Performance of a new fluorescence camera for detection of occlusal caries in vitro

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Abstract The aim of this study was firstly to assess inter- and intra-examiner reproducibility and accuracy in the detection of occlusal caries in extracted human teeth using the newly developed fluorescence-based camera VistaCam iX and secondly to compare the performance to the established fluorescence device VistaProof. The occlusal surfaces of 101 teeth were assessed. The distribution of the lesions were characterized first visually using ICDAS-II (consensus score). The investigation sites were assessed by two examiners with different levels of experience in cariology (one experienced dentist, one final-year dental student) by both fluorescence-based cameras VistaCam iX (FC1) and VistaProof (FC2). The teeth were hemisectioned and assessed for lesion depth. Intra-class-correlation coefficients for inter- and intra-examiner reproducibility were 0.88–0.97 (FC1) and 0.82–0.98 (FC2), respectively. There was significant positive correlation (r, p<0.01) between all methods (ICDAS-II, fluorescence, and histological examinations: 0.63–0.89) and between FC1 and FC2 (r, 0.85–0.90), respectively. Areas under the ROC curves (AUC) were 0.87–0.92 (D1 and D2 diagnostic threshold, FC1) and 0.91–0.96 (FC2). There were no significant differences between the AUC of both fluorescence cameras (p values>0.05). Both fluorescence cameras demonstrated high reproducibility and good performance for the detection of occlusal caries at various stages of the disease process. The novice and the experienced examiner were able to apply both systems for detection of lesions. The in vitro performance of both devices was comparable to each other, although there was a tendency of a better performance for the FC2. Thus, within the limitations of an in vitro study, measurements with the FC2 can be continued by the new fluorescence camera (FC1) and data formerly assessed can be compared without significant loss of information.

Keywords Occlusal caries · Fluorescence camera · ICDAS-II · Reproducibility · Sensitivity · Specificity

Introduction

Dentists have many different methods at their disposal for detecting and diagnosing occlusal caries. As a rule, the initial examination is supposed to be done using visual procedures which should ideally be capable of enabling all stages of dental caries to be detected, from small enamel lesions up to perceptible dentin caries. One validated visual system which fulfills this requirement is the “International Caries Detection and Assessment System” (ICDAS-II) [1–3].

Along with visual caries detection systems, it can be referred to fluorescence assessment as a suitable method [4, 5]. It is based on the principle that chromophores in the dental enamel and dentin cause auto-fluorescence which is reduced by demineralization. Chromophores in caries lesions and bacteria also cause fluorescence which can be quantified and measured by subtracting the fluorescence of a sound tooth surface from that of a carious tooth surface. Some examples would be laser fluorescence measurement.
(DIAGNOdent and DIAGNOdent pen) and quantitative light-induced fluorescence (QLF) [6]. Another fluorescence-based device is VistaProof (Dürr Dental, Bietgheim-Bissingen, Germany), a camera which was developed for detection of occlusal caries lesions and has been on the market since 2007. Light-intense LEDs with a wavelength of 405 nm project high-energy violet light onto the tooth surface. Light from this wavelength stimulates porphyrins to emit red light, which contains less energy. Sound enamel, by contrast, sends out green light [7]. These light signals are recorded by the optics and analyzed by special software (Dürr DBSWIN). In this way, carious lesions, calculus, and plaque can be measured [7]. Caries lesions are identified when the red/green ratio is higher than that of sound tissue. On the monitor, caries lesions are shown in different colors (red, blue, orange, yellow) and are defined on a scale from 0 to 4 regarding the depth of the lesion. Further technical details on this method have already been described elsewhere [7–10]. In USA, this system is available under the name of "Spectra" (Air Techniques, Melville, NY, USA).

The VistaCam iX camera system is an advanced development of VistaProof and has been on offer from the same company since 2011 (Dürr Dental). This consists of a camera hand piece with two interchangeable lenses so that it can be used not only with the fluorescence attachment for detecting caries, but also as a conventional intra-oral camera. The DBSWIN evaluation software is also used with the new camera, so that both the VistaCam iX as well as the new VistaCam IX camera can be used with the same computer.

An advantage of the two fluorescence cameras is that they enable data to be digitally visualized and stored. This can make communication with the patient as well as therapy planning more effective. The long-term "monitoring" of incipient lesions can also be improved, since all images can be accessed at any time. Furthermore, a patient's oral hygiene status can be recorded with the aid of the plaque representation in so-called "plaque mode" and the patient's motivation and compliance thereby optimized. A disadvantage of this system is the hardware and software it requires. The device and the program must be installed beforehand and thus cannot be used everywhere. In addition, it cannot be used for approximal sites.

The VistaProof has already been validated for detection of occlusal caries [5, 8, 10, 11] and has been used in clinical studies as well [9]. By contrast, there are at present no scientifically corroborated data on the application of the new fluorescence camera.

Thus the aim of this in vitro study was to assess the reproducibility and validity of the new VistaCam IX (FC1) fluorescence camera for occlusal caries detection and to compare the findings to the established VistaProof (FC2) device when used by two examiners.

Materials and methods

Sample selection and visual examination

We had 101 extracted permanent teeth (65 molars and 36 premolars) available for the study. The teeth were stored in a thymol solution after extraction for 1 day. They were then cleaned carefully and stored in water afterwards. The occlusal surfaces were photographed digitally and one site on the occlusal surface of each tooth was marked on a black and white image of the tooth surface for ease of re-location. The distribution of sound and carious lesions was assessed visually by two investigators using the International Caries Detection and Assessment System (ICDAS-II) [3] and a consensus score for each site was achieved. The chosen sites were recorded as:

0 sound (n=45);  
1 first visible sign of a non-cavitated lesion, seen only when the tooth is dried (n=23);  
2 clinically visible non-cavitated lesion, seen when wet and dry (n=9);  
3 microcavitation in enamel (n=9);  
4 non-cavitated lesion extending into dentin, seen as an undermining shadow (n=0);  
5 small cavitated lesion with visible dentin: less than 50 % of surface (n=13);  
6 large cavitated lesion with visible dentin: more than 50 % of surface (n=2).

Assessments with the fluorescence-based VistaCam iX (FC1) and VistaProof (FC2) devices

The examinations were conducted on two different computers. The test device VistaCam iX (FC1) was connected to one computer while the control device VistaProof (FC2) was installed on a second computer. Thus, the in vitro examinations could be conducted by both devices independently. All investigation sites were measured independently and at different times within a maximum time of 1 week after extraction by two examiners with different experience in dentistry. Examiner A had been qualified for approximately 12 years in cariology, restorative, and pediatric dentistry. Examiner A also had experience with the FC2 [10, 11]. Examiner B was a final-year dental student (ninth semester) who did not have any particular training with the fluorescence devices. Examiners A and B independently examined all teeth with both devices, FC1 and FC2, at different times and repeated all the examinations 1 day after the first examination. Images of the occlusal surfaces were taken and analyzed by the software of the DBSWIN program. In order to eliminate external light irradiation as far as
possible, the teeth were each put into a dark box to make the fluorescence images.

The various lesions in all examinations were then evaluated using the digital images according to the manufacturer’s scale:

- 0.0–0.9 = sound enamel;
- 0.9–1.5 = initial caries, beginning enamel caries;
- 1.5–2.0 = enamel caries to enamel–dentin limit;
- 2.0–2.5 = dentin caries;
- >2.5 = deep dentin caries.

Validation

For the histological examination, the roots were resected from the teeth apical to the cementum–enamel junction. The crowns of the teeth were then hemisected at the investigation site using a cutting band, 200 μm thick with grade D64 diamonds (Exakt, Hamburg, Germany) cooled under water, a method which was described elsewhere before [12]. Both section faces were photographed digitally (Leica Zoomsystem Z6 Apo M 420/QWin Standard V 3.4.0). The images were then viewed by two experienced examiners on an 18-inch TFT (thin-film transistor) color monitor (FlexScan L 768, EIZO, Avnet Technology Solutions, Nettetal, Germany) at a constant observation distance (60 cm) [13]. Both section faces were examined by two examiners with experience in the evaluation of histological sections and then a consensus decision was made. For each investigation site the worst/deepest score was taken as the definitive score for further analysis. The following histological classification system was used to record caries severity at each investigation site [14]:

0 no enamel demineralization or a narrow surface zone of opacity (n = 15);
1 enamel demineralization limited to the outer 50% of the enamel layer (n = 13);
2 demineralization involving the inner 50% of the enamel, up to the enamel–dentin junction (n = 22);
3 demineralization involving the outer 50% of the dentin (n = 21);
4 demineralization involving the inner 50% of the dentin (n = 30).

Statistical analyses

Statistical evaluation was performed by SPSS, version 15.0. Intra-class-correlation coefficients (ICC) were calculated for intra- and inter-examiner reproducibility. The Bland and Altman method [15] was applied to identify systematic differences and the extent of concordance between the measurements of both devices. Correlations among all fluorescence methods were assessed using Spearman’s rank correlation coefficient ($r_s$). The extent of the correlations (ICC, $r_s$) was as follows [16]: 0.1–0.3 = weak, 0.3–0.5 = moderate and 0.5–1.0 = strong correlation.

Sensitivity, specificity, accuracy, and the area under the ROC curve (AUC) were calculated at $D_1$ and $D_2$ diagnostic thresholds. At the $D_1$ diagnostic threshold (enamel and dentin) all histological scores 1–4 were classed as caries and each FC1/FC2 cutoff was used to calculate sensitivity and specificity for each examiner. Similarly for the $D_2$ diagnostic threshold (dentin), histological scores 3 and 4 were classed as caries only and sensitivity and specificity calculated at each FC1/FC2 cutoff. Using these sensitivity and specificity values, ROC analyses were carried out at the $D_1$ and $D_2$ thresholds for each examiner. Optimum sensitivity and specificity values were obtained at the cutoff values which were determined by the highest sum of sensitivity and specificity at each threshold ($D_1$, $D_2$) and for each examiner. The area under the ROC curve was interpreted by using the following classification: 0.50–0.60 = fair, 0.60–0.70 = poor, 0.70–0.80 = fair, 0.80–0.90 = good, and 0.90–1.00 = excellent [17]. To assess the difference among the AUC for both examiners, a non-parametric test was performed [18] using the MedCalc 11.3.4.0 program. The significance level was set at $\alpha = 0.05$.

Results

The occlusal sites of 101 teeth were investigated. While examiner A could investigate all the sites with both devices, examiner B could investigate 97 of the sites with the device FC1, since four investigation sites could not be assessed by this camera due to technical problems. Thus, further statistical calculation was performed using 97 sites.

Intra-class-correlation coefficients (ICC) for intra- and inter-examiner reproducibility were 0.88–0.97 for the FC1 and 0.82–0.98 for the FC2 (Table 1).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Intra-class-correlation coefficients and 95% confidence intervals for intra- and inter-examiner reproducibility of FC1 (VistaCam iX) and FC2 (VistaProof) for examiner A (experienced dentist) and examiner B (dental student)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examiner</strong></td>
<td><strong>FC1 (VistaCam iX) vs. FC2 (VistaProof)</strong></td>
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<td></td>
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<tr>
<td><strong>Examiner</strong></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.97 (0.96–0.98)</td>
</tr>
<tr>
<td>B</td>
<td>–</td>
</tr>
<tr>
<td><strong>FC2 (VistaProof)</strong></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.90 (0.92–0.97)</td>
</tr>
<tr>
<td>B</td>
<td>–</td>
</tr>
<tr>
<td><strong>FC1 (VistaCam iX) vs. FC2 (VistaProof)</strong></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.80 (0.71–0.86)</td>
</tr>
</tbody>
</table>
The limits of agreement (mean±1.96 SD) for the measurement reproducibility of both devices can be observed in the Bland–Altman plots. The range between the upper and lower limits of agreement for intra- and inter-examiner reproducibility was between 0.21 and 0.41 for FC1 (Fig. 1) and between 0.24 and 0.65 for FC2 (Fig. 2). The range between the upper and lower limits of agreement between the devices was 0.91 for examiner A and 1.11 for examiner B, respectively (Fig. 3).

Spearman’s rank correlation coefficients are presented in Table 2. All methods showed significant positive correlation ($p<0.01$). The highest $r_s$ value (0.90) was found between the devices FC1 and FC2.

Figures 4 and 5 show the ROC curves for the devices at the $D_1$ and $D_2$ diagnostic thresholds. The corresponding areas under the curve (AUC), accuracy, sensitivity, and specificity values are presented in Tables 3 and 4. Optimum sensitivity and specificity at the $D_1$ threshold was achieved at the 1.2/1.3 cutoff. The optimum sensitivity and specificity at the $D_2$ threshold was achieved at the 1.4/1.5 cutoff of the device (Table 3). Table 4 shows the corresponding numbers for the FC2.

No significant differences were observed between the AUC of the examiners for each device. $P$ value for FC1 at the $D_1$ threshold was 0.15, and 0.88 at the $D_2$ threshold. $P$ values for the FC2 were 0.16 ($D_1$) and 0.54 ($D_2$), respectively. The AUC difference between both devices was not statistically significant. The $P$ values were 0.07 ($D_1$) and 0.06 ($D_2$) for examiner A and 0.12 ($D_1$) and 0.16 ($D_2$) for examiner B.

For the ICDAS-II AUC, sensitivity and specificity values were calculated using the consensus score of both examiners. At the $D_1$ diagnostic, thresholds AUC was 0.96 (95% CI 0.94–1.00) and sensitivity and specificity values amounted to 97.7 and 80%, respectively. At the $D_2$ diagnostic, thresholds AUC was 0.92 (95% CI 0.88–0.97) and
Fig. 2 Bland-Altman plots for intra- and inter-examiner reproducibility of the FC2 (VistaProof). Examiner: a experienced dentist; b dental student

Fig. 3 Bland-Altman plots for reproducibility between the fluorescence cameras FC1 (VistaCam iX) and FC2 (VistaProof). Examiner: a experienced dentist; examiner b dental student
sensitivity and specificity values amounted to 70.6 and 96 %, respectively. The area under the ROC curves could be classified as good to very good.

Discussion

Caries detection and diagnosis is one of the main duties of a dentist, and the initial examination of the oral cavity and the teeth is usually done visually. In recent years, the requirements for precise assessment and confident diagnosis have increased, since early detection of carious lesions is now being given a high priority. At the same time, detection tools for dentists have become more numerous and various methods are constantly being invented or further developed. Along with the visual detection of lesions, other common optical or fluorescence-based devices, such as DIAGNODent and DIAGNODent pen (KaVo, Biberach, Germany), QLF (Inspektor Research Systems BV, Amsterdam, The Netherlands), Midwest Caries I.D. (DENTSPLY Professional, New York, USA) and the systems VistaProof and VistaCam iX (DürrDental, Bietigheim-Bissingen, Germany) can be listed. Basically it is important to consider quantitative methods as adjunct to visual examination and radiographs whenever indicated.

Along with detecting the current caries prevalence of a patient, monitoring clinically suspicious discolorations is another area of application for apparatus-based methods. Hence, the reproducibility of such devices is important. The reproducibility of the devices studied was in the high range (Table 1). The results already published for the VistaProof were confirmed [8, 10]. The reproducibility of the new VistaCam iX camera compared well with the values of the VistaProof. High reproducibility was also reported for one of the newest tools for the detection of caries lesions, the Midwest Caries I.D. [5, 19].

The cameras studied here work in similar ways and have similar properties to the QLF (quantitative light-induced fluorescence) which, for example, uses a CCD camera and software to analyze and store the images of individual carious lesions for longitudinal monitoring [20]. Reported reproducibility data for the QLF show values comparable to our results (ICC for QLF between 0.95 and 0.99) [21]. In our study, the cameras were evaluated by two examiners with different experience in cariology. Both devices showed good reproducibility, whether it was done by an experienced or less experienced investigator. Although the ICC-values were high in general, examiner B (dental student) tended to have lower values than examiner A (Table 1). Also, examiner B could not assess a lesion depth of four teeth due to

| Table 2 | Spearman rank correlation (r) between different methods for examiner A and B |
|-----------------|-----------------|-----------------|
|                 | FC1 (VistaCam iX) | FC2 (VistaProof) | Histology |
| Ex. A (experienced dentist) |                 |                 |           |
| ICDAS-II        | 0.67            | 0.70            | 0.89      |
| FC1 (VistaCam iX) | –               | 0.85            | 0.69      |
| FC2 (VistaProof) | –               | –               | 0.75      |
| Ex. B (dental student) |                 |                 |           |
| ICDAS-II        | 0.64            | 0.68            | 0.63      |
| FC1 (VistaCam iX) | –               | 0.90            | 0.74      |
| FC2 (VistaProof) | –               | –               | 0.79      |

Fig. 4 Receiver operating characteristics curves (ROC) for the FC1 (VistaCam iX) at the D1 (left) and D2 (right) diagnostic threshold. Examiner: a experienced dentist, examiner b dental student. The corresponding areas under the curves are given in Table 3
technical problems. In a study using the QLF [22], one examiner, new to the technique, demonstrated differences in intra-examiner reliability compared to other examiners who had more training. Thus, it was recommended that novices should be trained in the technique before analyzing experimental data. This should be taken into account in further studies.

In Bland and Altman plots, there should ideally be no systematic deviation (mean difference = 0) and only a small range between the upper and the lower limits of agreement [23]. The line shown in the plots for both devices indicate the mean of the differences between two measurements. These values would only be zero in an ideal situation where on average no differences between the measurements were observed. For the FC2, the interval in which the measurements were more reliable corresponds with values between 1 and 2, which is comparable to findings in other studies [8, 10]. In previous studies using this camera, the range between the upper and the lower limits of agreement were between 0.80 and 1.12 [8] and between 0.4 and 0.9 [10] for both intra- and inter-examiner reproducibility. No comparable figures have yet been published for the FC1.

The measurements of the fluorescence cameras showed a strong correlation with histological findings (Table 2). Rodrigues et al. [8] found a rank correlation of 0.41 between the prototype of the VistaProof fluorescence camera and histology, which is lower than our findings. The authors mention that the device exhibited difficulties in detecting enamel caries lesions. A similar correlation coefficient with histology was found in a previous study when a laser fluorescence device was used to detect occlusal caries ($r_s = 0.51$) [24]. Another study using the commercially available VistaProof showed rank correlation coefficients of 0.47–0.55 with histological findings [10]. The authors investigated between one and three sites on the occlusal surface of each tooth. In the present study only one investigation site was chosen and teeth were hemisectioned, which may have simplified the allocation of a histological depth to the

Table 3 Area under the ROC curve, accuracy, optimum sensitivity, and specificity and for each examiner at each diagnostic threshold ($D_1$, $D_2$) for the VistaCam IX (FC1)

<table>
<thead>
<tr>
<th>FC1 (VistaCam IX)</th>
<th>AUC (95% CI)</th>
<th>SE (%)</th>
<th>SP (%)</th>
<th>Accuracy (%)</th>
<th>Cutoff point*</th>
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<tr>
<td>Examiners A (experienced dentist)</td>
<td></td>
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<tr>
<td>$D_1$</td>
<td>0.87 (0.78–0.96)</td>
<td>76.6</td>
<td>86.7</td>
<td>82.2</td>
<td>1.2/1.3</td>
</tr>
<tr>
<td>$D_2$</td>
<td>0.87 (0.80–0.95)</td>
<td>86.0</td>
<td>67.3</td>
<td>77.2</td>
<td>1.4/1.5</td>
</tr>
<tr>
<td>Examiners B (dental student)</td>
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<tr>
<td>$D_1$</td>
<td>0.92 (0.86–0.98)</td>
<td>80.5</td>
<td>86.7</td>
<td>84.8</td>
<td>1.2/1.3</td>
</tr>
<tr>
<td>$D_2$</td>
<td>0.87 (0.79–0.94)</td>
<td>88.4</td>
<td>67.3</td>
<td>77.2</td>
<td>1.4/1.5</td>
</tr>
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</table>
investigated site and thus led to a higher correlation. There was also strong correlation between the visual and fluorescence findings (Table 2) and the figures were similar to the findings of previous studies with the VistaProof [11].

In this study, the performance of the new fluorescence camera FC1 was assessed for the first time, thus the results can only be compared to the results of the already-established FC2. The AUC of the FC1 is lower overall than the AUC of the FC2 (Tables 3 and 4). However, these do not significantly differ from each other. Studies using the VistaProof were also able to achieve AUC values between 0.58 and 0.82 [10, 11]. In the present study, there was no significant difference between the diagnostic performances of both examiners and devices. This is in accordance with previous studies using the VistaProof [11]. Thus, the devices can be said to hold promise as tools for dental education.

It might be argued that the sample is unbalanced since no tooth presented an ICDAS-II score of 4 (dentin caries) in the sample under study and hence the results may not be comparable with previous studies. In other in vitro studies the number of lesions with ICDAS-II code 4 was quite low [8, 10]. Furthermore in the presented study, the proportion of teeth with obvious dentinal decay (ICDAS-II code 5 and 6) was moderately high. Gathering human teeth is challenging and becomes increasingly difficult because of ethical formalities. So there is not always the possibility to have a balanced sample size [12]. Nevertheless, the distribution of the visual appearances determined by ICDAS-II may reflect the caries presentation of the population where the teeth were collected.

In the present study, teeth were stored in a thymol solution after extraction. It could be argued that the storage method led to wash out of some of the bacterial fluorophores affecting this relationship [25]. This would however, have lead to a systematic error. Rodrigues et al. [8] used teeth which were stored frozen at −20°C until use since this storage method does not change the red fluorescence significantly [25]. They reported an accuracy of 0.72 and sensitivity of 0.86 for the fluorescence camera which is comparable to the values found in our study (Tables 3 and 4).

However, the good performance of the apparatus-based procedure must be observed in a somewhat differentiated way: different cutoff points were predefined by the manufacturer upon the launch of the VistaProof and also the new VistaCam iX camera. These cutoff points were intended to facilitate differentiation of the caries stages from sound to dentin caries with the help of the numerical scale. According to this, values $\geq 1.0$ should be considered proof of the beginning of enamel caries, while dentin caries supposedly produced values $\geq 2.0$. Looking at the optimum sensitivity and specificity (Tables 3 and 4) it can be shown that this cutoff point should be set at 1.4/1.5 in order to detect dentin lesions appropriately, which means that lesions $>1.5$ can be expected to indicate dentin caries. A comparable cutoff point ($>1.4$) for the determination of dentin caries was found in other studies using the VistaProof [5, 10, 11]. The values observed for the differentiation between enamel and dentin lesions also seem to be very close to each other [5, 10].

Jablonski-Momeni et al. [10] calculated sensitivity and specificity of the VistaProof at different cutoff points: first at the cutoff point specified in the manufacturer’s instructions and second at the highest sum of sensitivity and specificity (optimum sensitivity and specificity). The authors concluded that sensitivity and specificity values of caries detection methods are always to be observed in the context of the relevant cutoff point and that the study conditions (in vitro or in vivo studies) have to be taken into account with regard to the results. In the present study, the cutoff points for the differentiation of a lesion on the D1 or D3 level were very close together, as was also reported in previous studies [8, 10]. Since the clinical database of the suggested cutoffs for enamel and dentin caries is limited to date, the values should be interpreted carefully until more clinically validated results with the fluorescence cameras are available. It was suggested that the software used to analyze the digital images should be reviewed by the manufacturer in order to provide useful values for clinical practice [5]. The same could be stated for the recently introduced MID device, which showed the same cutoff limits for caries-free sites and enamel caries in vitro and hence was not able to differentiate those lesions from sound surfaces [5].
Conclusion

The VistaCam iX and VistaProof fluorescence-based devices offer a potential tool to objectify the caries lesions for detection and monitoring purposes. There were no significant differences between the reproducibility and the performance of examiners and devices. The in vitro performance of both devices was comparable to each other, although there was a tendency to a better performance of the FC2. The VistaCam iX (FC1) can be expected to replace the established VistaProof (FC2) in the long term, since it combines the advantages of fluorescence capability with those of a regular intra-oral camera. Thus, within the limitations of an in vitro study, it can be concluded that measurements with the older device can be continued by the new fluorescence camera and data formerly assessed can be compared without significant loss of information.

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