horizontally. A film was placed perpendicular to the occlusal plane and parallel to the line connecting the interproximal contact points of the first molar. The axis of horizontal rotation was set at the furcation entrance of the first molar. The distance between the focus and film was set at 37.5 cm. An angle of 0° was defined as when the centre of the X-ray beam was directed at a right angle to the film through the rotation axis. The projection angle was varied horizontally from -30° to +30° using the rotation table. A positive angle was defined as a projection from the mesially shifted position. Radiographs were taken every 5°, and 13 radiographs were obtained for each step of bone reduction (Figure 3).

Evaluation of radiographs

Simulated defects were classified into four grades according to the degree of bone loss determined by CT examinations (Figure 1) with reference to the classification suggested by Hamp *et al*¹⁶ and Tarnow and Fletcher.¹² This classification was carried out by two examiners (TH and MN) using i-View software (Morita, Kyoto, Japan). Almost all defects could be classified into the same grade between the two examiners. When their opinions were different, the final decisions were reached by consensus after discussion. These classifications were used as the gold standard for ROC analyses.

The definitions are as follows:

- Grade 0: Absorption is seen only in the buccal cortical bone and is not observed in the interradiacal bone.
- Grade 1: Interradiacal bone absorption is less than one-third of the buccolingual width of the tooth crown.
- Grade 2: Absorption is greater than one-third but less than two-thirds of the buccolingual width of the tooth crown.
- Grade 3: Absorption is greater than two-thirds of the buccolingual width of the tooth crown.

With the CT verifications of 5 molar areas, 19, 14, 16 and 17 defects were classified as Grades 0, 1, 2 and 3, respectively. Consequently, a total of 247 radiographs were obtained at 13 different angulations of 19 defects for Grade 0. A total of 182, 208 and 221 radiographs were obtained for Grades 1, 2 and 3, respectively.

All radiographs were randomly set in paper mounting frames (Hanshin, Osaka, Japan). Images were evaluated on a light box without magnification. Five

Figure 2 Device for standardizing the projection angle

Figure 3 Examples of radiographs obtained at different angulations. A furcation defect with Grade 1 depth between the roots of the first molar is more clearly observed on the radiograph obtained at 10° angulation (b) than on that at 0° angulation (a). Note the difference in the findings regarding the proximal surface between the first and second molars

observers (three periodontists and two radiologists) interpreted the radiographs independently under dark and quiet conditions. Each observer's interpretation was divided into three sessions to provide rest and refreshment for the observers. During the 3 sessions, a total of 858 radiographs were assessed. Short breaks were taken every 100 interpretations, and long rests were added between sessions of approximately 300 interpretations.

For the ROC analysis, each observer was asked to define the probability of the presence or absence of a furcation defect according to a five-point rating scale: 1, definitely absent; 2, probably absent; 3, unsure; 4, probably present; 5, definitely present.

Before viewing sessions, instructions were given to each observer using radiographs that were not used for actual assessments.

Anatomical measurements on CT images

To investigate anatomical characteristics of furcation areas in the mandibular first molar, 59 areas of the first molar with 2 roots in 30 adult dried mandibles (race, gender and age unknown) were investigated. The exposure conditions of CT examination were the same as for the furcation disease model examinations mentioned above. The angles of the tangential lines were measured on CT images to clarify the influence of root morphology on the detection of furcation defects (Figure 4). Two representative slices of 1 mm thickness were selected from the slice data parallel to the occlusal plane. One was the slice in which the crown showed the

Figure 4 Anatomical measurements of the horizontal angles that are thought to be suitable for detecting furcation defects. Black lines show the traced outline of the roots just below the furcation. Grey lines show the traced outline of the teeth crowns at the level of mesiodistal contact points of the first molar. Lines A and B show the mesial and distal limits, respectively

maximum area, and the other was the adjacent slice just beneath the furcation roof. Thereafter, the outlines were traced (Figure 4). The line with 0° projection angulation was determined as the line perpendicular to the line connecting the mesial and distal contact points. These slices were superimposed and the angles of the two tangential lines (Lines A and B) relative to the projection angulation of 0° were measured. These two lines passed through the inner surfaces of the distal and mesial roots. The projection directions between the angles of the two lines might be adequate for depicting furcation defects.

The traces and measurements were operated by TH and the reproducibility of these measurements (SE) was ensured using Dahlberg's formula:

$$SE = \sqrt{\sum (d1 - d2)^2 / 2n}$$

where *d1* and *d2* are measured values and *n* is the sample size.

The mean of the measurement error for the five randomly selected areas was 0.174°, which was sufficiently small, and the measurement was verified to have high reproducibility.

Statistical analysis

ROC curve analysis was used to investigate the rating data. SPSS II software (SPSS Inc., Chicago, IL) was used to perform the calculation for each observer, each angle and each grade of bone loss. The area under the ROC curve (*A_z*) was calculated as an index of accuracy. The *A_z* values for each angle in each grade were statistically compared using Welch's test.

Results

Effects of angulation

The diagnostic accuracy, as expressed by *A_z* values, was lower in Grade 1 than in Grades 2 and 3 at all angulations (Figure 5). In Grade 2 and Grade 3, the accuracies of each angulation were almost the same. The accuracies were decreased dramatically in Grades 2 and 3 at angulations of -20° or less, and at -30° they were almost the same as that in Grade 1.

In Grade 1, the *A_z* values at -30°, 30° (*P* < 0.01), -25° and -20° (*P* < 0.05) were significantly lower than the highest value (0.770) at 15°. At 0°, the *A_z* value was 0.659.

In Grades 2 and 3, high accuracies were found over a range of angulations between -15° and 25°. The highest values were 0.976 and 0.988 at angulations of 10° and 20° in Grades 2 and 3, respectively. The *A_z* values at -30°, -25°, -20° (*P* < 0.01), -15° and 30° (*P* < 0.05) in Grade 2, and at -30°, -25° (*P* < 0.01), -20°, -15°, 0°, and 5° (*P* < 0.05) in Grade 3 were significantly

Figure 5 Diagnostic accuracy (A_z value) in relation to the horizontal projection angle. The highest A_z values are observed at angulations of 15°, 10° and 20° for Grades 1 (*), 2 (**) and 3 (***), respectively. Grey vertical dotted lines are the means of Lines A and B, which indicate the mesial and distal limits, respectively, of adequate angulation

lower than the highest values noted above. At 0° angulation, the A_z values in Grades 2 and 3 were 0.939 and 0.952, respectively.

The highest A_z values were shifted towards the mesial direction in all grades (15°, 10° and 20° for Grades 1, 2 and 3, respectively), as were the ranges of angulations that showed high accuracy (Figure 5).

Anatomical measurements

The average mesial limit (Line A) was 25.8° (SD 5.5°) relative to the 0° angulation that was perpendicular to the line connecting the mesial and distal contact points. The mean distal limit (Line B) was -9.7° (SD 5.7°). The range is added in Figure 5. The accuracy (A_z value) was fairly constant within this range and decreased in either direction outside of this range.

Discussion

Because it can be difficult to measure the depth of artificially created defects with a caliper due to a thin interradicular trabecula, a new compact CBCT apparatus was used, the accuracy of which had already been verified.⁹ With this CT, it was possible to acquire a sufficient number of images to perform a ROC study and the defects could be accurately classified into one of four grades.

Although this study used the classification suggested by Hamp *et al*¹⁶ because of practical use in our clinics, Gürkan *et al*⁸ also reported that the horizontal depth of the defect had the greatest effect on observer performance when the beam angle was limited to the interdental area between the first and second molars and perpendicular to the film. In their study, defects with a horizontal depth from one-third to one-half of the width of the interradicular area were compared with those with depths less than one-third of the width. The angle used in their study corresponded to the 0°

angulation in the present study and a Lesion 1 defect in their study was almost the same as a Grade 1 defect in the present study. The results of the present study support their finding because Grade 1 defects (less than one-third depth) showed lower detectability than Grade 2 and 3 defects. However, the lack of a difference between Grade 2 and 3 defects indicated that the depth did not affect the detectability of deeper defects. The A_z value (0.676) in their study was similar to that of a Grade 1 defect (0.659) in the present study. As for Lesion 2 defects, the A_z value (0.862) was somewhat lower than that for Grade 2 defects in the present study (0.949). This discrepancy may be due to the difference in the horizontal depth of the defects. Their Lesion 2 defects ranged from one-third to one-half of the buccolingual width of the interradicular area, whereas the present study included defects beyond the midpoint. The variance in A_z values was found to be large in the Grade 1 defects, whereas it was relatively small in Grade 2 and Grade 3. This might be due to the difference in interpretation ability among observers. In Grade 3, the A_z value of 30° angulation was larger than that of 25° angulation. The cause was not clear, but there was no statistical difference between the A_z values of each angulation.

Based on the A_z value (0.659), the Grade 1 furcation involvement is somewhat difficult to detect by intraoral radiograph, and it may also be difficult by probing procedure because the bone loss is not accompanied with severe gingival recession or soft tissue attachment loss. For such defects, a compact CBCT could be effective. Actually, the evaluations of furcation defect grade on dried mandibles were almost consistent between the two observers. Although the compact CBCT is a promising tool for detecting furcation defects, we should pay attention to the radiation dose to the patients.

The present study verified that the X-ray beam projection angle affects the accuracy of the diagnosis of a furcation defect. It is evident that changes in horizontal angulation cause geometric distortion in intraoral radiography.¹⁷ Moreover, morphological factors, such as the shape of the furcation entrance, the width of the periodontal ligament space and root configurations, are considered to be related to image distortion, and they may alter the detectability of furcation involvement.

Although the angle with the highest accuracy was shifted mesially, the best projection angle for detecting proximal caries was included within the range showing high accuracy for the detection of furcation defects. As in the detection of caries in the proximal surface, the greatest accuracy is seen with 0° angulation in which the beam projects tangentially to the surface, and decreases symmetrically on both sides of 0° angulation.¹⁸ In the present study, higher detectability was observed in mesial angulations and the highest values were obtained with angulations of 10–20°. This may be due to the anatomical relationship of the mesial and distal roots with the interradicular bone between them. To investigate this

morphological relationship, reconstructed CT images were used. The angle that was thought to be appropriate for depicting the furcation area was 0° angulation, which was shifted mesially to a slight degree, similar to the A_z values (diagnostic accuracy), for the created defects.

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