Friederike Söchtig

Caries detection and diagnostics with near-infrared light transillumination: Clinical experiences

Friederike Söchtig, DDS[1]/Reinhard Hickel, DDS[2]/Jan Kühnisch, DDS, MDS[3]

Objective: The aim of this paper was to present the function and potential of diagnosing caries lesions using a recently introduced near-infrared (NIR) transillumination technique (DIAGNOcam, KaVo). **Method and Materials:** The study included 130 adolescents and adults with complete permanent dentition (age > 12). All patients underwent visual examination and, if necessary, bitewing radiographs. Proximal and occlusal surfaces, which had not yet been restored, were photographed by a NIR transillumination camera system using light with a wavelength of 780 nm rather than ionizing radiation. Of the study patients, 85 showed 127 proximal dentin caries lesions that were treated operatively. **Results:** A cross table shows the correlation of radiography and NIR transillumination. Based on our practical clinical experiences to date, a possible classification of diagnosis is introduced. The main result of our study was that NIR light was able to visualize caries lesions on proximal and occlusal surfaces. **Conclusion:** The study suggests that NIR transillumination is a method that may help to avoid bitewing radiographs for diagnosis of caries in everyday clinical practice. *(Quintessence Int 2014;45:531–538; doi: 10.3290/j.qi.a31533)*

Key words: caries detection, caries diagnostics, DIAGNOcam, near-infrared light, photo-optics, proximal caries

In daily clinical practice the dentist has to cope with the challenge of detecting noncavitated dental caries on proximal and occlusal surfaces. In addition to this yes/no decision, the actual stage of the caries process should be defined in order to obtain a diagnosis and prognosis leading to a clinical decision.[1] Therefore, the dentist should know the extent of the caries lesion as an important prerequisite. The traditional methods of clinical inspection and review of radiographic bitewings are the most common strategies to detect, diagnose, and monitor visual caries lesions in proximal and occlusal surfaces.[2,3] Both these methods have limitations: Clinical examination alone may lead to an underestimation of caries decay, especially on the proximal/cavitated dentin level of lesions.[4-7] Obtaining satisfactory bitewings in children and teenagers is often problematic and sometimes impossible. Overlapping effects on the radiograph and fixed orthodontic appliances make the detection of primary lesions more difficult. Furthermore, the indication and repeatability of dental x-rays are considerably limited because of the associated ionizing radiation. Consequently, alternative diagnostic methods that do not rely on using dental x-rays may balance out the aforementioned disadvantages.

[1] Clinician, Department of Conservative Dentistry and Periodontology, Ludwig-Maximilians-University of Munich, Munich, Germany.

[2] Professor, Department of Conservative Dentistry and Periodontology, Ludwig-Maximilians-University of Munich, Munich, Germany.

[3] Assistant Professor, Department of Conservative Dentistry and Periodontology, Ludwig-Maximilians-University of Munich, Munich, Germany.

Correspondence: Dr Friederike Söchtig, Ludwig-Maximilians-Universität München, Poliklinik für Zahnerhaltung und Parodontologie, Goethestraße 70, 80336 München, Germany. Email: soechtig@dent.med.uni-muenchen.de

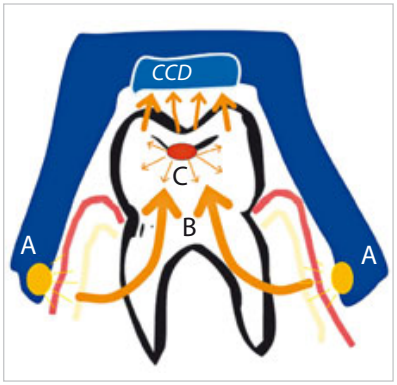
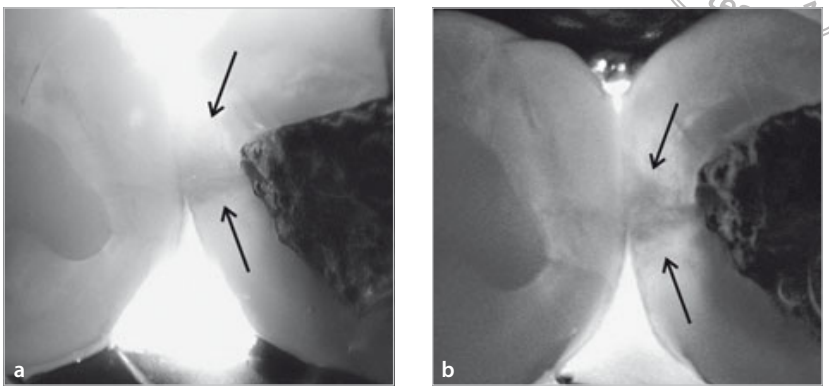


Fig 1 Schematic illustration of the mode of function of the near-infrared light transillumination (see text for abbreviations).



Figs 2a and 2b Two images comparing the appearance of enamel caries using digital fiber optic transillumination *(a)* and near-infrared transillumination *(b)*. Considerable light scattering makes FOTI technique more difficult to interpret.

Transillumination (diaphanoscopy) of limbs was a common diagnostic procedure prior to the discovery of x-rays. Based on the developments in digital fiber optical transillumination (FOTI and DiFOTI) using cold visible light,[8-11] there is a new diagnostic device (DIAGNOcam, KaVo) available that uses invisible near-infrared (NIR) light for transillumination of the tooth. In addition, the light is transmitted directly through the alveolar process (Fig 1), but not into the proximal space. These modifications seem to have considerably improved the quality of diagnostic imaging (Fig 2).

This diagnostic tool was introduced into the European market in Autumn 2012 and comprises a camera system including a NIR light source, a USB connection to a computer screen, and specially developed software. The elastic arms with optical fibers transmit the light through the ginigiva and the alveolar bone to the dental root (Fig 1, A) and from there up the crown (Fig 1, B). In case of the presence of a caries lesion the light is scattered and finally reduced (Fig 1, C). A charge-coupled device (CCD) sensor captures the clinical data. The image created always displays the tooth from its occlusal surface.

Photo optical methods are based mainly on light that shines on to or through a tooth. Light intensity can be reduced by absorption (eg, photons are lost to the hard tissue or the caries lesion) or scattering, in which the direction of the photons is changed without loss of energy. In the enamel and dentin, scattering is usually the dominant process, and it is also dependent on wavelength and the illuminated material.[12] In the NIR range of light (700 to 1500 nm), wavelengths are significantly longer than in the range of visible light. Longer wavelengths scatter less and thus can penetrate objects more deeply.[13-15] Several studies have demonstrated that enamel appears to be transparent when NIR light is used to illuminate the tooth, while dentin scatters more strongly.[13,16,17] Furthermore, studies have shown that NIR light transillumination can visualize caries lesions.[12,16,17]

This study seeks to introduce a new caries diagnostic device by the documentation of characteristic findings according to noncavitated occlusal and proximal caries lesions and the presentation of a correlation between bitewing radiographs and NIR light images of noncavitated proximal dentin lesions.

METHOD AND MATERIALS

Patients

This study was based on clinical, radiologic, and NIR optical examination data systematically collected from 130 patients. Subsequently, 85 of these patients showed caries lesions and underwent a detailed diagnostic evaluation.

The subjects were healthy (American Society of Anesthesiologists [ASA] Status 1) adolescents or adults with full permanent dentition (aged > 12). All patients

Fig 3a Clinical set-up of the near-infrared light device.

Fig 3b Position of the near-infrared camera in the maxilla.

provided written informed consent. The ethics committee at the medical faculty of the University of Munich approved the study (Project No. 013-12).

Clinical examination

The procedure for the examinations involved an initial professional tooth cleaning, followed by visual examination of the full dentition. Each patient was examined with a plane dental mirror (Rhodium Front, Orbis Dental Handels), a blunt CPI probe (CP-11.5B6, Hu-Friedy), compressed air, and the light source of the dental unit. All surfaces of the permanent dentition were examined according to the World Health Organization (WHO) criteria.[18] In addition, noncavitated caries lesions were scored according to the diagnostic principles of the International Caries Detection and Assessment System (ICDAS)[19] and the Universal Visual Scoring System for Caries Detection and Diagnosis (UniViSS) (http://univiss.net).[20,21] Photographic documentation was also prepared.

Next, all premolars and permanent molars were examined under NIR light (wavelength ~780 nm), whereby each tooth was dried with compressed air before the DIAGNOcam camera was centered over an area of interest. In order to focus the region of interest as precisely as possible only one tooth was photographed per image. The optimal position of the intraoral tip with the sensor on the teeth could be verified by the live image appearing on the computer screen next to the dental unit (Fig 3a). The light source of the dental unit was switched off while the images were being taken to prevent any light interference. An image was taken when the camera was positioned at a correct focus-object distance (Fig 3b) and when the CCD sensor was centered parallel to the occlusal surfaces of the dental arch (Fig 1). The tip was sterilized after each application. All the other surfaces of the device were wiped with a cloth and an approved disinfectant for disinfection in accordance with the manufacturer's information.

Each patient was asked to recall whether bitewing images had been taken in the preceding 4 months. If the answer was positive, these images were requested and evaluated. If the clinical indicators (eg, the presence of cavitated caries lesions, active initial lesions, or detectable demineralization between teeth) warranted bitewings, they were prescribed. In this case, a dental intraoral x-ray machine (Sirona) with a 200-mm FHA (source-skin distance) cone was used with a charge-coupled device (CCD) sensor (Intraoral II, sensor size 30.7 × 40.7 mm, Sirona). A film plate holder was used at all times. The exposure time was 0.06 seconds at a cathode voltage of 60 kV and 7 mA amperage.

Following the diagnostic examination, all the findings were analyzed. The correctness of the diagnosis was confirmed by the supervising experienced dentist (JK) to achieve a consensus diagnosis. Different findings

Table 1 Cross table of radiographs and near-infrared images of 127 validated caries lesions in dentin

		NIR light transillumination			
		D0	D1–2	D3–4	Total
Bitewing radiograph	D0–2	0	0	5	5
	D3	0	1	94	95
	D4	0	0	27	27
Total		0	1	126	127

were discussed, sometimes resulting in the modification of the initial diagnoses.

If noncavitated caries lesions were diagnosed, preventative care was advised; these measures included optimal fluoride supplementation at home and during recall appointments, nutritional anamnesis, advice on tooth-friendly diets, and guidance on optimal oral hygiene. In cases of noncavitated occlusal caries lesions, after the exclusion of dentin caries, the main priority was applying a pit and fissure sealant. In cases involving noncavitated proximal enamel caries lesions and those with minimal penetration of the dentinoenamel junction (DEJ) into the outer dentin, the patient was offered the option of resin infiltration, which was often performed. Clearly detectable dentin caries lesions were treated operatively.

RESULTS

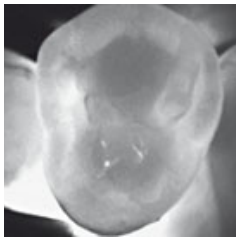
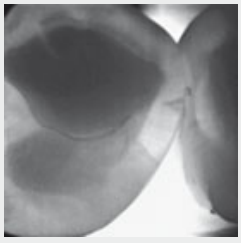
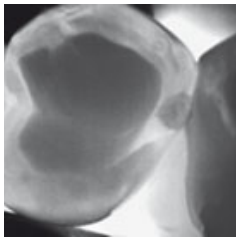
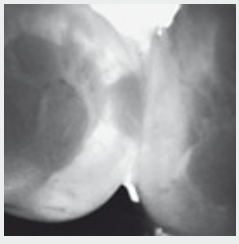
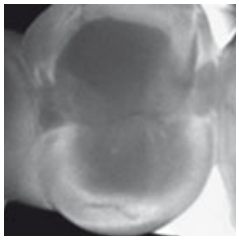
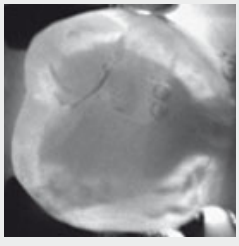
Out of 130 study patients who were examined, 85 participants revealed 127 proximal dentin caries lesions on posterior teeth (premolars and molars) which needed operative care.

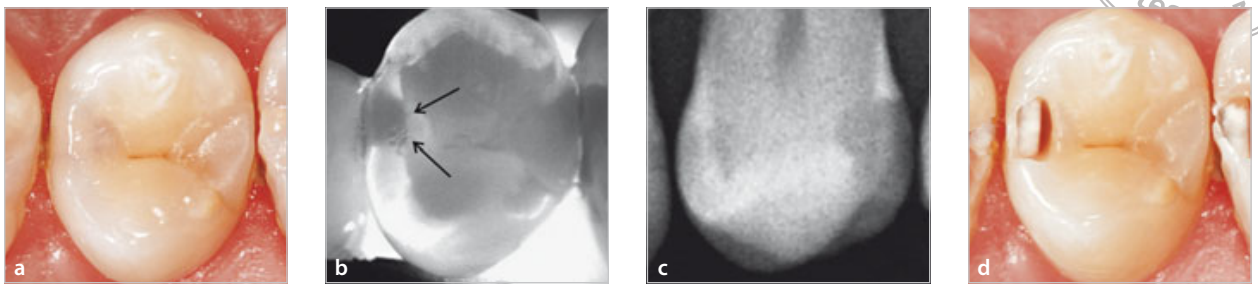
The findings from the bitewing radiographs were used as gold standard, and compared to the corresponding NIR light images of the 127 proximal dentin lesions. The results were summarized in a cross table (Table 1). It was not possible to apply a complete semiquantitative diagnosis (D-Score)[22] on the NIR light images, as the pulp could not be taken as a reference. Consequently, Score-D3 and Score-D4 were combined. Table 1 shows that 121 of the lesions, which were identified radiologically as D3 or D4 proximal dentin lesions, were also classified as dentin lesions using the NIR light method. Comparison of the results from both methods showed 95.3% agreement in the diagnoses with regard to the dentin caries. The study material of 127 validated proximal dentin caries lesions did not enable calculation of sensitivity and specificity of the method. The results are therefore based on the correlation of bitewing radiographs and NIR light images according to a selection of positively validated dentin caries lesions.

In addition, our clinical experiences with the new diagnostic device were summarized by presenting a classification that helped to interpret different proximal caries lesions according to their extension within the dental hard tissue (Table 2). It has to be underlined that scores 1, 2, and 3 of the classification represented enamel lesions and were not validated in a study, but are solely based on our clinical experiences. It was particularly important to evaluate the configuration of the enamel lesions carefully to be able to draw conclusions about the dentin involvement. Early proximal caries lesions on the outer dentin cannot always be visualized, as the optical characteristics of such lesions differ only slightly from those of healthy dentin (Fig 4). Therefore, early dentin caries can only be detected indirectly. The leading indicator seems to be the involvement of the DEJ, which is frequently associated with a rectangular configuration of the enamel lesion. If the caries progression reached deeper parts of dentin and discolored, the translucency might be reduced, leading to the visibility of the lesion on the NIR light image (Fig 5).

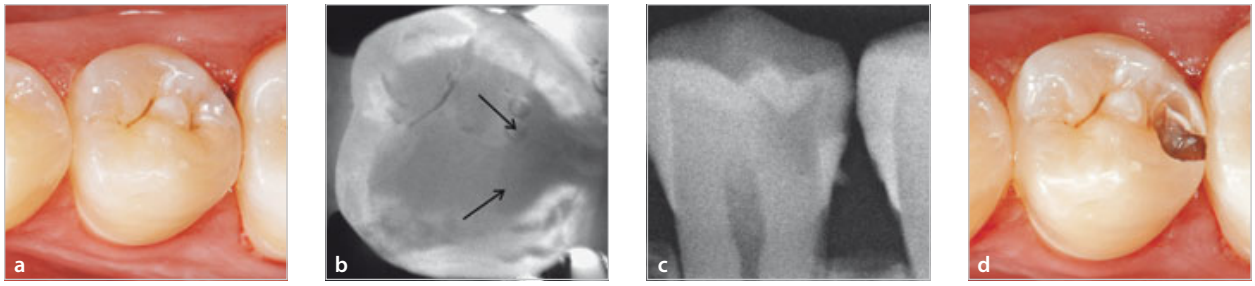
NIR light transillumination was also able to record occlusal caries lesions (Fig 6). Significant markers of occlusal caries involve possible discoloration or micro-

Table 2 Classification of proximal dentin caries lesions based on clinical experiences

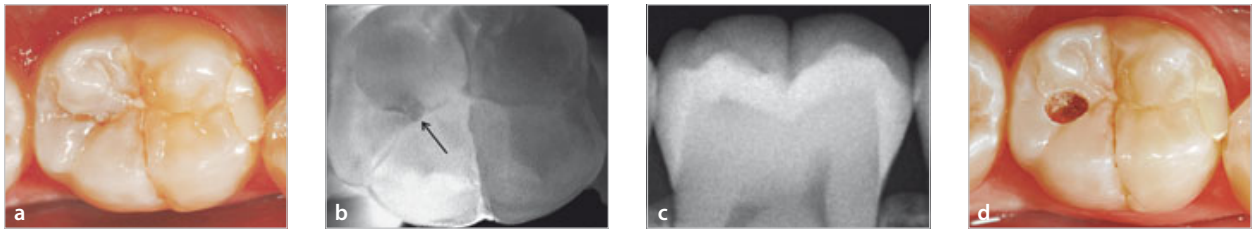
	Description	NIR light	Caries extension	Consequences for diagnostics and therapy
0	Sound surfaces			Caries monitoring, no active care advised
1	First visible signs of enamel caries			Caries monitoring, preventive care advised
2	Established caries lesion			Caries monitoring, preventive care advised
3	Established enamel caries with an isolated spot reaching the dentino-enamel junction			Caries monitoring, preventive care advised
4*	Dentin caries penetrating the enamel-dentin junction linearly			(Bitewing) Radiography, minimal operative care advised
5*	Deep dentin caries lesion			(Bitewing) Radiography, operative care advised



Figs 4a to 4d The left maxillary second premolar reveals a proximal dentin lesion on the mesial surface and a distal composite restoration *(a)*. Assessing the mesial surface depicted in the near-infrared light image *(b)*, the caries-penetrated enamel and wide involvement of the dentino-enamel junction (arrows) is clearly visible. The extension of the lesion inside the dentin is not as clearly detectable.



Figs 5a to 5d A deep undermining caries lesion: the near-infrared light image of this lesion shows clearly the caries extension inside the dentin (arrows).



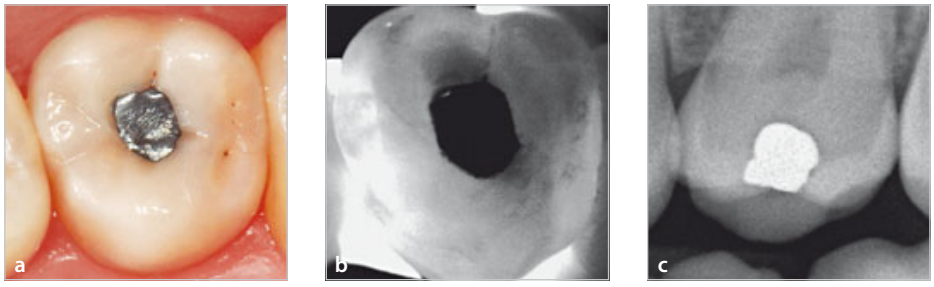
Figs 6a to 6d Hidden caries in a 14-year-old patient. The near-infrared light and the bitewing radiograph show a circumscribed area of significantly changed occlusal translucence (arrows).

cavitation in pits and fissures and/or reduced transillumination as signs of undermined dentin.

DISCUSSION

This study focused on detecting dentinal proximal noncavitated caries lesions. The bitewing radiograph has been seen as the gold standard and this was compared with the findings of NIR light transillumination. The high consensus between the two methods has to be considered with regard to the two major conditions of the study design. Firstly, as there was no control group, sensitivity and specificity could not be calculated, and therefore no conclusions can be drawn regarding false diagnoses using the NIR light. Secondly, we were unable to validate enamel caries lesions as they require preventive therapy, which prohibits in-vivo validation due to ethical reasons. An in-vitro model must be established to simulate the clinical setting. This model is necessary to enable light to be transmitted through the embedding material and the root to the crown. This is not possible with conventional in-vitro methodology as yet, indicating the need for developing innovative laboratory concepts in the future.

The only data available to date[23] have shown that the method offered a high level of diagnostic efficiency in the clinically correct detection of proximal dentin lesions when compared to the actual extent of the car-



Figs 7a to 7c Metallic-based restorations absorb the near-infrared light completely. It is not possible to evaluate the dental hard tissue underneath.

ies. In the course of the study, dentin caries were diagnosed using the NIR light image when the carious process had reached the DEJ, and no translucent enamel was detectable between the lesion and the dentin (Fig 4). Consequently, even lesions that showed no signs of carious penetration beyond the DEJ in the NIR light image were classified as dentin caries lesions as soon as the DEJ was affected (Table 2). These cases were associated with less deep caries lesions (D3). However, findings where there was a large shadow inside the dentin core clearly detectable were considered to be deeper dentin lesions (D4) (Fig 5).

In clinical daily practice, the utilization of NIR light transillumination is not able to supersede radiographic radiation in all respects. It is limited to the tooth itself and does not give information about the periodontal structures. Also the detection of a carious process underneath restoration materials such as amalgam, ceramic, composite resin, or gold (except for fissure sealant) is not possible (Fig 7).

With regard to the detection of hidden proximal and occlusal caries that cannot be diagnosed using visual diagnostic procedures, the method has the potential to reduce the prescription of bitewing radiographs in these situations. Furthermore, the NIR transillumination of teeth can be repeated as often as necessary and offers the opportunity to examine both proximal and occlusal surfaces simultaneously.

By creating one image per surface within 40 milliseconds and storing it digitally, the dentist is able to screen a quadrant within half a minute and to monitor proximal enamel caries lesions. In addition, we observed a high level of acceptance of the NIR light camera system by the study participants, which may have resulted from the absence of radiation and the relatively pleasant examination.

Question remains regarding the specific circumstances under which an existing carious process should be operatively treated. As restorative intervention should no longer be performed based merely on the simple evidence of a (small) dentin lesion, other clinical parameters should also be considered. These include the patient's ability to maintain adequate hygiene on the affected tooth surface, the presence of (micro)cavitations, as well as the overall caries risk and the extent of the caries.[24] The latter cannot, however, be ascertained for deep dentin caries lesions using transillumination because the pulp is not shown as a point of reference. As such, detecting a cavity using NIR light and then, if necessary, defining its actual depth clearly by taking a bitewing radiograph, might offer a suitable combination of diagnostic devices. On the one hand, the dentist can make a decision about the need to take radiographs for caries diagnosis more precisely, and on the other they minimize the risk of overlooking a hidden caries lesion.

However, it should be noted that the criteria for operative intervention are currently the subject of controversial discussions both nationally and internationally, which can be applied to all diagnostic procedures.

CONCLUSION

The introduction of NIR light transillumination represents the integration of an imaging procedure into everyday dental practice that may lead to a reduced usage of radiographic bitewings for detecting proximal and occlusal dental caries. Although this diagnostic

case study suggests its potential for clinical use, the innovative nature of NIR light transillumination does create the need for detailed information, which must be systematically obtained through well-designed scientific studies.

ACKNOWLEDGMENT

The authors would like to thank all patients who participated in this study. The clinical phase of this study was financially supported by KaVo (Biberach, Germany).

REFERENCES

1. Pitts NB. Modern concepts of caries measurement. J Dent Res 2004;83(Spec No C):C43–C47.
2. Poorterman JHG, Aartman ICH, Kalsbeek H. Underestimation of the prevalence of approximal caries and inadequate restorations in a clinical epidemiological study. Community Dent Oral Epidemiol 1999;27:331–337.
3. Espelid I, Mejare I, Weerheijm, K. EAPD guidelines for use of radiographs in children. Eur J Paediatr Dent 2003;4:40–48.
4. Poorterman JHG, Weerheijm KL, Groen HJ, Kalsbeek H. Clinical and radiographic judgment of occlusal caries in adolescents. Eur J Oral Sci 2000;10:93–98.
5. Poorterman JHG, Aartman ICH, Kieft JA, Kalsbeek H. Value of bite-wing radiographs in a clinical epidemiological study and their effect on the DMFS index. Caries Res 2000;34:159–163.
6. Selwitz RH, Ismail AI, Pitts NB. Dental Caries. Lancet 2007;9555:51–59.
7. Bader JD, Shugars DA, Bonito AJ. Systematic reviews of selected dental caries diagnostic and management methods. J Dent Edu 2001;65:960–968.
8. 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;31:103–110.
9. Wenzel A, Verdonschot EH, Truin GJ, Konig KG. Accuracy of visual inspection, fiber-optic transillumination, and various radiographic image modalities for the detection of occlusal caries in extracted non-cavitated teeth. J Dent Res 1992;71:1934–1937.
10. Young DA, Featherstone JD. Digital imaging fiber-optic transillumination, F-speed radiographic film and depth of proximal lesions. J Am Dent Assoc 2005;136:1682–1687.
11. Young DA. New caries detection technologies and modern caries management: merging the strategies. Gen Dent 2002;50:320–331.
12. Karlsson L, Maia AM, Kyotoku BB, Tranaeus S, Gomes AS, Margulis W. Near-infrared transillumination of teeth: measurement of a system performance. J Biomed Opt 2010;15:036001.
13. Darling CL, Huynh GD, Fried D. Light scattering properties of natural and artificially demineralized dental enamel at 1310 nm. J Biomed Opt 2006;11:34023.
14. Fried D, Glena RE, Featherstone JD, Seka W. Nature of light scattering in dental enamel and dentine at visible and near-infrared wavelengths. Appl Opt 1995;34:1278–1285.
15. Hall A, Girkin JM. A review of potential new diagnostic modalities for caries lesions. J Dent Res 2004;83:89–94
16. Staninec M, Lee C, Darling CL, Fried D. In vivo near-IR imaging of approximal dental decay at 1,310 nm. Lasers Surg Med 2010;42:292–298.
17. Wu J, Fried D. High contrast near-infrared polarized reflectance images of demineralization on tooth buccal and occlusal surfaces at lambda = 1310-nm. Lasers Surg Med 2009;41:208–213.
18. WHO. Oral Health Surveys. Basic methods. 4th edition. Geneva: World Health Organization, 1997.
19. Clara J, Bourgeois D, Muller-Bolla M. DMF from WHO basic methods to ICDAS II advanced methods: a systematic review of literature. Odontostomatol Trop 2012;139:5–11.
20. Kühnisch J, Bucher K, Henschel V, Albrecht A, Garcia-Godoy F, Mansmann U. Diagnostic performance of the universal visual scoring system (UniViSS) on occlusal surfaces. Clin Oral Investig 2011;15:215–223.
21. Kühnisch J, Berger S, Senkel H, et al. Development, methodology and potential of the new Universal Visual Scoring System (UniViSS) for caries detection and diagnosis. Int J Environ Res Public Health 2009;6:2500–2509.
22. Marthaler TM. A standardized system of recording dental conditions. Helv Odontal Acta 1966;1:1–18.
23. Söchtig F, Hickel R, Kühnisch J. Proximal dentine caries detection with near-infra-red light: First clinical results. IADR 2013:Abstract 3721.
24. Kidd EA, Fejerskov O. What constitutes dental caries? Histopathology of carious enamel and dentin related to the action of cariogenic biofilms. J Dent Res 2004;83:35–38.