Occlusal caries detection and quantification by DIAGNOdent and Electronic Caries Monitor: in vitro comparison

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The Electronic Caries Monitor (ECM) and the recently introduced laser-based KaVo DIAGNOdent have been developed as clinical diagnostic aids in the detection and quantification of occlusal carious lesions. The aim of this in vitro study was to compare their reproducibility and validity. The ability of DIAGNOdent to retrieve sites of occlusal carious lesions without reference to photographs or drawings from previous assessments was also tested. The material comprised 87 premolar teeth: the occlusal surfaces were sound or exhibited non-cavity carious lesions of varying severity. All were photographed and measured by DIAGNOdent and ECM on 2 occasions, 2 weeks apart. The teeth were then sectioned into 300 μm thick slices. Two observers independently classified the sections according to the histopathology, into 5 categories, ranging from sound to dentinal caries in the inner part of the dentin. Statistical analysis comprised intra-class correlation coefficients (ICC) to test reproducibility and regression analysis of validity. Sensitivity and specificity were also calculated for detection of D3 lesions for both devices. DIAGNOdent recorded maximum readings at identical sites on both occasions in 89% of the teeth. The ICC for readings on 2 separate occasions was 0.97 for DIAGNOdent and 0.71 for ECM. The correlations with histology were $r = 0.93$ and 0.83, for DIAGNOdent and ECM, respectively. For detection of D3 lesions, the sensitivity and specificity were 0.8 and 1 for DIAGNOdent and 0.75 and 0.88 for ECM. In this in vitro study, DIAGNOdent was superior to ECM for occlusal caries detection. □ *Caries detection; laser fluorescence; occlusal caries*

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Caries prevalence has decreased in most industrialized countries as a result of improved oral hygiene and/or change of diet in combination with regular fluoride exposure. At the same time, the proportion of occlusal caries has increased (1, 2). Studies have shown conventional visual and radiographic examination to be inadequate for the detection of early occlusal lesions (3–5). Detection is complicated by the emergence of the phenomenon of so-called hidden caries (6–8): cavitation now occurs much later and a carious lesion in dentin may progress beneath a clinically intact enamel surface. Such factors as the presence of plaque, stains, and anatomical variations further add to the difficulty of diagnosis of early occlusal caries. Lesions frequently remain undetected by visual inspection and may present as radiolucent areas in dentin on bitewing radiographs, i.e. as advanced lesions.

While it is now widely recognized that progression of an early carious lesion may be arrested or that the lesion may even remineralize, the prognosis for arresting advanced lesions is less favorable. To facilitate clinical detection of occlusal caries at an early stage, the need has arisen for diagnostic aids to complement conventional methods.

In response to this challenge, several diagnostic techniques have been introduced and tested, inter alia electrical conductance measurement and quantitative laser/light-induced fluorescence (9–15):

- Electronic Caries Monitor, ECM, (Lode Diagnostic, Groningen, The Netherlands) is a method based on electrical conductance measurement. The high electrical resistance of sound dental tissue decreases when pores created by carious demineralization are filled with water and soluble electrolytes. ECM has been tested as a useful diagnostic technique for fissure lesions (14, 16–18).
- DIAGNOdent (KaVo, Biberach, Germany) is a relatively new laser-based instrument. The underlying mechanism is that carious tissue emits stronger fluorescence than sound tissue in the red and infrared part of the spectrum ($\lambda = 655$ nm), (19, 20). Thus, the fluorescence from a carious region, greater than that from sound tissue, is expressed as a higher numerical readout by the device. Although the origin of fluorescence in carious tissue has not been fully clarified, recent experiments have implicated oral bacterial metabolites, possibly porphyrins (21, 22). In several studies evaluating the device for detection and quantification of occlusal carious lesions (23–26), DIAGNOdent has shown greater accuracy and reproducibility than conventional methods, such as bitewing radiography or visual inspection.

In vitro, DIAGNOdent has shown excellent reproducibility, provided that the site measured is well localized and the instrument frequently calibrated. For longitudinal application in the dental clinic, however, dentists require good reproducibility without the need to record the location of the site as a reference for follow-up measurements.

In this in vitro study of the above diagnostic aids, the aims were: 1) to test the reliability of DIAGNOdent in retrieving locations of occlusal lesions, 2) to compare the reproducibility of DIAGNOdent and ECM for quantification of occlusal caries, and 3) to compare the validity of DIAGNOdent and ECM for detection and quantification of occlusal caries.

Materials and methods

The material comprised a sample of 87 premolar teeth extracted from young adolescents on orthodontic indications. The occlusal surfaces were either visually intact or had non-cavity lesions.

The teeth were rinsed thoroughly under tap water and cleaned with a toothbrush, and calculus was carefully removed with a scaler. The teeth were then stored under refrigeration in thymol-saturated saline in individual plastic containers.

Reproducibility study

The teeth were randomly numbered from 1 to 87 and each occlusal surface was photographed with a digital camera (FinePix 4700 zoom, Fuji Photo Film Co., Ltd). The images were saved on a PC and printed out on paper. The magnification factor was about 3.

Each tooth was retrieved from the thymol-saturated saline, wiped with a paper tissue, dried in air for approximately 10 sec, and then measured by DIAGNOdent using a conical probe in accordance with the manufacturer's instructions. Room temperature was about 23°C. The device was calibrated against a ceramic standard before each measurement session. The standard value for each tooth was calibrated before each measurement by measuring at a sound site. The occlusal surface was carefully scanned with the conical probe to locate the site of the highest reading. This reading was recorded and the site was indicated as a dot on the photograph. After an interval of 2 weeks, the same procedure was repeated by the same operator, under identical conditions, without access to the data from the previous session. The photographs of each tooth from the 2 measurement sessions were then superimposed to test the match of the measuring sites. The sites were considered to match when the distance between 2 dots was <3 mm on the paper copy, or <1 mm in reality, which corresponds to the diameter of the conical tip. By comparing the two sets of photographs indicating lesion sites, the percentage of teeth for which maximum readouts from the 2 sessions corresponded with matching sites on the photographs was calculated.

After completion of the DIAGNOdent experiments, the teeth with matching sites for maximum readouts from the two sessions were monitored twice with ECM, by the same operator, at an interval of 2 weeks.

For measurements with ECM, both the tooth and the reference electrode were held in the same hand without direct contact with each other. A measurement was made in accordance with the manufacturer's instructions by touching the occlusal site indicated on the photographs with the instrument probe. The air-flow was 7.5 L/min. Data shown on the front panel of the instrument were registered.

Validity study

The teeth with matching measuring sites at the 2 measurement sessions were used for the validity study. To provide a gold standard for verification, the teeth were sectioned into approximately 300 μm thick slices in a bucco-lingual direction, perpendicular to the occlusal surfaces, using a water-cooled saw, at the sites indicated in the photographs. When the photographs indicated that the slice deviated from the test sites, 2 or more slices were prepared. Lesion depth was determined by histopathological analysis. Two observers independently examined both sides of the tooth slices under a microscope at 16× magnification. When a discrepancy occurred, consensus was reached by repeating the histological analyses at a joint session. The lesions were defined by the extension of a whitish demineralized zone or a brown zone in the occlusopulpal direction.

The sites were classified in accordance with the following 5-point scale: 1 = sound; 2 = enamel caries limited to the outer half of enamel; 3 = caries extending into the inner half of the enamel but not to the dentinoenamel junction (DEJ); 4 = caries penetrating the DEJ but limited to the outer half of the dentin (D3); 5 = caries involving the inner half of the dentin.

Data analyses

For DIAGNOdent, the percentage of matching sites from the 2 measurement sessions was calculated. These teeth were used for comparison of reproducibility tests of the DIAGNOdent and the ECM. Readings from 2 occasions with both methods were analyzed using repeated measures ANOVA. Intra-class correlation coefficient (ICC) was calculated for DIAGNOdent and ECM. For DIAGNOdent, intra-class correlation coefficient was also calculated for all the specimens including the teeth with non-matching sites from the 2 measurements.

The relationships between the gold standard, determined by histopathology, and DIAGNOdent and ECM readings, respectively, were studied by regression analysis. Correlation coefficients between the two methods and the lesion depth were calculated. Cut-off points at the D3 level were

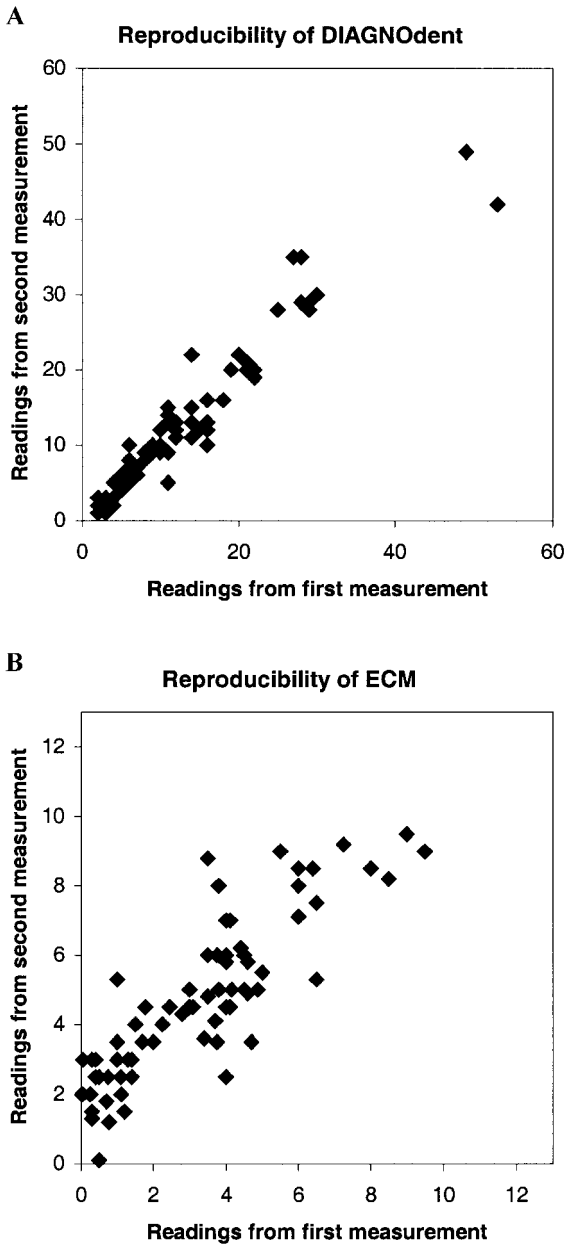

Fig. 1. A. Reproducibility of DIAGNOdent reading. B. Reproducibility of ECM reading.

determined according to the regression lines, with some minor adjustment to balance the sensitivity and specificity. Subsequently, the sensitivity and specificity of caries detection at the D_3 level were calculated for each method.

Results

Seventy-seven pairs of photographs were found to have matching sites, i.e. for 89% of the sample, the highest DIAGNOdent readings on two separate measurement

Table 1. Results of histopathological validation: number (n) and percentage (%) of sound teeth and teeth with enamel and dentin carious lesions

	Teeth	
	n	%
Sound	17	22.1
Enamel caries	40	51.9
Dentin caries	20	26
Total	77	100

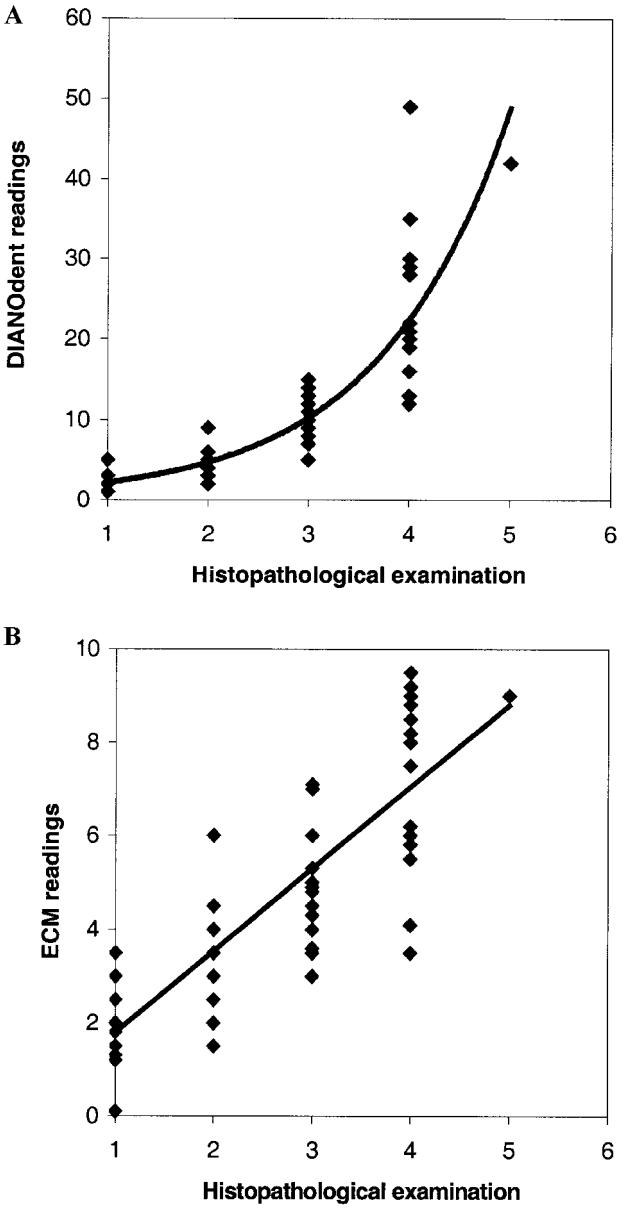

Fig. 2. A. The relationship between histopathological classification and DIAGNOdent readings was exponential, with a dramatic increase in DIAGNOdent readings for deeper lesions. B. The relationship between histopathological classification and ECM readings was linear.

Table 2. Correlation between DIAGNOdent and ECM measurements and histopathology

	r	Cut-off	Sensitivity	Specificity
DIAGNOdent	0.93	18	0.80	1.00
ECM	0.83	6	0.75	0.88

occasions were recorded at matching sites. The intra-class correlation coefficient was based on these readings.

Figs 1A and 1B show the relationship between readings on 2 occasions by DIAGNOdent and ECM, respectively. Repeated measures ANOVA showed no statistically significant difference between the 2 groups of data for DIAGNOdent, but the difference between the 2 sets of ECM measurements was statistically significant. The intra-class correlation coefficients between the two measurements were 0.97 and 0.71, for DIAGNOdent and ECM, respectively. Intra-class correlation coefficient for DIAGNOdent was 0.96 if all the specimens including the teeth with non-matching sites from the 2 measurements were included. The results of the histopathological validation are presented in Table 1.

Figs 2A and 2B show the relationships between the histopathological classification in categories 1–5 and DIAGNOdent and ECM, respectively. Exponential function was found to have the best fit for the relationship between histology and DIAGNOdent readings. A linear curve fit was employed for histological analysis and ECM readings. The correlation coefficients and the cut-off points for DIAGNOdent and ECM were calculated from Figs 2A and 2B, respectively, and sensitivity and specificity for caries detection at D3 level are shown in Table 2.

Discussion

A fundamental requirement of a diagnostic method for both clinical and epidemiological studies of dental caries is that it should provide consistent and standardized measurements between and within observers. This highlights the importance of establishing the reliability of new diagnostic methods.

The present study evaluated a new laser method, KaVo DIAGNOdent, with respect to reliability in retrieving the sites of carious lesions, without recording the location of the site for reference at follow-up measurement sessions. Matching sites were retrieved in 89% of the samples. Of the remainder, 90% had readings <4, representing mainly sound teeth. The measuring site was the location giving the highest reading, corresponding to the deepest part of the carious lesion. On a sound surface, the highest reading was in fact, irrelevant. This suggests that when a carious lesion is present the ability of DIAGNOdent to retrieve the location of a severe lesion site would in reality exceed 89%.

High intra-examiner reproducibility of DIAGNOdent has been reported in vivo, with Kappa value = 0.93 (26) and in vitro, with ICC = 0.96–0.97 and Kappa value = 0.88–0.90 (23, 24, 27, 28). This is confirmed in the present study. The excellent reproducibility indicates that the method may be suitable for the longitudinal monitoring of carious lesions and thus, also, for assessing caries activity and the outcome of preventive interventions.

For ECM, a considerable range of reproducibility is reported, Kappa value = 0.53–0.92 and $r = 0.76$ (29). In the present study, the systematic difference in ECM measurements made on 2 separate occasions is puzzling. One explanation might be that by the second measurement session the operator was more experienced with ECM and measuring took less time: thus the teeth were not as dehydrated, which resulted in higher readings. In the present study the reproducibility of ECM, expressed as ICC, was much inferior to that of DIAGNOdent, 0.71 versus 0.97. The results do not support application of ECM for monitoring purposes.

Figs 2A and B demonstrate the correlation between lesion depth, determined by the histopathological examination and readings by DIAGNOdent and ECM, respectively. For DIAGNOdent, the results showed that with increasing lesion depth the values increased gradually when the lesion was confined to enamel, and increased dramatically once a lesion had penetrated the DEJ. This is in agreement with the results of a previous study (24). However, the DIAGNOdent readings in the present study were mainly <40, indicating shallower lesions than in the earlier study (24). This is partly because the material comprised exclusively non-cavity premolar teeth extracted from young adolescents on orthodontic indications: deep dentinal lesions would be very rare in such material. The distribution of lesion types according to the histopathology disclosed only one sample in category 5. The regression line would have been more reliable if there had been more samples in this category. For ECM, a linear regression function gave a better curve fit and was therefore applied.

The correlation coefficient with the gold standard was higher for DIAGNOdent than for ECM (Table 2). This indicates a potential role for DIAGNOdent in the decision-making process for diagnosis of occlusal caries, as a second opinion in case of doubt after conventional examination. Furthermore, DIAGNOdent is more practical to use than ECM, since it allows scanning of the entire tooth surface by moving the probe tip, whereas for ECM a specific site has to be defined.

As sensitivity and specificity are determined largely by a single cut-off point, it is important that this is selected appropriately. In the present study, the preliminary cut-off point was determined using the regression line of each method as a guideline, and subsequently adjusted, in order to have acceptable specificity, preferably >0.8.

In detecting occlusal caries at the D3 level, DIAGNOdent had higher sensitivity and specificity than ECM (Table 2). It was difficult to create a sample with prevalence similar to that of the real population, because the caries prevalence in the sampled extracted teeth was unknown at the start of the investigation. The prevalence of carious lesions in this in vitro study was higher than under typical clinical

conditions (Table 1). Thus, the sensitivity could have been exaggerated. Under conditions of low caries prevalence and slow disease progression, the potential risk of unnecessary restoration is greater than the risk of not detecting early decay. As DIAGNOdent showed high specificity, it may be a feasible method for a population with low caries prevalence, where specificity is critical.

Cut-off values derived from in vitro studies of DIAGNOdent should not be applied uncritically to clinical conditions. Potential sources of error should be considered. In the clinical setting, DIAGNOdent and ECM readings may be influenced by variables in the oral environment, such as saliva, bacteria, and body temperature. DIAGNOdent measurements on extracted teeth may also be affected by storage media (28).

Important prerequisites for reliable measurements with DIAGNOdent were calibration against a ceramic standard before every measurement session and calibration of each tooth by measuring at a site of sound tissue. Furthermore, the tooth surface should be carefully cleaned before measurement because the instrument is sensitive to the presence of stains, deposits, and calculus: these may be falsely registered as a change in enamel or dentin. The probe tip of the instrument should be rotated and tilted around its axis during measurement, thus ensuring that the instrument tip picks up the highest fluorescence reading from the measuring sites.

In conclusion, the results of the present in vitro study indicate that: 1) the ability of DIAGNOdent to retrieve the site of a carious lesion was very good; 2) reproducibility of DIAGNOdent was excellent and superior to that of ECM; and 3) for detection of non-cavity occlusal carious lesions, DIAGNOdent was superior to ECM in terms of both correlation with histopathology and specificity/sensitivity.

References

1. Marthaler TM. Caries status in Europe and predictions of future trends. Caries Res 1990;24:381–98.
2. Mejàre I, Källestal C, Stenlund H, Johansson H. Caries development from 11 to 22 years of age: a prospective radiographic study. Prevalence and distribution. Caries Res 1998;32:10–6.
3. Wenzel A, Fejerskov O, Kidd E, Joyston-Bechal S, Groeneveld A. Depth of occlusal caries assessed clinically, by conventional film radiographs, and by digitized, processed radiographs. Caries Res 1990;24:327–33.
4. Lussi A. Comparison of different methods for the diagnosis of fissure caries without cavitation. Caries Res 1993;27:409–16.
5. Ie YL, Verdonchot EH. Performance of diagnostic systems in occlusal caries detection compared. Comm Dent Oral Epidemiol 1994;22:187–91.
6. Sawle RF, Andlaw RJ. Has occlusal caries become more difficult to diagnose? Br Dent J 1988;164:209–11.
7. Pitts NB. The diagnosis for dental caries. Diagnostic methods for assessing buccal, lingual and occlusal surfaces. Dent Update 1991;18:393–6.
8. Kidd EAM, Ricketts DNJ, Pitts NB. Occlusal caries diagnosis: a changing challenge for clinicians and epidemiologists. J Dent Res 1993;21:323–31.
9. Angmar-Mansson B, ten Bosch JJ. Advances in methods for diagnosing coronal caries: a review. Adv Dent Res 1993;7:70–9.
10. Angmar-Mansson B, Al-Khateeb S, Tranaeus S. Monitoring the caries process: optical methods for clinical diagnosis and quantification of enamel caries. Eur J Oral Sci 1996;104:480–5.
11. Pine CM, ten Bosch JJ. Dynamics of and diagnostic methods for detecting small caries lesions. Caries Res 1996;30:381–8.
12. Ekstrand K, Ricketts DNJ, Kidd EAM. Reproducibility and accuracy of three methods for assessment of demineralization depth on the occlusal surface: an in vitro examination. Caries Res 1997;31:224–31.
13. Huysmans M-CDNJM, Longbottom C, Pitts NB. Electrical methods in occlusal caries diagnosis: an in vitro comparison with visual inspection and bitewing radiography. Caries Res 1998;32: 324–9.
14. Huysmans M-CDNJM, Longbottom C, Hintze H, Verdonschot EH. Surface-specific electrical occlusal caries diagnosis: reproducibility, correlation with histological lesion depth, and tooth type dependence. Caries Res 1998;32:330–6.
15. Verdonschot EH, Angmar-Mansson B, ten Bosch JJ, Deery CH, Huysmans M-CDNJM, Pitts NB, et al. Developments in caries diagnosis and their relationship to treatment decisions and quality of care. Caries Res 1999;33:32–40.
16. Lussi A, Firestone A, Schoenberg V, Hotz P, Stich H. In vivo diagnosis of fissure caries using a new electrical resistance monitor. Caries Res 1995;29:81–7.
17. Ie YL, Verdonchot EH, Schaeken MJM, vant Hof MA. Electrical conductance of fissure enamel in recently erupted molar teeth as related to caries status. Caries Res 1995;29:94–9.
18. Ricketts D. Electrical conduction detection methods. In: Stookey G, editor. Early detection of dental caries. Indianapolis, Indiana; 1996. p. 67–80.
19. Hibst R, Gall R. Development of a diode laser-based fluorescence caries detector. Caries Res 1998;32:294.
20. Hibst R, Paulus R, Lussi A. Detection of occlusal caries by laser fluorescence: basic and clinical investigation. Med Laser Appl 2001;16:205–13.
21. Hibst R, Paulus R. Caries detection by red excited fluorescence investigation on fluorophores. Caries Res 1999;33:295.
22. Hibst R, Paulus R. Molecular basis of red excited caries fluorescence. Caries Res 2000;34:323.
23. Lussi A, Imwinkelried S, Pitts NB, Longbottom C, Reich E. Performance and reproducibility of laser fluorescence system for detection of occlusal caries in vitro. Caries Res 1999,33:261–6.
24. Shi X-Q, Welander U, Angmar-Mansson B. Occlusal caries detection with KaVo DIAGNOdent and Radiographic examination: an in vitro comparison. Caries Res 2000; 34:151–8.
25. Attrill DC, Ashley PF. Occlusal caries detection in primary teeth: a comparison of DIAGNOdent with conventional methods. Br Dent J 2001;190:440–3.
26. Lussi A, Megert B, Longbottom C, Reich E, Francescut P. Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. Eur J Oral Sci 2001;109:14–9.
27. Shi X-Q, Tranaeus S, Angmar-Mansson B. Comparison of QLF and DIAGNOdent for quantification of smooth surface caries. Caries Res 2001;35:21–6.
28. Shi X-Q, Tranaeus S, Angmar-Mansson B. Validation of DIAGNOdent for quantification of smooth-surface caries: an in vitro study. Acta Odontol Scand 2001;59:74–8.
29. Huysmans M-CDNJM. Electrical measurements for early caries detection. In: Stookey G, editor. Early detection of dental caries. Indianapolis; 1999. p. 123–42.

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