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ORIGINAL ARTICLE

In vivo detection of non-cavitated caries lesions on occlusal surfaces by visual inspection and quantitative light-induced fluorescence

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Abstract

Objective. The aim of this clinical caries detection study was to compare the outcome of quantitative light-induced fluorescence (QLF) and meticulous visual inspection (VI) in detecting non-cavitated caries lesions on occlusal surfaces in young adolescents. It was hypothesized that the respective diagnostic performances of meticulous VI and QLF are similar. ***Material and methods.*** The subjects were 34 fifteen-year-old students. Five-hundred-and-seventeen cleaned occlusal surfaces were air-dried and examined using VI. Fluorescence images were captured with QLF equipment and custom software was used to display, store and analyze the images. The area of the lesion (area; mm^2), fluorescence loss (ΔF;%) and ΔQ (Area$^\star\Delta F$; $mm^{2\star}$%) were determined at a QLF threshold of -5%. The presence/absence of non-cavitated lesions was independently recorded with both methods. ***Results.*** 78.8% of all untreated surfaces were classified as sound or as having a non-cavitated lesion with both methods uniformly (VI+QLF). On 7.1% of all surfaces a lesion was detected by VI only and on 14.1% by QLF only. All parameters (Area, ΔF, ΔQ) differed significantly between lesions registered with both methods (VI+QLF) and lesions recorded with QLF only. ***Conclusions.*** It was concluded that our hypothesis cannot be confirmed. The study shows that QLF detects (1) more non-cavitated occlusal lesions and (2) smaller lesions compared to VI. However, taking into consideration time-consuming image capturing and analysis, QLF is not really practical for use in the dental office.

Key Words: *Caries detection, dental caries, QLF, visual examination*

Introduction

Epidemiological studies have shown a general drop in the prevalence of caries among children and young adults in many industrialized countries, together with a concentration of caries lesions in the pits and fissures of their permanent molars [1,2]. Whereas caries progression generally appears to slow down with increasing age [3–5], dentists are diagnosing young patients and adults with non-cavitated occlusal lesions more frequently [2]. Early detection of those lesions would therefore constitute a major cornerstone in the effort to move away from operative towards non-operative, preventive treatment, while aiming to manage and control the disease process throughout life [6].

Visual inspection (VI) is a non-invasive method of caries detection on accessible surfaces, and for clinical examination it is simple, quick and cost-effective. While different visual diagnostic systems have been proposed for occlusal surfaces in the past [7–10], it is mainly the criteria of Ekstrand et al. [11–13] that have gained clinical acceptance in recent years. While these criteria are easy to follow and allow most prevalent clinical situations on occlusal surfaces to be registered, each visual scoring system has considerable limitations: lesions are usually detectable only at an advanced stage, while mineral loss in enamel lesions is not quantifiable, and changes in mineral content – loss or gain due to de- or remineralization – cannot be monitored. It is

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therefore suggested that objective methods could enhance the conventional intra-oral examination and improve caries detection and diagnosis [14].

The quantitative laser-/light-induced fluorescence method (QLF) is reported to be a valuable tool for early detection, quantification, and monitoring of non-cavitated caries lesions [15]. So far, only a few QLF reports focusing on the application of the method on occlusal surfaces have been published. Ferreira Zandona et al. [16], in using QLF to detect occlusal caries lesions *in vitro*, only inspected occlusal lesions visually and did not subject them to quantitative analysis. Further QLF studies were conducted on artificial lesions and validated VI and QLF *in vivo* on primary teeth [17,18] as well as on extracted permanent molars [19,20]. However, there is no information available on the ability of QLF to detect non-cavitated caries lesions on permanent occlusal surfaces *in vivo* compared to meticulous VI. Since clinical QLF studies are limited, the present *in vivo* study aimed at a comparison between QLF and meticulous VI in detecting caries lesions on non-cavitated occlusal surfaces based on the hypothesis that meticulous VI could achieve a similar performance as QLF. Furthermore, the benefit of QLF for clinical use could be evaluated.

Material and methods

Study subjects

All subjects were participants in a longitudinal caries risk assessment study (1993–2001), and were accustomed to annual clinical, microbiological and biochemical examinations [21]. General dental practitioners had undertaken the regular dental care of the participants. At baseline, 189 eight-year-old children attending the second grade were randomly selected from all schools in a non-fluoridated city (Erfurt, Germany). At a later follow-up examination, the remaining participants were invited to take part in an additional QLF investigation of their teeth, followed by a preventive program including professional tooth-cleaning, 3-monthly application of a fluoride varnish, and oral health instructions. After a preliminary clinical investigation carried out to register caries status, 34 patients aged 14 and 15 years agreed to take part. After the study protocol had been explained in detail, informed consent was obtained from the subjects and from their parents to participation in this investigation. 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 plaque score of each subject was estimated with a modified proximal plaque index (PPI), while gingival status was assessed with a modified papillary bleeding index (PBI) [22,23]. The surface-related caries prevalence (DMFS) and fissure sealants were recorded in accordance with the WHO criteria [24].

Non-cavitated and non-filled occlusal surfaces of premolars and molars were classified according to the visual criteria of Ekstrand et al. [12], as indicated in Table I. In cases where it was impossible to allocate a lesion to one distinct Ekstrand score with absolute certainty, the lower score was registered. Due to the limited number of non-cavitated caries lesions, criteria 1 and 2 were summarized as white opacities, and criteria 1a and 2a as brown discolorations on occlusal pits and fissures. Cavitated lesions with dentin exposure (Score 4) were included in the DMFS index. Furthermore, the additional presence or absence of developmental disorders (e.g. hypoplasia, fluorosis, mineralization disturbances) was noted. Because of the similar appearance of hypoplastic/fluorotic enamel and caries lesions in the fluorescence images, the detection of enamel developmental disorders ($n = 3$) was the decisive criterion for exclusion of the surface from further QLF image analysis. All visual decisions were made under standardized conditions using a dental unit equipped with compressed air and evacuation facilities. Non-cavitated caries lesions were recorded with the aid of a dental magnifying glass ($3.5\times$). The VI was performed by one dentist (R.H-W.) with considerable experience in the clinical assessment of caries lesions. The intra-examiner reproducibility of VI on occlusal surfaces according to the criteria set by Ekstrand et al. [12] was assessed in a second examination of 10 randomly selected subjects 1 week after their first clinical examination. The kappa value was found to be 0.84.

Table I. Visual criteria of Ekstrand et al. [12]

Score	Criteria
0	No or slight change in enamel translucency after prolonged air drying (>5s)
1	Opacity (white) hardly visible on the wet surface, but distinctly visible after air drying
1a	Opacity (brown) hardly visible on the wet surface, but distinctly visible after air drying
2	Opacity (white) distinctly visible without air drying
2a	Opacity (brown) distinctly visible without air drying
3	Localized enamel breakdown in opaque or discolored enamel and/or grayish discoloration from the underlying dentine
4	Cavitation in opaque or discolored enamel exposing the dentine beneath

Quantitative light-induced fluorescence 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 (Inspektor Research Systems BV, 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 highpass filter ($\lambda > 520$ nm) to exclude any excitation or ambient light from reaching the detector. After prolonged air-drying (about 5 s), QLF images were taken of all permanent maxillary and mandibular premolars and molars by a trained examiner (R.H.-W.) in a completely darkened dental practice. The presence or absence of non-cavitated caries lesions was not noted on the fluorescence images. QLF 2.00f software (Inspektor Research Systems BV) was used to display, store, and analyze the images.

The QLF analysis was performed independently by two calibrated investigators (J.K. and S.I.) who did not know the outcome of the VI. At the beginning of the analysis, each QLF image was visually inspected for signs of caries lesions, which appear as dark areas surrounded by bright green fluorescing sound tooth tissue [25]. When a lesion was detected, the lesion area (Area; mm^2), the fluorescence loss (ΔF;%), and the fluorescence loss integrated over the lesion area (ΔQ; mm^2*%) were determined using the analysis software in order to quantify the severity of the lesion. For cases with a detectable lesion, the entire surface was analyzed. For accurate quantitative results, we compared the lesion in the original fluorescence image with the computed pseudocolor images of each lesion, as well as the gray-scale pictures. During the repeated patch adjustment, we obtained a uniform gray-scale reproduction of the lesion surface. The area of the pseudocolour image had to match exactly that of the original lesion in the QLF image. To prevent examiner bias, all images were then re-assessed by the two independent investigators (J.K. and S.I.) after a 2-week interval. When the examiners came to different findings, they discussed the discordant results and repeated the image analysis until reaching agreement. For every detected lesion, the fluorescence loss (ΔF in%), the area of the lesion (Area in mm^2), and the product of these two parameters (ΔQ in%*mm^2) were calculated by the software at the QLF threshold of -5%.

The examiners had received training from the manufacturer and were familiar with the QLF software before the study. After 1 week of intensive calibration training, 60 lesions were randomly selected in order to assess the reproducibility of QLF analysis by calculating the intra/inter-examiner reproducibility. The selected QLF images were analyzed (blindly) twice within an interval of 10 days by two independent investigators (J.K. and S.I.). Intra/inter-examiner reliability was determined using the intra-class correlation coefficient (ICC). The intra-examiner reproducibility for both examiners was: J.K. -0.90 (Area), 0.95 (ΔF), 0.81 (ΔQ); S.I. -0.96 (Area), 0.99 (ΔF), 0.95 (ΔQ), and the inter-examiner values 0.92 (Area), 0.88 (ΔF) and 0.85 (ΔQ).

Statistical analysis

For all sound and non-cavitated occlusal surfaces, lesion detection as a yes/no decision was performed independently with VI and QLF. All lesions were grouped in accordance with the following detection methods: lesions detected only by VI, lesions detected by VI and QLF combined (VI+QLF), and lesions detected only by QLF. In cases where lesions were detected by just one method, a clinical re-examination was conducted to verify the clinical appearance of the occlusal surface independently from the basic investigation.

For the QLF-related groups, descriptive statistics included mean values, standard deviations, maximum values and 95% confidence intervals for the parameters Area, ΔF and ΔQ. The Mann-Whitney test was used to determine differences between each of the QLF parameters in the subgroup of lesions detected by VI+QLF and by QLF alone. Each comparison was made for occlusal surfaces on premolars, molars, and both together. A p-value <0.05 was considered statistically significant.

Results

The mean value of the caries experience for the study population was 7.7 DMFS. The detailed status of all

Table II. Status of the occlusal surface based on the clinical examination of 15-year-old subjects (n = number of teeth; mean = mean number of surfaces per patient)

	Sound		Non-cavitated caries lesions		DF		Sealants		M		Σ	
	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
Premolars	152	4.5	73	2.1	12	0.4	17	0.5	18	0.5	272	8.0
Molars	15	0.4	71	2.1	114	3.4	89*	2.6*	9	0.3	272	8.0
Σ	167	4.9	144	4.2	126	3.8	106*	3.1*	27	0.8	544	16.0

*26 sealants/0.8 surfaces were recorded simultaneously as non-cavitated caries lesions.

occlusal surfaces is presented in Table II. The PPI was 71.1% and PBI 76.2%.

A total of 311 sound and non-cavitated caries occlusal surfaces were examined with both detection methods (Table III); 67.9% ($n=211$) of all surfaces were assessed as sound, 2.9% ($n=9$) as whitish opaque, 38.6% ($n=89$) as brown discolorations, and 0.7% ($n=2$) as lesions with a localized enamel breakdown. The proportion of non-cavitated caries lesions detected by VI amounted to only 7.1% ($n=22$) and reached 14.1% ($n=44$) when only QLF was used (Table III).

The analysis of QLF images of occlusal surfaces on which non-cavitated caries lesions were detected visually but not by QLF ($n=22$) revealed that in many cases red fluorescing areas masked visually detectable opacities or brown discolorations ($n=8$). Furthermore, discolored sealant borders and/or lesions located beneath fissure sealants appeared likewise as red fluorescing areas ($n=4$). For some cases ($n=4$) it was not possible to perform a valid analysis of the QLF image. In three cases, technical limitations led to very bright images, which masked the lesion completely. In addition, three surfaces with filling/sealant placement between visual examination and QLF image-capturing resulted in exclusion from further analysis.

Table IV presents the QLF parameters as a function of the teeth analyzed. There were significantly lower QLF values with respect to the area, ΔF and ΔQ of lesions detected with QLF only when all occlusal surfaces as well as those of premolars were selected ($p<0.05$). No statistical differences were found in the case of molars.

Discussion

The present study was conducted under standardized clinical conditions and compared between QLF and meticulous VI for detecting non-cavitated occlusal surface lesions. Since lesion detection can be regarded as the basic step of a structured diagnostic examination – followed by formulation of the concrete diagnosis, the activity assessment, and an appropriate treatment decision [26] – it is essential to evaluate the performance of new diagnostic methods for caries detection. Owing to the fact that most QLF studies on occlusal surfaces are performed under *in vitro* conditions [16–20], there is a need to collect clinical experiences with the QLF method. For ethical reasons, the study design did not include a histological validation. Further research is necessary to validate the diagnostic performance.

Basically, the participating adolescents had to be designated as high-risk patients on the basis of their caries experience as well as high plaque and gingival bleeding scores. In this context, the high number of occlusal restorations in molars also reflects this finding (Table II).

One of the major findings in this study was that 79% of all occlusal surfaces were scored similarly by VI and QLF. In 7% of all surfaces, non-cavitated caries lesions were detected by meticulous VI alone. The above-mentioned reasons for non-detection by QLF indicate confounding factors, such as red fluorescence, or technical limitations, e.g. very bright images and depressed software analysis. On the other hand, 14% of all surfaces were scored as non-cavitated caries lesions by QLF only. This is the portion of surfaces for which QLF was more precise in detecting lesions than meticulous VI. This can clearly be attributed to the study design, which was focused on the screening of all maxillary and mandibular occlusal surfaces with both methods. No restrictions – such as investigating only visually detectable lesions – were made. It was therefore possible to compare the ability of the two methods to detect lesions.

The quantitative analysis of all non-cavitated caries lesions detected by QLF only showed that these lesions had a significantly smaller area and a lower fluorescence loss than lesions detected by VI+

Table III. Distribution of non-cavitated caries lesions on occlusal surfaces in relation to clinical appearance and detection method: lesions detected by visual inspection alone (VI alone), lesions detected by both methods (VI and QLF), and lesions detected only by quantitative light-induced fluorescence (QLF alone)

	VI alone		VI and QLF		QLF alone		Σ	
Visual inspection	*n*	%	*n*	%	*n*	%	*n*	%
Molars	22	7.1	58	18.7	6	1.9	86	27.8
Sound	–	–	15	4.8	6	1.9	21	6.8
White opacities	2	0.7	7	2.3	–	–	9	2.9
Brown discolorations	20	6.4	34	10.9	–	–	54	17.4
Localized enamel breakdown	0	0.0	2	0.7	–	–	2	0.7
Premolars	0	0.0	187	60.1	38	12.2	225	72.3
Sound	–	–	152	48.9	38	12.2	190	61.1
White opacities	0	0.0	0	0.0	–	–	0	0.0
Brown discolorations	0	0.0	35	11.2	–	–	35	11.2
Localized enamel breakdown	0	0.0	0	0.0	–	–	0	0.0
Σ	22	7.1	245	78.8	44	14.1	311	100.0

Table IV. Quantitative analysis of all non-cavitated caries lesions on occlusal surfaces detected by visual inspection and QLF as well as with QLF alone ($^{\star}p \leq 0.05$, Mann-Whitney test)

	Parameter	Mean	SD	Maximum	−95% CI	+95% CI
All occlusal surfaces of molars and premolars						
	Area (mm^2)	5.9*	4.9	21.4	4.8	7.0
VI and QLF ($n=78$)	ΔF (%)	−12.8*	5.4	−26.0	−14.4	−11.1
	ΔQ ($mm^{2\star}$%)	−71.3*	73.6	−287.6	−93.7	−48.9
	Area (mm^2)	2.5*	2.9	15.4	1.6	3.4
QLF alone ($n=44$)	ΔF (%)	−8.1*	3.4	−17.1	−9.1	−7.0
	ΔQ ($mm^{2\star}$%)	−24.7*	41.9	−245.0	−37.5	−12.0
Occlusal surfaces of molars only						
	Area (mm^2)	8.9	4.8	21.4	7.5	10.4
VI and QLF ($n=43$)	ΔF (%)	−14.4	6.2	−26.0	−16.3	−12.5
	ΔQ ($mm^{2\star}$%)	−136.8	108.0	−499.6	−170.1	−103.6
	Area (mm^2)	8.4	4.5	15.4	3.7	13.1
QLF alone ($n=6$)	ΔF (%)	−11.4	3.5	−15.9	−15.1	−7.7
	ΔQ ($mm^{2\star}$%)	−101.6	79.9	−245.0	−185.4	−17.7
Occlusal surfaces of premolars only						
	Area (mm^2)	2.2*	1.0	4.8	1.8	2.5
VI and QLF ($n=35$)	ΔF (%)	−10.0*	3.9	−21.6	−11.4	−8.7
	ΔQ ($mm^{2\star}$%)	−21.3*	11.2	−49.2	−25.1	−17.4
	Area (mm^2)	1.6*	0.7	3.2	1.4	1.8
QLF alone ($n=38$)	ΔF (%)	−7.5*	3.2	−17.1	−8.6	−6.5
	ΔQ ($mm^{2\star}$%)	−12.6*	8.4	−36.0	−15.3	−9.8

*$p \leq 0.05$, Mann-Whitney test.

QLF (Table IV). The separate analysis for each tooth type showed significant differences of the QLF parameters between VI and VI+QLF for premolars (Table IV). But no differences were observed in molars due to the low number ($n=6$) of non-cavitated caries lesions detected by QLF alone ($n=6$). While in molars the large number of surfaces scored as decayed/filled ($n=126$) or sealed ($n=89$) led to small numbers of sound and non-cavitated caries surfaces, the opposite was observed in premolars. More than half of all premolars were classified as sound ($n=152$) followed by non-cavitated caries lesions ($n=73$). This observation was found to be in accordance with epidemiological findings of lesion distribution and progression in relation to the patient's age [3–5].

The present study could not confirm our previous assumption that the two methods would perform similarly in caries detection. Based on our results, it became obvious that QLF was the method that detected more non-cavitated caries lesions (Table III) as well as significantly smaller lesions than VI (Table IV). But the clinical relevance of this finding has to be evaluated critically if the following aspects are taken into account. First, the majority of all occlusal lesions registered with QLF only were found in premolars ($n=38$ out of 44; Table III), which generally show a slower progression rate compared to molars [3–5]. Second, the majority of lesions appeared as brown discolorations which are easily detectable by VI (Table III). Third, the determined QLF parameters of these lesions detected by QLF only were fairly small (Table IV). Fourth, the clinical re-examination in direct comparison with each QLF image revealed that most lesions that were not visually detected showed a barely visible brown or white discoloration, which was overviewed or assessed as clinically negligible during the basic examination. At present, for clinical purposes, it would seem essential to diagnose lesions at a non-cavitated stage, but not at such an early stage that they are invisible to the naked eye [26]. Considering all this, it is questionable whether the time-consuming QLF investigation of all occlusal surfaces, as can be seen from the expensive study protocol, in order to detect clinically invisible lesions improves the diagnostic outcome substantially. From our point of view, meticulous VI is the method of choice for the routine dental examination. VI, focusing on the detection of non-cavitated caries lesions, enables the dentist to assess lesion activity and provides further information about the individual caries risk [3,10,27]. Due to the fact that such general information cannot be collected from QLF images, the VI should be the basic examination method. In contrast, the potential of the QLF system lies in the possibilities for long-term monitoring of non-cavitated caries lesions. Therefore, future QLF studies should be focused on the reproducibility, the validity of caries monitoring, and the diagnostic performance on occlusal surfaces, too.

In summary, it was concluded that the hypothesis assuming a similar detection outcome of both meticulous VI and QLF could not be confirmed. Our data support the theory that QLF detects: 1) more non-cavitated occlusal lesions and 2) smaller lesions than VI. Besides, taking into consideration the time-consuming image-capturing and image

analysis, QLF does not seem practical for regular use in the dental office at the present stage – the method's domain remains scientific study.

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