RESEARCH ARTICLE

The development of new image receptor-holding instruments with appropriate horizontal X-ray beam angulation for periapical radiographs

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Objectives: This study aimed to develop new image receptor-holding instruments with appropriate horizontal X-ray beam angulation, based on the anatomical data of posterior region interproximal surfaces derived from archived CT images.

Methods: CT images of 92 patients with sound upper and lower dental arches were collected from our CT database and analyzed to determine the angles between the tangential interproximal contact line and the central groove line of posterior teeth. The average angle for each site was calculated and used to modify instruments using a three-dimensional printer. The utilities of the conventional and the modified instruments for viewing proximal surfaces were compared using two dry skulls.

Results: The right and left sides of each site, except for the lower second premolar and first molar sites, did not differ significantly. The difference between the sites was 2.0°; hence, we calculated mean values for the two sides at each site. In the maxilla, the angles of the first and second premolar, second premolar and first molar, and first and second molar to the groove line were 83.9° (±5.4°), 84.4° (±3.9°), 81.6° (±5.1°), while those in the mandible were 85.0° (±9.2°), 85.0° (±4.0°), and 90.6° (±4.9°), respectively. The holding instruments modified to 80° demonstrated better proximal viewing ability in the upper molar region than conventional instruments.

Conclusions: The mean angles of the interproximal surfaces were determined from CT data. The image receptor holding-instruments were modified according to these angles to allow appropriate X-ray angulation, which facilitated improved observation of the proximal surfaces of teeth in the posterior region in this pilot *in vitro* study.

Dentomaxillofacial Radiology (2019) 48, 20180354. doi: [10.1259/dmfr.20180354](https://doi.org/10.1259/dmfr.20180354)

Cite this article as: Wamasing P, Watanabe H, Tsuchida Y, Ohbayashi N, Suzuki T, Kurabayashi T. The development of new image receptor-holding instruments with appropriate horizontal X-ray beam angulation for periapical radiographs. *Dentomaxillofac Radiol* 2019; 48: 20180354.

Keywords: dental radiography; holding instruments; periapical radiograph; X-ray beam

Introduction

Periapical radiographs are commonly used for examination of teeth and their periodontal structures in dental practice.¹ There are two types of periapical

projections, based on either bisectonal or paralleling techniques; in Japan and Thailand, these are usually obtained using image receptor-holding instruments.² These instruments are composed of an image receptor holder, external guiding ring, bite piece for fixation *per se*, and arm connecting the latter two elements

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Received 24 September 2018; revised 13 December 2018; accepted 14 December 2018

Figure 1 The conventional and modified image receptor-holding instruments for periapical radiography. (a) The photograph shows the Uni-GripAR (Dentsply RINN, York, PA), which was composed of a receptor holder (1), external guiding ring (2), bite piece (3), and connecting arm (4), shown in (b). (c) The photograph shows the conventional arm at 90° on the left, and the modified arm with 80° on the right. The latter was made using a three-dimensional printer. (d) The photograph shows the modified instruments. A putty-type impression paste was used to compare the conventional and modified instruments.

(Figure 1a,b). The external guiding ring orients the X-ray beam direction perpendicular to the image receptor and plays a role in preventing a cone cut.² However, this ring is parallel to the bite piece; therefore, the X-ray sometimes does not quite pass through the contact points between interproximal surfaces. Consequently, overlapping of the crowns occurs, which makes it difficult to diagnose caries present on proximal surfaces.^{3,4}

We speculated that this issue was related to the instrument's design, particularly the orientation of the guiding ring parallel to the bite piece, and that the issue could be addressed by identifying the appropriate horizontal angulation. Thus, the aim of this study was to develop a new image receptor-holding instrument with more appropriate horizontal X-ray beam angulation for use in periapical radiography.

Methods and Materials

To attain the aim of this study, we used CT images of patients with sound dental arches, and determined the average horizontal angles between the tangential interproximal contact line to the interproximal surfaces and central groove line of the posterior teeth.

Then, we used this information to produce a modified instrument, using a three-dimensional (3D) printer, and explored its performance in two dry skulls.

Patients and CT data

To determine the horizontal direction angles in periapical radiographs, we collected CT images of patients who had sound upper and lower dental arches from our CT database. We identified 661 cases using the keyword “impacted teeth.” These patients underwent

CT between January 2010 and March 2017 at Tokyo Medical and Dental University, Dental Hospital, and this keyword indicated that the patients underwent CT for the diagnosis of multiple wisdom teeth and/or hyperdontia. The inclusion criteria were patients with sound upper and lower dental arches, especially normal posterior teeth contacts from the first premolar to the second molar. The exclusion criteria were cases with evident tooth crowding and severe metallic or motion artifacts. Eventually, 92 patients were enrolled in this study. These included 38 males and 54 females (mean age, 25.4 years; range, 11–43 years).

This study was approved by the institutional review board of Tokyo Medical and Dental University (D2017-043). The requirement for informed patient consent was waived due to the retrospective nature of this study.

CT image acquisition

CT examinations were performed using a Somatom Sensation 64 scanner (Siemens Medical Systems, Erlangen, Germany), which operated with the following parameters: tube voltage, 120 kV; effective tube current, 140 mA; collimation, 64×0.6 mm; and pitch, 0.6. Thin-slice bone images were retrieved from the imaging server; these had been reconstructed using a slice thickness of 0.6 mm, 0.3 mm increment, and H60s sharp kernel. The thin-slice images were imported to 3D card software

(Siemens) on the CT console, and a maximum intensity projection (MIP) image with a 2 mm slice thickness was obtained. All the contact points of premolar and molar teeth were included on that image (Figure 2a). The MIP images were printed on film with a Fuji Dry imager (Fuji Film Medical Co. Ltd., Tokyo, Japan) and used for evaluation. Patient information had been masked on the films and identification numbers had been converted to serial case numbers.

Image analysis for determining the angles of interproximal surfaces

The printed CT images were traced on tracing paper (Somar Co. Ltd., Tokyo, Japan). The posterior teeth outlines were contoured from the first premolar to the second molar, and their central grooves were also traced. Then, the grooves were connected by a simple line (Figure 2b). The tangential line was drawn, passing each interproximal contact point and assuming an appropriate horizontal X-ray beam angulation (Figure 2c). The angles between these two lines were measured in 12 locations (3 contact points $\times$ 4 posterior sites in an oral cavity) using a protractor APJ133 (Raymay Fujii Corp., Tokyo, Japan). This measurement process was repeated three times by one observer (PW), with a 2-week interval, to assess intraobserver reliability. In total, the 1104 interproximal angles of 368

Figure 2 Representative CT image and its tracing outlines and measured locations. (a) The CT image of the upper dental arch from one patient (female, 23-years-old). This minimal intensity projection image of 2 mm thickness included all the contact points in the posterior regions. The window width and the window level were set to 3500 and 500, respectively. (b) The tracing schema of the crown outlines and the central groove lines that were traced on the image in (a). (c) The tangential lines passing the contact points were drawn on image (b). The angles indicated in this figure were measured using a protractor.

posterior sites from 92 patients were each measured 3 times. Another observer (HW) independently measured the angles for 10 randomly selected cases to determine interobserver reliability.

Statistical analysis

Each measurement was performed three times and then the mean was calculated. The inter- and intraobserver reliabilities were determined using the intraclass correlation coefficient (ICC). Paired *t*-tests were used to compare the angles between the right and left sides. All statistical analyses were performed using IBM SPSS Statistics software v. 20.0 (IBM Corp., Armonk, NY). Data were deemed statistically significant if $p < 0.05$.

Design and trial of new holding instruments

Based on the obtained data, a new holding device was created. The Uni-GripAR (Dentsply RINN, York, PA) was employed as a template (Figure 1a,b). Its positioning arm has a 90° bend, which we customized to our desired angle. The arm size was measured manually and data were inputted into 3D computer-aided design software (FreeForm ModelingPlus v.12.0; Geomagic, Inc., Raleigh, NC). Next, the angle was altered to 80° on the software and a modified arm was printed with an inkjet printer (Objet30 Prime, Stratasys Ltd., Eden Prairie, MN) using a resin material (Figure 1c). The angle of 80° was employed, targeting the interproximal surface between the upper first and the second molars.

The constructed positioning arm was tested against two dry skulls. Both skulls were stored in our department, but lacked information about nationality, age, and sex, and also lacked several tooth contacts, except for the left upper posterior site. The conventional and modified arms were thus used to view the left upper posterior site. For an exact comparison between the two arms, we devised the bite piece to be set in the same position using an EXAFINE silicone impression putty-type material (GC corporation, Tokyo, Japan) as shown in Figure 1d. X-ray exposure was performed by using a maxiX generator (Morita Corp., Kyoto, Japan) with the following parameters: tube voltage, 70 kV; tube current, 7 mA; and 0.32 s. The image was visualized using a CS 7600 imaging plate-type system (Carestream Dental, Rochester, NY). The images were visualized using a high-speed scanning mode and exported as Digital Imaging and Communication in Medicine files. All

images were observed on ImageJ 1.43u software (<http://rsb.info.nih>) running on a personal computer.

Results

The interobserver reliability measurements yielded ICC values of 0.674, 0.719, and 0.733, which indicated substantial reliability. The intraobserver reliability of all three data sets yielded an ICC of 0.904, indicating excellent reliability. Following this, we calculated the mean value of the three data sets (Table 1 and Figure 3). As the right and left sides appeared to yield similar values, we assessed this by paired *t*-test. This confirmed that the sides were not significantly different, except for the LR5/6 and LL5/6 ($p = 0.002$) pairs (where LR5/6 and LL5/6 refer to the interproximal sites between the second premolar and first molar in the right and left sides of the lower dental arch, respectively; Figure 3). The angle in LR5/6 was significantly larger than LL5/6. However, the mean difference between these values was only 2.0°; therefore, we unified the angle data by calculating the mean left and the right values for each site. The angles for the interproximal surfaces of the first and second premolar, second premolar and first molar, and first and second molar in the maxilla were 83.9° ($\pm 5.4^\circ$), 84.4° ($\pm 3.9^\circ$), 81.6° ($\pm 5.1^\circ$), and those in the mandible were 85.0° ($\pm 9.2^\circ$), 85.0° ($\pm 4.0^\circ$) and 90.6° ($\pm 4.9^\circ$), respectively.

The periapical radiographs of the dry skulls using the conventional 90° and the modified 80° instruments are shown in Figure 4.

Discussion

Periapical radiographs are widely used for searching for proximal caries, but the overlap of interproximal surfaces can hamper their diagnostic performance.⁴ This is due to an error of horizontal angulation of the X-ray beam or tooth crowding.^{5,6} Image receptor-holding instruments are usually used for this examination, of which there are two types, for anterior and posterior teeth. The anterior type is used for incisal or canine teeth and enables the visualization of a proper image, because the targeted object and appropriate direction for the X-ray are directly visible to the practitioner. However, this is more difficult for posterior teeth, because the dental

Table 1 The horizontal angles for periapical radiographs, which were averaged from the data for the left and the right

	4/5	5/6	6/7
Upper dental arch	83.9 $\pm$ 5.4	84.4 $\pm$ 3.9	81.6 $\pm$ 5.1
Lower dental arch	85.0 $\pm$ 9.2	85.0 $\pm$ 4.0	90.6 $\pm$ 4.9

4/5, 5/6, and 6/7 indicate the angle between the first and the second premolars, the second premolar and the first molar, and the first and the second molars, respectively. The values were presented as average $\pm$ standard deviation.

Figure 3 The box plot graph of mean horizontal angles. The box represents the quartile range, the horizontal bar in the box represents the median, and the upper and lower whiskers represent maxima and minima, respectively. Circles indicate outliers. LR6/7 is the angle between the first and the second molars of the lower jaw on the right side. LL, UR, and UL are regions in the lower jaw on the left side, the upper jaw on the right side, and the upper jaw on the left side, respectively. The numbers 4, 5, 6, and seven indicate the first premolar, the second premolar, the first molar, and the second molar, respectively. * significant difference between the left and the right determined by a paired *t* test ($p < 0.05$).

arch is hidden behind the cheeks and cannot be visualized directly. Thus, the appropriate placement of the instruments depends on the practitioners' experience.

To overcome this problem, we considered the appropriate horizontal angulation in posterior regions. Literature suggests that the horizontal angulation should be at 70–80° and 80–90° to the sagittal plane of the head, and in the premolar region in the molar region, respectively.^{5,6} However, we considered that the sagittal plane could not be easily recognized, and a range of 10° in either region was large, making it unlikely to reduce an overlapping error. Hence, in this study we considered that the groove line in a posterior tooth should be the base plane, because the bite piece of Uni-GripAR has several parallel grooves on the bite plate that might potentially act as a guide parallel to the groove line or a cuspidis dentis line. If this was correct or could be modified to add further fitting mechanisms to a dental arch, our measurement would be valid.

We found that the horizontal angle of the Lower 6/7 site was almost 90° in patients with sound dental arches; however, for other sites, the angle was smaller: the Upper 4/5, Upper 5/6, Lower 4/5, and Lower 5/6 sites had angles of approximately 84°, and the Upper 6/7 site angle was approximately 80°. Thus, conventional instruments would be appropriate only for the lower molars, but for the other posterior sites, the X-ray projection angle should be shifted from the anterior by 6° or 10°, depending on the site. We demonstrated this in the upper molar region using our modified instruments. The periapical radiograph taken with the instrument with an 80° arm showed

better visualization of the proximal surfaces than the conventional instrument with a 90° arm. However, our demonstration in this study was based on dry skulls, and the utility of the modified instruments should be confirmed in a larger randomized clinical trial, once regulatory and institutional approval have been obtained for use of the prototype device.

We showed that the modified instrument reduced the amount of overlap in proximal surfaces in this pilot *in vitro* study. However, we used a Uni-GripAR as a template, the bite piece of which is also used for the receptor holder. Hence, we changed the connection arm angle to 80°, but the X-ray beam therefore inevitably penetrated into the receptor from a diagonal direction of 10 degrees, rather than perpendicularly. This potentially causes image distortion, especially when extending in the horizontal (from mesial to distal) direction. This could be avoided by using a design in which the receptor holder is separate from the bite piece, with a connecting arm, and with adjustment of only the bite piece to the appropriate angle possible. However, attempting this modification was not possible in the current study.

Use of mean values might be considered inappropriate due to interindividual variation in dental arches. The data were obtained from the patients in Tokyo Medical and Dental University, Dental Hospital, the majority of whom were of Asian (Japanese) origin, and thus might not be generalizable to other ethnic groups. We used images from patients with sound dental arches; these participants tended to be young (<41 years). Therefore, our data represented

Figure 4 Periapical radiographs taken of the upper molar region of two dry skulls, using the conventional (90°) and modified (80°) instruments. The images taken with the 90° arm showed some overlapping of the proximal surfaces between the first and second molars, but those taken with 80° arm are considerably improved.

relatively younger, rather than older, dental arches. The standard deviations of our measurements were small, within approximately 10°, and the angle values for sites, other than Lower 6/7, were considerably less than 90°. This meant that the angle adjustable instruments may be valuable in practice. Our data would be invalid in cases with crowded teeth, and the instrument's angle may need to be adjusted on the prepared plaster study model in advance, to allow individualized dental medicine. This study was performed assuming that the data would be used for periapical radiography, but they may also be applicable for bite-wing radiographs, because the angles determined here are the same between the two radiographic techniques.

This study was based on the medical CT images. We collected patients using the keyword, “impacted teeth”, but as a result we included a patient with multiple wisdom teeth and/or hyperdontia. It is standard perform a cone-beam CT for the examination of impacted teeth, and we also agree that this is preferred choice with regards to radiation exposure. However, for patients with multiple wisdom teeth, the medical

CT was often chosen because a single medical CT scan has a medical economical advantage compared with multiple cone-beam CT scans. Medical CT images could provide us with whole dental arches, which would enable efficient measurement of the interproximal angles.

Commercialization of these angle-adjustable instruments may permit more appropriate periapical imaging. In addition, such instruments could be used for the evaluation of interproximal bone loss and observation of root canals; it has been reported that evaluation of interproximal or furcation bone defects requires an optimal projection direction,^{7,8} and that three-rooted mandibular first molars could be observed with a specific projection angle.⁹ These lesion-specific situations, and the appropriate projection angles for their observation, cannot be known in advance; however, when previous imaging studies, such as CT examinations, are available, a follow-up periapical radiograph could be optimized using a more appropriate projection facilitated by this instrument modification.

Conclusion

The mean interproximal surface angles were determined from a CT database, and the image receptor holding-instruments were modified according to these angles to allow appropriate X-ray angulation, which facilitated improved observation of the proximal surfaces of teeth in the posterior region in this pilot *in vitro* study.

Acknowledgments

The authors would like to thank to Ms. Masako Akiyama, Research University Promotion Organization URA Room, for statistical analysis consultation.

References

1. Bohay RN. The sensitivity, specificity, and reliability of radiographic periapical diagnosis of posterior teeth. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology* 2000; **89**: 639–42. doi: <https://doi.org/10.1067/moe.2000.105908>
2. Rushton VE, Horner K. A comparative study of radiographic quality with five periapical techniques in general dental practice. *Dentomaxillofac Radiol* 1994; **23**: 37–45. doi: <https://doi.org/10.1259/dmfr.23.1.8181658>
3. Arijji Y, Shimizu Y, Okano T, Matsui O, Naitoh M, Yuasa H, et al. Influence of X-ray beam angulation in the detection of proximal caries: Interobserver agreement in the CCD system. *Oral Radiology* 1999; **15**: 27–35. doi: <https://doi.org/10.1007/BF02489754>
4. White SC, Pharoah MJ. *Oral radiology principles and interpretation*. 7th edn. St. Louis: Elsevier; 2014.
5. Iannucci JM, Howerton LJ. *Dental radiography principles and techniques*. 4th edn. St. Louis: Elsevier; 2012.
6. Ennis LM, Berry HM, Phillips JE. *Dental Roentgenology*. 6th edn. Philadelphia: Lea and Febiger; 1967.
7. Eickholz P, Hausmann E. Accuracy of radiographic assessment of interproximal bone loss in intrabony defects using linear measurements. *Eur J Oral Sci* 2000; **108**: 70–3. doi: <https://doi.org/10.1034/j.1600-0722.2000.00729.x>
8. Hishikawa T, Izumi M, Naitoh M, Furukawa M, Yoshinari N, Kawase H, et al. The effect of horizontal X-ray beam angulation on the detection of furcation defects of mandibular first molars in intraoral radiography. *Dentomaxillofac Radiol* 2010; **39**: 85–90. doi: <https://doi.org/10.1259/dmfr/99338642>
9. Wang Q, Yu G, Zhou XD, Peters OA, Zheng QH, Huang DM. Evaluation of x-ray projection angulation for successful radix entomolaris diagnosis in mandibular first molars in vitro. *J Endod* 2011; **37**: 1063–8. doi: <https://doi.org/10.1016/j.joen.2011.05.017>

The authors are grateful to Dr Kei Sakamoto from the Department of Oral Pathology, Tokyo Medical and Dental University, and Dr Atsushi Kaida from the Department of Oral Radiation Oncology, Tokyo Medical and Dental University, for providing useful suggestions. This work was supported in part by the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Number 16K11498. We would like to thank Editage (www.editage.jp) for English language editing.

Conflict of interest

The authors declare that they have no conflicts of interest.