ORIGINAL ARTICLE

A novel quantitative light-induced fluorescence device for monitoring molar-incisor hypomineralization

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Abstract

Background: The FluoreCam system is based on an innovative approach to the quantification of enamel health termed fluorescence enamel imaging (FEI). Enamel is both highly mineralized and semi-translucent. Because of its mineral composition, enamel will fluoresce when exposed to certain light wavelengths. The semi-translucent nature of enamel results in different enamel densities emitting different levels of fluorescence. As a result, with FEI technology, one can measure the density of tooth enamel by measuring its fluorescence when subjected to specific light wavelengths.
Purpose: To determine the ability of visual examination and the instrumental procedures of the FluoreCam to monitor molar-incisor hypomineralization (MIH) lesions.
Subjects and Methods: This study involved children with MIH at the Department of Paediatric Dentistry, Marmara University. In total, 11 patients with MIH were diagnosed on a visual MIH scale and evaluated with the FluoreCam. The equipment, data processing, and interaction between the equipment and operator were evaluated.
Results: Fluorescent images recorded with the custom software, the clinical view, and digital numeric values were evaluated to assess the potential for use of the device in clinical practice.
Conclusion: These preliminary data from an ongoing clinical study suggest that measurements with the FluoreCam are useful in monitoring MIH. This technique also provides visual and quantitative feedback to patients.

Key words: Diagnose, fluorescence imaging, molar-incisor hypomineralisation

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Introduction

Early caries diagnosis is important so that appropriate preventative and restorative treatments can be provided. Conventional modalities for the diagnosis of caries include visual inspection and tactile examination by probing, relying on subjective clinical criteria, and assessing dental radiographs. These diagnostic methods are subjective; however, they require standardization and training and do not appear to have sufficiently high sensitivity or specificity to effectively diagnose noncavitated caries.[1] To improve the accuracy and reliability of visual inspection, several detailed visual systems have been proposed and validated.[2]

Quantitative light-induced fluorescence (QLF) assessment is one suitable noninvasive novel diagnostic method for

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early caries detection. It is based on the principle that chromophores in the dental enamel and dentin cause auto-fluorescence, which is reduced by demineralization. When a tooth becomes carious, the fluorescence radiance at the location of the caries lesion decreases. The fluorescence image of enamel with incipient lesions can be digitized and the fluorescence loss in the lesion can be quantified in comparison with the fluorescence radiance level of sound enamel. Changes in the fluorescence radiance and lesion area can be followed over time to measure the lesion development. The amount of fluorescence radiance loss is related to the mineral loss in the lesion. This method has been successfully applied to smooth surfaces and occlusal surfaces.[3,4]

The fluorescence-based portable device FluoreCam (Therametric Technologies, Inc., Indiana, USA), consisting of a hand-held instrument plus accompanying software, is a nondestructive diagnostic method for the longitudinal assessment of early caries lesions over time. The detection system involves the use of a high-intensity light source with a filtered wavelength of 410 nm to induce fluorescence of the dental enamel, a CCD camera to capture the image, and a computer to store the images for future analyses. This system is based on an innovative approach to the quantification of enamel health termed fluorescence enamel imaging (FEI). FEI is based on the chemical and physical properties of tooth enamel. Enamel is both highly mineralized and semi-translucent. Because of its mineral composition, enamel will fluoresce when exposed to certain light wavelengths. The semi-translucent nature of enamel results in different enamel densities emitting different levels of fluorescence. As a result, with FEI technology, one can measure the density of tooth enamel by measuring its fluorescence when subjected to specific light wavelengths.[5]

The development of caries detection systems with improved sensitivity and specificity over traditional techniques has strengthened the field of cardiology, enabling more preventative interventions to be used more successfully in preventing caries and the remineralization of early carious lesions. Unfortunately, the advances in caries diagnoses have not been reflected in the studies of molar-incisor hypomineralization (MIH), where visual inspection remains the gold standard. MIH is a term used to describe a specific pattern of enamel defects. This pattern consists of asymmetric, well-demarcated defects affecting the enamel of the first permanent molars and is associated with similar defects in permanent incisors and canines. Clinically, the defects appear white, yellow, or brown and, in the molars, are susceptible to posteruptive breakdown, reflecting their hypocalcified nature.[6] Several studies have been reported on the prevalence of MIH with the wide range of values 2.8–40.2% in the literature, which seems to have increased in recent years.[7,8]

The aim of this preliminary *in vivo* study was to evaluate the validity of a novel fluorescence-based system (the FluoreCam) to monitor MIH lesion progression and to determine the level of association with a standard clinical index in children.

Materials and Methods

The protocol of this preliminary observational study was approved by our Institution's Ethics Committee (document number SEP-YC-2014-0135). The study was conducted in accordance with the ethical standards laid down in the 1964 declaration of Helsinki and its later amendments.

In total, 39 occlusal and buccal surfaces were investigated in 11 children with MIH (5 girls and 6 boys) 7–10 years of age. The aim, procedures, and benefits of this clinical study were explained to the participants, and informed consent was obtained before the study. The volunteer participants were recruited from Department of Paediatric Dentistry. A single well-trained pediatric dentist (B.D) examined the patients for MIH, which was clinically diagnosed based on the diagnostic criteria established by Weerheijm *et al.*[9] in 2003 [Table 1].

Inclusion criteria

Children with MIH in at least one first permanent molar with or without involvement of the incisors were included. Related teeth had demarcated opacities with no need for treatment, no enamel loss from fracturing in opaque areas, no history of dental hypersensitivity, and no caries associated with the affected enamel. The severity of MIH was classified as mild.[10]

Exclusion criteria

Children who were uncooperative or had enamel malformation, dental fluorosis, amelogenesis imperfect a, tetracycline staining, or completely damaged or restored MIH teeth were excluded from the study.

The MIH group comprised the affected first and second permanent molars-premolars and permanent incisors, and the control group comprised unaffected healthy permanent molars or premolars and incisors of the same patients.

Following the removal of debris with cotton rolls, a well-trained pediatric dentist assessed the index teeth (first permanent molars and incisors) using a mirror, blunt probe, and dental light while the patient was in a dental chair. The MIH examiner selected the MIH-affected and nonaffected teeth to be monitored throughout the entire study for those children with at least two or more qualifying MIH. During the observational study, all subjects had standardized conventional digital photographs taken of the affected permanent incisors and molars after the teeth had been cleaned and dried for 1 min with cotton rolls.

Fluorescence images of the occlusal and buccal surfaces of all related teeth were acquired with the FluoreCam device (Therametric Technologies, Inc., IN, USA) in a controlled darkened environment by two trained and calibrated examiners (A.D. and B.G).

To assess intra-examiner reproducibility of the fluorescence measurements, the occlusal surface of 20 extracted teeth were examined twice using the FluoreCam prior to the *in vivo* study. The intra-class correlation coefficient was 0.89 (95% of confidence interval = 0.76–0.95).

All image capture measurements were repeated while each subject was seated in a reclined position in a dental chair. The teeth were dried with cotton rolls as needed, and the tip of the window was maintained adjacent to the related surface of the tooth. When taking the images, the same examiner stood at the same angle/physical position for each visit and positioned the hand piece at the surface of the tooth. While watching the computer screen, and in consensus with the other examiner, the "best" images were captured using a laptop keyboard connected to the FluoreCam system. The optical tip of the FluoreCam was covered with a specific disposable protective cover, as recommended by the manufacturer, to avoid cross-infection. The examiners performed all measurements several times. With the click of a button on the instrument, the examiners saved the "best" snapshot from the video after several shots for analysis and future reference [Figures 1-3].

The FluoreCam system (Therametric Technologies, Inc.,) a modification of the original QLF light fluorescence system, was used. The portable system included a hand piece of the specialized camera connected to a personal computer containing custom software. To visualize and capture the tooth image, the FluoreCam device uses visually "white" light from an arc lamp based on Xenon Technology, which is filtered through a blue-transmitting band-pass filter with peak intensity of 410 nm and a band width of 80 nm (to ensure that only fluorescent light is detected) to illuminate the tooth with blue-violet light with the aid of a CCD sensor, which had a yellow transmitting filter of 520 nm positioned in front of it to filter out reflected and backscattered light. The FluoreCam uses disposable end caps that allow the hand piece to be placed directly on the surface of the tooth of interest, preventing scattering of light. Custom software can display and analyze suspicious lesions automatically, which is one difference from a typical QLF device. The software allows the clinician to record the subject's identification, date of visit, and images of the recorded teeth [Figure 4].

Results

In total, 21 permanent incisors and 18 permanent molars were imaged and classified at clinical inspection as healthy teeth (11) and teeth with MIH (28).

Two clinical cases are illustrated in Figures 5 and 6.

Demineralized enamel appeared darker (like a shadow) versus unaffected enamel. The FluoreCam imaging system provided automatic quantitative analysis of lesions via its

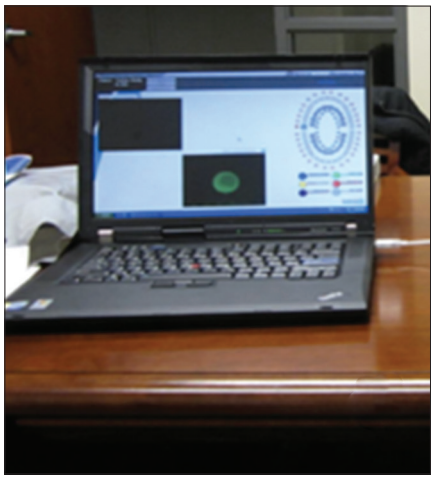


Figure 1: FluoreCam software system on the clinician's laptop

Figure 2: The FluoreCam hand-held device including the intraoral camera

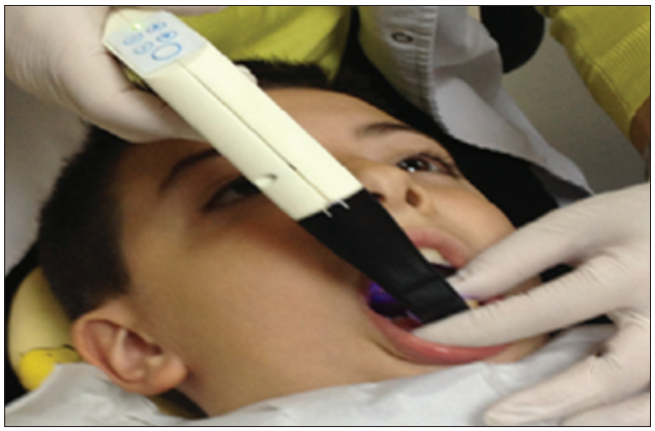
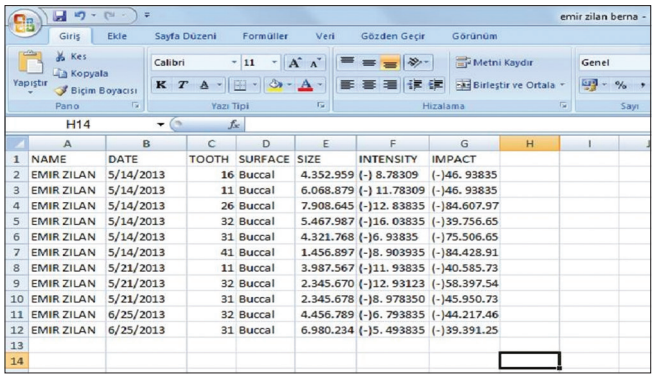


Figure 3: Patient in the dental chair while recording the image



	NAME	DATE	TOOTH	SURFACE	SIZE	INTENSITY	IMPACT
2	EMIR ZILAN	5/14/2013	16	Buccal	4.352.959	(-) 8.78309	(-)46. 93835
3	EMIR ZILAN	5/14/2013	11	Buccal	6.068.879	(-) 11.78309	(-)46. 93835
4	EMIR ZILAN	5/14/2013	26	Buccal	7.908.645	(-)12. 83835	(-)84.607.97
5	EMIR ZILAN	5/14/2013	32	Buccal	5.467.987	(-)16. 03835	(-)39.756.65
6	EMIR ZILAN	5/14/2013	31	Buccal	4.321.768	(-)6. 93835	(-)75.506.65
7	EMIR ZILAN	5/14/2013	41	Buccal	1.456.897	(-)8. 903935	(-)84.428.91
8	EMIR ZILAN	5/21/2013	11	Buccal	3.987.567	(-)11. 93835	(-)40.585.73
9	EMIR ZILAN	5/21/2013	32	Buccal	2.345.670	(-)12. 93123	(-)58.397.54
10	EMIR ZILAN	5/21/2013	31	Buccal	2.345.678	(-)8. 978350	(-)45.950.73
11	EMIR ZILAN	6/25/2013	32	Buccal	4.456.789	(-)6. 793835	(-)44.217.46
12	EMIR ZILAN	6/25/2013	31	Buccal	6.980.234	(-)5. 493835	(-)39.391.25

Figure 4: FluoreCam custom software view of related teeth, including those selected to be followed longitudinally

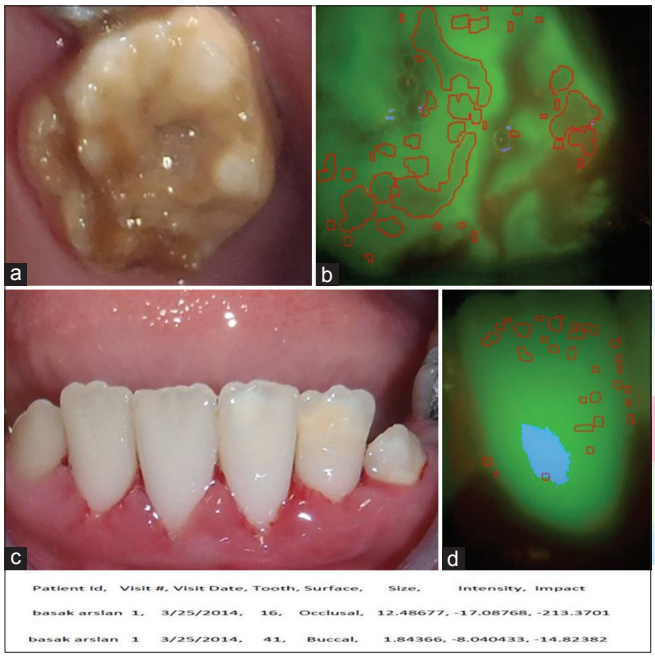


Figure 6: (a-c) Clinical examination of molar-incisor hypomineralisation right maxillary first permanent molar (tooth number 16) and unaffected right mandibular permanent central tooth (tooth number 41). (b-d) FluoreCam images of teeth number 16 and 41. (c) Numerical data of the occlusal lesion of teeth number 16 and 41 from the software

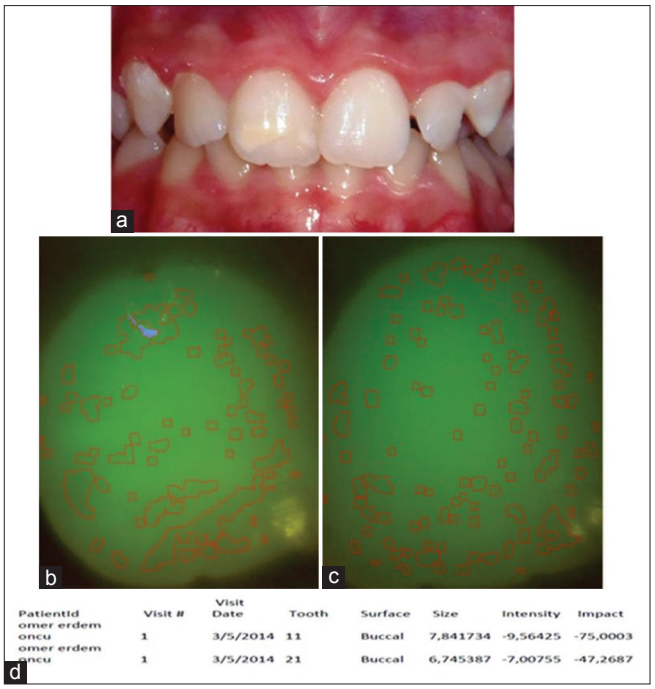


Figure 5: (a) Clinical molar-incisor hypomineralisation examination of right permanent central incisor (tooth number 11) and unaffected left permanent central incisor (tooth number 21). (b) FluoreCam image of tooth number 11. (c) FluoreCam image of tooth #21. (d) Numerical data of the surfaces of teeth number 11 and 21 from the software

Table 1: Weerheijm diagnostic criteria for MIH

Demarcated opacities
Posteruptive enamel breakdown
Atypical restoration
Extraction of molars due to MIH
Eruption failure of a molar or incisor

MIH=Molar-incisor hypomineralization

custom software [Figures 5 and 6]. Calculations performed of these lesions included lesion area (mm^2), percent fluorescence loss (ΔF), and lesion volume (ΔQ; $mm^2\%$). These lesion parameters provided data for the surface area and mineral content of the hypomineralized lesions.

Discussion

Dentistry is moving from a restorative-based approach toward a preventative and therapeutic approach; thus, early detection and quantification of lesions to monitor their arrest or progression over time is essential. Fluorescent imaging measurements permit the measurement of small changes in tooth mineral content and provide objective, quantitative measurements in caries lesions.[1,11-14]

For longitudinal studies, these devices may be used for the assessment of new lesions as well as changes, progression, or regression in existing lesions on smooth tooth surfaces. Based on this idea, we performed *in vivo* tooth surface fluorescent imaging in a noninvasive real-time manner using the FluoreCam to test its clinical potential in the quantification of MIH and determine the level of association with a standard clinical index.

The subjects were 11 children with MIH, 7–10 years of age. The data were based on the examination of 39 occlusal and buccal surfaces in total. The subjects tolerated the short time spent performing the imaging (mean time, 5 min) and the noninvasive, relatively simple procedure.

The fluorescent imaging technique described herein is performed in a similar way and has similar properties to QLF,

which also uses a CCD camera and software to analyze and store images of individual lesions for longitudinal monitoring.[12] Both the FluoreCam and QLF are methods based on fluorescence and are designated for the detection of early caries lesions. These methods are not diagnostic tools by themselves, but they may help to complete a diagnosis.[15-17] They also allow the monitoring of lesions over time. This ability is of great importance in the field of "conservative" dentistry because it enables dentists to quantitatively identify progressing lesions, which is not possible with conventional tools.[18,19]

There are few *in vivo* studies related to the performance of fluorescence-based devices in the literature for the quantification of enamel mineralization abnormalities. In several studies, QLF was used *in vivo* to follow lesions after the removal of fixed orthodontic appliances, indicating the ability of the method to quantitate changes in the lesions.[20,21] However, to our knowledge, no studies have evaluated the *in vivo* performance of a fluorescent imaging device in monitoring MIH.

QLF and other fluorescent imaging techniques have been used to detect caries, with agreement in outcome measures.[22] Histological examination using light microscopy and microradiography is the gold standard technique for caries detection. These techniques have enabled the development of more accurate assessment of the agreement with fluorescent device QLF metrics, such as those related to caries detection with cut-off thresholds for the fluorescence device.[23,24] However, there is an inherent difficulty in determining the potential of fluorescent imaging devices as a means of quantifying enamel mineralization abnormalities because there is no currently accepted gold standard with which to compare the output metrics of a fluorescent imaging system. The strengths and weaknesses of fluorosis quantification by fluorescent imaging techniques have been identified in previous studies.[25,26]

Fluorescence devices certainly still have some limitations. In the current study, statistical and interpretive problems occurred for two reasons. The first was the lack of an appropriate gold standard for comparison with the FluoreCam metrics, and the second is that data from the Clinical MIH severity index is nonnumerical whereas the output from the FluoreCam comprises continuous data. The consequence is that there is no appropriate statistical method with which to assess agreement. Thus, similar issues raised in previous reports[25,26] remain unresolved. We did not seek to determine a cut-off threshold for ΔQch from the MIH quantification; thus, the numerical results should not be interpreted as a transferable threshold for FluoreCam analysis to other populations because they were not validated.

The design of each system's image capturing and data analysis functions operate differently; thus, the characteristic properties of each system are worth noting because their functioning can affect the results. The settings of the instruments ultimately define the clarity of each image. Success in taking well-matched follow-up images from visit to visit and success in selecting the same area for future analyses and comparison purposes are also factors upon which the results depend.

FluoreCam imaging produces a live video image of the tooth surface being examined. When the image appears optimal, the user captures the image, which is then stored. For the initial reference image using the FluoreCam, the system will perform an automatic analysis to identify possible lesion areas in the entire image. The clinician selects or deselects the suspicious outlined areas in red, which are automatically shown by the FluoreCam, based on clinical experience to follow the lesion activity. Because of this, selection of the initial reference area depends on the skills of the examiner/clinician.

Mild MIH lesions observed with the FluoreCam will give a similar appearance to white spot lesions and appear as darker areas surrounded by brightly fluorescent sound enamel. The clinician records the data when selecting the outline areas for analysis to observe progress. Ambient light, daylight, or office light may influence the quality of the FluoreCam image. Thus, images should be captured under partial black-out conditions using a roller blind in windows to exclude direct daylight, which may cause reflections on the enamel surface. This precaution is especially important during longitudinal monitoring of lesions.[27]

On successive visits, capturing a follow-up image that replicates the original baseline image is important for comparing changes over time. However, this means the selection process is important and affects the results in determining the follow-up images for comparison.

Notably, defined areas selected on multiple visits might not align well with the baseline image because of being out of focus, inadequate lighting/darkness, and subject position/stillness, resulting in a less-than-optimal image. Should this occur, the secondary image must be manually moved up/down or right/left on the screen in an attempt to match the selected areas as far as possible for a comparative analysis. The examiner always has the choice to take another image if not satisfied with the quality of the follow-up image. The FluoreCam allows the examiner to be in control of capturing successive images and displays the actual baseline image on the screen for ease of reproducibility. However, areas of interest within the image, which is surrounded by a red border, must be selected or de-selected per image in the comparisons. The FluoreCam is a technique- and focus-sensitive device.

There is a need for more information about the suitability of the FluoreCam for the assessment of MIH. For a dentist using this method, it would be useful to have guidelines with respect to suitable cut-off values for the FluoreCam parameters (fluorescence loss and/or area) to guide the

clinician in decision-making regarding preventative or operative interventions. The dark appearance of the lesions, as viewed with the FluoreCam, is very obvious, and patients can follow the development and appearance of their own lesions on the screen. Thus, for patients with MIH, we suggest that the FluoreCam is also used to increase motivation.

Apart from the fact that a technology provides added value and can practically be integrated in the often finely tuned logistics of dental health care, one of the deciding factors is its economic value. Like any new technology, development is expected to continue and new hard- and soft-ware will emerge relatively fast. The use of fluorescence technologies in the dental clinical practice is becoming more common place as the available range of diagnostic devices increases and the relative cost of these devices reduces.[3,13,15,18] Finally, integration of the technology in the daily practice is not only simple but also economically affordable to be used as a diagnostic measure.

Conclusion

It is difficult to determine the potential of any fluorescent imaging system as a means of quantifying MIH because there is no currently accepted gold standard with which to compare the output data from a system. Moreover, there are other data derived from a subjective clinical index that cannot be readily compared with the data from the FluoreCam software. Despite these limitations, the FluoreCam imaging system provides objective, blinded quantification and provides a system for longitudinal monitoring as well as visual and quantitative feedback to patients.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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