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Quantitative Light Fluorescence: A Technology for Early Monitoring of the Caries Process

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There has been a remarkable decline in the prevalence of dental caries in US children and adults during the past 40 years attributable primarily to the widespread use of fluoride, improved oral hygiene, and a greater emphasis by the dental profession on disease prevention and control. Nevertheless, dental caries continues to be the most prevalent oral disease and a major public health problem, particularly in select portions of the US population [1,2]. Approximately 60% of the caries occurs in 20% of the population, and fewer than 5% of adults are caries free [2]. Dental caries has been identified as the single most common chronic disease of childhood. In addition, the fastest growing populations of children (black, Native American, Hispanic) are those with the highest disease rates and the lowest access to care [3]. Despite the remarkable strides made in treating and preventing dental caries, more needs to be done to combat the problem. Further improvements in the ability to prevent and control dental caries require the identification of even more effective and innovative measures to identify the early stages of the disease process [4–6].

The availability of fluoride has led to a dramatic increase in the time required for carious lesions to progress from early demineralization to frank cavitation [7–9]. Before fluoridation, caries progression could be extremely quick owing to rapidly progressive demineralization. Consequently, detection of the resulting large carious lesions was relatively straightforward [7–10], and practitioners were inclined to restore rather than monitor suspicious or questionable areas. Because of fluoride availability, carious

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lesions progress more slowly, and smaller lesions may even arrest and reverse [11–12]. Caries is now seen as a dynamic process in which multiple factors determine whether the process begins, progresses, stops, or reverses. The demineralization-remineralization concept is of great importance in determining whether a lesion must be restored, or if more conservative treatment is appropriate for caries reversal or control [9,12–18]. The prevention, control, and treatment of dental caries should be based on appropriate diagnosis and detection of the disease in its earliest stages. All pathologic changes attributable to the disease should be registered from early demineralization to cavitation. Unfortunately, the conventional clinical caries diagnosis does not take into account the dynamics of dental caries or the possibility of reversibility; rather, this continuum is reduced into a dichotomous variable of the presence or absence of disease [12–19].

The traditional visual-tactile and radiographic methods of detecting dental caries, although commonly accepted and universally used, can only detect lesions that are well advanced, involving at least 300 to 500 μm of the enamel. Several studies conducted since the widespread use of fluoride indicate that these lesions have been in progress for a significant period. Schwartz and coworkers [20] reported that the average time required for progression of lesions through the enamel in a group of Swedish and US children was about 4 years for children aged 10 to 11 years and more than 7 years for young adults aged 17 to 22 years. Mejàre and Stenlund [21] noted that there were no significant differences in the rate of progression of lesions through the outer half of enamel in children and young adults (aged 6–12 and 12–22 years, respectively), but the progression rate through the inner half of enamel was about four times faster in the younger age group. Similar rates of caries progression were observed in adults. Berkey and coworkers [22] observed two groups of adults aged 41 and 51 years, respectively, for a period of 10 years and concluded that about 6 years was required for lesions to progress through the enamel.

Lesions that have progressed through the outer half of the enamel (observed as white spots) are difficult to reverse with fluoride or improved oral hygiene and often require several years of concerted effort. The common procedure involving the use of a dental explorer for the detection of caries may, in fact, extend the scope of the lesion and reduce the possibility of remineralization because of physical disruption of the thin layer covering the body of the lesion [7,12,23,24]. The limitations and disadvantages of the traditional caries detection methods have led to growing interest in the use of more advanced technologies to detect the caries process at an earlier stage of formation.

There is a significant problem related to use of the term *dental caries* when referring to demineralized areas that have progressed to the point of cavitation. Such areas have a break in the surface of the enamel and a consistency often described as a tactile softness and tackiness with an explorer. There is often visual evidence of demineralization, including dull

white or chalky areas with a loss of surface luster and frequent staining of occlusal pits and fissures. As noted earlier, caries at this stage of development has progressed into the inner half of the enamel and often into the outer half of the dentin. As a result, restoration is a common prognosis, although many of these lesions can be arrested with professional fluoride treatments.

The term *early detection of dental caries* as used herein refers to the detection of demineralized areas that are in the so-called ''white spot'' stage or earlier that have not progressed to the cavitation stage. For nearly 40 years, it has been known that, at this stage of formation, the caries process can be reversed [25]. It is now accepted that several strategies can be used to facilitate the remineralization process, including measures such as the concerted use of topical fluoride treatments (dentifrices, varnishes, or gels), improved oral hygiene, and reducing the number of daily exposures to fermentable carbohydrates. In view of this situation, it might be more realistic to refer to the early detection of demineralized enamel areas rather than the early detection of dental caries.

Enamel autofluorescence

Enamel fluorescence was first described by Benedict [26] and subsequently proposed as a means to detect dental caries [27]. Fluorescence results from a change in the characteristics of light caused by a change in the wavelength of the incident light rays following reflection from the surface of a material. The intensity of the emitted fluorescence can be measured by using a filter system through which only the fluorescent rays pass. The inherent fluorescence of a material is often referred to as autofluorescence. The physical characteristics of dental hard tissue fluorescence have been described on several occasions [28–31]. The nature or type of fluorescence is dependent on the wavelength of the incident light. Near-ultraviolet light is emitted as blue fluorescence, whereas incident light in the blue and green region emits yellow and orange fluorescence, and incident light in the red or near-infrared region emits red fluorescence.

The exact identity of the material responsible for the fluorescence remains to be established. Booij and ten Bosch [32] have suggested that the chromophores responsible for blue fluorescence are dityrosine. Scharf [33] has suggested that yellow fluorescence is attributable to cross-linked chains of structural proteins, whereas red fluorescence has been attributed [34,35] to the presence of various protoporphyrins that are considered to be products of bacterial decomposition and other oral bacterial metabolites [36,37]. These and other investigators have suggested that fluorescence is attributable to the presence of chromophores within the enamel, and that the observed differences in fluorescence between sound and carious enamel are due to the loss of chromophores in the lesion [38,39]. de Josselin de Jong and coworkers [40] suggested that the observed differences in fluorescence between sound and carious enamel could be explained by altered amounts of light scattering

and absorption. ten Bosch [41] has noted that, "this phenomenon can entirely be explained from light scattering effects, although a loss of fluorescing chromophores from a lesion cannot be excluded as a supplemental cause. Observing a specific spot on a sound tooth, fluorescence is observed from many photons of the excitation light that pass the observed spot along their light path in the tissue and excite fluorescence there. In lesion material, the path length is short and an exciting photon has only a small chance of being absorbed and to cause fluorescence along its short path inside the material." ten Bosch [41] has suggested that the amount of light scattering in a lesion is much greater than in sound enamel, and that the resultant absorption per unit volume is less in a lesion with less observed fluorescence.

Quantitative laser fluorescence

Because of these various reports, several technologies have been proposed or developed for the detection of dental caries and are described elsewhere in this issue. All of these methods or technologies have been proposed as adjuncts to a visual clinical examination. Among the most extensively investigated of these technologies is quantitative laser or light-induced fluorescence (QLF) [9,42].

The first significant investigation leading to the development of this system was reported by Bjelkhagen and Sundström [43]. These Swedish scientists used a broad beam of blue-green light from an argon laser light source and observed the fluorescence in the yellow region by using a 520-nm high-pass filter to remove the tooth-scattered blue light. With this instrument, they observed in vitro that there was a much greater contrast between incipient lesions and sound enamel using the laser light in a comparison with conventional light. Further studies by these investigators indicated that the enhanced contrast between incipient lesions and sound enamel could be observed in vivo, and they proposed that this technology could be used for the early detection of dental caries [38,44]. For these studies, they used a powerful argon laser and a wavelength of 488 nm at a 50-mW continuous wave with a yellow cut-off filter ($\lambda \geq 520$ nm) placed in front of the eye to view the lesion. This instrumentation was subsequently modified and improved to permit its intraoral use [45]. These improvements included the use of a CCD microvideo camera and computerized image analysis software. Further studies with the instrument indicated that the laser light source could be replaced with a high-intensity halogen lamp without altering the ability of the instrument to detect demineralized areas and to quantify the amount of mineral loss [46–48]. More recently, a video repositioning software program was added to the instrument to facilitate the acquisition of essentially identical images on two different occasions to monitor changes in the lesions.

Fig. 1 illustrates the essential components of a quantitative laser/light fluorescence (QLF) system. The illumination system consists of a 50-W

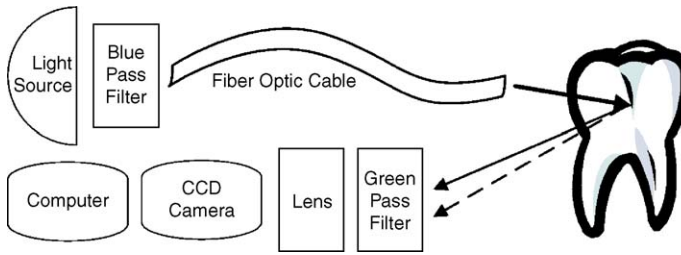

Fig. 1. Schematic outline of QLF system. Current instruments use high-intensity discharge lighting that is passed through a blue band pass filter to provide narrow band blue light by removing longer wavelength components. This excitation light is conveyed to the handpiece through a fiberoptic cable that then illuminates the tooth, resulting in autofluorescence. The emitted dental fluorescence is predominantly green (*dashed line*) and is separated from the reflected blue excitation light (*solid line*) by a long pass filter. Optics focus the image onto a CCD camera, which is connected to a computer data acquisition system.

xenon microdischarge arc lamp provided with an optical band pass filter with a peak intensity of 370 nm (full-width half-measure of 80 nm) to produce blue light. The light illuminating the tooth is transported through a liquid-filled light guide. The fluorescent filtered images (high-pass filter, $\lambda \geq 520$ nm) are captured using a color CCD camera and a frame grabber. Data are collected, stored, and analyzed by custom-made software. Since the first attempts at in vivo quantification of mineral changes in the enamel, the QLF method has continued to undergo further development (Inspektor Research Systems BV, Amsterdam, The Netherlands) with respect to the software and hardware. The current version that will be marketed in 2005, the Inspektor Pro (Omnii Oral Pharmaceuticals, West Palm Beach, Florida), is shown in Fig. 2.

Several investigations were subsequently conducted to determine the relationship between the amount of fluorescence radiance and the mineral content of the area [39,46,49–52]. The investigations by Hafström-Björkman and coworkers [39] used three polyester strips to calibrate the system. The strips contained different levels of titanium that had been calibrated against a barium sulfate reference standard. After calibration, the quantitative version of the laser fluorescence method was compared with longitudinal microradiography for assessment of mineral changes in enamel slices using an in vitro caries model. Within individual slices, the mineral losses as assessed by microradiography were closely correlated to the loss of fluorescence ($r = 0.97$). Similarly, the other in vitro studies typically involved the controlled decalcification of enamel to form white spots with varying degrees of mineral loss and lesion size and depth. The artificial lesions were examined using laser fluorescence, and the enamel specimens were sectioned and examined by microradiography. In some instances, natural incipient lesions were similarly examined. In the natural and artificial lesions, a strong correlation was observed between the amount of mineral loss and the observed fluorescence;

Fig. 2. QLF instrument. (Courtesy of Inspektor Research Systems BV, Amsterdam, The Netherlands; with permission.)

therefore, it was determined that there is a direct relationship between fluorescence and mineral content in enamel.

The use of QLF for determining the amount of mineral loss involves a software program developed by de Josselin de Jong [50]. Following a clinical examination and the acquisition of an image of the tooth surface with the demineralized area (darkened area owing to decreased fluorescence), a "patch" is placed around the image of the lesion such that the demineralized area is entirely surrounded by sound enamel. The established relationship between the enamel fluorescence and the mineral content of the enamel is used by the software to calculate the amount of mineral loss that has occurred in the area with decreased fluorescence. The relative amounts of mineral loss in different regions within the demineralized area can be color coded to further illustrate the pattern of decalcification. The image of the demineralized area is stored in the computer for future reference.

To monitor the progression or regression of the demineralized area, a second image is obtained after a period of time. It is critical that the image obtained at the second examination is superimposed as accurately as possible over the original image of the demineralized area. The QLF software includes a quick and convenient means of accurately superimposing the images during the second visit. The image from the second visit is analyzed as described previously, and the differences between the two images indicate the changes that have occurred. This information should be useful to the patient and dentist to provide guidance on the procedures that need to be implemented to reverse the demineralization process.

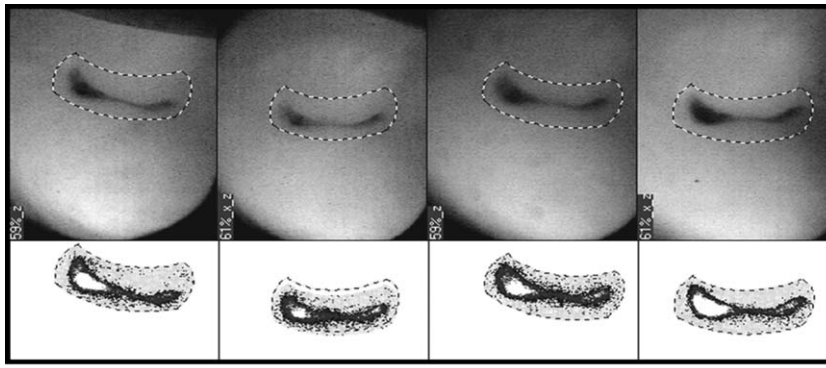

Fig. 3. Caries progression: occlusal surface at 0, 4, 8, and 12 months.

Fig. 3 illustrates the changes that occurred during a series of examinations performed at 4-month intervals over a 1-year period in a clinical trial. The images indicate that the lesion regressed during the first 4 months and then progressed during the remainder of the study period.

A loss of fluorescence from enamel exposed to QLF occurs whenever there is a decrease in the mineral content of the area being examined. Because mild enamel fluorosis observed with QLF provides an image that is similar to a demineralized area [53], a clinical examination is required to distinguish the fluorotic area from a possible lesion based on the location, appearance, and pattern. Similarly, other types of developmental defects that result in hypoplastic enamel areas require a clinical examination to differentiate them from possible demineralized areas.

Clinical studies using quantitative light fluorescence

Al-Khateeb study

The first clinical trial using QLF was reported by Al-Khateeb and coworkers [54] in 1998. The investigation involved seven adolescents aged 13 to 15 years who had just completed orthodontic treatment and who had white spot lesions on the buccal surfaces of the teeth that were apparent after debanding and debonding the appliances. There were a total of 15 white spots (10 first molars, 3 bicuspids, 2 cuspids) in the panelists. At baseline, enamel fluorescence images of the affected teeth were recorded immediately after removal of the appliance, and subsequent images were obtained at monthly intervals for 1 year. At each visit, three images were obtained for each tooth. Following the analyses of the images, mean values for the fluorescence loss (ΔF) and lesion area were obtained from the three readings. Panelists were given instructions about dietary habits and efficient

oral hygiene, including the twice-daily use of a fluoride dentifrice (1450 ppm) during the 1-year test period.

The results of the QLF examinations indicated that there were highly significant differences between the baseline and 1-year examinations. During this period, the white spot lesion area decreased by 50.5% and the loss of fluorescence decreased by 29.0%, indicating an increase in the mineral content of the lesions by that amount. A plot of the rate of change indicated that the greatest amount of remineralization occurred during the first 3 months after removal of the appliances and continued at a lesser rate during the remainder of the test period.

Connersville study

Despite prior in vitro studies [55,56] suggesting the possible use of QLF on occlusal tooth surfaces, the author's group was the first to demonstrate the use of QLF clinically [57]. In 1998, the author and his colleagues initiated the first large-scale clinical pilot study using QLF in the United States. A total of 150 prescreened subjects (caries rate of 0 to 8 decayed or filled surfaces) aged 9 to 12 years were examined using the traditional visual-tactile examination supplemented with standard bite-wing radiographs plus three newer technologies: QLF, direct digital radiography, and electrical conductivity. The traditional visual-tactile examination used an explorer on two randomly designated teeth throughout the study. A trained examiner performed an assigned examination procedure throughout the study (one examiner per method). The children were advised to brush twice daily with a fluoride dentifrice; no treatments were performed. Panelists were seen at baseline and at 4, 8, and 12 months following baseline with a subset examined at 1- to 2-month intervals. Exfoliated teeth were collected, and a collection of 100 teeth were sent to different investigators in Sweden, Glasgow, Amsterdam, Iowa City, and Indianapolis for sectioning and examination by various methods, including transverse microradiography, polarized light microscopy, and conventional histology. Although there was considerable disagreement between the laboratory methods, this early version of the QLF research instrument resulted in clinical sensitivity and specificity values of 79% and 75%, respectively [58].

The results from the clinical examinations [57] indicated that there was a learning period using this early version of the QLF system, and that the first examinations in the clinical pilot study showed significant variability. At the 4-month examinations and the subsequent examinations, it was possible to make some meaningful observations. First, it was noted that the caries increments from 4 to 12 months observed with QLF paralleled those observed with the traditional visual-tactile clinical examination, and that this observation was true for increments on the occlusal surfaces as well as the smooth buccal-lingual surfaces. These parallel increments would be expected if both detection methods were measuring the same disease but

with a different level of acuity. Second, it was proposed that if the QLF instrument detected the process at an earlier stage of development, a greater number of demineralized areas would be detected with QLF. Indeed, in the 20 children with the least caries prevalence, the number of lesions or demineralized areas detected with QLF was about ten times greater than that observed with traditional visual-tactile examination (0.60 ± 0.20 versus 5.45 ± 0.50). Similarly, in the 20 children with the greatest caries prevalence, the caries scores for the traditional and QLF examinations were 2.50 ± 0.56 and 10.60 ± 1.27, respectively. As expected, QLF detected a greater number of demineralized areas that had not yet advanced to the stage where they could be detected with a visual-tactile examination. It was concluded that the QLF system was practical for controlled clinical trials, reproducible after adequate training experience, useful for assessing changes on occlusal surfaces as well as buccal and lingual tooth surfaces, and detected a greater number of demineralized areas or carious lesions than found on visual-tactile examination.

Tranæus study

This clinical trial [59] used QLF to compare two different treatment regimens (a fluoride varnish versus professional cleaning) with regard to their impact on the remineralization of white spot lesions in regular patients seen at the Department of Pediatric Dentistry at the Karolinska Institute in Sweden. The study was initiated with a total of 34 adolescent patients aged 13 to 15 years, of whom 31 completed the study. Inclusion criteria included the presence of two or more white spot lesions on the buccal surfaces of bicuspids or permanent molars. At least one of these white spots had to be confined to a single surface to permit accurate QLF measurements. After stratification by gender, the subjects were randomly distributed into one of the two different treatment groups. At the beginning of each visit, the designated white spots were examined using QLF to characterize the lesions. After the QLF examinations, the subjects in the fluoride varnish group received a professional tooth cleaning immediately followed by the application of a fluoride varnish (Fluor Protector) at the initiation (baseline) of the study, after 1 week, and once every 6 weeks for 6 months for six treatments. The subjects in the professional cleaning group received a dental prophylaxis at baseline and every 6 weeks for 6 months, for a total of five professional cleanings. Thirteen subjects with a total of 32 lesions completed all of the appointments in the fluoride varnish group, whereas 18 subjects with a total of 30 lesions completed all of the appointments in the prophylaxis group. The results indicated that the fluoride varnish group had a significant decrease in the surface area of the lesions and a significant increase in the mineral content as a function of time in the study (baseline versus 6 months), whereas no significant change was observed in the professional cleaning group. Intergroup comparisons indicated that the

fluoride varnish significantly increased the mineral content of the lesions compared with that observed in the professional cleaning group. Similarly, the fluoride varnish tended to decrease the surface area of the lesions in a comparison with the cleaning group, with the difference approaching statistical significance ($P = .055$). The investigators concluded that using QLF to monitor lesion changes was a sensitive clinical method, and that measurements after 6 months were capable of demonstrating the beneficial impact of repeated fluoride varnish treatments.

Tranæus and coworkers [60] also conducted a study to determine the clinical repeatability and reproducibility. To test the repeatability of the image-capturing procedure, three clinical examiners made 15 images each of one natural incipient smooth surface lesion and a single person subsequently analyzed all of the images. To test the reproducibility of the image-capturing procedure, three clinical examiners made one image each of 15 different natural incipient smooth surface lesions on the buccal surfaces of mandibular left first molars in 15 teenagers. The selected lesions were considered to be active with a visible border and were not stained. A single person subsequently analyzed all of the images. Strenuous efforts were made to minimize any possible biases throughout the study. The results with regard to the capturing of the images indicated that there were no significant differences between the examiners in terms of the observed lesion area or the maximum change in fluorescence. In addition, the interexaminer reliability was good, with r values ranging from 0.95 to 0.98. The intraexaminer reliability values for the three examiners measuring the test variables were also good, with r values ranging from 0.93 to 0.99. The investigators concluded that the in vivo repeatability and reproducibility of the QLF method was excellent.

Osaka study

A double-blind clinical trial using QLF to measure the treatment effect of a fluoride dentifrice was conducted recently in Japan [61]. This 1-year clinical trial was initiated with 145 patients ranging in age from 9 to 45 years, with an average age of 20.0 $\pm$ 8.4 years. A total of 132 subjects completed the study. Participants were required to have at least one incipient white spot lesion at baseline and were randomly distributed into two groups—test and placebo. The average numbers of white spots at baseline were 4.0 and 4.8 in the test and placebo groups, respectively. During the study period, the patients were provided plain-coded tubes containing either a fluoride dentifrice (950 ppm) or a placebo dentifrice without fluoride and were instructed to brush their teeth with the assigned dentifrice twice daily. No instructions about dietary habits were given to the panelists.

Clinical examinations were performed by three well-trained dentists, each of whom examined approximately one third of the patients. All of the examinations performed on a given panelist were conducted by the same

examiner. At each visit, the patients were given an oral visual examination by the assigned investigator. QLF images and photographs were taken on a single designated white spot lesion in each patient using the QLF Clin System (Inspektor Research System RV, Amsterdam, The Netherlands). Three QLF images were obtained for each white spot lesion. Each image was subsequently analyzed by measuring four parameters: average fluorescence loss, ΔF (%); maximum fluorescence loss (%); lesion area (mm^2); and ΔF times area ($\% \cdot mm^2$), ΔQ. The dentist who performed the clinical examinations also performed the analyses of the QLF images for that patient. When the images were analyzed and the results tabulated, the mean values of the data obtained for the three recorded images were used for each white spot lesion. These examinations were performed in the same manner at baseline and after study periods of 3, 6, and 12 months. For the statistical analyses, the change from baseline was computed for the three follow-up visits for lesion area, ΔF, ΔQ, and maximum fluorescence loss. Repeated measures analysis of variance was performed to compare the test and placebo groups. The models included fixed effects for month, group, and the month-by-group interaction, along with the baseline measure as a covariate.

The results observed for changes in lesion area are illustrated in Fig. 4. The test group using the fluoride dentifrice had statistically significant changes from baseline at each of the subsequent lesion area examinations for all study parameters, reflecting decreases in lesion area and lesion volume with an increased mineral content of the lesion. The placebo group

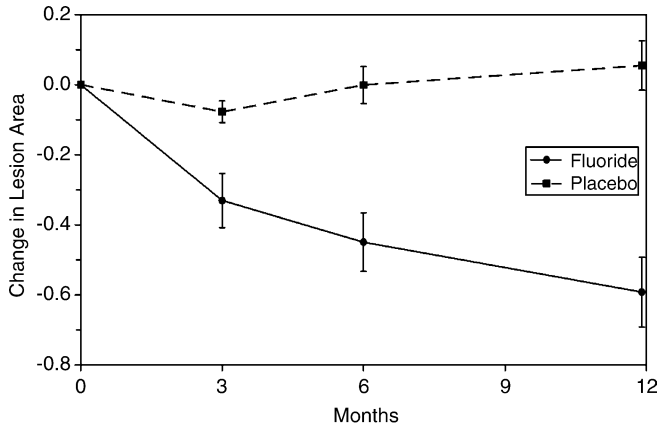

Fig. 4. Changes in lesion area (mean ± standard error). (*From* Kambara M, Uemura M, Miyake T, et al. Results of clinical trial of fluoride dentifrice using quantitative light fluorescence. In: Stookey G, editor. Proceedings of the Indiana Conference on Early Detection of Dental Caries III, May 22–23, 2003, Indianapolis, Indiana. Cincinnati (OH): SpringDot Publishing; 2004. p. 232; with permission.)

using the nonfluoride dentifrice showed a significant change from baseline for all parameters at the 3-month visit but no differences from baseline at the 6- and 12-month examinations. Intergroup comparisons indicated that the fluoride dentifrice group was significantly different from the placebo dentifrice group for lesion area, lesion volume, and mineral content at all examinations after the baseline and for maximum fluorescence loss at the 6- and 12-month examinations. The investigators concluded that the benefits of a fluoride dentifrice (compared with a placebo dentifrice) could be demonstrated within 3 months using the QLF system to monitor clinically visible white spot lesions.

Indiana-Iowa validation study

A 2-year collaborative clinical trial was conducted recently on children at Indiana University and the University of Iowa. This investigation was designed to compare various methods that have been proposed for the early detection of dental caries and to determine the validity of these technologies by examining exfoliated teeth using polarized light microscopy as the gold standard. A total of 119 schoolchildren aged 8 to 12 years residing in a recently fluoridated community were recruited for the study. The panelists were instructed to maintain their usual oral hygiene procedures and encouraged to brush with a fluoride dentifrice twice daily. At baseline and at 6-month intervals for 2 years, the first and second primary molars of the participants were examined for the presence of dental caries using a visual examination supplemented with two or four bite-wing radiographs (ICDAS), QLF, infrared laser fluorescence (DIAGNOdent), fiberoptic transillumination (FOTI), and digital imaging fiberoptic transillumination (DiFOTI). The panelists were instructed to send all exfoliated primary teeth to the investigators. The teeth then were examined by QLF to verify they were legitimate and forwarded to the University of Iowa for sectioning and examination by polarized light microscopy. The results were sent to an independent team of statisticians for analysis.

The preliminary results of the study were reported by Ferreira Zandona and coworkers [62] and are summarized in Table 1. Using polarized light microscopy findings as the gold standard, QLF with a 5% threshold (detection of areas with 5% mineral loss) had a sensitivity of 95.8%, indicative of its ability to detect areas of mineral loss in the enamel. Nevertheless, the specificity was only 11%, indicating that there were many false-positive findings, as would be expected, because QLF detects any area where there is a mineral deficiency regardless of whether it is due to demineralization or developmental defects. By combining QLF with a visual examination to eliminate obvious noncaries sites (eg, enamel hypoplasia, dental fluorosis), the sensitivity decreased to 49.9% but the specificity increased to 90.9%. Nevertheless, the results of the QLF visual examinations resulted in substantially greater sensitivity than was observed with the

Table 1
Preliminary data from the Indiana-Iowa study

	Sensitivity		Specificity	
Examination	Found/total	%	Found/total	%
Delta F −5%	121/126	95.8	34/303	11.0
Delta F −10%	105/126	83.5	97/303	32.3
Delta F −15%	88/126	64.1	183/303	54.7
Visual examination	34/149	26.3	357/364	98.1
QLF visual	68/139	49.9	308/340	90.9
FOTI	32/148	22.2	349/363	96.4
DiFOTI	28/143	19.0	348/361	96.4
DIAGNOdent	11/147	8.2	358/362	98.9

Data from Ferreira Zandona AG, Ando M, Eggertsson H, et al. Clinical validation of caries detection methodologies: preliminary results. J Dent Res 2004;83(Special issue A):2812a.

visual clinical examination or any of the other evolving caries detection technologies.

Early detection of active caries

The foregoing data indicate the need to refine the QLF technology to identify enamel areas that are actively undergoing demineralization. Because the QLF image is related to the amount of light scattering in the enamel area, and because light scattering is strongly influenced by the presence or absence of water within the area, it has been suggested that the behavior of the suspicious area or the QLF image should change on dehydration, with a decrease in the amount of observed fluorescence. Angmar-Månsson and ten Bosch [63] noted that, during the caries process, some of the mineral component of enamel is lost and replaced with water, which results in an increase in light scattering and less observed fluorescence. Al-Khateeb and coworkers [54] observed this effect in vitro and noted that the rate of change (or the rate of dehydration) was much greater in demineralized enamel when compared with sound enamel or remineralized areas. Similar observations were subsequently noted by several investigators [64–70]. The results obtained by Ando and coworkers [48,66] indicated that dehydration for 3 seconds using the air syringe in the dental operatory resulted in a significant difference between the demineralized area and sound or remineralized enamel [42]. With current QLF technology, it is possible to use this approach for determining whether a suspicious area is actively undergoing demineralization. The method involves capturing an initial image of the area, drying the area with an air syringe for 3 seconds, and then acquiring a second image of the same area. If there is active demineralization, there will be a significant decrease in the fluorescence observed in the second image. These changes are illustrated in Fig. 5. Although this method is somewhat cumbersome, use of the QLF system in this manner can be

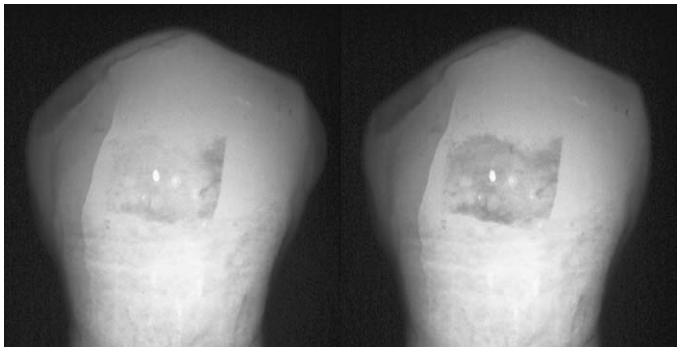

Fig. 5. Effect of dehydration. The increase in fluorescence associated with dehydration is illustrated in these photographs in which an induced demineralized area was imaged wet and again after dehydration.

helpful for identifying patients at caries risk in dental practice, as well as for selecting panelists with active precavitation lesions for clinical research to investigate measures to arrest or reverse the caries process.

Application of quantitative light fluorescence for hidden caries

The definition of so-called "hidden caries" has been published on several occasions and is clearly described elsewhere in this issue. In essence, this term refers to a relatively large lesion that undermines significant sections of enamel that develops from a small cavitated area, most frequently in a pit or fissure, that is not detected during several previous conventional visual-tactile examinations. As a result, there is little cavitation of the surface enamel with a large loss of inner enamel and dentin that eventually can be seen on a radiograph.

As noted earlier, QLF is about twice as sensitive as a visual examination for the detection of demineralized areas or early white spots. The technology should be of significant value for detecting the focal aspect of the lesion that has led to "hidden lesions," although there have been no reports using QLF in this manner. In reality, QLF is designed to detect demineralized areas or "lesions" before cavitation and may be expected to reduce the number of hidden caries lesions that develop.

Summary

QLF has been investigated extensively and has made significant advances during the past decade. The loss of mineral from an area of enamel results in a change in its optical properties, with an increase in the scattering of incident light and a decrease in the amount of fluorescence. Furthermore, there is a direct relationship between the amount of mineral loss and decreased fluorescence, allowing for quantification of the mineral loss or

changes in the mineral content of an area monitored over time. Because the decreased fluorescence occurs whenever there is a decreased mineral content of an area, an accompanying clinical examination is required to eliminate obvious noncarious areas (enamel hypoplasia, dental fluorosis, other developmental defects). QLF can detect about twice as many demineralized precavitated enamel areas as a conventional visual examination or any other caries detection instrument available at this time. The technology has been used in several controlled clinical trials with the consistent observation that it is capable of monitoring and quantifying changes in the mineral content and size of clinically visible noncavitated white spot lesions; therefore, it can be used to assess the impact of caries preventive measures on the remineralization and reversal of the caries process. Moreover, this assessment of beneficial impact can be measured with significant differences noted within test periods of 3 months using relatively small groups of subjects. The anticipated future use of QLF with dehydration to identify active areas of demineralization will markedly enhance the utility of this technology in clinical dental research and dental practice. QLF is the most effective technology currently available for the early detection of dental caries.

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