



In Vitro Comparison of Several Methods for Initial Proximal Caries Detection

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Abstract

Introduction: Initial proximal caries is both diagnostic and therapeutic challenge. The disadvantages of the conventional methods for caries detection and the development of technologies led to the creation of contemporary optical devices for early caries detection.

Aim: In vitro comparison of the diagnostic accuracy of several methods for early proximal caries detection – visual-tactile, bitewing radiography and laser fluorescence device (DIAGNOdent pen).

Materials and methods: Fifty-eight proximal surfaces of extracted human permanent premolars and molars were examined by two examiners using visual inspection, bitewing radiography, DIAGNOdent with proximal contact, and DIAGNOdent directly in the lesion. Results were compared with the histological gold standard. Statistical analysis with ROC curve, sensitivity, specificity and diagnostic accuracy of each detection method was performed. Analysis was conducted in 3 diagnostic thresholds – initial, developed and advanced demineralization.

Results: Sensitivity of visual inspection was 16%–33%, specificity 93.3%–100%, sensitivity of bitewing radiography 54%–67%, specificity 93%–94%, sensitivity of DIAGNOdent with proximal surfaces in contact 88%–91%, specificity 79%–89%, sensitivity of DIAGNOdent directly 89%–92.5%, specificity 81.29%–93%. The highest diagnostic accuracy, increasing with the rise of the level of demineralization, was shown by DIAGNOdent directly, followed by DIAGNOdent with proximal contact, bitewing radiography, and visual inspection with the lowest accuracy.

Conclusion: The use of contemporary diagnostic devices significantly increases the possibility for early detection of proximal lesions. DIAGNOdent can be used as an adjunct to and increasing the diagnostic accuracy of the conventional caries detection methods.

Keywords

detection, initial proximal caries lesion

INTRODUCTION

Initial proximal caries is both a diagnostic and therapeutic challenge. The knowledge about the caries process and the invention of new dental materials make non-invasive treatment of non-cavitated proximal caries possible. Caries must be detected at its earliest stage of development so that

non-invasive and micro-invasive treatment methods can be applied. Early caries diagnostics needs caries detection devices. Direct visual inspection and examination of the proximal surface is not possible because of the wide contact area. Bitewing radiography, which is considered a gold standard in diagnosing proximal caries, tends to underestimate the real lesion depth and exposes the patient to ionizing

radiation. The disadvantages of the conventional methods for caries detection and the development of technologies led to the creation of modern optical devices for early caries detection. One of these methods is the laser fluorescence method with DIAGNOdent pen (KaVo, Biberach, Germany) which generates laser light with a wavelength of 655 nm. The laser light is absorbed by both organic and inorganic tooth substances, and re-emitted as a fluorescent signal within the infrared region, which is then transformed into a digital value from 0 to 99 on a display with a moment and a peak value. The caries process alters the amount of fluorescence, which is measured as an elevated reading – the higher the number, the deeper the lesion.¹⁻³

AIM

In vitro comparison of the diagnostic accuracy of several methods for early proximal caries detection – visual-tactile inspection, bitewing radiography, the laser fluorescence device (DIAGNOdent pen), using the histological examination as a gold standard.

MATERIALS AND METHODS

Thirty-one extracted human permanent premolars and molars without visible cavitations and obturations on the proximal surfaces, stored into 0.1% of thymol solution were examined in the study. Soft tissues and calculus were removed (with an ultrasound device) and teeth were polished with polishing rubbers and fluoride free paste. The mesial and distal surfaces were examined for white spot lesions on at least one of the proximal surfaces. From all the sixty-two surfaces, four were cavitated and excluded from the study, thus fifty-eight proximal surfaces finally participated in the study. Plastic impression trays were used to simulate jaws, and silicone impression material was used as a base to include teeth in a dental row with proximal surfaces contacting each other. Three teeth (a premolar and two molars) were placed in each tray. Proximal tooth contact was checked with dental floss.

Proximal surfaces were examined by two independent examiners with the following diagnostic methods:

Visual-tactile examination

Each proximal surface was assessed at a distance of 30 cm from the examiner's eyes, with no magnification, but adequate illumination from the light reflector. Surfaces were first examined wet, then air-dried for five seconds and inspected again. Visual examination was aided by a rounded tip dental probe to evaluate the surface smoothness. ICDAS (International Caries Detection and Assessment System)⁴ was used with the following codes:

0 – Sound enamel, no visual changes in translucency even after prolonged drying – corresponds to E0.

1 – First visual changes in enamel (cariou opacity), visible only after prolonged drying, not present on a wet surface – corresponds to E1.

2 – Distinct visual changes in enamel when wet – cariou opacity or discoloration, not consistent with clinical appearance of sound enamel, corresponds to E2 or D1.

3 – Initial breakdown in enamel due to caries with no visible dentine – cavitated lesion.

4 – Underlying dark shadow from dentin with or without enamel breakdown – corresponds to D1 and participates in the study, if not cavitated.

Bitewing radiography

Digital bitewing radiographs were taken using photosensitive phosphor plate system (Dürr Dental) and individual X-ray holder (Icon X-Ray Holder, DMG). The Planmeca dental X-ray machine operated at 60 kV, 2 mA, 0.315 s. exposition time, focus-to-film distance – 20 cm. Radiographic interpretations were made on a computer screen, using Dürr Dental computer program at ×2 magnification. Criteria for radiographic interpretations were set according to Pitts, 1984.⁵

R0 – No radiolucency- no caries – corresponds to E0.

R1 – Zone of increased radiolucency confined to the outer half of the enamel – corresponds to E1.

R2 – Zone of increased radiolucency involving both inner and outer halves of the enamel, including lesion, extending up to, but not beyond the dentino-enamel junction – corresponds to E2.

R3 – Zone of increased radiolucency penetrating the enamel and dentino-enamel junction and progressing into the dentine – corresponds to D1.

Laser fluorescent examination (DIAGNOdent pen) with teeth in proximal contact

The tip A for proximal surfaces was used according to the manufacturer's instructions. Measurements with the DIAGNOdent pen were carried out as follows: first, the device was calibrated for every tooth using a ceramic reference. The fluorescence of a sound spot on the coronal part of the facial surface (zero value) was recorded. For the measurement, the tip of the device was introduced from the facial side of the proximal surface and moved towards the other side underneath the contact area. The peak value was registered. The procedure was then repeated from the oral side. The highest peak value was taken for further analysis. The extent of caries was determined according to the following scores³:

Readings from 0-7 – no changes in enamel – corresponds to E0.

Readings from 8-10 – initial demineralization – corresponds to E1.

Readings from 11-15 – developed demineralization – corresponds to E2.

Readings from 16 and more – advanced demineralization, affecting also dentine – corresponds to D1.

Laser fluorescent examination (DIAGNOdent pen) directly in the caries lesion

The measurement was performed before placing the teeth in a dental row with proximal surfaces contacting each other. The tip was applied directly onto the lesion on the tooth's proximal surface. The highest reading was recorded. The device was again calibrated and standardized before measuring each proximal surface respecting the manufacturer's instructions.

Histological examination of lesion depth

After the examination of the proximal surfaces with the described methods for caries detection, the roots of the teeth were removed and the crowns were cut in a mesio-distal direction, across the caries lesions perpendicular to the surface. A microtome for cutting hard dental tissues Leica SP 1600 was used. Two halves of each lesion were produced. Subsequently, cut surfaces were examined by a stereomicroscope ($\times 16$ magnification) and classified with respect to histological lesion extension, according to the criteria, described by Russel and Pitts^{6,7}:

C0 – No caries lesion – corresponds to E0

C1 – Caries lesion in the outer half of the enamel – corresponds to E1

C2 – Caries lesion into the inner part of enamel, but not involving dentine – corresponds to E2

C3 – Caries lesion through enamel and dentine – corresponds to D1

Data analysis was performed with statistical program IBM SPSS, version 25 (2017)⁸, specialized program for medical analysis MedCalc version 18.11.3 (2019)⁹ and statistical program Minitab version 18.1 (2017)¹⁰.

The examination of the proximal surfaces was conducted by two independent examiners according to the scores described above. The extent of correlation between the two examiners was established by calculating the Interclass Correlation Coefficient (ICC) with specialized medical statistical program Medcal version 18.11.6.

The diagnostic accuracy of the detection methods was compared to the histological evaluation, which served as a gold standard. To achieve this aim, analysis with ROC curve was performed and sensitivity, specificity and diagnostic accuracy of each detection method were calculated. Sensitivity is defined as the probability that a test result will be positive when the disease is present (true positive rate). Specificity is defined as the probability that a test result will be negative when the disease is not present (true negative

rate). The ROC curve is a fundamental tool for diagnostic test evaluation. In a ROC curve the true positive rate (sensitivity) is plotted in function of the false positive rate (100-specificity) for different cut-off points of a parameter. Each point on the ROC curve represents a sensitivity/specificity pair corresponding to a particular decision threshold. The area under the ROC curve (AUC) is a measure of how well a parameter can distinguish between two diagnostic groups (diseased/normal). Diagnostic accuracy is the overall probability that a patient is correctly classified according to the formula: Overall Accuracy = Sensitivity \times Prevalence + Specificity \times (1 – Prevalence)

To assess the validity of the detection methods, the sensitivity, specificity, area under the curve and overall diagnostic accuracy were calculated at three diagnostic thresholds for the three caries levels, using the histological examination as a gold standard. At each caries level the disease negative (sound=0) and the disease positive (caries=1) were defined respectively, as follows:

1. Initial demineralization – diagnostic threshold Dg1, analysis determined the diagnostic accuracy of the detection methods in differentiating the presence of caries in the outer half of the enamel or deeper from absence of caries (E0=sound while E1, E2 and D1=caries).

2. Developed demineralization – diagnostic threshold Dg2, analysis determined the diagnostic accuracy of the detection methods in differentiating the presence of caries in the inner half of the enamel and the outer part of the dentine from absence of caries and caries in the outer half of the enamel (E0, E1=sound while E2, D1=caries).

3. Advanced demineralization – diagnostic threshold Dg3, analysis determined the diagnostic accuracy of the detection methods in differentiating the presence of caries in the outer part of the dentine from absence of caries and caries in the inner and outer half of the enamel (E0, E1, E2=sound, D1=caries).

RESULTS

The values of ICC showed high level of correlation between the two examiners which indicates high reliability and reproducibility of the corresponding method. The lowest ICC values were received for the visual inspection (**Table 1**).

The aim of the analysis of the first caries level was to determine the diagnostic accuracy of the detection meth-

Table 1. Correlation between the two examiners

Method of detection	ICC	95% Confidence interval
1. Visual inspection	0.758	0.623 – 0.849
2. Bitewing radiography	0.952	0.920 – 0.971
3. DIAGNOdent with contact	0.959	0.924 – 0.971
4. DIAGNOdent directly	0.957	0.930 – 0.973
5. Histology – gold standard	1.00	-

ods in differentiating the presence of caries from absence of caries. The ROC curve, sensitivity, specificity and accuracy for each method were calculated. The highest value of the area under the curve was found for DIAGNOdent directly – AUC=0.803, $p=0.005$. This method was the closest to the gold standard in determining initial demineralization. The second method was DIAGNOdent in contact – AUC=0.793, $p=0.006$, followed by bitewing radiography – AUC=0.768, $p=0.016$. The visual inspection showed significant deviation from the gold standard with an area under the curve with the lowest value and no statistical significance – AUC= 0.580, $p=0.098$. The ROC curves analysis was complemented by calculation of sensitivity, specificity and overall accuracy of each detection method (Table 2):

The second level of the analysis determined the diagnostic accuracy of the detection methods in differentiating

Table 2: Sensitivity, specificity and overall accuracy of detection methods in Dg1 threshold

Method of detection	Sensitivity	Specificity	Overall accuracy
Visual inspection	16%	100%	27.59%
Bitewing radiography	54.08%	93.50%	80.46%
DIAGNOdent in contact	88%	87%	82.76%
DIAGNOdent directly	89%	86%	85.48%

the presence of caries in the inner half of the enamel and the outer part of the dentine from absence of caries and caries in the outer half of the enamel (E0, E1=sound, E2, D1=caries). The ROC curve, sensitivity, specificity and accuracy for each method were calculated. The highest value of the area under the curve was again found for DIAGNOdent directly – AUC=0.864, $p<0.001$. This method was the closest to the gold standard in determining developed demineralization. The second method was DIAGNOdent in contact – AUC=0.850, $p<0.001$, followed by bitewing radiography – AUC=0.776, $p<0.001$. The visual inspection again showed significant deviation from the gold standard with an area under the curve with the lowest value, nearly reaching statistical significance – AUC= 0.652, $p=0.052$. All caries detection methods presented higher diagnostic accuracy in Dg2 threshold in comparison to Dg1 threshold (Table 3).

The third level of the analysis determined the diagnostic accuracy of the detection methods in differentiating the presence of caries in the outer part of the dentine from absence of caries and caries in the inner and outer half of the enamel (E0, E1, E2=sound, D1=caries). The ROC curve, sensitivity, specificity and accuracy for each method were calculated. The area under the curve presented the highest values from all the previous levels of analysis. The highest value of the area under the curve was again found for

Table 3. Sensitivity, specificity and overall accuracy of detection methods in Dg 2 threshold

Method of detection	Sensitivity	Specificity	Overall accuracy
Visual inspection	26.92%	93.3%	63.43%
Bitewing radiography	60.87%	94.29%	81.03%
DIAGNOdent in contact	88.48%	79.14%	92.10%
DIAGNOdent directly	91.65%	81.29%	94.15%

DIAGNOdent directly – AUC=0.980, $p<0.001$. This method was the closest to the gold standard in determining advanced demineralization. The second method was DIAGNOdent in contact – AUC=0.961, $p<0.001$, followed by bitewing radiography – AUC=0.786, $p=0.017$. The visual inspection was with the lowest of all methods value for the area under the curve, but higher from the previous diagnostic thresholds – AUC= 0.714, $p=0.068$ (Table 4).

Table 4. Sensitivity, specificity and overall accuracy of detection methods in Dg3 threshold

Method of detection	Sensitivity	Specificity	Overall accuracy
Visual inspection	32.86%	100%	73.27%
Bitewing radiography	67.20%	94.03%	85.83%
DIAGNOdent in contact	91.07%	89.45%	93.15%
DIAGNOdent directly	92.45%	93.09%	95.35%

DISCUSSION

The values of ICC showed high level of correlation between the two examiners which indicates high reliability and reproducibility of the corresponding method. Similarly, high ICC values have been found in other studies.^{3,11-13} The lowest ICC values were received for the visual inspection.

The statistical analysis of the sensitivity, specificity and accuracy of the different caries detection methods in the different diagnostic thresholds showed that visual examination is the least sensitive method to diagnose initial proximal caries. Sensitivity increased with the increase of the level of demineralization – from 16% for initial demineralization, through 26% for developed demineralization, to nearly 33% for advanced demineralization, reaching dentine. Despite this, it remains low, which means a high number of initial lesions failed to be detected. Specificity of visual examination, on the other hand, is high – 93.3%

to 100%. These results correlate with the values, presented by another *in vitro* study¹⁴ – 15%–32.5% sensitivity and 94.5%–99% specificity, which also compares visual inspection, bitewing radiography and laser fluorescence for proximal caries detection, the visual method being with lowest accuracy. Other studies also report similar results – low sensitivity and high specificity for visual examination.^{15–17} Pitts¹⁸, as well as other authors¹⁹ find significant increase of sensitivity and overall accuracy when visual and radiographic examinations are combined. It is worth mentioning the *in vivo* study of Bahrololoomi et al.²⁰, which reports an extremely low sensitivity – 2.8% (0.7%–4.9%) of visual examination for detection of proximal white spot lesion, specificity is correspondingly high – 99%–100%. The authors speculate that the *in vitro* studies do not recreate the proximal contact point precisely enough and visualization of the proximal surface is easier than it is in a clinical situation with a tight contact point. For this reason, according to Bahrololoomi et al., clinical studies of visual examination demonstrate lower sensitivity. Similarly, another *in vivo* study²¹ finds higher sensitivity of both visual and laser fluorescence detection after temporary tooth separation. In the current study, visual examination was performed using ICDAS, which is the most popular visual system in scientific studies due to the high correspondence to histology.⁴

Bitewing radiography demonstrated sensitivity from 54 to 67%, increasing with the increase of diagnostic threshold. Specificity is 93% to 94% and stays high in all scientific studies.^{3,13,14,22–24} The values of sensitivity, reported by different studies are more variable. Studies, similar to ours and comparative in design, are conducted by Lussi et al.³ on permanent teeth, and by Virajsilp et al.¹³ on primary teeth. The first authors report sensitivity from 45%–68%, the second group of authors – 41%–69%, and specificity – correspondingly 67%–89%³ and 100%¹³, which are similar to the values in the present study. Similar sensitivity – 50%–60% is found in other studies as well.^{15,22,25} Lower sensitivity values are also reported – 28%–36%¹⁴, 43%¹⁷, as well as higher – 59%–86%²⁰ and 90%²⁶. These significant differences in the values of sensitivity of radiography can be explained by the use of different X-ray techniques and by the different study design. In the current study, the radiography is digital, using photosensitive phosphor plate system, which, according to Wenzel²⁴ does not change the diagnostic accuracy as compared to conventional radiography with a film. This is confirmed by another study²³, which does not find a significant difference in the performance of bitewing radiography with film, PSP plate and CCD sensor for the detection of proximal caries. However, the authors recommend the use of digital radiographic systems because of the lower radiation dose. In the present study, the film/plate holder is Icon X-Ray Holder, the design of which reduces the chance of overlapping of the proximal surfaces.

In the current study the laser fluorescence method (DIAGNOdent pen) demonstrated the highest sensitivity

for teeth in contact (88%–91%) and directly in the proximal lesion (89%–92.5%). These values correlate with the ones reported by other similar studies – 87%–89%³ and 75%–89%¹³, when teeth are in contact and 84%–92%³ and 86%–94%¹³ directly in the lesion, without proximal contact. At all caries levels, the detection of proximal caries using DIAGNOdent showed similar values of sensitivity for both examinations when teeth had contact and when they did not, the sensitivity when the device is directly applied in the lesion being slightly higher. Thorough cleaning of proximal surfaces is a prerequisite for accurate inspection with DIAGNOdent and must precede its use. It is well known that deposits like dental plaque, staining, calculus, fluorescing dental materials could produce a fluorescent signal and increase the readings of the device.^{11,27} Most *in vivo* studies also demonstrate similar sensitivity – 77%–94%¹⁴, 92% for non-cavitated lesions²⁸, 75%–86% for white spot lesions²⁰, 70%–92%^{22,29}. Slightly lower values are also reported – 66% for lesions, extending to dentino-enamel junction²⁶, 49.1% for primary teeth³⁰. In terms of specificity, the laser fluorescence method is inferior (79%–89% when there is proximal contact and 81.29%–93% directly in the lesion) to visual examination and bitewing radiography in all diagnostic thresholds. These values correlate with the ones, reported by other similar studies – 82%–92%³ and 86%–94%¹³ when teeth are in contact and 81%–93%³ and 81%–94%¹³ directly in the lesion, without proximal contact. Similar specificity is also found in other studies – 90%²⁸, 87.9%⁷, 68–93%³. Lower 63%–79%¹⁴, as well as higher values – 92%–97%²⁰ are also reported. All comparative studies declare that radiography shows superior specificity than laser fluorescence.

In the current study, despite the lower specificity and the higher number of false positive results than radiography, the laser fluorescence represents the highest of all methods in diagnostic accuracy in early proximal caries detection.

CONCLUSION

The use of adjunct contemporary diagnostic methods significantly increases the possibility of early detection of non-cavitated proximal lesions and their non-operative treatment. The diagnostic accuracy of the tested methods increases with the increase of the diagnostic threshold and the level of demineralization. Visual inspection has the lowest sensitivity and diagnostic accuracy, and cannot serve for detection of initial proximal caries. Bitewing radiography represents higher sensitivity and similar specificity to the visual method, but higher satisfactory diagnostic accuracy, however, it exposes the patient to ionizing radiation. The laser fluorescence appears to be with the highest sensitivity and diagnostic accuracy of all methods for the early proximal caries detection. The bigger number of false-positive readings of DIAGNOdent imply that the

device should be used as an adjunct to and increasing the diagnostic accuracy of the conventional means of detection, not as a single method for early caries detection. The examination with DIAGNOdent can be repeated as much as necessary, as it is safe, non-invasive and highly reproducible.

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In vitro сравнение нескольких методов установления начального проксимального кариеса

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Резюме

Введение: Первичный проксимальный кариес является одновременно и диагностическим, и терапевтическим испытанием. Недостатки традиционных методов выявления кариеса и развитие технологий привели к созданию современных оптических устройств для ранней диагностики кариеса.

Цель: Сравнение in vitro диагностической точности нескольких методов раннего выявления проксимального кариеса – визуально воспринимаемые методы, ультразвуковая рентгенография и лазерное флуоресцентное устройство (DIAGNOdent pen).

Материалы и методы: Пятьдесят восемь проксимальных поверхностей удалённых человеческих постоянных премоляров и моляров были осмотрены двумя специалистами путём визуального осмотра, bitewing рентгенографии, применения DIAGNOdent с проксимальным контактом и применения DIAGNOdent непосредственно в зону поражения. Результаты сравнивали с гистологическим золотым стандартом. Статистический анализ был выполнен с учётом кривой ROC, чувствительности, специфичности и диагностической точности каждого из методов установления. Анализ проводился по 3 диагностическим порогам – начальная, прогрессивная и поздняя деминерализация.

Результаты: Чувствительность визуального осмотра составила 16–33%, специфичность 93,3–100%, чувствительность рентгенографии 54–67%, специфичность 93–94%, чувствительность DIAGNOdent при контакте проксимальных поверхностей – 88–91%, специфичность 79–89%, чувствительность DIAGNOdent непосредственно 89%–92,5%, специфичность 81,29–93%. Самая высокая диагностическая точность, повышающаяся с увеличением уровня деминерализации, была установлена при применении DIAGNOdent непосредственно, за которой следовали DIAGNOdent с проксимальным контактом, рентгенографический контроль и визуальный осмотр с наименьшей точностью.

Заключение: Использование современных диагностических приборов значительно улучшает возможности раннего выявления проксимальных поражений. DIAGNOdent может использоваться как дополнительный метод для повышения точности диагностики по сравнению с традиционными методами выявления кариеса.

Ключевые слова

установление, начальное проксимальное кариозное поражение
