Evaluation of a Near-Infrared Light Transillumination Device for Caries Detection in Interproximal Primary Molar Surfaces

Sahar Alrayyes, DDS, MS[1]
Allison Horn, DDS, MS[2]
Evelina Kratunova, BDS, MDS, DChDent[3]
Anne Koerber, DDS, PhD[4]

ABSTRACT

Purpose: To evaluate the sensitivity and specificity of the near-infrared light transillumination caries detection method by using DEXIS CariVu (DCV) for imaging of interproximal primary molar surfaces (IPMS).

Methods: A retrospective evaluation of patient records at a university pediatric dentistry (PD) clinic identified 22 patients with unrestored IPMS, which had images of both bitewing radiography (BW) and DCV. A scoring system (no caries, incipient caries, dentinal caries) was developed for the study. Two investigators (pediatric dental faculty) identically scored 90 IPMS in both BW and DCV images, establishing benchmark IPMS scores. The 180 images were then compiled in a randomized order in a questionnaire, which was answered by 24 raters (PD residents and faculty) using the study caries scoring system. Data analysis included raters and experts' percent agreement, Vassar Stats for sensitivity and specificity, and Kendall's correlation coefficient for interrater reliability.

Results: The overall agreement between raters and experts for DCV images was 48 percent (54 percent for no caries, 23 percent for incipient caries, and 68 percent for dentinal caries). The DCV's sensitivity and specificity to detect any caries were, respectively, 0.72 and 0.54, 0.60 and 0.53 for incipient caries, and 0.82 and 0.53 for dentinal caries. The BW's sensitivity and specificity to detect any caries were respectively, 0.82 and 0.87, 0.98 and 0.86 for incipient caries, and 0.99 and 0.87 for dentinal caries. The overall interrater reliability was 0.48 (95 percent confidence interval equals 0.46 to 0.50).

Conclusion: The use of DCV as a stand-alone caries detection method for IPMS is limited. **(J Dent Child 2021;88(3):180-6)**

Received March 2, 2021; Last Revision April 19, 2021; Accepted April 20, 2021.

KEYWORDS: RADIOGRAPHY, DECIDUOUS TEETH, PEDIATRIC DENTISTRY, NEAR-INFRARED LIGHT TRANSILLUMINATION

Drs. [1]Alrayyes and [3]Kratunova are clinical associate professors, Department of Pediatric Dentistry, and [4]Dr. Koerber is a professor, Department of Oral Medicine, all in the College of Dentistry, University of Illinois Chicago; [2]Dr. Horn is a pediatric dentist in private practice, all in Chicago, Ill., USA. Correspond with Dr. Alrayyes at salray1@uic.edu

Dental caries is a dynamic process with multiple cycles of demineralization and remineralization occurring on the tooth surface over time.[1] It presents a continuum from incipient enamel lesion through dentinal involvement to, ultimately, frank

cavitation.[2] Dental caries can be reversed if detected early; therefore, successful identification of incipient enamel lesions is important.[3,4] There is a lack of strong correlation between the depth of a carious lesion evident on a radiograph and its true cavitation status, particularly for radiographically hypodense lesions that penetrate the enamel and approach the dentinoenamel junction (**DEJ**).[5] Practitioners may disagree on the ideal management of incipient caries, with therapeutic approaches varying from rigorous preventive measures to definitive operative interventions.[3,4]

Bitewing radiography (**BW**), in conjunction with a clinical visual examination, is currently the gold standard method for detection of interproximal carious lesions.[6-8] However, it poses certain disadvantages.[6-8] For a carious lesion to be detected on a radiograph, 40 to 60 percent structural decalcification must be present.[9] As a result, BW is a method reported to have high sensitivity for detection of interproximal caries into dentin than in enamel.[6-9] It is shown to have a sensitivity range of 0.54 to 0.66 and a specificity of 0.83 to 0.95 for dentinal caries.[10,11] BW is a less reliable technique for the detection of enamel caries, with a reported sensitivity range of 0.3 to 0.41 and a specificity of 0.76 to 0.78.[10-12] Consequently, enamel carious lesions may go undetected.[6-12] The American Academy of Pediatric Dentistry recommends posterior radiographs at six- to 12-month intervals to detect interproximal caries when it cannot be examined visually or with a probe for patients who are at increased risk for caries and with clinical caries, versus 12- to 24-month intervals for patients without clinical caries.[13] Introducing alternative methods for detecting incipient caries that use less or no radiation would be beneficial to the contemporary practice of pediatric dentistry. The ideal caries detection method should be accurate, precise, easy to use, and applicable for every surface of the tooth.[12]

Near-infrared light transillumination (**NIRTI**) is a caries detection method that has been in development for the past two decades.[13-16] Fiber optic transillumination (**FOTI**) and digital imaging FOTI use high intensity visible light to identify tooth demineralization through transillumination.[17,18] Demineralized tooth structures have an increased scattering of light and appear darker than healthy hard tissues.[17,18] DEXIS CariVu ([**DCV**] DEXIS, LLC, Hatfield, Pa., USA) is a NIRTI device commercially available in the United States, while DIAGNOcam (KaVo, Biberach, Germany) is the alternative European brand. It is a handheld device that uses NIRTI and an intraoral camera to transilluminate teeth. The captured images are software-processed and viewed on a computer screen. Its clinical practice application can potentially reduce patient radiation exposure. Furthermore, the intraoral camera might be better tolerated than intraoral sensors, offering ease of use and time efficacy. To date, there is a lack of research trials evaluating the clinical practice application of the DCV in primary teeth.

The purpose of this study was to evaluate the sensitivity and specificity of the NIRTI caries detection method by using DCV for imaging of interproximal primary molar surfaces (**IPMS**). The study objectives were to: (1) determine the percent agreement between pediatric dentistry (**PD**) residents and faculty members and experts for the rating of IPMS caries status using DCV images and BW images; and (2) calculate the sensitivity and specificity of DCV and BW for detection of any caries (enamel and/or dentinal), incipient caries, and dentinal caries in IPMS.

METHODS

This study was approved by the Institutional Review Board of the University of Illinois Chicago (**UIC**), Chicago, Ill., USA (IRB #2016-0899). A query was run on the Electronic Health Record (**EHR**) system of the UIC College of Dentistry to generate a list of all pediatric patients who had a comprehensive dental examination (code D0150) completed from the beginning of July 2016 to the end of September 2016. The principal investigator (**PI**) reviewed the EHR of all patients from this list to identify eligible subjects. The criteria for eligibility included: (1) mixed dentition stage of dental development (age group of six to 11 years); (2) all primary molars present in the dentition; (3) closed contacts between the primary molars and adjacent teeth; (4) primary molars that had no restoration; (5) primary molars without developmental dental anomalies (e.g., amelogenesis imperfecta, dentinogenetic imperfecta, enamel defects, etc.); and (6) primary molars examined with both BW and DCV at the same patient visit (i.e., both BW and DCV images of identical IPMS were available in the EHR).

All DCV images were taken by PD residents, and the BW were exposed either by PD residents or dental assistants. The equipment available in the PD clinic included intraoral radiographic units with an antidrift mechanism (Kavo FOCUS, Kavo Dental, Charlotte, N.C., USA) and digital intraoral sensors (either DEXIS Platinum Sensor, or Gendex GXS-700 Sensor, Gendex Dental Systems, KaVo Dental, Brea, Calif, USA). All radiographs were digital and were captured using the DEXIS dental imaging software program (DEXIS Imaging Suite, Kavo Dental). The NIRTI photography was done using the DCVdevice.

Of the 286 patients on the EHR generated list, the PI identified 22 subjects who fulfilled the inclusion criteria. Their BW and DCV images of primary molars were exported from the EHR, deidentified, and collided in a Microsoft PowerPoint (Microsoft Corp., Redmond, Wash., USA) file. Twenty-two subjects had two BW each; thus, a total of 44 BW were collected. Each BW portrayed the images of two primary maxillary molars and two primary mandibular molars. The four molars together had eight interproximal (mesial and distal) surface images

visible on a single BW. Hence, the 44 BW portrayed a total of 352 IPMS. The PI assigned study numbers to all IPMS (e.g., #X-A-D, with X being the study number of the subject, A being the tooth type according to the Universal numbering system; and D being the type of interproximal surface, distal or mesial).

For each IPMS, the PI obtained the corresponding DCV image. The PI assessed the quality of the images (both BW and DCV) of all 352 IPMS based on the following inclusion criteria: (1) appropriate image coverage with visualization of the entire interproximal surface; (2) absence of interproximal overlap; and (3) lack of technical errors, such as blurring, distortion, and overexposure. Additionally, only IPMS that had both BW and DCV images that satisfied the inclusion criteria were selected for further use in the study. After evaluation, the PI identified 221 eligible IPMS.

The images (BW and their corresponding DCV) of these IPMS were shuffled (mixed in no particular order) and presented in a questionnaire in a Microsoft PowerPoint format. Each question required an assessment of a specified IPMS shown on the image (either BW or DCV) according to a caries status scoring system especially developed for this study. The scores of this system included one (no caries), two (incipient caries) three (dentinal caries). "Incipient caries" was defined as caries in enamel only, not touching the DEJ, while "dentinal caries" was defined as any caries in the dentin (i.e., extending beyond the DEJ). Two investigators, both full-time PD faculty members with ample experience in using DCV and digital radiography, formed the study expert committee. Each expert independently completed the questionnaire, providing scores for all 221 IPMS from both the BW and DCV images. Therefore, each IPMS received two scores from an expert for a total of four scores (two from BW and two from DCV). Before completing the questionnaire, the experts were calibrated by reviewing the study protocol and undergoing DCV theoretical and practical instruction provided by a commercial representative. The PI reviewed the completed expert questionnaires and identified a total of 90 IPMS, which received four identical scores. If a DCV or radiographic image was deemed nonideal or undiagnostic per the expert committee members, that IPMS was excluded. The experts' scores were accepted as the benchmark describing the caries status of the selected 90 IPMS. Of the 90 IPMS, 33 had a score of one (no caries), 26 had a score of two (incipient caries), and 31 had a score of three (dentinal caries).

The PI compiled the 180 images (90 BW and 90 DCV)of IPMS into a second questionnaire, which was distributed to 24 raters. The chronological order of appearance of these images in the questionnaire was randomized. The randomization was done by creating a random digit table in Microsoft Excel 14.0 (Microsoft Corp., Redmond, Wash., USA), and the generated numbers determined the allocation of the images of the IPMS. The 24 raters included nine first year PD residents, eight second year PD residents, and seven PD faculty members (other than the experts). All raters were recruited verbally and given the option to opt out of the study at any time. They all had prior DCV theoretical and practical training provided by a commercial representative. Sample images from the DCV user manual were made available to the raters as a reference guide during questionnaire completion. As all images in the questionnaire were presented in a random order, the raters were blinded to the pairing of the BW and DCV in portraying identical IPMS. The experts' scores were considered the benchmark against which the raters' scores were evaluated to determine the percent agreement between rates and experts.

The scores for all IPMS were gathered in a Microsoft Excel document, and statistical analysis was completed using SPSS 20.0 software (IBM Corp., Armonk, N.Y., USA). The sensitivity and specificity of DCV and BW were calculated for any caries (enamel and/or dentinal) detection, incipient caries, and dentinal caries detection in IPMS. Determination of sensitivity and specificity was performed using Vassar Stats, a website for statistical computation (Lowry 2017, Poughkeepsie, N.Y., USA). Interrater reliability (for the raters only and not for the experts) was calculated using Kendall's correlation coefficient, which is a measure of the correlation of the three categories of ranked data (no caries, incipient caries, and dentinal caries) ranging from -1 (perfect inversion) to +1 (perfect agreement). Analysis of variance (**ANOVA**) was used to detect any differences between the mean interrater reliability of first year PD residents, second year PD residents, and PD faculty members for BW and DCV images. A P-value of <0.05 was used to determine significance.

RESULTS

A total of 2,160 scores for DCV images of the 90 IPMS were collected in the questionnaire from the 24 raters.

Table 1. Raters percent agreement with the experts rating (study standard) in detecting no caries, incipient caries, and dentinal caries in primary molars using DEXIS Carivu

Diagnostic function	% agreement with expert rating	95 % confidence interval for percent agreement	Sample sizes
Overall	48	0.48-0.52	90 cases, 24 raters
No caries	54	0.50-0.57	33 cases, 24 raters
Incipient caries	23	0.20-0.27	26 cases, 24 raters
Dentinal caries	68	0.64-0.71	31 cases, 24 raters

Table 2. Sensitivity and specificity of DEXIS CariVu (DCV) and bitewing radiography (BW) using the experts' scores as a standard

		Sensitivity	95% confidence interval	Specificity	95% confidence interval
Any caries (incipient + dentinal)	*BW*	0.92	0.90-0.93	0.87	0.84-0.89
	DCV	0.72	0.69-0.74	0.54	0.50-0.57
Incipient caries	*BW*	0.98	0.97-0.99	0.86	0.85-0.88
	DCV	0.60	0.57-0.64	0.53	0.50-0.57
Dentinal caries	*BW*	0.99	0.98-0.99	0.87	0.84-0.89
	DCV	0.82	0.79-0.84	0.53	0.50-0.57

The results of the comparison between the raters' scores and the experts' scores (study standard) showing the percent agreement (between raters and experts) in the three categories (no caries, incipient caries, and dentinal caries) are presented in Table 1. For the BW images of the 90 IPMS, the same number of 2,160 scores were received from the 24 raters. The overall percent agreement between the rates' scores and the experts' scores using BW images was 84 percent, with 87 percent for the category of no caries, 69 percent for incipient caries, and 93 percent for dentinal caries.

Sensitivity and specificity for DCV were calculated (Table 2). The ability of the raters to score dentinal caries on DCV images in the same way as the experts was contrasted with their ability to score no caries as the raters did (sensitivity=0.82 and specificity=0.53). The ability of the raters to score incipient caries on DCV images in the same way as the experts was contrasted with their ability to score no caries as the raters did (sensitivity = 0.60 and specificity = 0.53). Likewise, the raters' ability to score any caries (incipient caries and/or dentinal caries) as the experts was contrasted to their ability to score no caries (sensitivity = 0.72 and specificity = 0.54).

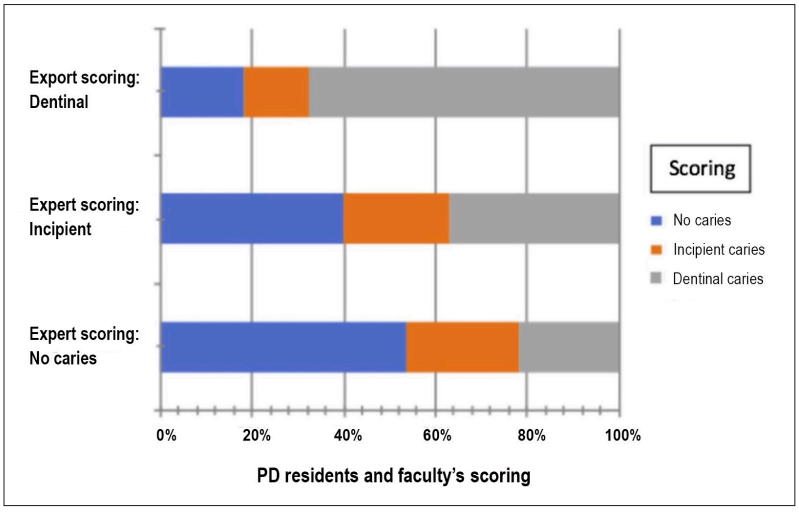

Figure 1. Distribution of raters' scoring DEXIS CariVu images with 'no caries', 'incipient caries' and 'dentinal caries.

In a parallel analysis, the sensitivity and specificity for BW were calculated. The ability of the raters to score dentinal caries on BW images in the same way as the experts was contrasted with their ability to score no caries as the raters did (sensitivity=0.99 and specificity=0.87). The ability of the raters to score incipient caries on BW images in the same way as the experts was contrasted with their ability to score no caries as the raters did (sensitivity=0.98 and specificity=0.86). Similarly, the raters' ability to score any caries (incipient caries as well as dentinal caries) as the experts was contrasted with their ability to score no caries (sensitivity = 0.82 and specificity = 0.87).

The distribution of incorrect scoring of the DCV images by the raters in comparison to the experts' scores was examined (Figure 1). In all three categories (no caries, incipient caries, and dentinal caries [Figure 2]), the errors were almost evenly divided.

Interrater reliability was calculated for the DCV scores for the 24 raters using Kendall's correlation coefficient. The mean interrater reliability for DCV images was 0.48 (95 percent confidence interval **[95% CI]**=0.46 to 0.50). The same calculation was completed for the BW, and the interrater reliability was 0.78 (95% CI=0.77 to 0.79). First year PD residents, second year PD residents, and PD faculty members were compared on their interrater reliability, with no differences found for either BW (ANOVA, *P*=0.90) or DCV (ANOVA, *P*=0.30).

DISCUSSION

In recent years, the concept of minimally invasive dentistry has become increasingly popular, and clinical therapies that foster remineralization of incipient carious lesions and preservation of tooth structure have been encouraged and promoted.[19,20] The successful application of conservative caries management requires the utilization of diagnostic modalities that can detect the carious process in its early stages.[21] Along with traditionally used methods such as dental radiography, alternative caries detection systems, such as NIRTI, have been developed and are now available to clinicians.[21] These methods should be evaluated for their validity and reliability. A method with good validity can produce results that are comparable to the benchmark standard.[21]

In the present study, the sensitivity and specificity of DCV for detecting caries in IPMS were investigated under specific circumstances. The diagnostic value of static DCV images, presented outside the mouth through a questionnaire, was determined.

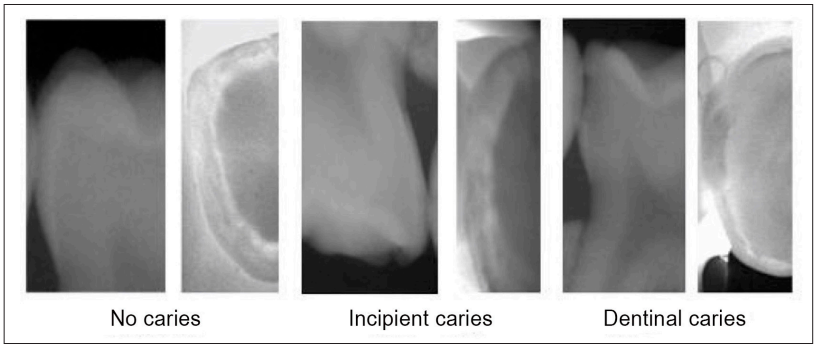

Figure 2. Comparison of lesions in near-infrared light transillumination and bitewing radiographs for 'no caries, 'incipient caries' and 'dentinal caries'.

The functionality was evaluated by comparing the IPMS caries status diagnosed by PD residents and faculty members from DCV images to the standard set by an expert committee. The raters had the highest percent agreement at detecting dentinal caries with DCV and the least percent agreement at detecting incipient caries. Generally, an agreement of 90 percent or higher (Kendall's coefficient) is considered to be very good; however, the raters were able to recognize caries-free IPMS and overall caries in only approximately half of the cases. This finding was disappointing, as one of the perceived values in the clinical use of DCV is the early detection of caries. By comparison, the percent agreement between raters and experts was much higher when BW images were used for determining the caries status of IPMS. In addition to that, since the sensitivity and specificity of DCV were below 90 percent, its diagnostic performance may be considered limited.

DCV has been found to be a useful diagnostic aid in assessing caries in permanent teeth.[22] To the best of the authors' knowledge, the present study was the first to use DCV for caries detection of IPMS. Minimally invasive diagnostic methods offer an advantage in minimizing ionizing radiation and in improving the diagnostic capacity of radiographs. A limitation of the study design was that the DCV images were assessed for their own merit and outside a clinical situation. Therefore, future research should test the diagnostic efficacy of DCV in more clinically realistic settings, where the dentist could adjust the DCV placement intraorally until the image is clearly visible, move the light source to maximize effectiveness, and enhance the images in other ways.

While histological evaluation of the hard tissues may offer objective determination of the caries status of tooth surfaces, it is not a viable method for wide clinical practice use. The authors had to establish a study standard against which they could evaluate the caries detection ability of the DCV images. They evaluated existing BW and DCV images obtained from in vivo examinations. The images with unacceptable technical quality were excluded. The present study employed an expert committee, which rated the caries status of IPMS from BW and DCV images using a simple scoring system. Out of the 221 IPMS, only 90 received identical scores from both experts and for both imaging techniques. The study design also strived for a rigorous selection of images with optimal diagnostic value to ensure appropriate evaluation of the DCV.

It has been demonstrated that the DCV was better able to detect lesions in the inner half of the enamel compared to the outer half of the enamel.[23] It has been suggested as a possible explanation the fact that increased demineralization may lead to increased light scattering and absorption.[23,24] Similarly, in the present study, DCV was least likely to detect incipient caries in the outer enamel and most likely to detect dentinal caries. Enamel thickness, tooth shape and convexity, and mineral content in primary teeth differ from permanent teeth. Hence, further research is needed to examine the properties of NIRTI in primary teeth. Additionally, future studies may investigate the effect of demineralization of thin enamel layers on the light scattering and absorption, which could contribute to the difficulty in detecting incipient lesions in primary teeth with DCV.

This study utilized a caries scoring system, which was concise and deemed user-friendly by the investigators. The categories of no caries, incipient caries, and dentinal caries were clearly defined for the study purposes. While this scoring system was not validated by previous research, it used categories that directly correspond to the criteria of the American Dental Association's Caries Classification System (**CCS**).[25] According to CCS' radiographic presentation of approximal surfaces, a sound tooth surface means no radiolucency (**R0**) and initial caries includes radiolucency within the outer half of enamel (**RA1**), up to the DEJ (**RA2**), and beyond the DEJ up to the outer half of dentin (**RA3**). Furthermore, moderate caries is depicted by radiolucency extending into the middle third of the dentin (**RB4**) while advanced caries is defined as a radiolucency extending into the inner third of the dentin (**RC5**). When the caries scoring system used in our study is compared to CCS, no caries corresponds directly to R0, incipient caries relates to RA1 and RA2, and dentinal caries matches the criteria of RA3, RB4, and RC5. These correlations were explained to all raters for clarity. The reason CCS was not adopted in this research was the need for simplicity and differentiation between caries in enamel and any dentinal caries. In clinical practice, the ability to confirm that the extent of caries is limited to the enamel layer poses the advantage of introducing conservative management and remineralization therapy contrary to operative intervention. Therefore, testing the DCV's ability to diagnose incipient lesions (within enamel only) presented a direct clinical practice value.

A recent meta-analysis on the diagnostic validity of NIRTI for the detection of caries in dentin showed moderate validity, with no strong evidence that NIRTI

can replace traditional radiographs for caries diagnosis.[22] The findings of the present study show similar outcomes for dentinal caries detection with DCV.

A strength of this study was the blinding of the raters to the pairing of BW and DCV images. The authors enrolled multiple raters with various experience in PD to mirror the wider practice use of the DCV. The authors achieved good inter-rater reliability for BW images. The ability of the raters to diagnose caries with these preselected images was also adequate. This is evidence of the appropriateness of the authors' benchmark standard.

The low inter-rater reliability for DCV may be attributed to the inexperience of users with the DCV technology compared to the years of experience of the raters in interpreting BW radiographs. Future studies should test the DCV on practitioners with more routine experience with the device and among a less heterogenous group of raters.

CONCLUSIONS

Based on the results of the study, the following conclusions can be made:

1. The percent agreement between PD residents, faculty members and experts on the caries status rating of IPMS when using DCV images was low (48 percent).
2. The sensitivity and specificity of DCV for detection of any caries (enamel and/or dentinal) as well as for dentinal caries detection in IPMS were low.
3. The percent agreement between PD residents, faculty members and experts on the caries status rating of IPMS when using BW images was higher (84 percent) than for DCV. The sensitivity and specificity of BW for detection of any caries (enamel and/or dentinal) as well as for dentinal caries detection in IPMS were also higher.
4. DCV may have limitations as a stand-alone method for interproximal caries detection in primary molars.

ACKNOWLEDGMENT

The authors wish to thank DEXIS, LLC, Hatfield, Pa., USA, for donating a DEXIS CariVu instructional and training session for all faculty and residents in the Department of Pediatric Dentistry, College of Dentistry, University of Illinois Chicago, Chicago, Ill., USA.

REFERENCES

1. Featherstone JD. Dental caries: A dynamic disease process. Aust Dent J 2008;53(3):286-91.
2. Featherstone JD. The continuum of dental caries: Evidence for a dynamic disease process. J Dental Res 2004;83(Spec No C):c39-c42.
3. Featherstone JD. Prevention and reversal of dental caries: role of low level fluoride. Community Dent Oral Epidemiol 1999;27(1):31-40.
4. Mount GJ. Defining, classifying, and placing incipient caries lesions in perspective. Dent Clin North Am 2005;49(4):701-23.
5. Nascimento MM, Bader JD, Qvist V, et al. DPBRN Collaborative Group. Concordance between preoperative and postoperative assessments of primary caries lesion depth: Results from the Dental PBRN. Oper Dent 2010;35(4):389-96.
6. Abdelaziz M, Krejci I, Perneger T, Feilzer A, Vazquez L. Near infrared transillumination compared with radiography to detect and monitor proximal caries: A clinical retrospective study. J Dent 2018;70:40-5.
7. Fejerskov O, Nyvad B, Kidd EAM. Dental Caries the Disease and Its Clinical Management. 3rd ed. Ames, Iowa: Wiley-Blackwell; 2015:466S.
8. Russotto F, Tirone F, Salzano S, et al. Clinical evaluation of near-infrared light transillumination (NIRT) as an interproximal caries detection tool in a large sample of patients in a private practice. J Radiol Imaging 2016;1(1):1-5.
9. Yang J, Dutra V. Utility of radiology, laser fluorescence, and transillumination. Dent Clin North Am 2005;49(4):739-52.
10. Bader JD, Shugars DA, Bonito AJ. Systematic reviews of selected dental caries diagnostic and management methods. J Dent Educ 2001;65(10): 960-8.
11. Schwendicke F, Tzschoppe M, Paris S. Radiographic caries detection: A systematic review and meta-analysis. J Dent 2015; 43(8):924-33.
12. Zandoná AF, Zero DT. Diagnostic tools for early caries detection. J Am Dent Assoc 2006;137(12): 1675-84.
13. American Academy Pediatric Dentistry. Guidelines on prescribing dental radiographs for infants, children, adolescents, and individuals with special health care needs. Pediatr Dent 2017;39(6):205-7.
14. Fried D, Glena RE, Featherstone JD, Seka W. Nature of light scattering in dental enamel and dentin at visible and near-infrared wavelengths. Appl Opt 1995;34(7):1278-85.
15. Litzenburger F, Heck K, Pitchika V, et al. Inter- and intraexaminer reliability of bitewing radiography and near-infrared light transillumination for proximal caries detection and assessment. Dentomaxillofac Radiol 2018;47(3):20170292.
16. Fried D, Featherstone JD, Darling CL, Jones RS, Ngaotheppitak P, Bühler CM. Early caries imaging and monitoring with near-infrared light. Dent Clin North Am 2005;49(4):771-93.

17. Lara-Capi C, Cagetti MG, Lingström P, et al. Digital transillumination in caries detection versus radiographic and clinical methods: An in-vivo study. Dentomaxillofac Radiol 2017;46(4):20160417.
18. Astvaldsdottir A, Ahlund K, Holbrook WP, de Verdier B, Tranæus S. Approximal caries detection by DIFOTI: In vitro comparison of diagnostic accuracy/efficacy with film and digital radiography. Int J Dent 2012;2012:326401.
19. American Academy of Pediatric Dentistry. Caries-risk assessment and management for infants, children, and adolescents. The Reference Manual of Pediatric Dentistry. Chicago, Ill.: American Academy of Pediatric Dentistry; 2020:197-204.
20. Ericson D. What is minimally invasive dentistry? Oral Health Prev Dent 2004;2(suppl 1):287-92.
21. Gomez J. Detection and diagnosis of the early caries lesion. BMC Oral Health 2015;15(Suppl 1): S3.
22. Marmaneu-Menero A, Iranzo-Cortés JE, Almerich-Torres T, Ortolá-Síscar JC, Montiel-Company JM, Almerich-Silla JM. Diagnostic validity of digital imaging fiber-optic transillumination (DIFOTI) and near infrared light transillumination (NILT) for caries in dentine. J Clin Med 2020;9(2):420.
23. 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.
24. Bosch JT. Light scattering and related methods in caries diagnosis. In: Stookey GK, ed. Early Detection of Dental Caries: Proceedings of the 1st Annual Indiana Conference. Indianapolis: Indiana University School of Dentistry; 1996:81-90.
25. Young DA, Nový BB, Zeller GG, et al. The American Dental Association Caries Classification System for clinical practice: A report of the American Dental Association Council on Scientific Affairs. J Am Dent Assoc 2015;146(2):79-86.