RESEARCH

Preliminary results of a study comparing conventional radiography with phase-contrast radiography for assessing root morphology of mandibular third molars

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Objectives: The aim of this study was to evaluate the usefulness of phase-contrast radiography for assessing root morphology of mandibular third molars in comparison with conventional radiography.

Methods: We studied 37 extracted mandibular third molars. One oral surgeon compared the number of roots and root curvature of the extracted teeth on conventional radiographs with those on phase-contrast images.

Results: The number of roots and root curvature on conventional images differed significantly from those on phase-contrast images.

Conclusions: Our results suggest the possibility that phase-contrast radiography is more useful than conventional radiography for assessing the root morphology of mandibular third molars.

Dentomaxillofacial Radiology (2011) **40**, 91–95. doi: 10.1259/dmfr/13833682

Keywords: phase-contrast radiography; conventional radiography; root morphology; mandibular third molar

Introduction

Extraction of mandibular third molars is one of the most common procedures performed by oral surgeons. Difficulty in mandibular third molar extraction can be caused by many factors.^{1,2} Diagnostic imaging can facilitate surgical planning and risk assessment in patients scheduled to undergo extraction of mandibular third molars. Root morphology, including the number of roots and root curvature, is an important factor because a complex structure can lead to root fracture and increased operation time. Panoramic radiographs help surgeons to assess the position of third molars in relation to the surrounding anatomical structures. Extraoral radiography (EOR) with lateral oblique mandibular body projection is a well-established method for examining

lesions in the mandibular body. This method also provides information on mandibular third molars.

It is well known that radiographs are generated from the attenuation of X-rays owing to the absorption of objects. This phenomenon is called absorption-contrast imaging. A phase shift of the X-rays takes place after penetrating objects so that X-rays refract or interfere. The imaging using this phase shift in X-rays is called phase-contrast imaging. For example, the image contrast owing to the refraction of X-rays is added to the absorption-contrast images and the radiographs are sharpened by an edge effect. Recently, phase-contrast technologies were studied intensively using X-rays from synchrotron radiation and micro-focus X-ray sources.³ This technology can depict soft-tissue images such as breast cancer.⁴ Moreover, we and other investigators have previously demonstrated that phase-contrast images can depict hard tissues such as micro-calcification associated with breast cancer or trabeculae associated with the hand.^{5–7} To our knowledge, whether this

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Received 28 October 2009; revised 20 January 2010; accepted 22 January 2010

new method is useful for assessing mandibular third molars has not previously been examined.

In this study, we investigated whether phase-contrast radiography (PCR) has the potential to enhance visibility of tooth root morphology and compared the usefulness of PCR with that of conventional radiography for assessing root morphology of the mandibular third molars.

Materials and methods

Participants

All patients who consulted the Department of Oral Surgery at Saitama Medical University Hospital for extraction of mandibular third molars between February 2008 and January 2009 underwent pre-operative panoramic radiography (PR). Of these patients, 27 (12 men and 15 women; mean age, 35 years; range, 19–74 years) agreed to participate in this prospective study and underwent additional examinations by conventional EOR with lateral oblique mandibular body projection and PCR. We designated PR and EOR as conventional radiography. A total of 37 teeth were extracted and photographed. This study was approved by our institutional review board and written informed consent was obtained from all participants.

Phase-contrast radiography: theory

A phase shift is observed as refraction or interference of X-ray. Phase imaging is classified into four techniques as follows: microscopic, interferometric, refraction-based and propagation-based.⁸ The method used in this study is the propagation-based technique. Under

spatially incoherent illumination, the refraction is observed at a distance away from an object even in the hard X-ray region. Setting a proper distance between an object and an X-ray image detection plane is essential. In this system there are two properties: (1) the X-ray source is a usual clinical tube, and (2) the X-ray emitted from the source forms a polychromatic cone beam that spreads through propagation. From an interpretation of Snell's law of refraction for PCR, an X-ray beam refracts after penetrating the object. Because the X-ray refractive index of solids $n = 1 - \delta$ ($\delta \ll 1$) is less than unity, the object acts as a diverging lens. Thus, X-ray intensity is increased just outside the fringe of the object image, and is decreased just inside the image fringe resulting in the so-called edge effect shown in Figure 1. This edge-enhancing effect that was obtained by using a clinical X-ray source equipped with approximately 100 μm of focal spot is not the same as that obtained by Fresnel diffraction. While the interference of waves plays a leading role in Fresnel diffraction,⁵ this system captures and extracts the subtle refraction of incoherent X-rays through magnification of the image.

Equipment

Phase-contrast X-ray imaging: We used a prototype X-ray tube with a tungsten anode and a nominal 100 μm focal spot, the UH-3FD-070E (Hitachi Medical, Tokyo, Japan). The distance from the focal spot of the X-ray tube to the object table (R1), and from the object table to the phosphor plate (R2) were $R1 = 0.69$ m and $R2 = 0.51$ m (Figure 2). Consequently, the X-ray image was magnified 1.75 times. The voltage of the X-ray tube was set at 65 kVp and the current of the

Figure 1 A schematic diagram of edge effect caused by phase contrast. The difference in X-ray intensity is caused by absorption by the object and edge enhancement is caused by refraction of X-ray

Figure 2 A phase-contrast radiography machine, the technique used for exposure and the position of a patient. The geometry of the apparatus was as follows: R1, distance between X-ray source and object; and R2, distance between object and imaging plane

tube was set at 25 mA (exposure time 400 ms). The phosphor plate and the computed radiography (CR) system were the RP-6PM and the Regius Model 190, respectively (Konica Minolta, Tokyo, Japan), which were designed for the phase-contrast mammography system. The sampling pitch was 43.75 μm . The X-ray images were printed by a dry photographic printer Drypro Model 793 (Konica Minolta), which uses 25 μm pixels, so that the 1.75 times-magnified image at image acquisition was reduced to the original object size on the film. To obtain suitable images of the mandibular third molar it is necessary to tilt the head toward the unaffected side (Figure 2).

Conventional X-ray imaging: For EOR, DRX-3724HD (Toshiba, Tochigi, Japan) was operated at a tube voltage of 64 kVp and a tube current of 200 mA (exposure time 0.28 s). We used the X-ray tube with a nominal 600 μm focal spot with a tungsten anode. The geometric distance R1 for EOR is 1.2 m, and R2 is 0 m. For PR, we used Auto2000EX (Asahi Roentgen, Kyoto, Japan), which was operated at 72–80 kVp, and a tube current of 10 mA (exposure time 12 s). A phosphor plate RP-3S (Konica Minolta) and a CR system Regius 190, where the sampling pitch was 87.5 μm , were used. The

acquired images were printed by a dry photographic printer Drypro 793 with 87.5 μm pixels.

Evaluations

We evaluated whether the root morphology on radiographic images, as interpreted by one oral surgeon (an observer), was in concordance with that of the extracted tooth regarded as standard. Root morphology was evaluated on the basis of (1) the number of roots and (2) root curvature as described below, and the images were classified as “concordant” or “non-concordant”. Briefly, the observer looked at the extracted tooth and subsequently at the radiographs and decided if the images were concordant or non-concordant. If the image coincided with the extracted tooth it was classified as concordant. If the image did not coincide with the extracted tooth it was classified as non-concordant. The concordance rate was defined as the number of teeth showing concordance divided by the number of participants $\times 100$. Some examples are shown in Figure 3.

Number of roots: The number of roots was classified as concordant (including one, two or three roots) or non-concordant. We defined a root that had many root canals with no alveolar septum among the root furcation as a single root. Figure 3a shows an example of non-concordance. The number of roots was two on the phase-contrast image, but could not be determined on the conventional image. The conventional radiographic image was categorized as non-concordant.

Root curvature: Root curvature was categorized as concordant (*i.e.* the presence or absence of curvature could be determined) or non-concordant. Figure 3b shows an example of non-concordance. Root curvature was present on the phase-contrast image, but could not be identified on the conventional image. The conventional radiographic image was categorized as non-concordant.

Statistical analysis

Statistical analysis was performed using the McNemar test and Cochran’s Q test (SPSS Statistics 17.0 for Windows, SPSS Inc., Chicago, IL). A *P*-value of <0.05 was considered to indicate statistical significance.

Results

The numbers of roots showing concordance (concordance rate) on each type of radiographic examination were as follows: 28 (75.7%) on PR, 28 (75.7%) on EOR and 34 (91.9%) on PCR. The difference between PR (or EOR) and PCR was significant ($P = 0.0313$). As for root curvature, the numbers of roots showing concordance (concordance rate) on each type of radiographic examination were as follows: 22 (59.5%) on PR, 22 (59.5%) on EOR and 33 (89.2%) on PCR. The difference between PR (or EOR) and PCR was significant ($P = 0.001$). The data are shown in Table 1.

Figure 3 Examples of evaluations of root morphology. (A) Extracted tooth with two roots. The number of roots on the phase-contrast radiography (PCR) image coincided with that of the extracted tooth. (B) The extracted tooth showed root curvature. Root curvature on the PCR image coincided with that of the extracted tooth. EOR, extraoral radiography

Discussion

In the present study of root morphology the concordance rate of phase-contrast images was higher than that of conventional images owing to phase-contrast images being more legible than conventional images. Clinically, phase-contrast images are useful for evaluating root morphology of mandibular third molars. Gbotolorun *et al*⁹ reported that root curvature was associated with increased surgical difficulty in the removal of mandibular third molars. Sharp images of root morphology provide useful information about the need for root separation and the direction of root division, leading to decreased removal of alveolar bone, a shorter time for extraction and less surgical stress.

Although phase-contrast techniques were developed using synchrotron radiation in the 1990s, synchrotron radiation equipment was too large to be used clinically.^{10–12} Subsequently, Wilkins *et al* applied the Fresnel theory of diffraction and obtained sharpened

images better than those produced by contact imaging, but the power of the microfocus X-ray tube was too weak to permit medical use.¹³ Tanaka *et al* established a digital X-ray imaging system for mammography with an improved, more practical X-ray tube.⁵ We have previously shown that an image of the hand of a patient with rheumatoid arthritis was more clearly depicted when obtained on PCR than on conventional radiography because of the higher spatial resolution of the former.⁶ The Talbot-Lau-type method, which is a phase-contrast technology, is normal for practical use.¹⁴ This method does not need a special X-ray tube; however, it is essential to use special grating to obtain images. At present, minute processing for special grating is so difficult that this method does not apply for clinical use.

CT analysis is the most valuable method for pre-operative assessment of the mandibular third molar, but cannot be used routinely to assess root morphology because of its high cost and high radiation exposure to

Table 1 Number of concordant images and concordance rate for root morphology

	<i>Number of roots</i>	<i>Root curvature</i>
	<i>Number of concordant roots (concordance rate %)</i>	<i>Number of concordant roots (concordance rate %)</i>
PR	28 (75.7)	22 (59.5)
EOR	28 (75.7)	22 (59.5)
PCR	34 (91.9)*	33 (89.2)**

PR, panoramic radiography; EOR, extraoral radiography; PCR, phase-contrast radiography

**P* = 0.0313

***P* = 0.001

patients.^{15–17} Phase-contrast techniques, however, provide higher-resolution images than those obtained by conventional radiography despite a similar radiation dose. PCR may, therefore, replace conventional radiography in the long term. PCR has four advantages over cone beam CT (CBCT). First, the cost of PCR equipment is only about one-tenth that of CBCT. Second, the resolution of PCR is about ten times that of CBCT and PCR can provide excellent images about clinical information. Third, the effect of the blur owing to body movement is minimized in PCR because of the short exposure time, which is within 1 s. The exposure time of CBCT takes about 10 s to obtain images. Fourth, while the amount of irradiation in CBCT is 79.8 mAs (6 mA $\times$ 13.3 s), in PCR it is only 10 mAs (25 mA $\times$ 0.4 s). Since the distance between an object and an X-ray tube of CBCT is similar to that of PCR and the tube voltage of CBCT is higher than that of PCR, we can estimate that the amount of radiation absorbed in PCR is not quite one-tenth of CBCT.

As the X-ray tube for PCR was improved with a slight change of conventional X-ray tube, the cost of the X-ray tube for PCR is almost equal to that of the conventional X-ray tube. While the PCR machine is very large at present, it is possible to improve the machine to minimize

the size as well, to be comparable to a conventional machine. We believe that PCR can be used for routine workups and diagnosis regarding anatomical characteristics and lesions of the jaw because it provides sharp images and high spatial resolution. The use of PCR for dental and cephalometric evaluations may improve diagnostic accuracy and contribute to further progress in root-canal and orthodontic treatment. We are now collaborating with Konica Minolta to develop phase-contrast cephalometric equipment for practical use. In this study, a subjective evaluation of image quality still remains because the observer already knew the image type (PR, EOR or PCR) in advance. To remove this subjective judgement, it is necessary to increase the number of observers. Further studies are needed to obtain exact results as to whether PCR is more useful than conventional radiography.

In conclusion, our results suggest that PCR may be more useful than conventional radiography for assessing the root morphology of mandibular third molars.

Acknowledgments

The authors declare no conflict of interest.

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