Dentomaxillofacial Radiology (2020) 50, 20200153

birpublications.org/dmfr

RESEARCH ARTICLE

Effects of healthcare policy and education on reading accuracy of bitewing radiographs for interproximal caries

[1]Hiroki Sato, [2]John D Da Silva, [3]Cliff Lee, [1]Hisashi Yonemoto, [4]Yukinori Kuwajima, [5]Hiroe Ohyama, [6]Robert Fredrick Lambert, [7]Mitsuru Izumisawa, [4]Noriaki Takahashi and [2]Shigemi Nagai

[1]Research Collaborator, Harvard School of Dental Medicine, Boston, Massachusetts, United States; [2]Associate Professor, Harvard School of Dental Medicine, Boston, Massachusetts, United States; [3]Research Associate, Harvard School of Dental Medicine, Boston, Massachusetts, United States; [4]Lecturer, Iwate Medical University, School of Dental Medicine, Morioka, Japan; [5]Assistant Professor, Harvard School of Dental Medicine, Boston, Massachusetts, United States; [6]Pediatric Dentistry Resident, Boston Children's Hospital, Boston, United States; [7]Associate Professor, Iwate Medical University, School of Dental Medicine, Morioka, Iwate, Japan

Objectives The aim of this study is to assess the accuracy of bitewing radiograph interpretation of predoctoral students, residents and general dentists who work under different core curriculum of dental education and healthcare policy.
Methods A total of 118 examiners including predoctoral dental students, residents and general dentists from USA and Japan were tasked with evaluating a series of bitewing radiographs and diagnosing interproximal carious lesions. This study was approved by the Harvard Medical School Institutional Review Board (IRB). Participants graded interproximal aspects of those images and categorized the following criteria; "intact", "enamel caries <1/2 width", "enamel caries >1/2 width" or "caries into dentin". The gold-standard was determined by the consensus of two HSDM full-time faculty.
Results There was significant difference in the sensitivity for all three caries levels between the two groups but there was no significant difference on specificity. The positive-predictive and negative-predictive values of the USA group for the enamel caries (<1/2 of enamel) were significantly higher than the Japanese group. The average of AUC (ROC) was significantly higher in the USA group (0.885 ± 0.04) than the Japanese group (0.785 ± 0.08, $p<0.01$).
Conclusion Teaching and adopting BW radiographs for diagnosis of interproximal caries is integral for dental providers to accurately and efficiently use them in their practices. It is critical that all dental educators approach policymakers to explain the importance of BW radiographs and promote their efficacy for prevention and early diagnosis of interproximal caries.
Dentomaxillofacial Radiology (2020) **50**, 20200153. doi: 10.1259/dmfr.20200153

Cite this article as: Sato H, Da Silva JD, Lee C, Yonemoto H, Kuwajima Y, Ohyama H, et al. Effects of healthcare policy and education on reading accuracy of bitewing radiographs for interproximal caries. *Dentomaxillofac Radiol* 2020; **50**: 20200153.

Keywords: Bitewing radiograph; Reading accuracy; Healthcare policy; Dental education; Sensitivity and specificity

Introduction

Understanding the economic burden is essential for addressing and preventing oral diseases. Although largely preventable, dental caries is the most common chronic disease in the USA among children aged 6–11 years, and adolescents aged 12–19 years, with 9 out of 10 adults over the age of 20 having some degree of tooth decay.[1] This equates to direct treatment costs reaching US$298 billion worldwide, corresponding to 4.6% of global health expenditure.[2] Early detection of dental caries is critical for the management, prevention and

Correspondence to: Dr Shigemi Nagai, E-mail: shigemi_nagai@hsdm.harvard.edu

Received 10 April 2020; revised 23 July 2020; accepted 26 July 2020

treatment of the disease. Non-surgical interventions for interproximal dental caries are gaining in popularity as alternatives to mechanical replacement of damaged tooth structure with artificial materials but are only effective if the lesion is detected early. Consequences of late detection of caries include irreversible surgical intervention, the need for endodontic treatment and even tooth loss. Although there have been many developments in the methods for caries detection, such as transillumination,[3,4] quantitative light fluorescence[5] and laser fluorescence,[6–8] radiographs are still the primary diagnostic tool for the detection of interproximal dental caries. Appropriate radiographical interpretation is critical to accurate diagnosis of caries.

Digital radiographs that eliminate the use of conventional X-ray film by capturing radiographical images on photostimulable phosphor imaging plates or charge-coupled devices may improve the detection of dental caries.[9] The images acquired with these technologies can be processed or analysed to enhance diagnostic performance, gaining sensitivity without reduction in specificity. Bitewing (BW) radiographs have been shown to be superior to periapical (Pa) or panoramic radiographs for diagnosing interproximal carious lesions, especially at an early-stage caries formation before the decay has reached the dental-enamel-junction.[10]

In the USA, BW radiography is the standard of care for diagnosing interproximal carious lesions and is taught in all dental schools. Dental curricula accredited by CODA in USA require competency in both interpreting dental radiographs and making appropriate diagnoses.[11] Board examinations for regional and state licenses require students to interpret BW radiographs to diagnose posterior interproximal caries lesion.[12,13]

In addition to core dental education, dental insurance policy plays an important role in when and what kind of radiographs are taken to diagnose caries, evaluate marginal integrity of restorations and assess bone levels. In the USA, BW radiographs are taken routinely for these diagnostic purposes, and major dental insurance companies typically cover the cost for diagnostic radiographs every 6 month to 1 year. Therefore, predoctoral students, residents, and dentists are routinely exposed to reading and interpreting BW radiographs. In contrast, there are differences in education and dental policy on BW radiographs in other countries. For example, the core dental curriculum in Japan does not require students to be clinically competent in the interpretation of BW radiographs.[14] In general, BW radiographs are not covered by the Japanese Universal Health Care System for the routine preventive and diagnostic purposes. In addition to Japan, China and South Korea are other countries where BW radiographs are not a part of routine examination for diagnosing interproximal caries.[15–18]

The ultimate goal of this project is to enhance core dental education and insurance coverage of BW radiography for the purpose of diagnosing interproximal caries in countries where it is not currently the standard. The specific aim of this study is to compare the accuracy of BW radiograph interpretation by predoctoral students, residents and dentists who are under the different dental education and healthcare policy systems.

Methods

Two groups of examiners from the USA and Japan, with different education and dental policies, were selected. First, frequency of radiographs taken in Japan was compared with periapical radiographs and panoramic radiographs using Japanese National Universal Health Care Database from 2013 to 2017.[19]

A total of 111 examiners including predoctoral dental students, residents and general dentists were tasked with evaluating a series of BW radiographs and diagnosing interproximal carious lesions. The four BW radiographs taken at Harvard School of Dental Center from 2014 to 2017 were randomly exported from the electronic health record system without any personal identifiers. The radiographs were taken by Planmeca ProxTM (PLANMECA USA INC,Hoffman Estates, IL) using digital Schick 33 sensors (Dentsply Sirona, Charlotte, NC) operating at 65 kVp and 7 mA at 0.08 s according to manufacturer's settings. The images were carefully reviewed by the study Principle Investigator (PI) at Harvard School of Dental Medicine (HSDM). Image sets were included if they contained images of posterior teeth from the distal surface of the first premolar to the mesial surface of the second molar. I reviewed quality of the radiographs and selected 10 sets of BWs. Interproximal surfaces were excluded if they had interproximal restorations, cone cuts, overlapping surfaces or if they were significantly over/under exposed or distorted (Figure 1). Out of 120 interproximal surfaces, a total of 96 interproximal surfaces were used for the evaluation.

In the "no coverage group," 53 participants consisting of 36 predoctoral students (sixth years) from five dental schools and 17 general practitioners from three prefectures in Japan were involved. In the "coverage group," 58 participants consisting of 45 DMD-4 predoctoral students (fourth year) and 13 restorative dentists from HSDM were involved. All examiners performed BW interpretations of 96 interproximal surfaces. Participants graded interproximal surfaces with the following criteria: "intact", "enamel caries < 1/2 width", "enamel caries > 1/2 width" or "caries into dentin". The gold standard was determined by the consensus of two HSDM full-time faculty with 37 and 29 years of clinical and teaching experience. Each faculty evaluated images separately, and the consensus was obtained by discussion for any readings where there was a disagreement. This study was approved by the Harvard Medical School Institutional Review Board (IRB 17–1266).

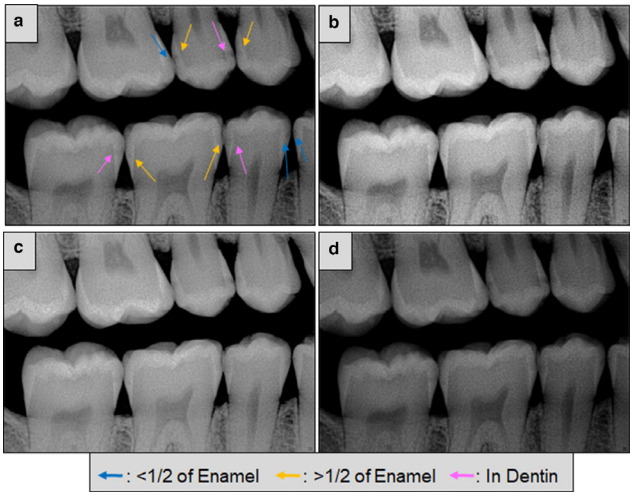

Figure 1 Sample images of intraoral bitewing radiograph in this investigation with different contrast and lightness. (A) arrows indicate caries lesion determined by the consensus of two HSDM full-time faculty: Gold-standard. (B) Image with a higher contrast and lightness than A. (C) Image with same contrast and higher lightness. (D) Image with a higher contrast and darker lightness.

Statistical analysis

Agreement between the two HSDM faculty-independent grading prior to any discussion was assessed by Cohen's κ coefficient. Specificity, sensitivity, positive-predictive value and negative-predictive value were calculated for the different level of caries progression and compared between coverage group and the no coverage group by the Student's t-test. Receiver operating curves (ROC) of BW for each evaluator were calculated with two groups ("1" truly positive or "0" truly negative) and four ranking categories (4: dentin caries, 3: enamel caries > 1/2, 2: enamel caries < 1/2 and intact, 1: intact). The areas under the curve (AUC) of BWs were compared between the coverage and no coverage groups.

Results

BW radiographs are rarely taken in clinical dentistry in Japan under the universal healthcare coverage system

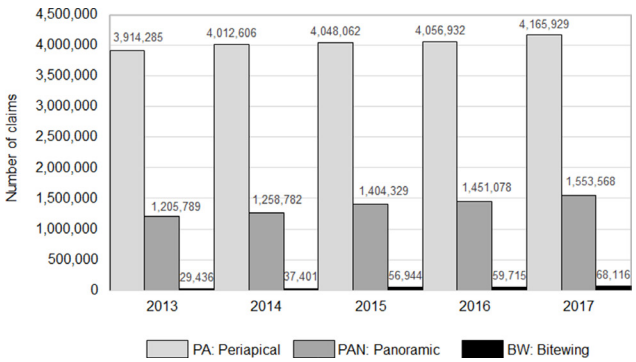

Figure 2 Frequency of dental radiographs taken per month from 2013 to 2017 in Japan.

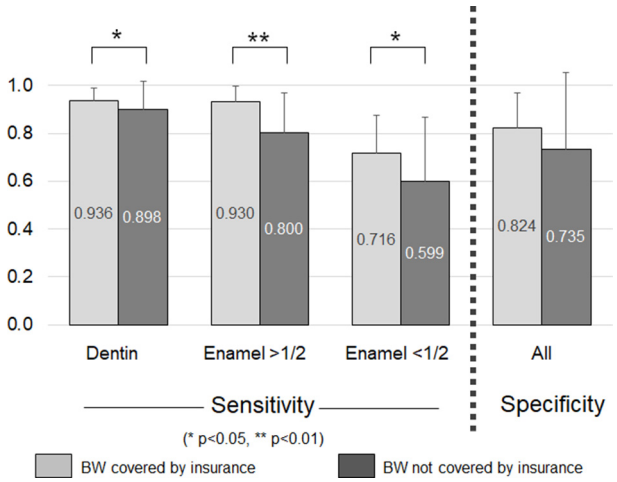

Figure 3 Comparison of sensitivity and specificity between two groups with different policies on bitewing radiography.

(Figure 2). Although there is a slight trend of increasing BW claims, calculations (claim number submitted/number of practices registered) indicate that the average frequency of BW radiographs taken per dental office is still less than one per month. There was a high level of agreement between the two HSDM faculty to establish the gold-standard, with a 90% agreement and Cohen's κ coefficient of 0.88, indicating near-perfect agreement. There was a significant difference in the sensitivity for all three caries levels between the two groups but there was no significant difference on specificity (Figure 3). In each group, the sensitivity of the enamel caries <1/2 width was significantly lower than the dentin caries and enamel caries >1/2 width ($p < 0.01$). The positive-predictive and negative-predictive values of the coverage group for the enamel caries <1/2 width were significantly higher than the no coverage group (Table 1). The ROCs are shown in Figure 4. The average of AUC (ROC) was significantly higher in the coverage group (0.885 ± 0.04) than the no coverage group (0.785 ± 0.08, $p < 0.01$).

Discussion

The care model for treating dental caries is moving towards non-operative/preventive care,[20] with the FDI World Dental Federation supporting Minimal Intervention Dentistry (MID) as the contemporary manner for the management of dental caries.[21] Patients overall respond very favourably to non-invasive treatment, with the overwhelming majority of them accepting the recommendation of non-invasive treatment given by their dentist for non-cavitated early dental caries.[22] This suggested that patient's education is also essential to enhance MID addition to dental education and dental caries needs to be diagnosed in an early stage.

Higher sensitivity is preferred over specificity for MID, as false-negative may have significantly higher repercussions than false-positive. Undiagnosed and

Table 1 The mean value of PPV and NPV among those covered by insurance and those not covered stratified by caries progression

	PPV		*NPV*	
Insurance coverage Caries progression	Covered	Not covered	Covered	Not covered
Dentin	0.858 ± 0.097	0.829 ± 0.163	0.929 ± 0.061a	0.897 ± 0.096a
Enamel > 1/2	0.872 ± 0.088	0.834 ± 0.154	0.919 ± 0.067**	0.774 ± 0.190**
Enamel <1/2	0.793 ± 0.129a	0.719 ± 0.200a	0.785 ± 0.111a	0.713 ± 0.198a

[a](*$p < 0.05$, **$p < 0.01$)

untreated decay could grow and lead to loss of healthy tooth structure, possible need for endodontic therapy or tooth loss, while a false-positive would lead to conservative MID treatment, including topical fluoride application and closer monitoring of lesions. Our previous study showed that BW radiographs offered a significant advantage over periapical radiographs in the diagnoses of early-stage interproximal carious lesions.[10] In this study, the coverage group had a significantly higher sensitivity for enamel caries than the no coverage group, as well as higher positive-predictive and negative-predictive values. This indicates that if insurance in other countries cover BW radiographs as the standard of care for caries diagnosis, diagnostic ability and prevention could be enhanced. When caries which is already in the dentin, either Pa or BW radiographs can be used without a statistical difference in diagnostic accuracy. In both group, sensitivity for detection of enamel caries < 1/2 width was lower than other two caries progression levels. This is not surprising, as various factors make diagnosing <1/2 width enamel caries difficult, such as the small surface area for analysis or Mach bands.[23] Alternative methods to BW examination for interproximal caries detection have been introduced.[24–27] Recent studies showed that performances of near-infrared light transillumination, fiber-optic transillumination, and laser fluorescence may be comparable to the radiographic examination. However, concerns for false-positive and the need for validation for detection of early stage of caries are also indicated, and further investigations are needed. Therefore, BW radiographs are still an efficient and standard tool for diagnosis of interproximal caries and BW radiography should be routinely implemented for examination.

Dental curricula accredited by CODA in USA require clinical competency in diagnosis of interproximal caries[11] by both formative and summative examinations. Students routinely make treatment plan based on the diagnosis by full mouth radiograph FMX and capture four BWs in checkup visit in teaching practice. In contrast, the no-coverage group has no requirement of clinical competency on interproximal caries diagnosis by BWs. Therefore, the first approach to improve the ability of dental student and dentists in detection of interproximal caries will be implementation of clinical education of BWs with competency examination.

The Consortium of Oral Health-Related Informatics (COHRI) developed EZCodes terminology for the diagnostic codes to be included in the electronic health record software used in North American dental schools, including diagnostic codes with two stages of enamel caries.[28–30] Diagnostic codes present a potent opportunity to teach clinically relevant critical thinking.[28,31] These diagnostic codes are currently being used in North American dental schools in the realm of caries management.[28] In order to facilitate accurate diagnosis

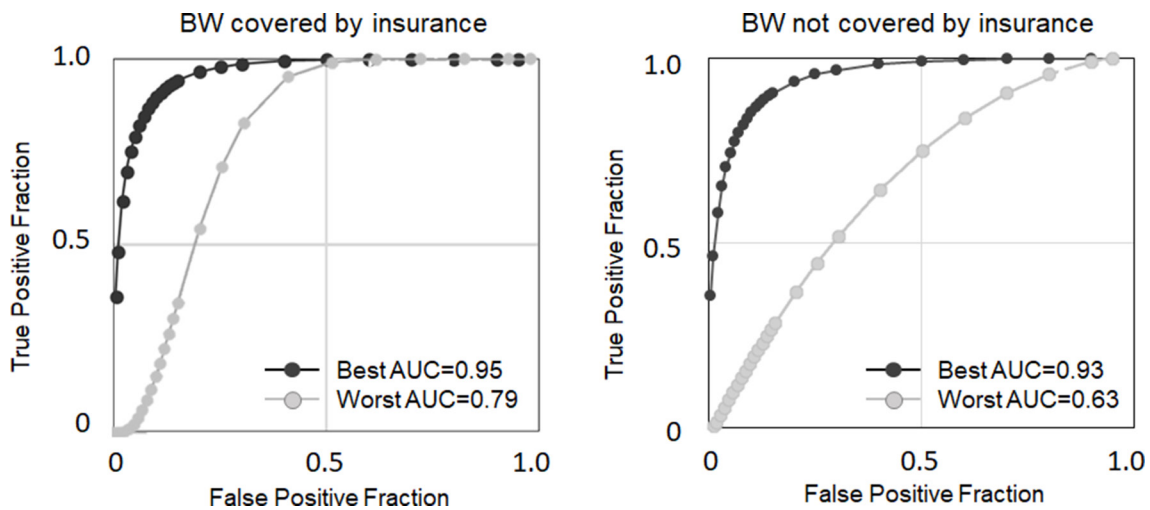

Figure 4 Representative of receiver operating characteristics (ROCs) and area of under the curve (AUC).

of early caries in enamel, BW radiographs need to be implemented as a standard for preventive and diagnostic imaging and taught in the dental education in countries where it is not the current standard. A recent study assessing the accuracy of dental faculty members' utilization of diagnostic codes based on radiographic interproximal tooth radiolucencies indicated that the majority of the participants selected the correct diagnostic code on all types of lesions,[28,32] These studies also emphasized that diagnostic codes present a potent opportunity to teach clinically relevant critical thinking-connecting the "what" of practice (treatment) to the "why" (diagnosis). BW radiographs are a critical component for diagnosing and educating dental students on early diagnosis of dental caries.

Artificial intelligence and deep learning have demonstrated promising performance in medical applications, especially in radiology.[33] In the field of dental and maxillofacial radiology, pre-clinical studies have indicated that AI diagnostic models may be used to identify root canal-treated teeth,[33–36] detect vertical root fractures,[37] and detect proximal caries.[33,36,38] Even in these advancements in radiology and artificial intelligence, BW radiographs are an essential component for the diagnosis of interproximal caries. Its inclusion in insurance coverage is imperative for success.

The findings of this study suggest that dental insurance policy may be an important factor in dentists' ability to diagnose interproximal caries using BW radiographs. Policymakers should be aware of this fact and consider covering them routinely. This may lead to a reduction of costly surgical treatment of caries and an increase in economical non-surgical strategies.

Conclusion

Teaching and adopting BW radiographs for diagnosis of interproximal caries is key for dental providers to accurately and efficiently use them in their practices. Insurance coverage of BW radiographs for early caries diagnosis should be prioritized in dental healthcare policy. It is critical that all dental educators work with policymakers to explain the importance of BW radiographs and promote its efficacy for the prevention and early diagnosis of interproximal caries.

REFERENCES

1. Hyattsville M. National center for health statistics. *Health* 2019; **2018**United States.
2. Listl S, Galloway J, Mossey PA, Marcenes W. Global economic impact of dental diseases. *J Dent Res* 2015; **94**: 1355–61. doi: https://doi.org/10.1177/0022034515602879
3. Schneiderman A, Elbaum M, Shultz T, Keem S, Greenebaum M, Driller J. Assessment of dental caries with digital imaging Fiber-Optic transillumination (DIFOTI): in vitro study. *Caries Res* 1997; **31**: 103–10. doi: https://doi.org/10.1159/000262384
4. Lara-Capi C, Cagetti MG, Lingström P, Lai G, Cocco F, Simark-Mattsson C, et al. Digital transillumination in caries detection versus radiographic and clinical methods: an in-vivo study. *Dentomaxillofac Radiol* 2017; **46**: 20160417. doi: https://doi.org/10.1259/dmfr.20160417
5. Heinrich-Weltzien R, Kühnisch J, van der Veen M, de Josselin de Jong E, Stösser L. Quantitative light-induced fluorescence (QLF)--a potential method for the dental practitioner. *Quintessence Int* 2003; **34**: 181–8.
6. Shi XQ, Welander U, Angmar-Månsson B. Occlusal caries detection with KaVo DIAGNOdent and radiography: an in vitro comparison. *Caries Res* 2000; **34**: 151–8. doi: https://doi.org/10.1159/000016583
7. Menem R, Barngkgei I, Beiruti N, Al Haffar I, Joury E. The diagnostic accuracy of a laser fluorescence device and digital radiography in detecting approximal caries lesions in posterior permanent teeth: an in vivo study. *Lasers Med Sci* 2017; **32**: 621–8. doi: https://doi.org/10.1007/s10103-017-2157-2
8. Bizhang M, Wollenweber N, Singh-Hüsgen P, Danesh G, Zimmer S. Pen-type laser fluorescence device versus bitewing radiographs for caries detection on approximal surfaces. *Head Face Med* 2016; **12**: 30. doi: https://doi.org/10.1186/s13005-016-0126-9
9. Dove SB. Radiographic diagnosis of dental caries. *J Dent Educ* 2001; **65**: 985–90. doi: https://doi.org/10.1002/j.0022-0337.2001.65.10.tb03474.x
10. Takahashi N, Lee C, Da Silva JD, Ohyama H, Roppongi M, Kihara H, et al. A comparison of diagnosis of early stage interproximal caries with bitewing radiographs and periapical images using consensus reference. *Dentomaxillofac Radiol* 2019; **48**: 20170450. doi: https://doi.org/10.1259/dmfr.20170450
11. Accreditation CoD. 2019. Accreditation standards for dental education programs.
12. CDCA. ADEX dental exam series, restorative and periodontal procedures, candidate manual. 2020.
13 WREB. 2019. Dental exam candidate guide.
14. The Ministry of Education C, Sports, Science and Technology. 2019. Dental Education Core Curriculum in Japan.
15. Kweon HH-I, Lee J-H, Youk T-M, Lee B-A, Kim Y-T. Panoramic radiography can be an effective diagnostic tool adjunctive to oral examinations in the National health checkup program. *J Periodontal Implant Sci* 2018; **48**: 317–25. doi: https://doi.org/10.5051/jpis.2018.48.5.317
16. Gao X, Ding M, Xu M, Wu H, Zhang C, Wang X, et al. Utilization of dental services and associated factors among preschool children in China. *BMC Oral Health* 2020; **20**: 9. doi: https://doi.org/10.1186/s12903-019-0996-x
17. Yuan C, Wang XZ, Sun XY, Wang X, Feng XP, Tai BJ, et al. Oral health status of 12-year-olds from regions with and without coverage of the National oral health comprehensive intervention program for children in China. *Chin J Dent Res* 2018; **21**: 299–306. doi: https://doi.org/10.3290/j.cjdr.a41088
18. Chu CH, Chung BTO, Lo ECM. Caries assessment by clinical examination with or without radiographs of young Chinese adults. *Int Dent J* 2008; **58**: 265–8. doi: https://doi.org/10.1111/j.1875-595X.2008.tb00198.x
19. Ministry of Health LaWJ. 2018. Statistics of health care practice.
20. Pitts NB. Are we ready to move from operative to non-operative/preventive treatment of dental caries in clinical practice? *Caries Res* 2004; **38**: 294–304. doi: https://doi.org/10.1159/000077769
21. FDI World Dental Federation. Fdi policy statement on minimal intervention dentistry (mid) for managing dental caries: adopted by the general assembly: September 2016, Poznan, Poland. *Int Dent J* 2017; **67**: 6–7. doi: https://doi.org/10.1111/idj.12308
22. Mitchell ST, Funkhouser E, Gordan VV, Riley JL, Makhija SK, Litaker MS, et al. Satisfaction with dental care among patients who receive invasive or non-invasive treatment for non-cavitated

early dental caries: findings from one region of the National dental PBRN. *BMC Oral Health* 2017; **17**: 70. doi: https://doi.org/10.1186/s12903-017-0363-8
23. Panikkath R, Panikkath D. Mach band sign: an optical illusion. *Baylor University Medical Center Proceedings* 2014; **27**: 364–5. doi: https://doi.org/10.1080/08998280.2014.11929161
24. Abogazalah N, Ando M. Alternative methods to visual and radiographic examinations for approximal caries detection. *J Oral Sci* 2017; **59**: 315–22. doi: https://doi.org/10.2334/josnusd.16-0595
25. Abogazalah N, Eckert GJ, Ando M. In vitro performance of near infrared light transillumination at 780-nm and digital radiography for detection of non-cavitated approximal caries. *J Dent* 2017; **63**: 44–50. doi: https://doi.org/10.1016/j.jdent.2017.05.018
26. Baltacioglu IH, Orhan K. Comparison of diagnostic methods for early interproximal caries detection with near-infrared light transillumination: an in vivo study. *BMC Oral Health* 2017; **17**: 130. doi: https://doi.org/10.1186/s12903-017-0421-2
27. Ozkan G, Guzel KGU. Clinical evaluation of near-infrared light transillumination in approximal dentin caries detection. *Lasers Med Sci* 2017; **32**: 1417–22. doi: https://doi.org/10.1007/s10103-017-2265-z
28. Sutton JC, Fay R-M, Huynh CP, Johnson CD, Zhu L, Quock RL. Dental faculty accuracy when using diagnostic codes: a pilot study. *J Dent Educ* 2017; **81**: 554–60. doi: https://doi.org/10.21815/JDE.016.018
29. Tokede O, White J, Stark PC, Vaderhobli R, Walji MF, Ramoni R, et al. Assessing use of a standardized dental diagnostic terminology in an electronic health record. *J Dent Educ* 2013; **77**: 24–36. doi: https://doi.org/10.1002/j.0022-0337.2013.77.1.tb05439.x
30. White JM, Kalenderian E, Stark PC, Ramoni RL, Vaderhobli R, Walji MF. Evaluating a dental diagnostic terminology in an electronic health record. *J Dent Educ* 2011; **75**: 605–15. doi: https://doi.org/10.1002/j.0022-0337.2011.75.5.tb05086.x
31. Reed SG, Adibi SS, Coover M, Gellin RG, Wahlquist AE, AbdulRahiman A, et al. Does use of an electronic health record with dental diagnostic system terminology promote dental students' critical thinking? *J Dent Educ* 2015; **79**: 686–96. doi: https://doi.org/10.1002/j.0022-0337.2015.79.6.tb05942.x
32. Baghdady MT, Carnahan H, Lam EWN, Woods NN. Dental and dental hygiene students' diagnostic accuracy in oral radiology: effect of diagnostic strategy and instructional method. *J Dent Educ* 2014; **78**: 1279–85. doi: https://doi.org/10.1002/j.0022-0337.2014.78.9.tb05799.x
33. Hung K, Montalvao C, Tanaka R, Kawai T, Bornstein MM. The use and performance of artificial intelligence applications in dental and maxillofacial radiology: a systematic review. *Dentomaxillofac Radiol* 2020; **49**: 20190107. doi: https://doi.org/10.1259/dmfr.20190107
34. Saghiri MA, Asgar K, Boukani KK, Lotfi M, Aghili H, Delvarani A, et al. A new approach for locating the minor apical foramen using an artificial neural network. *Int Endod J* 2012; **45**: 257–65. doi: https://doi.org/10.1111/j.1365-2591.2011.01970.x
35. Saghiri MA, Garcia-Godoy F, Gutmann JL, Lotfi M, Asgar K. The reliability of artificial neural network in locating minor apical foramen: a cadaver study. *J Endod* 2012; **38**: 1130–4. doi: https://doi.org/10.1016/j.joen.2012.05.004
36. Devito KL, de Souza Barbosa F, Felippe Filho WN. An artificial multilayer perceptron neural network for diagnosis of proximal dental caries. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; **106**: 879–84. doi: https://doi.org/10.1016/j.tripleo.2008.03.002
37. Johari M, Esmaeili F, Andalib A, Garjani S, Saberkari H. Detection of vertical root fractures in intact and endodontically treated premolar teeth by designing a probabilistic neural network: an ex vivo study. *Dentomaxillofac Radiol* 2017; **46**: 20160107. doi: https://doi.org/10.1259/dmfr.20160107
38. Lee J-H, Kim D-H, Jeong S-N, Choi S-H. Detection and diagnosis of dental caries using a deep learning-based convolutional neural network algorithm. *J Dent* 2018; **77**: 106–11. doi: https://doi.org/10.1016/j.jdent.2018.07.015