Original Contributions

Accuracy of extraoral bite-wing radiography in detecting proximal caries and crestal bone loss

Micah Chan, DDS, MS; Tenzin Dadul, MDS; Robert Langlais, DDS, MS; David Russell, DDS; Mansur Ahmad, BDS, PhD

ABSTRACT

Background. Extraoral bite-wing (EB) radiography is an imaging technology used in dentistry. The authors conducted an in vivo study comparing the accuracy of intraoral bitewing (IB) radiographs and EB radiographs for proximal caries and bone loss diagnosis.

Methods. The authors recruited 116 patients who received IB radiographs to receive EB radiographs. The 5 calibrated authors made a consensus radiographic diagnosis of proximal caries and crestal bone loss. For this study, they assumed IB radiographs as the criterion standard. Next, they obtained EB radiographs for the 116 patients and calculated sensitivity, specificity, and false-positive rates against each patient's IB radiograph.

Results. The patients' EB radiographs revealed a significantly greater number of caries and crestal bone loss findings compared with their IB radiographs. The EB radiographs had a high to excellent sensitivity and moderate to low specificity of caries and crestal bone loss findings, respectively. Considering IB radiographs to be the criterion standard, the false-positive rate for EB radiographs was moderate for caries and high for bone loss diagnosis.

Conclusions. The EB radiographs, which generate fewer images of overlapping proximal surfaces, have the advantage of detecting more carious lesions and bone loss findings than the IB radiographs do, but with the disadvantage of more false-positive diagnoses. Further research is needed to evaluate if the false-positive findings represent true carious lesions and bone loss.

Practical Implications. EB radiography is a promising technology, which has several advantages over traditional IB radiography. Clinicians should be aware of false-positive diagnosis of caries and bone loss with EB radiography.

Key Words. Bite-wing radiography; caries; periodontal bone loss.

JADA 2018:149(1):51-58
https://doi.org/10.1016/j.adaj.2017.08.032

Widely used intraoral bite-wing (IB) radiography is less than perfect in diagnosing proximal caries or crestal bone loss. For proximal caries diagnosis, both visual-tactile methods and bite-wing radiography result in a limited sensitivity and a high specificity.[1-3] Traditional bite-wing radiographs are reported to reveal only approximately 60% of proximal carious lesions.[4] Although intraoral radiographs underestimate crestal bone loss,[5,6] bite-wing radiography remains the preferred clinical tool for examination. Other diagnostic tools—for example, fiber-optic transillumination or cone beam computed tomography—provide limited diagnostic information in caries or periodontal disease detection.[7,8]

Using film-based panoramic radiographs, several studies showed low diagnostic utility of panoramic radiographs in detecting proximal caries or crestal bone levels.[9-15] Those studies, therefore, affirmed bite-wing radiography remained the sole radiographic mode of examination for proximal caries and crestal bone diagnosis.

In the last 10 years, some panoramic x-ray units have been developed that generate extraoral bite-wing (EB) radiographs using digital sensors and the robotic motion of a panoramic x-ray tube. Several in vivo and in vitro reports have shown promising results of EB radiography in proximal caries diagnosis.[4,16-19] Marginal bone loss diagnosis using panoramic radiography is comparable to bite-wing radiographs.[15] Using a small sample size of 20 participants, Terry and colleagues[17] showed that proximal caries diagnosis was not significantly different between intraoral and extraoral panoramic bite-wings.

Given these reports on EB radiography, understanding uses and limitations would be important to identifying practical clinical integration. The purpose of this study was to evaluate the diagnostic ability of EB radiography, in contrast to that of IB radiography, for proximal caries and proximal bone loss diagnoses.

METHODS

For this study, we used a radiography program (True Bitewing [Planmeca]) on a panoramic machine (ProMax 2D S3, [Planmeca]), which used a patented technology (SCARA [Selectively Compliant Articulating Robotic Arm]). This technology used a fully programmable 3-axis robot to control the rotation and angles of the radiographic beam aimed perpendicularly with the long axis of the patient's teeth.[17,19] The radiography program generated bilateral EB radiographs with 1 movement of the machine. Each EB radiograph typically captured complete crowns and roots of canines to third molars of both arches. Using this program, our prospective study's specific aims were to compare the diagnostic accuracy of IB and EB radiographs generated by the panoramic unit for proximal caries, and to compare the diagnostic accuracy of IB and EB radiographs generated by the panoramic unit for proximal bone loss.

Participants

The Institutional Review Board of the University of Minnesota approved the study. We screened new patients from the University of Minnesota School of Dentistry in Minneapolis, MN, to identify those who had radiographic evidence of caries or bone loss. We exposed patients' dentitions diagnostically using IB (horizontal or vertical) radiographs (Schick intraoral digital x-ray sensors, Schick AimRight adhesive positioning system, Sirona Dental) before inclusion in the study, as a part of their diagnostic workup. Inclusion criteria for this study was presence of posterior dentition, normal tooth alignment, and contacts between posterior teeth. Exclusion criteria were orthodontic or prosthetic appliances that compromised proximal views of teeth, severe posterior crowding, and pregnancy.

We enrolled participants. Informed consent was obtained. Their dentitions were exposed for EB radiographs (True Bitewing, ProMax S3). Participants were then compensated financially. All identifying information was removed from the resulting digital EB radiographs.

Examiners

Five examiners—2 board-certified oral and maxillofacial radiologists (R.L. and M.A.), 1 general dentist in private practice (D.R.), 1 radiology clinical assistant professor (T.D.), and 1 periodontal resident (M.C.)—reviewed the radiographs. We viewed images on individual 22-inch monitors (Dell) in a dimly lit room. We examined all images using viewing software (Romexis, Planmeca).

Interexaminer calibration

All examiners reviewed 20 vertical IB radiographs, 20 horizontal IB radiographs, and 20 EB radiographs to reach $\geq$ 90% interexaminer reproducibility on identification of proximal caries and proximal bone loss before examining the study participants' radiographs.

Evaluation of the radiographs

We separately evaluated each participant's IB and EB radiographs and generated for each patient's tooth and each proximal surface, a consensus caries and bone loss diagnoses. For the diagnosis of caries, our observations were coded as follows: 0, proximal surface with no caries; 1, caries less than one-half way through the enamel; 2, caries more than one-half way through the enamel but not into dentin; 3, caries into dentin but less than one-half way through the dentin; 4, caries more than one-half way through the dentin; 5, overlapping contacts; 6, missing tooth; 7, surface not seen on image; and 8, defective margin of a restoration. If multiple characteristics were observed (such as overlapping contacts, yet evident carious lesion), we recorded the most critical observation, the presence of caries.

For the diagnosis of bone loss, recorded observations were 0, proximal bone not visible; 1, bone loss evident (> 1.5-millimeter distance from alveolar crest to cementoenamel junction); 2, normal

ABBREVIATION KEY

EB: Extraoral bite-wing.
IB: Intraoral bite-wing.

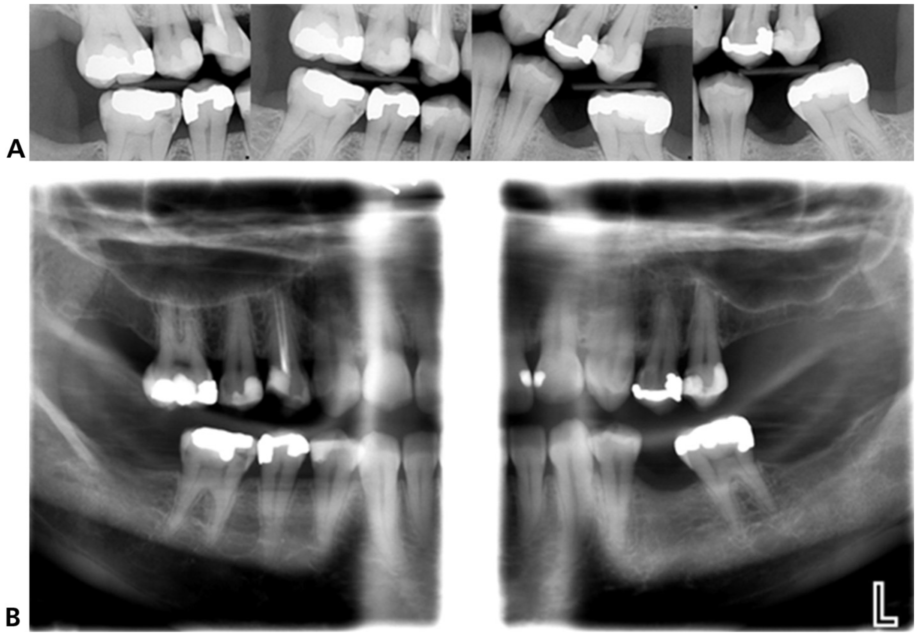

Figure. A. Intraoral bite-wing radiographs revealing proximal caries and status of the crestal bone level. These images captured the crowns and most of the alveolar crests. B. Extraoral bite-wing radiographs revealing proximal caries and the status of the alveolar crest. These images captured areas beyond the periapical regions.

bone level (≤ 1.5-mm distance from alveolar crest to cementoenamel junction); 3, tooth not in image; and 4, missing tooth. If multiple characteristics were observed (for example, normal bone level on the mesial aspect, although bone loss on the distal aspect), we recorded the most critical observation, bone loss. Observations for bone loss were designated for a single tooth, regardless of aspect (mesial or distal) and severity.

Statistical analysis

We used counts and percentages to summarize the caries and bone loss assessments. Using a generalized estimating equations model, we calculated percentage agreement along with a 95% confidence interval for the subset of locations in which caries (or bone loss) could be assessed on both IB and EB images. This model takes into account within-participant correlation. In addition, we calculated sensitivity, specificity, and false-positive rates. We used similar models to compare caries detection (or bone loss) rates between images. We used statistical software (SAS Version 9.3, SAS Institute) for the analyses.

The primary outcome for this study was the level of agreement between IB and EB radiographs in the diagnosis of proximal caries and bone loss. Secondary outcomes evaluated were presence of overlap, number of diagnostic surfaces, and observations of pathologies.

RESULTS

The study population of 116 patients who had conventional IB radiographs for their diagnostic workup (Figure 1A) was evaluated in our study using EB radiographs (Figure 1B).

Caries

For caries evaluation, 4,056 potential proximal surfaces were examined (Table 1). Owing to the size of the intraoral sensor, 918 proximal surfaces (22.63%) were not visible on IB radiographs. In comparison, only 55 proximal surfaces (1.36%) were not visible on EB radiographs. In addition, 104 (IB radiograph) and 105 (EB radiograph) surfaces were considered nondiagnostic for various reasons. Examination of the IB radiographs revealed 1,437 proximal surfaces (35.43%) with no radiographic signs of caries, whereas EB radiographs revealed 1,364 (33.63%) surfaces without signs of caries. For all caries categories, fewer surfaces were detected with carious lesions on IB radiographs.

Table 1. Distribution of diagnoses for proximal caries on 4,056 potential surfaces.*

CARIES CODE	INTRAORAL BITE-WING NO. (%)	EXTRAORAL BITE-WING NO. (%)
0 = Proximal Surface With No Caries	1,437 (35.43)	1,364 (33.63)
1 = Caries Less Than One-Half Way Through Enamel	49 (1.21)	431 (10.63)
2 = Caries More Than One-Half Way Through Enamel, Not Into Dentin	97 (2.39)	177 (4.36)
3 = Caries Into DEJ but Less Than One-Half Way Through the Dentin	179 (4.41)	321 (7.91)
4 = Caries More Than One-Half Way Through the Dentin	60 (1.48)	128 (3.16)
5 = Overlapping Contacts	473 (11.66)	538 (13.26)
6 = Missing Tooth	553 (13.63)	742 (18.29)
7 = Surface Not Seen on Image	918 (22.63)	55 (1.36)
8 = Defective Margin and Restoration	186 (4.59)	195 (4.81)
Nondiagnostic	104 (2.56)	105 (2.59)

*Percentage agreement (58.52; 95% confidence interval, 55.25 to 61.72) from a generalized estimating equations model for binary outcome that takes into account potential within-participant correlation (that is, multiple locations per participant).

Table 2. Caries detection rates in 1,416 surfaces that were diagnostic in both intraoral bite-wing and extraoral bite-wing.

CARIES CODES	INTRAORAL BITE-WING NO. (%)	EXTRAORAL BITE-WING NO. (%)
0	1,117 (78.88)	761 (53.74)
1-4	299 (21.12)	655 (46.26)
0-2	1,228 (86.72)	1,121 (79.17)
3-4	188 (13.28)	295 (20.83)

Within the subset of proximal surfaces (n = 1,416), which were diagnostic in both IB and EB radiographs (Table 2), there was statistically significantly greater ($P < .0001$) caries detection with EB radiographs (46.26%), compared with IB radiographs (21.12%). In the same subset of 1,416 surfaces, EB radiographs revealed significantly more ($P < .0001$) surfaces (20.83%) with caries extending into the dentin and further (caries code 3 and 4) contrasted to 13.28% with IB radiographs.

On a site-to-site level, there was 63.95% agreement (95% CI, 60.56 to 67.19%) between caries detection from IB and EB radiographs (Table 3). Assuming the criterion standard is the IB radiographs, the EB radiographs have a sensitivity of 71.91% and specificity of 61.99% with a false-positive rate of 38.01%. Assuming the criterion standard is the EB radiographs, the IB radiographs have a sensitivity of 33.71% and a specificity of 89.06% with a false-positive rate of 10.94%.

Of the potential 918 proximal surfaces that were not visible on the IB radiographs, 353 surfaces did not provide diagnostic information on EB radiographs (code categories 5-seen on image). Of these 918 proximal surfaces, 400 surfaces (43.57%) were diagnosed as caries-free on EB radiographs. Carious lesions of different depths were visible on 165 surfaces.

Bone loss

For crestal bone loss, we examined 2,184 teeth (Table 4). On IB radiographs, bone loss was evident with 981 teeth (44.92%), whereas EB radiographs revealed this with 1,474 (67.49%) teeth. The crestal bone level was not visible with 166 teeth (7.6%) on IB radiographs, whereas bone level was not visible with 83 (3.80%) teeth on EB radiographs. On IB radiographs, 442 teeth (20.24%) could not be seen. On EB radiographs, 15 (0.69%) teeth were not displayed.

Of the subset of teeth that appeared diagnostic in both IB and EB radiographs for the evaluation of bone loss, the percentage agreement between the 2 types of radiographs was 80.86% (95% CI) (Table 5). The bone loss detection rate was significantly ($P < .0001$) greater for EB radiographs with 1,076 teeth (90.19%) compared with IB radiographs with 930 teeth (77.95%). Assuming the

Table 3. Site-to-site comparison between intraoral bite-wing and extraoral bite-wing radiographic caries diagnosis.*

RADIOGRAPH TYPE, N = 1,416	INTRAORAL, 1-4 N = 299	INTRAORAL, 0 N = 1,117
Extraoral, 1-4; N = 655	219 (73.24)	436 (39.03)
Extraoral, 0; N = 761	80 (26.76)	681 (60.97)

*Percentage agreement (95% confidence interval), 63.95% (60.56 to 67.19%) from a generalized estimating equations model for binary outcome that takes into account potential within-participant correlation (that is, multiple locations per participant).

Table 4. Distribution of teeth (n = 2,184) with diagnoses for bone loss.

CODE	INTRAORAL NO. (%)	EXTRAORAL NO. (%)
0 = Proximal Bone Not Visible	166 (7.60)	83 (3.80)
1 = Bone Loss Evident (> 1.5-Millimeter Distance From Alveolar Crest to Cementoenamel Junction)	981 (44.92)	1,474 (67.49)
2 = Normal Bone Level (≤ 1.5-mm Distance From Alveolar Crest to Cementoenamel Junction)	280 (12.82)	197 (9.02)
3 = Tooth Not in Image	442 (20.24)	15 (0.69)
4 = Missing Tooth	252 (11.54)	358 (16.39)
Nondiagnostic	63 (2.88)	57 (2.61)

Table 5. Site-to-site comparison (n = 1,193 teeth) between intraoral and extraoral bone loss diagnosis.*

CODE	INTRAORAL NO. (%)	EXTRAORAL NO. (%)
1 = Bone Loss Evident (> 1.5-Millimeter Distance From Alveolar Crest to Cementoenamel Junction)	930 (77.95)	1,076 (90.19)
2 = Normal Bone Level (≤ 1.5-mm Distance From Alveolar Crest to Cementoenamel Junction)	263 (22.05)	117 (9.81)

*Percentage agreement (80.86; 95% confidence interval, 75.75 to 85.10) from a generalized estimating equations model for binary outcome that takes into account potential within-participant correlation (that is, multiple locations per participant).

criterion standard is IB radiographs, the EB radiographs had a sensitivity of 94.50% and specificity of 26.86% with a false-positive rate of 73.14% for diagnosis of bone loss. Assuming the criterion standard is the EB radiographs, the IB radiographs have a sensitivity of 90.78% and a specificity of 64.40% with a false-positive rate of 35.60%.

Of the 422 teeth that were not visible on the IB radiographs, 224 teeth (55.20%) had radiographic bone loss evident on EB radiographs. Of the 422 teeth not visible on IB radiographs, 102 teeth were coded as category 3 or 4 on EB radiographs.

DISCUSSION

Our results showed that EB radiographs recorded wider fields of view, both mesiodistally and craniocaudally. Compared with EB radiographs, fewer proximal surfaces and carious lesions were detected on IB radiographs. Fewer carious lesions were detected on IB images on the surface that were visible on both EB and IB radiographs. Overall, in the our study, the EB radiographs resulted in a high sensitivity (71.91%) and moderate specificity (61.99%) for the diagnosis of proximal caries. Although IB radiographs are far from perfect in revealing proximal caries, we made the assumption that IB radiographs were the diagnostic criterion standard. With IB radiographs as the criterion standard, EB radiographs have a false-positive rate of 38.01%. For detecting bone loss, in which the same teeth were visible on both IB and EB radiographs, fewer teeth with bone loss were identified on IB radiographs. Again, considering IB radiographs as the criterion standard, EB radiographs had a high sensitivity (94.50%), low specificity (26.86%), and false-positive ratio of 73.14% for diagnosing bone loss.

However, if we consider EB radiographs to be the criterion standard, the IB radiographs have a low sensitivity (33.71%) and a high specificity (89.06%) for caries diagnosis. The false-positive rate of IB radiographs in caries diagnosis is low (10.94%). For periodontal bone loss, the IB radiographs have a high sensitivity (90.78%) and a moderate specificity (64.40%). The false-positive rate of bone loss diagnosis is 35.60%.

In a clinical practice, bite-wing radiographs are frequently rejected from overlapped proximal surfaces.[20,21] Traditional IB radiographic examination consists of images of each side to assist in reducing overlap. EB radiographs of both the sides were recorded in 1 exposure. Our study showed that EB radiographs had a similar number of overlapped proximal surfaces as 2 IB radiographs on each side. A 2016 study by Terry and colleagues[17] reported that EB radiographs resulted in 81.7% open contacts compared with 48.5% with standard panoramic radiography.[17] Terry and colleagues[17] reported no significant difference in the detection of proximal surface caries between EB radiographs and IB radiographs. However, high false-positive caries diagnosis with EB radiographs remained an issue in our study as well as in other studies that had used this panoramic equipment (Planmeca).[4,19] One of those studies raised concern about caries treatment decisions based on false-positive findings.[4] The authors[4] suggested that the false-positive findings are probably related to streak artifacts arising from the contralateral body of the mandible, which may have mimicked carious lesions. In the ex vivo studies, the final diagnosis of caries was achieved by histologic sections. In our in vivo study, histologic confirmation of a carious lesion was not possible. This is a limitation of our study.

Other limitations of our study were related to logistic issues. Two of the examiners who reviewed the radiographs had traveled from far away and because of the time constraint, all the radiographs were evaluated within 2 days. Human fatigue, therefore, could have affected the diagnoses. Because of the university setting, the IB radiographs in our study were obtained by dental students, under the supervision of radiology technicians who approved the diagnostic quality. The included IB images were diagnostic, but not necessarily perfect. The EB radiographs were acquired by a single operator who had adequate instruction on acquiring such images.

Using digital or film-based panoramic radiography, several studies had compared the diagnostic accuracy of IB radiographs.[10,11,22,23] Because such studies did not include EB radiographs generated by robotic motion of x-ray tube and sensor, the results of those studies are not necessarily comparable with our study. In addition, image interpretation in film-based panoramic radiography may also have been affected by several factors, including film crystal size, use of intensifying screen, darkroom processing methods, overlapped crowns, and viewing of radiographs on light boxes. In other studies, specifically those not using EB radiographs, panoramic radiography resulted in lower agreement in marginal bone height.[24] The conclusion was that panoramic radiography alone was insufficient to diagnose marginal bone loss.[24] Additional studies have compared traditional panoramic radiographs with intraoral bite-wing and periapical radiographs in diagnosing periodontal bone loss.[14,25] These studies reported panoramic radiographs had less diagnostic quality compared with intraoral radiographs, due to overlapping of teeth seen in the panoramic radiographs.[25] In our study, there was minimal overlapping of teeth (3.80%) in EB radiographs. This was even less than the proportion of teeth that could not be properly assessed with IB radiographs (7.60%).

Interestingly, detection of carious lesions into dentin (caries codes 3 and 4) was higher for EB radiographs (20.83%) than for IB radiographs (13.28%). IB radiographs often underestimate the depth of carious lesions.[26,27] Our in vivo study could not confirm if radiographic depth of caries on EB radiographs is closer to the true clinical finding.

The use of EB radiography does offer several advantages over IB radiography including increased patient comfort, decreased time required for multiple images, and an increased field of view. During our review of the EB images, we had noted several periapical radiolucent and radiopaque lesions, and sinus findings. Although these findings were not recorded, it appeared that EB radiographs might provide additional diagnostic information otherwise not available on IB images. Our study did not evaluate actual benefit of such additional diagnostic information available on EB radiographs. Studies will be needed to determine if a protocol of anterior periapical and posterior EB radiographs will provide better diagnostic information than the widespread practice of taking both panoramic and posterior intraoral bite-wing radiographs.

The imaging performance of EB radiographs for caries and alveolar bone diagnoses appears promising. However, the use of EB radiographs comes with equipment costs. Most dental offices have adequate equipment for IB radiographs. To be able to acquire EB radiographs, most clinicians require new equipment. We used a Planmeca unit, technology, and program. A 2016 study showed insignificant difference in proximal caries diagnostic accuracy between EB radiographs generated by a different brand panoramic unit and direct digital and phosphor plate intraoral imaging.[18] That ex vivo study was performed using a different panoramic manufacturer than the 1 from our study, but its similar finding supports those of our study.

Apart from diagnostic information, radiation dose should also be considered if EB radiographs are to replace IB radiographs. The manufacturer reported that the effective dose from EB radiographs is 4.4 microsieverts. In comparison, the effective dose from four IB radiographs using PSP or F-speed film and rectangular collimation is 5 microsieverts (John Ludlow, DDS, Professor Emeritus, University of North Carolina, personal email communication, March 2017).[28] Use of a round collimation would significantly increase the dose.

CONCLUSIONS

Based on our study and other studies,[17,18] EB radiographs as generated by the equipment used can be a viable option for caries and periodontal bone loss diagnoses. The EB radiographic examination is an important technological development as it reduced the number of overlapping contacts compared with traditional panoramic radiography. When making a diagnosis of caries and bone loss, the clinician should be aware that we defined IB radiographs as the criterion standard in the hypothesis, thus, the false-positive language in the findings on EB radiographs. If EB radiographs were the criterion standard, IB radiographs were less sensitive than EB radiographs for caries and bone loss. At the same time, clinicians should also remember that traditional IB radiographs are not highly sensitive for detecting early carious lesions,[1] and often underestimate the depth of carious lesions.[26,27] The use of EB radiographs provides numerous advantages over IB radiographs, but comes at a financial cost with equipment as well as a risk of experiencing false-positive findings. Clinicians should consider the advantages and disadvantages of both the technologies when choosing how to radiographically evaluate patients for caries and periodontal bone loss. It appears that there is place for both IB and EB radiography in dentistry, and the clinician can decide which is more advantageous to patient outcomes. ■

Dr. Chan was a resident, Division of Periodontology, University of Minnesota School of Dentistry, Minneapolis, MN, at the time this article was written. He is now in private practice in Richfield, MN.

Dr. Dadul was a clinical assistant professor, Oral and Maxillofacial Radiology, University of Minnesota School of Dentistry, Minneapolis, MN, at the time this article was written. He is now a resident at the University of North Carolina, Chapel Hill, NC.

Dr. Langlais is a professor emeritus, University of Texas Health Sciences Center at San Antonio, School of Dentistry, San Antonio, TX.

Dr. Russell is in private practice in Sauk Rapids, MN.

Dr. Ahmad is an associate professor, Oral and Maxillofacial Radiology, University of Minnesota School of Dentistry, 7-536 Moos Tower, 515 Delaware Street SE, Minneapolis, MN 55455, e-mail ahmad005@umn.edu. Address correspondence to Dr. Ahmad.

Disclosures. Dr. Langlais is a paid consultant for Planmeca USA, Chicago, IL. Dr. Ahmad received funding from Planmeca to conduct this research. None of the other authors reported any disclosures.

1. Schwendicke F, Tzschoppe M, Paris S. Radiographic caries detection: a systematic review and meta-analysis. *J Dent*. 2015;43(8):924-933.

2. Bader JD, Shugars DA, Bonito AJ. Systematic reviews of selected dental caries diagnostic and management methods. *J Dent Educ*. 2001;65(10):960-968.

3. Bader JD, Shugars DA, Rozier G, et al. Diagnosis and management of dental caries. *Evid Rep Technol Assess (Summ)*. 2001;(36):1-4.

4. Gaalaas L, Tyndall D, Mol A, Everett ET, Bangdiwala A. Ex vivo evaluation of new 2D and 3D dental radiographic technology for detecting caries. *Dentomaxillofac Radiol*. 2016;45(3):20150281.

5. Wolf B, von Bethlenfalvy E, Hassfeld S, Staehle HJ, Eickholz P. Reliability of assessing interproximal bone loss by digital radiography: intrabony defects. *J Clin Periodontol*. 2001;28(9):869-878.

6. Eickholz P, Hausmann E. Accuracy of radiographic assessment of interproximal bone loss in intrabony defects using linear measurements. *Eur J Oral Sci*. 2000;108(1):70-73.

7. Vaarkamp J, ten Bosch JJ, Verdonschot EH, Bronkhoorst EM. The real performance of bitewing radiography and fiber-optic transillumination in approximal caries diagnosis. *J Dent Res*. 2000;79(10):1747-1751.

8. Young SM, Lee JT, Hodges RJ, Change TL, Elashoff DA, White SC. A comparative study of high-resolution cone beam computed tomography and charge-coupled device sensors for detecting caries. *Dentomaxillofac Radiol*. 2009;38(7):445-451.

9. Kidd EA, Pitts NB. A reappraisal of the value of the bitewing radiograph in the diagnosis of posterior approximal caries. *Br Dent J*. 1990;169(7):195-200.

10. Hurlburt CE, Wuehrmann AH. Comparison of interproximal carious lesion detection in panoramic and standard intraoral radiography. *JADA*. 1976;93(6):1154-1158.

11. Scarfe WC, Langlais RP, Nummikoski P, et al. Clinical comparison of two panoramic modalities and posterior bite-wing radiography in the detection of proximal dental caries. *Oral Surg Oral Med Oral Pathol*. 1994;77(2):195-207.

12. Muhammed AH, Manson-Hing LR, Ala B. A comparison of panoramic and intraoral radiographic surveys in evaluating a dental clinic population. *Oral Surg Oral Med Oral Pathol*. 1982;54(1):108-117.

13. Douglass CW, Valachovic RW, Wijesinha A, Chauncey HH, Kapur KK, McNeil BJ. Clinical efficacy of dental radiography in the detection of dental caries and periodontal diseases. *Oral Surg Oral Med Oral Pathol*. 1986;62(3):330-339.

14. Akesson L, Rohlin M, Håkansson J, Håkansson H, Nässtroöm K. Comparison between panoramic and posterior bitewing radiography in the diagnosis of periodontal bone loss. *J Dent*. 1989;17(6):266-271.

15. Ivanauskaite D, Lindh C, Rangne K, Rohlin M. Comparison between Scanora panoramic radiography and bitewing radiography in the assessment of marginal bone tissue. *Stomatologija*. 2006;8(1):9-15.

16. Abdinian M, Razavi SM, Faghihian R, Samety AA, Faghihian E. Accuracy of digital bitewing radiography versus different views of digital panoramic radiography for detection of proximal caries. *J Dent (Tehran)*. 2015;12(4):290-297.

17. Terry GL, Noujeim M, Langlais RP, Moore WS, Prihoda TJ. A clinical comparison of extraoral panoramic and intraoral radiographic modalities for detecting proximal caries and visualizing open posterior interproximal contacts. *Dentomaxillofac Radiol*. 2016;45(4):20150159.

18. Abu El-Ela WH, Farid MM, Mostafa MS. Intraoral versus extraoral bitewing radiography in detection of enamel proximal caries: an ex vivo study. *Dentomaxillofac Radiol*. 2016;45(4):20150326.

19. Kamburoglu K, Kolsuz E, Murat S, Yüksel S, Ozen T. Proximal caries detection accuracy using intraoral bitewing radiography, extraoral bitewing radiography and panoramic radiography. *Dentomaxillofac Radiol*. 2012;41(6):450-459.

20. McDonald SP. A method to reduce interproximal overlapping and improve reproducibility of bitewing radiographs for use in clinical trials. *Community Dent Oral Epidemiol*. 1983;11(5):289-295.

21. Safi Y, Esmaeelinejad M, Vasegh Z, et al. Utility of a newly designed film holder for premolar bitewing radiography. *J Clin Diagn Res*. 2015;9(11):TC04-TC07.

22. Flint DJ, Paunovich E, Moore WS, Wofford DT, Hermesch CB. A diagnostic comparison of panoramic and intraoral radiographs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 1998;85(6):731-735.

23. Akkaya N, Kansu O, Kansu H, Cagirankaya LB, Arslan U. Comparing the accuracy of panoramic and intraoral radiography in the diagnosis of proximal caries. *Dentomaxillofac Radiol*. 2006;35(3):170-174.

24. Molander B. Panoramic radiography in dental diagnostics. *Swed Dent J Suppl*. 1996;119:1-26.

25. Akesson L, Rohlin M, Hakansson J. Marginal bone in periodontal disease: an evaluation of image quality in panoramic and intra-oral radiography. *Dentomaxillofac Radiol*. 1989;18(3):105-112.

26. Wenzel A. Radiographic display of carious lesions and cavitation in approximal surfaces: advantages and drawbacks of conventional and advanced modalities. *Acta Odontol Scand*. 2014;72(4):251-264.

27. Sansare K, Raghav M, Sontakke S, Karjodkar F, Wenzel A. Clinical cavitation and radiographic lesion depth in proximal surfaces in an Indian population. *Acta Odontol Scand*. 2014;72(8):1084-1088.

28. Ludlow JB, Davies-Ludlow LE, White SC. Patient risk related to common dental radiographic examinations: the impact of 2007 International Commission on Radiological Protection recommendations regarding dose calculation. *JADA*. 2008;139(9):1237-1243.