Detection of initial caries lesions on smooth surfaces by quantitative light-induced fluorescence and visual examination: an in vivo comparison


The aim of this clinical study was to compare the outcome of quantitative laser/light-induced fluorescence (QLF) and visual inspection (VI) for the detection of initial caries lesions on all maxillary and mandibular smooth surfaces in caries-risk adolescents. The subjects were 34 students, mean age 15 yr. A total of 879 buccal and 882 lingual surfaces were air-dried and visually examined at a magnification of ×3.5. Fluorescence images of each smooth surface were captured with QLF-clin equipment, and QLF software 2.00 was used to display, store, and analyse the images. Fluorescence loss (ΔF; %) and area of the lesion (A; mm²), and fluorescence loss integrated over the lesion area (ΔQ; ΔF × A; % × mm²), were determined. The presence or absence of initial caries lesions was scored using both VI and QLF. A total of 87.2% of all smooth surfaces were scored as sound or initially carious when assessed by VI + QLF in combination: 4.9% were detected by VI alone and 7.9% by QLF alone. The parameters ΔF, A, and ΔQ differed significantly between lesions registered with VI + QLF and QLF alone. It was concluded that (i) QLF seems to be a sensitive method that is suitable for the detection of visually undetected initial caries lesions; and (ii) that the clinical use of QLF is limited by several confounding factors in caries-risk adolescents.

Visual inspection (VI) is a non-invasive method of caries detection on accessible smooth surfaces. For clinical examination, VI is simple, quick, and cost-effective. However, the method has considerable limitations. Lesions are usually detectable first at the white spot stage, but may be more advanced; mineral loss in enamel lesions is not quantifiable, and changes in mineral content – loss or gain as a result of de- or remineralization – cannot be monitored. It is suggested that objective methods would enhance conventional intraoral examination and improve the potential for correct diagnosis, especially in caries-risk patients (1).

The quantitative laser/light-induced fluorescence method (QLF) is reported to be valuable tool for the detection and quantification of initial caries lesions and for monitoring de- or remineralization on smooth surfaces (2, 3). The first in vivo applications of QLF (4, 5) were followed by clinical trials (1, 6–9). These studies disclosed an excellent repeatability and reproducibility for permanent teeth. The histological validation of clinically detected smooth surface lesions with QLF performed on deciduous teeth revealed a sensitivity of 79% and a specificity of 75% (10). Moreover, histological studies verified the fluorescence loss of initial caries lesions measured by QLF as an excellent parameter for the expression of the mineral loss of the lesion. The amount of fluorescence radiance validated with the use of transversal and longitudinal microradiography is closely correlated (r² = 0.97) to the mineral loss in artificial and natural initial caries lesions (11–13).

To date there are only limited data – collected in the Indiana study – comparing the QLF method with visual and visual-tactile examination for the detection of caries lesions on smooth surfaces (8). The method of comparison in that study was based on a split-mouth design for clinical examination and QLF assessment of buccal and lingual surfaces in maxillary teeth and of buccal surfaces of mandibular teeth (8). As the presence or absence of a lesion was determined by placing a marker on the live QLF image indicating the lesion, the Indiana study design did not focus on an independent comparison of both methods. The aim of the present clinical study was therefore to assess the outcome of initial caries lesion detection on all maxillary and mandibular smooth surfaces by QLF and meticulous VI, with the hypothesis that a meticulous VI would show a similar performance.
as QLF. Furthermore, the potential of QLF for clinical use in high caries-risk subjects should be evaluated.

**Material and methods**

**Study subjects**

The study comprised 34 healthy subjects aged 14–15 yr. All subjects were participants in a longitudinal caries risk-assessment study (1993–99), and were accustomed to annual clinical, microbiological, and biochemical examinations (14). At baseline, 8-yr-old-children (n = 189), attending the second grade, were randomly selected from all schools of a non-fluoridated city (Erfurt). At a later follow-up examination, the remaining participants (n = 99) were invited to take part in an additional QLF investigation of their teeth, followed by a preventive programme, including professional tooth cleaning, 3-monthly application of a fluoride varnish, and oral health instructions. The subjects’ dental care was provided by general dental practitioners. Informed proxy consent was obtained from the subjects and their parents. The study was approved by the Ethics Committee of the Friedrich-Schiller-University of Jena.

**Clinical examination**

Prior to clinical examination and professional tooth cleaning, the subjects’ plaque scores were estimated using the proximal plaque index (PPI) (15) and gingival status was estimated using the papillary bleeding index (PBI) (16). The clinical investigation was performed by a dentist (R.H.-W.) with considerable experience in clinical assessment of caries lesions. World Health Organization criteria (17) were used for classification of the tooth surface status. According to the caries diagnostic system proposed by Nyvad et al. (18), white spots on smooth surfaces and discoloured fissures were recorded separately as initial caries lesions, but were not included in the decayed, missing or filled tooth surfaces (DMFS) index.

All examinations were conducted under standardized conditions using a dental unit equipped with compressed air and evacuation facilities. After prolonged air-drying (> 5 s) of the tooth surfaces, caries were recorded with the aid of a dental magnifying glass (×3.5). The buccal and lingual surfaces of all permanent teeth were classified according to one of the following criteria: 0, sound (normal enamel translucency and texture); 1, initial caries lesion (surface of the enamel is whitish, yellowish or brownish opaque with/without normal enamel translucency); 2, localized surface defect (enamel/dentin cavity); 3, filled surface with intact filling; 4, filled with marginal/recurrent decay, filled surface with intact filling and a separate lesion. Cavitated and filled surfaces were routinely excluded from the methodological comparison (39 buccal and 35 lingual surfaces). The additional presence or absence of developmental disorders (fluorosis, mineralization disturbances) was noted. Because of the similar appearance of the hypoplastic/fluorotic enamel and initial caries lesions in the fluorescence images, the detection of any enamel developmental disorder was the decisive criterion for exclusion of the surface from further QLF image analysis. If no clear differentiation could be made, the surface was excluded (n = 1).

Intra-examiner reliability of VI was assessed by a second examination of 10 randomly selected subjects 1 wk after their first clinical examination.

**QLF measurements**

A portable QLF device (QLF clin) was used, equipped with a xenon microdischarge arc lamp as the light source and an optical filter system producing blue light with a maximum wavelength of 370 nm, conducted by a liquid-filled guide (Inspexor Research Systems, Amsterdam, the Netherlands). The re-emitted fluorescence was collected with a micro-CCD-video camera (Panasonic WV-KS 152; Matsushita Electric Industrial Co., Ltd. Osaka, Japan) equipped with a yellow high-pass filter (λ > 520 nm) to exclude any excitation or ambient light from reaching the detector. To avoid interference to the fluorescence images by bubbles of saliva or blood from gingival bleeding, drying of the teeth was prolonged (> 5 s) before the images were captured in the darkened dental office. The QLF image capturing was performed on buccal and lingual surfaces of all permanent maxillary and mandibular teeth by a trained examiner (R.H.-W.) 2 wk after the clinical examination. No information about the visual scoring of presence/absence of an initial caries lesion was noted on the fluorescence image. QLF 2.00f software (Inspexor Research Systems) was used to display, store and analyse the images (19).

Initially, the QLF images were visually viewed for signs of decalcification, which appear as dark areas surrounded by bright green fluorescent sound tooth tissue (2, 4, 19). If a lesion was detected, the fluorescence loss (ΔF; %), lesion area (A; mm²) and the fluorescence loss integrated over the lesion area (ΔQ; % × mm²) were analysed using the system’s analysis software to determine lesion severity. The image analysis was considered to be optimal when the grey-level image showed a homogeneous status (2, 4, 19). Mean ΔQ values for the ~5% threshold were exported for subsequent statistical analysis. All QLF images were analysed in a blinded manner by two independent investigators (J.K., and S.I.).

The reproducibility of the QLF image analysis was assessed by calculation of the intra- and interexaminer reliability. After an intensive calibration training of 1 wk for the analysts (J.K., S.I.), 60 smooth surfaces with various appearance of initial caries lesions were randomly selected; a second image analysis was performed 3 d later by both analysts.

**Statistics**

For both VI and QLF methods of examination, the smooth surfaces were categorized as sound or with initial caries. Initial lesions were grouped, according to the method of examination, into the following: VI + QLF, VI alone, or QLF alone. The results were calculated separately for buccal and lingual surfaces. For the QLF-related groups, descriptive statistics included mean values and standard deviation (SD) with confidence intervals (95% CI) for the parameters A, ΔF, and ΔQ. The Mann-Whitney U-test was used to determine differences between the quantitative QLF parameter of smooth surface lesions detected by VI + QLF and by QLF alone. A P-value of less than 0.001 was considered as statistically significant. The correlation between VI and QLF was analysed by calculating the Spearman rank correlation coefficient (r_s) (20).

The quality of intraexaminer reliability for VI was calculated using Cohen’s kappa statistic. A kappa (κ) value of 1 represents perfect agreement, κ-values of < 1, but > 0.75, denote excellent agreement, those in the range of 0.4–0.75 denote good agreement, and values of < 0.4 denote marginal agreement (21). For determining the
intra- and interexaminer reliability of QLF image analysis, the intraclass correlation coefficient was estimated for both analysts (20).

Results

The study comprised 34, 15-yr-old students with a caries experience of 7.7 ± 5.8 D₃₋₄MFS. The PPI of 71.1% reflected poor oral hygiene, associated with a generalized gingivitis, scored as a PBI of 76.2%.

A k-value of 0.84 was calculated for the intraexaminer agreement of VI. A high intra- and interexaminer agreement was also determined for the three parameters of QLF analysis (Table 1). The relationship between VI and QLF revealed a Spearman rank correlation coefficient of rₛ = 0.63.

A total of 1,761 smooth surfaces were examined by VI and QLF (Table 2). The two methods were in agreement with respect to 87.2% (n = 1535) of the surfaces investigated: 72.2% (n = 1,272) were assessed as sound and 15.0% (n = 263) as initial carious. The proportion of initial caries lesions detected by VI alone represented 4.9% (n = 87) of the surfaces and increased to 7.9% (n = 139) with QLF alone. The distribution of the latter was fairly even: 4.3% (n = 76) on lingual surfaces and 3.6% (n = 63) on buccal surfaces.

The features of fluorescence images of smooth surfaces with visually scored initial lesions, not detected with quantitative laser-light-induced fluorescence (QLF) alone. There were significantly lower values with respect to A, ΔF, and ΔQ of lesions detected with QLF alone.

Table 3 presents the quantitative parameters of the QLF analysis of 263 initial lesions detected by both methods, compared to the 139 lesions that were detected with QLF alone. There were significantly lower values with respect to A, ΔF, and ΔQ of lesions detected with QLF alone.

Table 3

<table>
<thead>
<tr>
<th>Feature of QLF images</th>
<th>Initial caries lesion detected with VI only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface associated with an inflamed swollen gingival margin, which reduced the surface size</td>
<td>44</td>
</tr>
<tr>
<td>Very bright image, no fluorescence loss detectable</td>
<td>20</td>
</tr>
<tr>
<td>Image out of focus, no analysis possible</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>87</td>
</tr>
</tbody>
</table>

Discussion

The clinical management of dental caries has progressed from extraction to restoration and recently from minimally invasive to maximally interceptive approaches. With the shift from operative to non-operative intervention (22), the accurate early detection of caries lesions is a prerequisite for interceptive measures to arrest or reverse caries progression. In this context, QLF seems to be a promising method, which fulfills the essential requirements for detection, quantification and monitoring of caries lesions (1–3, 8, 9, 23, 24).

The present study was conducted under standardized clinical conditions and compared QLF with meticulous VI for detection of smooth surface initial caries lesions. The subjects were 34, 15-yr-old students, designated as high-risk patients on the basis of their caries experience of 7.7 D₃₋₄MFS as well as high plaque and gingival bleeding scores. The data are based on the examination of 1,761 smooth surfaces by VI and QLF.

One finding, in this study, was that QLF was able to detect a greater number of initial caries lesions than meticulous VI. This finding might be an effect of the study design, which was not restricted to visually detectable lesions but performed as a registration of all smooth surfaces with VI and QLF. Thus, it was possible to compare the outcome of lesion detection by the two methods, in contrast to the Indiana study (8).

Of all initial caries lesions, 263 (53.8%) were detected by both methods. Of the total number of initial caries
lesions registered on the buccal and lingual surfaces, 139 (28.4%) were registered by QLF alone, compared with 87 (17.8%) registered by VI only. As shown in Table 2, 55.5% of 137 initial caries lesions on lingual surfaces were detected by QLF alone (n = 76). In contrast, only 17.9% of lesions on the buccal surfaces were detected by QLF alone (63 of a total of 352 buccal lesions), whereas VI alone detected 76 buccal lesions (21.6%). This discrepancy between detection of lesions on buccal and lingual surfaces might be attributable to difficulty inspecting the lingual surfaces with VI. The results suggest that QLF enables more sensitive judgement than VI for the detection of smooth surface lesions. However, neither method could be validated against any histological reference standard in this study. As a consequence, it could not be excluded that sites which were qualified as carious by QLF or VI alone were really sound (false-positive diagnosis). Considering the results of former histologically validated studies comparing VI and QLF (9, 10, 13), the authors assume that QLF is superior to VI.

A dry and clean surface is essential for capturing an optimal QLF image as well as for meticulous VI. However, it was established that it is more difficult to ensure no saliva contamination during QLF image capturing, especially at lingual surfaces, owing to a longer examination time. This is in line with other QLF in vitro studies (25, 26), which determined the drying effect as a sensitive parameter that has to be controlled for lesion detection and quantification. To avoid any detection failure of initial caries lesions, as occurred in this study, effective air-drying of each surface (> 5 s) is of considerable importance for both methods, and should be controlled strictly.

With respect to lesions detected by VI alone, the features of the fluorescence appearance of these smooth surfaces reveal several problems (Table 3). In cases of inflamed and swollen gingiva (n = 44), lesion detection was as impossible as in cases with a tooth surface partially covered by plaque (n = 20), which may be invisible in daylight but clearly visible on the computer screen. In our experience, the use of QLF in children or adolescents with a high risk of caries is practical only when the gingiva is not inflamed and initial lesions located at the gingival margin are unobscured and accessible for detection and monitoring. These findings highlight the fact that lesion detection and quantification are limited when confounding factors are not controlled. As tooth surfaces or dental lesions may be covered with dental plaque, calculus and/or extrinsic discolorations, meticulous professional tooth cleaning is essential prior to the use of the QLF method for early caries detection.

In 23 cases, inadequate images may have contributed to failure of lesion detection by QLF: very bright images without any chance of determining fluorescence loss (n = 9), and those that were captured out of focus or not perpendicular to the tooth surface (n = 14) (Table 3).

Quantitative analysis of the data from images of non-cavitated lesions detected by QLF alone disclosed that these lesions had a significantly smaller area and a lower fluorescence loss than lesions detected by VI+QLF (Table 4). The clinical relevance and consequence of this finding should be considered critically. On the one hand, it seems to be desirable to detect and quantify any lesion as early as possible, in order to optimize the outcome of interceptive measures. On the other hand, the time-consuming QLF investigation of all smooth surfaces for clinically invisible lesions must be questioned. Meticulous VI is the method of choice for routine examination. Visual inspection focusing on the detection of initial lesions enables the dentist to assess the activity of the lesion (18) and provides further information about future caries risk and the appropriate intervention strategy (27–29).

Quantitative laser/light-induced fluorescence analysis of inactive lesions that appear visually smooth and glossy without loss of surface integrity (commonly localized at some distance from the gingival margin) does not seem to be practical. In contrast to these easily assessable lesions, active lesions, usually located at the gingival margin, are difficult to capture and analyse with QLF. There is a need for more information about the suitability of QLF for the assessment of active, extensive lesions at the gingival margin commonly found in high-risk patients. For the dentist using this method it would be helpful to have guidelines with respect to suitable cut-off values for the QLF parameters fluorescence loss and/or area, guiding the clinician’s decision-making towards preventive or operative intervention. The dark appearance of the lesions, as viewed with QLF, is very obvious and might therefore

<table>
<thead>
<tr>
<th>Initial caries lesion</th>
<th>Parameter</th>
<th>Mean</th>
<th>SD</th>
<th>−95% CI</th>
<th>+ 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detected with VI+QLF (n = 263)</td>
<td>A (mm²)</td>
<td>5.8*</td>
<td>5.4</td>
<td>5.1</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>ΔF (%)</td>
<td>−9.6*</td>
<td>8.0</td>
<td>−10.6</td>
<td>−8.6</td>
</tr>
<tr>
<td></td>
<td>ΔQ (% × mm²)</td>
<td>−84.6</td>
<td>148.4</td>
<td>−103.0</td>
<td>−67.0</td>
</tr>
<tr>
<td>Detected with QLF alone (n = 139)</td>
<td>A (mm²)</td>
<td>3.4*</td>
<td>3.7</td>
<td>2.7</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>ΔF (%)</td>
<td>−7.1*</td>
<td>6.6</td>
<td>−8.2</td>
<td>−6.0</td>
</tr>
<tr>
<td></td>
<td>ΔQ (% × mm²)</td>
<td>−38.8</td>
<td>94.5</td>
<td>−55.0</td>
<td>−22.0</td>
</tr>
</tbody>
</table>

A, lesion area; CI, confidence interval; ΔF, fluorescence loss; ΔQ, fluorescence loss integrated over the lesion area (ΔF × A; % × mm²); SD, standard deviation.

*P = 0.001.
serve to motivate the patient towards more effective oral hygiene (23, 24).

In summary, it was concluded that our hypothesis, assuming a similar detection outcome of a meticulous VI and QLF, should be rejected. The data seem to support the thesis that QLF is a sensitive method suitable for the detection of visually undetected initial caries lesions, and that the clinical use of QLF is limited by several confounding factors in caries-risk adolescents.

References