ORIGINAL ARTICLE

Comparison of different caries detectors for approximal caries detection

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Abstract *Background/purpose:* Detection of approximal caries may be difficult using conventional methods including visual inspection (VI) and radiography. The purpose of this *in vitro* research was to evaluate the efficiency of light-emitting diode (LED) and laser fluorescence (LF) devices, and radiographic and visual examination in approximal caries diagnosis.
Materials and methods: One hundred and fifty-six approximal regions were evaluated. All approximal regions were investigated using LED and LF tools after radiography and VI were performed. Histological evaluation of teeth was performed using stereomicroscopy. The area under the receiver operating characteristic curve and accuracy, specificity, sensitivity values calculated regarding approximal caries diagnose.
Results: The specificity of the bitewing examination was higher for both T1 and T2 thresholds (0.97 and 0.99, respectively), and the LF device showed better sensitivity at each threshold compared with the other devices used for caries diagnosis (0.94 at T1 and 0.79 at T2). The receiver operating characteristic curves presented that the LF device was more successful than the other techniques at T1 threshold and VI was better than the other caries detection methods at T2 threshold. The kappa values for interobserver agreements were 0.43 (LF pen), 0.33 (LED device), 0.55 (VI), and 0.75 (bitewing examination).

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Conclusion: The ability of bitewing radiography to identify sound surfaces was better than that of the other methods. The LF device was the most sensitive tool for detecting approximal surfaces with caries, followed by the LED device.

Introduction

Diagnosis of the decay present on the proximal area of posterior teeth is difficult because direct visual examination cannot be applied due to the wide contact areas.[1,2] Researchers are working to develop an efficient, cost-effective, and quantitative method, with high validity and reliability, for use in approximal caries detection. An ideal method for caries detection should offer high specificity, sensitivity, and reproducibility. Although visual inspection (VI) has shown high specificity in approximal caries detection, it displays low sensitivity and reproducibility.[2–4] To develop the currency and reliability of VI, a visible scoring system (International Caries Detection and Assessment System) for caries diagnosis was developed for the surveys. However, this system has yet to be validated for approximal surfaces.[2,5]

Although radiographic methods can be more sensitive than VI in approximal caries detection, these are is not quantitative. Bitewing radiography is the standard method for detecting approximal caries. However, it underestimates the actual depth of the lesion and is more suitable for detecting dentin caries. Another limitation of this radiography is that patients are exposed to ionizing radiation.[2,4,6,7]

New adjunct devices, such as a laser fluorescence pen (LF pen; Kavo, Biberach, Germany), have been proposed in the past number of years to increase the reproducibility and accuracy of caries diagnosis and to aid in objective assessments.[8] The LF pen device can diagnose occlusal and approximal caries by detecting the emitted fluorescence after practice of laser light emitting a wavelength of 655 nm. The LF device has shown good accuracy and reproducibility in the determination of proximal decay. Thus, the use of an LF pen in approximal surfaces has been proposed.[1,9–11] Both radiography and the LF pen have shown promise in increasing the sensitivity of approximal caries detection. Lussi et al[1] reported that the LF pen device was better than radiography in detecting approximal caries in permanent teeth. Other studies[4,12–14] also demonstrated that the LF pen was better than radiography in caries detection when used as an auxiliary method.

The Food and Drug Administration has approved another device, a light-emitting diode (LED) instrument, for the diagnosis of occlusal and approximal caries. This tool emits a soft LED light ranging from 635 nm to 880 nm. A sound tooth is more translucent than a tooth with a demineralized structure. The dissimilarity in translucency means that the optical appearance of the sound tooth is different from that of the decalcified teeth. The LED device includes a computer-based algorithm, which determines the various visual signatures of sound and demineralized teeth. This tool is based on an analysis of the projection and refraction of the emitted light from the tooth surface. The light is received by fiber optics and transformed to an electrical beam for examination.[15]

Although several *in vitro*[16–18] and *in vivo*[19] studies on the effectiveness of the LED device in detecting occlusal caries have been conducted, there are a few reports in the literature on its application to proximal caries.[20] Thus, the goal of the present investigation was to investigate the validity of the LED device in the diagnosis of approximal caries, and to compare the performance of the device with that of the LF pen and other diagnostic techniques.

Materials and methods

The current research was approved by the Gaziantep University Ethics Committee in Research, Gaziantep, Turkey (No. 03-2009/78). A total of 156 approximal surfaces of 789 teeth, making sure that they are kept in contact with the sound teeth, were evaluated in this study. Permanent molars without approximal restorations, hypoplasia, and cavitation on approximal and occlusal surfaces were selected. Teeth where it was difficult to simulate the contact point were excluded. Following extraction, the teeth were waited at −20°C and stored in individual closed containers. The teeth were not in contact with any storage solution until use. Distilled water was used in individual holders to avoid dehydration of the teeth. The teeth had no contact with the soaked roll, which provided 100% humidity in the closed holders. The stored teeth were later defrosted at room temperature for 4 hours before starting the experiment.[11]

The proximal areas were brushed with a rotating device and pumice. To imitate the proximal contact surfaces, the teeth were located in model arches and stabilized with melt utility wax. Contact areas were achieved, which were confirmed with dental floss. Each test site was assessed by two examiners.

A photostimulable phosphor plate system was introduced (Vista Scan Mini; Dürr Dental AG, Bietighiem-Bissingen, Germany) to acquire digital bitewing radiographs of the teeth. They were exposed for 0.6 seconds at 60 kVp, 10 mA, focus to distance 20 cm, using an X-ray unit (Trophy; Kodak, Rochester, NY, USA) for standardization. The bitewing radiographs were scored as follows: D0, no radiolucency; D1, radiolucent area in the enamel; and D2, radiolucent area in the dentin.[4]

After radiographic evaluation, VI was performed without removing any teeth from the arch. The specimens were placed at a distance of about 30 cm from the examiners' eyes. The specimens were evaluated using no

magnification, after drying in air for 5 seconds, using an aid probe and a light reflector. The VI was coded as follows: V0, sound enamel; V1, presence of opaque white or brown spots; and V2, gray discoloration in the underlying dentin.

The LF pen device fixed to a tip 1 (for proximal areas) was applied by the producer's instructions. The tool was calibrated using a standard ceramic target, and the teeth were dried. The teeth were scored as follows: D0, 0–9; D1, 9.1–15; and D2, >15.[1] The buccal and lingual contact areas were measured, and the top score of measurements was noted.

The same measurements were obtained with the LED device (Midwest Caries I.D.; Dentsply Professional, York, PA, USA) after calibration with the ceramic standard. A red LED radiation was transported to the occlusal or proximal areas using the tip of the probe in contact with the occlusal surfaces. The teeth were then scored as follows: the emission of a red light and an audible sound showed the existence of caries or demineralization of the tooth, and the emission of a green light and no audible sound showed that the tooth surface was noncarious. Three types of audible sound that accompanied the emission of the red light clarified the extent of the decay. The cutoff limits suggested by the producer were used to assess the performance of the device: Score 0, no signal/green light, sound; Score 1, slow or medium signal/red light, enamel caries; and Score 2, rapid or uninterrupted signal/red light, dentin caries.

For the purpose of histological evaluation, which was considered as a gold standard, the teeth were serially sectioned (700 μm-thick sections) in the mesiodistal direction, until the deepest aspect of lesions was reached on both proximal surfaces, using an Isomet low-speed saw (Buehler, Lake Bluff, IL, USA). One calibration investigator assessed the slices using a stereomicroscope (25×; Leica Microsystems, Wetzlar, Germany) under the reflected light. The extent of caries in the teeth was evaluated as follows: 0, caries free; 1, enamel caries; and 2, dentin caries. The greatest opacity along the way of the rods was evaluated when the depth of decalcification in enamel was seen. The depth of decalcification of dentin was evaluated at the region where the color turns from brown/yellow to gray.[21]

Statistical analysis

Kappa statistics was used to determine the interexaminer reliability of the caries detection. It has been proposed that a κ score of 0–0.20 indicates slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, and >0.81 near perfect agreement (Landis and Koch).[22] The specificity, sensitivity, accuracy, and area under the receiver operating characteristic (ROC) curve values of the four different processes (LF pen and LED devices, bitewing radiography, and VI) in the diagnosis of proximal decays were calculated from the cutoff scores and compared using MedCalc software (MedCalc, Ostend, Belgium). The McNemar test was used to compare the performance (sensitivity, specificity, accuracy, and ROC curve) of both tools. Comparing the performance of the four methods in detecting proximal decays, the area under the ROC curve was measured at T1 (criterion scores 1 and 2, as evidence of disease) and T2 (criterion score 2, as evidence of disease). All other statistics were applied using the SPSS program, version 11.5. The 95% confidence interval was taken as P = 0.05.

Results

The evaluation of histology showed that 73 of the 156 approximal surfaces had score 0 (sound tooth), 44 had score 1 (enamel caries), and 39 had score 2 (dentin caries). Table 1 shows the number of teeth, diagnostic methods, and caries scores evaluated by the two examiners.

The weighted interexaminer kappa values for the LF device, LED device, bitewing radiography, and VI in the current study were $\kappa = 0.43$, $\kappa = 0.33$, $\kappa = 0.75$, and $\kappa = 0.55$, respectively. The kappa coefficient of the interexaminer agreement for the bitewing radiographs showed substantial agreement ($\kappa = 0.75$).

For both observers, the specificity of the bitewing examination was higher for both T1 and T2 thresholds (0.97 and 0.99, respectively). The LF device recorded better sensitivity rates at both thresholds than the other decay diagnosis techniques (0.94 at T1 and 0.79 at T2). The accuracy of the LF device (0.78) was higher than that of the other methods at T1 threshold. At T2 threshold, the accuracy value (0.81) of the bitewing examination was higher than that of the other methods (Table 2).

At T1 threshold, areas under the ROC curve were 0.79–0.87 for the LF device, 0.74 for the LED device, 0.64–0.66 for the bitewing examination, and 0.75–0.77 for the visual examination. At T2 threshold, areas under the ROC curve were 0.78–0.83 for the LF device, 0.75–0.78 for the LED device, 0.83–0.84 for the bitewing examination, and 0.72–0.74 for VI. Areas under the ROC curves indicated that the LF device was better than the other methods at T1 threshold. However, at T2 threshold, the area under the ROC curves for VI was higher than that of the other caries detection methods. Areas under the ROC curves (Az values) for all the diagnostic methods used in the study are shown in Table 2.

Discussion

Approximal caries lesions are often overlooked during VI because approximal surfaces cannot be visualized directly.

Table 1 Distribution and number of teeth according to diagnostic methods and caries classification, as assessed by the two examiners.

		Score 0	Score 1	Score 2
LED-based device	Examiner 1	54	78	24
	Examiner 2	74	56	26
LF-based device	Examiner 1	49	52	55
	Examiner 2	74	25	57
Visual examination	Examiner 1	99	26	31
	Examiner 2	95	32	29
Bitewing examination	Examiner 1	127	17	12
	Examiner 2	123	20	13
Histologic examination		73	44	39

LED = light-emitting diode; LF = laser fluorescence.

Table 2 Sensitivity, specificity, accuracy, and Az values for caries detection methods at T1 and T2.

Tests	Methods	Examiner 1		Examiner 2	
		T1	T2	T1	T2
Specificity	LF-based device	0.603	0.795	0.753	0.769
	LED-based device	0.575	0.923	0.712	0.906
	Bitewing examination	0.973	0.991	0.959	0.983
	Visual examination	0.945	0.991	0.959	0.991
Sensitivity	LF-based device	0.94	0.795	0.771	0.769
	LED-based device	0.855	0.385	0.735	0.385
	Bitewing examination	0.325	0.282	0.361	0.282
	Visual examination	0.325	0.154	0.313	0.027
Accuracy	LF-based device	0.782	0.795	0.763	0.769
	LED-based device	0.724	0.788	0.724	0.776
	Bitewing examination	0.628	0.814	0.641	0.808
	Visual examination	0.615	0.782	0.615	0.75
Area under ROC curve (Az values)	LF-based device	0.876	0.838	0.793	0.788
	LED-based device	0.743	0.781	0.748	0.754
	Bitewing examination	0.648	0.742	0.66	0.727
	Visual examination	0.753	0.839	0.776	0.841

LED = light-emitting diode; LF = laser fluorescence; ROC = receiver operating curve; T1 = Threshold 1; T2 = Threshold 2.

Bitewing radiography has been used as the standard method for the diagnosis of proximal dentin decay because it is a more sensitive detection method than clinical inspections. However, only if caries is bigger that 2—3 mm deep into dentin or one-third the buccolingual area, then it can be detected in radiographs. In addition, if incorrect horizontal angulation is used in this technique, overlapping of proximal areas occurs in the radiographs.[1,15]

Adjunct methods, such as LF and LED devices, are used to overcome the aforementioned failings of visual and radiological examinations. Although some studies[1,2,4,14] have evaluated the performance of LF devices, to the best of our knowledge, there have been a few studies related to the use of LED devices to detect approximal caries. Therefore, the present study was the first to evaluate the performance of a novel LED tool in the diagnosis of proximal decay and to compare its performance with that of radiography, VI, and an LF device.

In the current study, while specificity measures the proportion of negatives that are correctly identified as healthy tooth structures, sensitivity measures the proportion of positives that are correctly identified as decalcified tooth structures. Out of the two different thresholds (T1 and T2) used to identify the extent of caries, decalcification occurring in enamel and dentin was accepted as caries at T1 threshold and that occurring in dentin was accepted as caries at T2 threshold. It is easy to say that finding the healthy tooth structure is more difficult at T1 threshold than at T2 threshold, and finding the carious lesion is more difficult at T2 threshold than at T1 threshold. Since the diagnosis of noncavitated approximal lesions via VI is more difficult than other methods, based on the results of the present study, it can be suggested that sensitivity values indicated that caries were decreased and specificity values showed that sound surfaces were relatively increased at T2 threshold.

Since the proximal carious lesions started being visualized radiographically at the level of half the inner enamel, radiography is not the most indicated method to detect incipient carious lesions confined to the enamel, being more effective for lesions that have already reached the dentinoenamel junction.[23] Therefore, bitewing radiography is useful for the diagnosis of dentin decay on both occlusal and proximal areas. Bitewing radiography was reported to have high sensitivity (50—70%) for detecting cavitated surfaces and caries lesions in dentin, but poor performance in distinguishing a sound surface from a noncavitated lesion.[24] It also underestimated the actual depth of the lesion. Studies[2—4,25] also reported that the sensitivity of conventional radiographic techniques in the diagnosis of proximal decay lesions in primary and permanent teeth was around 0.50—0.60 and that the specificity was usually higher than 0.90.

In the current study, bitewing radiography failed to detect many existing caries. The sensitivity of bitewing radiography was low compared with the other methods. However, it showed higher specificity than the other methods. Hence, the prevalence of caries could be found to be low in the study sample according to bitewing examination due to the lack of cavitation in caries lesions.

According to *in vitro* studies,[1,4,12,13] the LF device, which has a tip that helps in the diagnosis of proximal decay, shows promising sensitivity, specificity, and reproducibility values. Studies[1,4,11,14] using primary or permanent teeth also demonstrated that the ability of the LF tool to diagnose advanced caries lesions was similar to that of radiographic methods. In two studies[1,7] using permanent teeth, the specificity and sensitivity of the LF device ranged from 0.68 to 0.93 and from 0.7 to 0.92, respectively. In our study, the specificity and sensitivity ranged from 0.63 to 0.79 and from 0.76 to 0.94, respectively. Lussi et al[1] reported that the LF device showed good performance in detecting both initial and advanced enamel approximal caries lesions.[1] In the current study, performance of the LF tool to distinguish surfaces without caries was significantly worse than that of the radiographic and visual methods. However, it showed good performance in terms of detecting both initial and advanced enamel approximal caries.

The LED device detects approximal caries by slightly angling and moving the probe along the marginal ridge over the vulnerable approximal surface. By sending and capturing the light signal in a direct line toward the vulnerable regions inside the enamel, it ensures minimal

dilution of the light signal from all surrounding structures. Due to this approach, the LED device can be much more convenient to use than the LF device. However, it can give false positive signals in cases of teeth with growth malformations in the enamel or dentin and teeth with alterations in the translucency of enamel, such as hypermineralization, hypocalcification, and dental fluorosis. Light penetration into the enamel is limited and that in the approximal area is restricted to 3 mm.[26] A few studies[16,17,19] have evaluated the effectiveness of the LED tool in the diagnosis of occlusal decay. These studies reported that the LED device did not identify surfaces without caries, but it was more accurate than the LF device in detecting dentin caries. Besides, only one study focused on the approximal caries detection using an LED-based device comparing with the LF-based devices and other conventional diagnostic techniques.[20] In the present study, the specificity of the LED device was higher than that of the LF device at T2 threshold, but lower at T1 threshold. Thus, it performed poorly in detecting surfaces without caries but well with respect to distinguishing enamel-dentin without caries according to the LF device, which is in accordance with the previous study.[20] The accuracy of the LED device was also higher than that of the visual and radiographic examinations.

In the current study, the interexaminer reproducibility of the LED tool was the lowest (0.33) among the methods tested, but bitewing radiography showed good interexaminer reliability (0.75). The evaluation of the LED device to grade decay lesions is not objective because it is not based on numerical values. In addition, the extent of the caries was expressed using three types of audible sounds, which accompanied the emission of the red light. The inadequate approach to the vulnerable approximal surface may be another limitation of this device. The reliability (0.43) of the LF device in the present study was lower than that reported in other diagnostic studies,[1,2,4,7] which reported high reliability (0.66–0.98).

In the present study, bitewing radiography was better than the other methods in detecting approximal surfaces without caries at both thresholds. The accuracy of bitewing radiography was also higher than the other methods at T2 threshold. The LF device was better than the other techniques in diagnosing proximal decay at both thresholds. The LED device had the lowest specificity at T1 threshold.

In conclusion, the ability of bitewing radiography to identify sound surfaces was better than that of the other methods. The LF device was the most sensitive tool for detecting approximal surfaces with caries, followed by the LED device. VI was least sensitive in detecting caries lesions.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

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