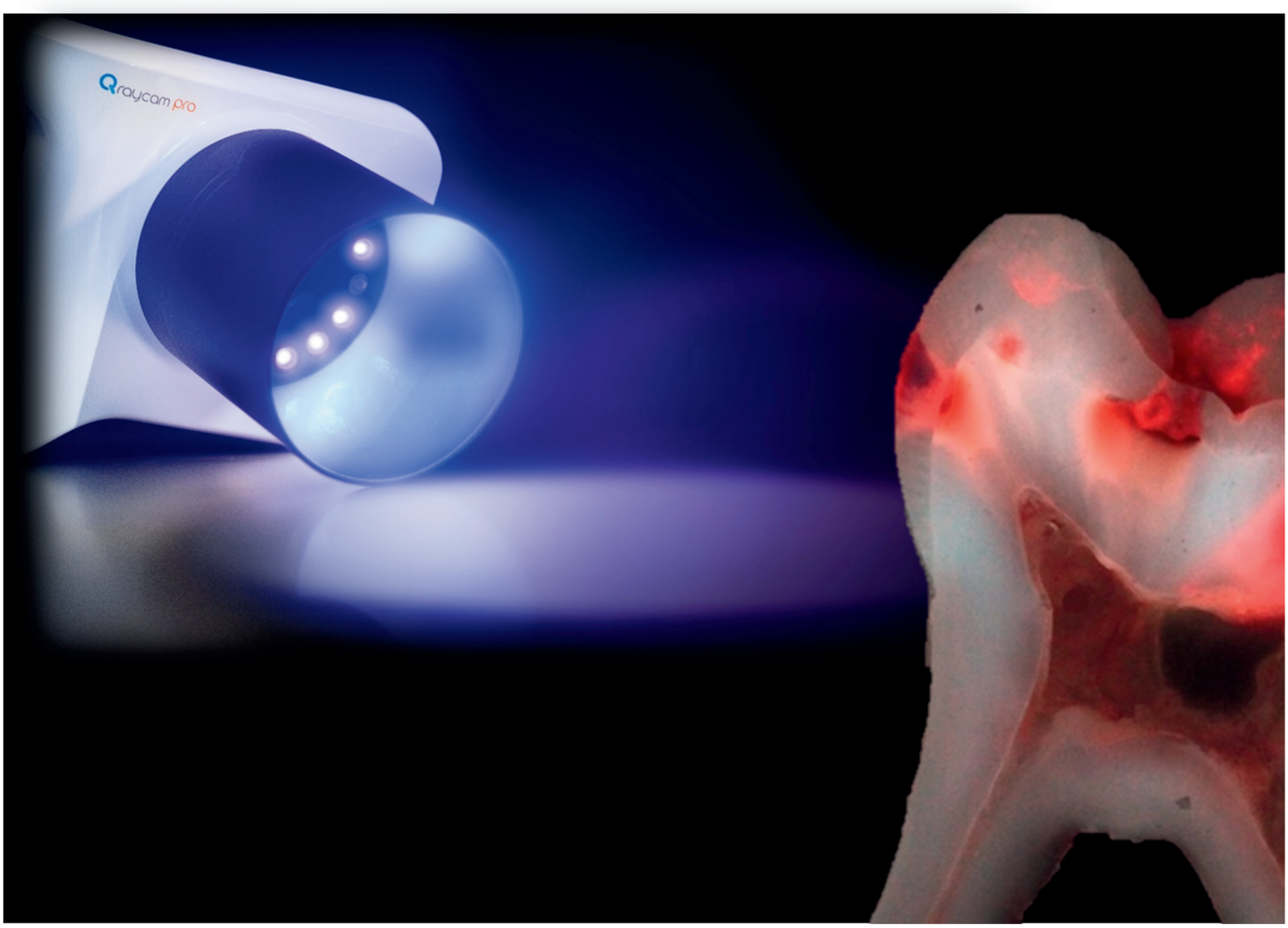
Biofluorescence Image Screening (BIS) technology

SCIENTIFIC LITERATURE REVIEW on BIS TECHNOLOGY

Last updated in January 2025



AIOBIO

YONSEI UNIVERSITY COLLEGE OF DENTISTRY

TABLE OF CONTENTS

Powered by BIS™

Proven Indications

Oral Biofilms

Dental Caries

See What's Unseen

With the Most Rigorously Researched Fluorescence Imaging

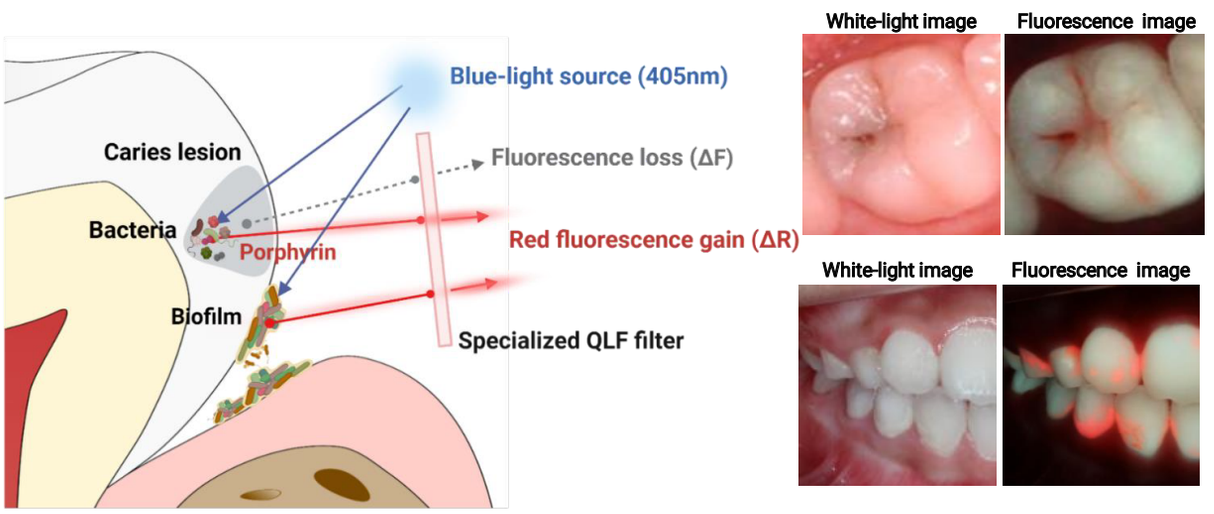
Naked eye observations and even X-rays can be misleading for dentists. Quantitative Light-Induced Fluorescence (QLF™) **quantifies the fluorescence change** percentage in demineralized enamel compared to surrounding sound enamel, offering an alternative solution for **assessing oral biofilm and dental caries**.

Welcome to the Future of Dental Care

Introducing QLF Technology

How it works:

Step into the realm of cutting-edge dentistry with QLF technology. QLF operates on a remarkably simple principle: **By emitting a safe and non-intrusive blue-violet light**, QLF stimulates the tooth structure or bacterial deposits to emit fluorescent light back. Using specialized QLF filters, **QLF can detect the autofluorescence** from these structures with greater clarity and sensitivity. Therefore, it is possible to observe the **loss of fluorescence from defective hard tissue** (such as dental caries, tooth wear, etc.) and to observe a **red fluorescence from bacterial deposits** accumulated on the tooth surface or within the tooth lesions. These fluorescence properties can be captured immediately in images. The captured images then offer a vivid portrayal of early lesions and demineralization invisible to the naked eye. This innovative approach transcends traditional examination methods, providing a comprehensive insight into the oral health landscape.



Early Detection's Crucial Role:

The **importance of detecting dental caries at their inception** cannot be overstated. However, the challenge lies in their elusive nature, often escaping detection through conventional means. **Traditional methods struggle to identify lesions in their infancy, leading to delayed intervention and more invasive treatments**. This is where QLF shines. Its ability to **unveil incipient lesions and demineralization** empowers dental practitioners to intervene early, **mitigating the progression of caries and preserving tooth structure.**

Advancing Preventive and Minimally Invasive Dentistry:

At the heart of QLF's transformative impact lies its capacity to revolutionize preventive and minimally invasive dentistry. The technology empowers practitioners with **real-time insights into enamel health**, enabling tailored interventions that arrest the advancement of carious lesions. This precision translates to **minimally invasive treatments, as pinpointed areas** can be treated with utmost accuracy. **Patient compliance receives a boost** through visualized explanations, fostering a proactive approach to oral health maintenance.

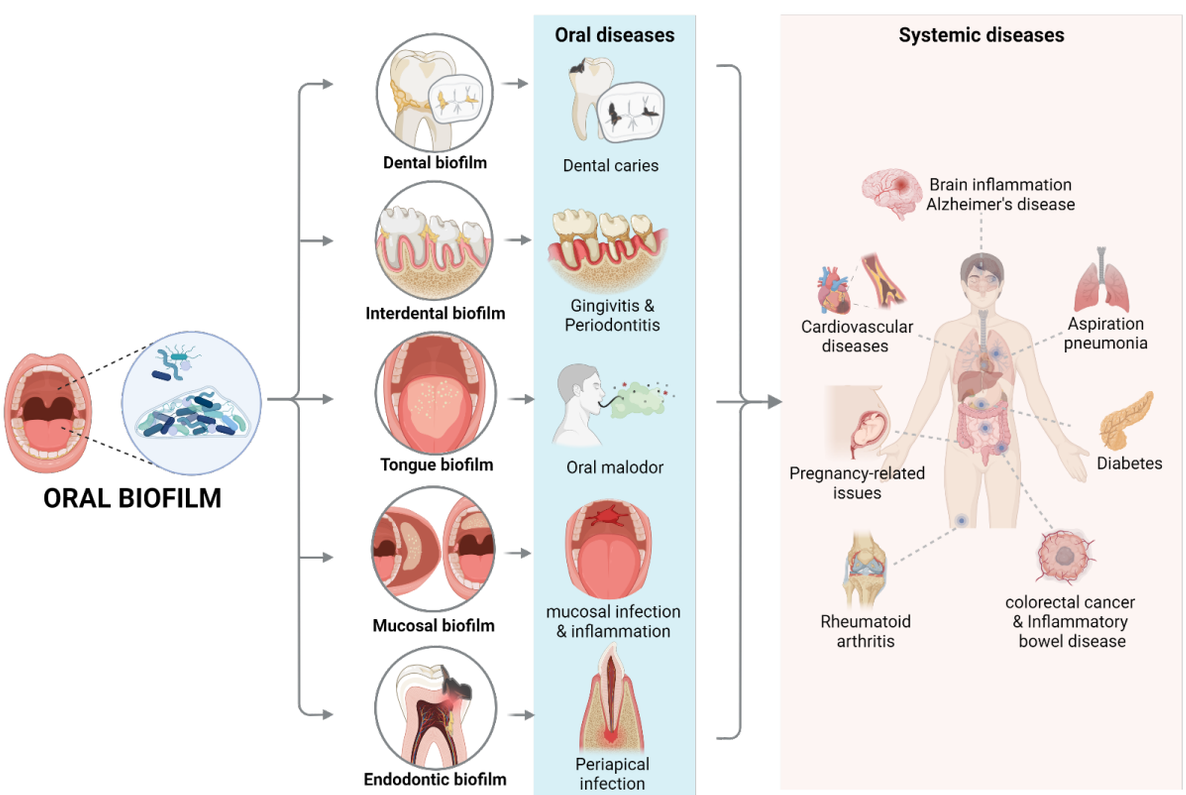
QLF's Unmatched Superiority:

While a myriad of new non-conventional methods and technologies have surfaced, QLF stands tall with its unparalleled advantages. **QLF's foundation in rigorous clinical research spanning a decade solidifies its credibility**. The technology's simplicity ensures seamless integration into existing workflows. Furthermore, QLF's patient-centered approach transforms patient engagement, as vivid **images facilitate transparent communication and inspire commitment to treatment plans**. This harmonious blend of science, simplicity, and patient-centricity positions QLF as the ultimate choice for dental practitioners seeking to elevate their diagnostic and treatment efficacy.

Breakthrough in Biofilm Visualization and Systemic Health Implications:

QLF technology is a powerful tool that allows us to visualize oral biofilms – complex bacterial communities in the mouth that are often invisible to the naked eye. **By detecting porphyrin, a metabolic byproduct of these oral bacteria, it emits a vivid red fluorescence.** This groundbreaking technology **illuminates biofilms in various areas within the oral cavity**, including commonly affected **tooth surfaces, interdental spaces, tongue surfaces, mucosal regions, and even dental pulp chambers**.

Extensive research has validated the **significant links between the red fluorescence emitted by these biofilms and various oral diseases** that stem from bacterial overgrowth (see the “oral biofilm” category for more details). As we delve deeper into the connections between the oral microbiome and systemic health conditions, there's growing optimism that QLF technology can play a pivotal role in both detecting and managing these biofilms, ultimately contributing to the prevention and treatment of systemic diseases.



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Monitoring the maturation process of a dental microcosm biofilm using Quantitative Light-induced Fluorescence-Digital (QLF-D)

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Objectives

The aim of this study was to investigate whether Quantitative Light-induced Fluorescence-Digital (QLF-D) could monitor the degree of maturation of dental microcosm biofilms by observing the red fluorescence emitted from the biofilms.

Methods

Dental microcosm biofilms were grown on bovine enamel discs. They were initiated from human saliva and then grown in 0.5% sucrose growth media for 10 days. On days 1, 2, 3, 7, and 10 after the inoculation, fluorescence images of the biofilms were captured using the QLF-D, and the red fluorescence intensity was quantified by calculating the red/green ratio (R/G value). Total and aciduric bacteria within the biofilms were counted, and the degree of demineralization was evaluated by measuring the percentage of surface micro-hardness change (ΔVHN) and lesion depth in the enamel.

Results

The R/G values of the biofilms assessed by the QLF-D increased significantly over time up to 7 days after inoculation ($p < 0.0001$) (Fig. 1). The R/G values of the biofilms increased significantly from day 1 (0.83) through day 7 (2.07), and the R/G value of the 7-day biofilm was the highest and the value was saturated ($p < 0.0001$) (Table 1). This R/G value was not significantly different from that of the mature 10-day biofilm. Also, the R/G value of the biofilm matured over 3 days was significantly higher compared to that of the 1-day and 2-day biofilms ($p < 0.0001$). According to the results of bacterial counts in the microcosm biofilms depending on the maturation time, the total bacterial CFUs and aciduric bacterial CFUs were significantly increased from day 1 through day 7 ($p < 0.0001$). However, there was no difference in the total and aciduric bacterial CFUs between day 7 and day 10. The ratio of aciduric bacterial count to total bacterial count was significantly increased over time, from 88% on day 1 to 98% on day 10 ($p < 0.0001$). The mean values of ΔVHN and lesion depth in the enamel were significantly increased with the maturation time ($p < 0.001$).

Conclusions

The red fluorescence detected by the QLF-D increased according to biofilm maturation and was significantly associated with the cariogenicity of the biofilm. Therefore, this device could be used to monitor the degree of biofilm maturation by observing the red fluorescence emitted from cariogenic biofilms.

Key result 1

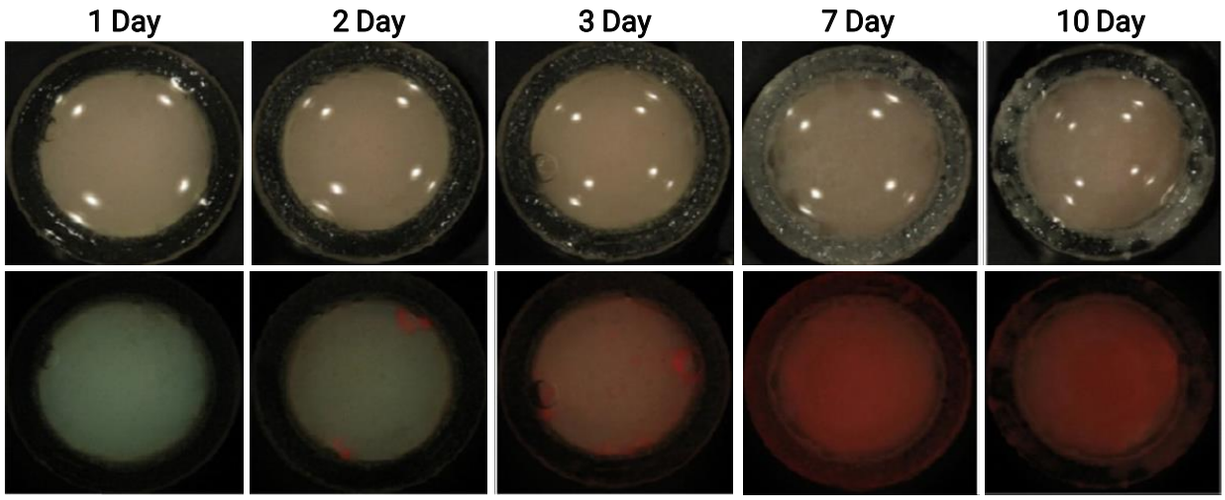

Figure 1. White light images (upper line) and QLF-D fluorescence images (lower line) of dental microcosm biofilms formed on the bovine enamel discs 1 day, 2 days, 3 days, 7 days, and 10 days after inoculation.

Key result 2

Table 1. Red fluorescence (R/G value) and cariogenicity variables of dental microcosm biofilms according to the maturation time.

Days	R/G values (ratio)	Total bacterial CFUs	Aciduric bacterial CFUs	ΔVHN (%)	Lesion depth (um)
1	0.83 ± 0.06^{a}	7.31 ± 0.05^{a}	6.45 ± 0.15^{a}	96.5 ± 33.2^{a}	25.5 ± 10.4^{a}
2	0.99 ± 0.08^{a}	7.67 ± 0.48^{b}	6.92 ± 0.36^{b}	230.0 ± 36.3^{b,c}	46.6 ± 12.4^{b}
3	1.35 ± 0.22^{b}	7.68 ± 0.48^{b}	7.26 ± 0.45^{c}	252.0 ± 12.0^{b}	79.1 ± 11.8^{c}
7	2.07 ± 0.29^{c}	9.10 ± 0.57^{c}	8.48 ± 0.13^{d}	268.4 ± 25.7^{b,c}	117.6 ± 13.4^{d}
10	2.04 ± 0.29^{c}	8.55 ± 0.40^{c}	8.38 ± 0.51^{d}	309.8 ± 25.5^{c}	124.7 ± 23.1^{d}

All values are expressed as mean ± standard deviations.
Different letters within the same column indicate significant differences between groups by Bonferroni's post hoc analysis at α=0.05.
R/G values represent the ratios of red pixels to green pixels in red fluorescence images of biofilms captured by the QLF-D.
CFUs indicate colony-forming units.

Plain language summary

This study aimed to assess the potential of using the Quantitative Light-induced Fluorescence-Digital (QLF-D) technique to monitor the maturation of oral biofilms by measuring red fluorescence. Oral biofilms were inoculated with saliva and allowed to mature on bovine specimens for 10 days. QLF-D images of the biofilms were captured on days 1, 2, 3, 7, and 10, and the red/green ratio was calculated to gauge red fluorescence intensity. Additionally, the study determined the total bacterial and acidogenic bacterial counts within the biofilm. It also evaluated micro-hardness changes on the specimen surface and the depth of damage within the enamel layer to assess mineral loss. The results demonstrated a strong correlation between red fluorescence measured by QLF-D, biofilm maturity, and susceptibility to dental caries. Therefore, QLF-D can be effectively used as a monitoring tool to observe the maturity of cariogenic biofilms.

Assessing the use of Quantitative Light-induced Fluorescence-Digital as a clinical plaque assessment

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[b] Department of Dental Hygiene, Yonsei University Wonju College of Medicine, Wonju, Republic of Korea

Objectives

The aim of this study was to compare the relationship between red fluorescence plaque (RF plaque) area by Quantitative Light-induced Fluorescence-Digital (QLF-D) and disclosed plaque area by two-tone disclosure, and to assess the bacterial composition of the RF plaque by real time-PCR.

Methods

Fifty healthy subjects were included and 600 facial surfaces of their anterior teeth were examined. QLF-D was taken on two separate occasions (before and after disclosing), and the RF plaque area was calculated based on the Plaque Percent Index (PPI). After disclosing, the stained plaque area was analyzed to investigate the relationship with the RF plaque area. The relationship was evaluated using Pearson correlation and paired *t*-test. Then, the RF and non-red fluorescence (non-RF) plaque samples were obtained from the same subject for a real-time PCR test. A total of 10 plaque samples were compared to the ratio of the 6 bacteria using the Wilcoxon signed rank test.

Results

Regarding the paired *t*-test, the blue-staining plaque area (9.3 ± 9.2) showed significant similarity with the RF plaque area (9.1 ± 14.9, $p = 0.80$) at ΔR20, however, the red-staining plaque area (31.6 ± 20.9) presented difference from the RF plaque area ($p < 0.0001$). The correlation coefficient of the PPI_{blue} was gradually increasing as the level of ΔR was getting higher. The scatterplot matrix demonstrated that the PPI_{blue} observed a slightly linear distribution, on the other hand, there was no linear association in the PPI_{red} (Fig. 1). In addition, the bacterial composition of *Prevotella intermedia* and *Streptococcus anginosus* was associated with substantially more RF plaque than non-RF plaque ($p < 0.05$) (Fig. 2).

Conclusions

The plaque assessment method using QLF-D has the potential to detect mature plaque, and the plaque area was associated with the blue-staining area using two-tone disclosure.

Key result 1

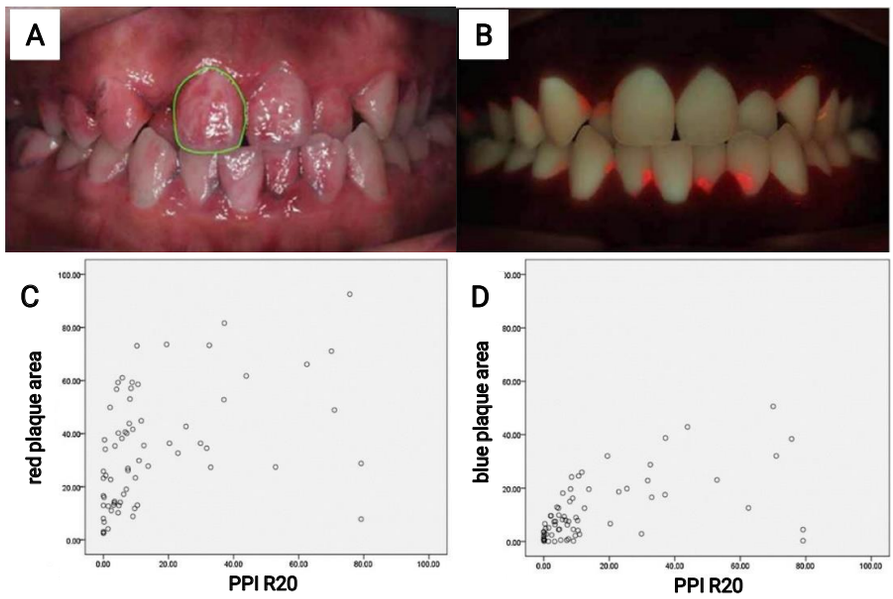

Figure 1. Image of stained plaque on the tooth surface (A) and RF plaque area with QLF-D (B). The scatterplot matrix of red (C) and blue (D) stained the area with the RF plaque area at the highest correlation threshold.

Key result 2

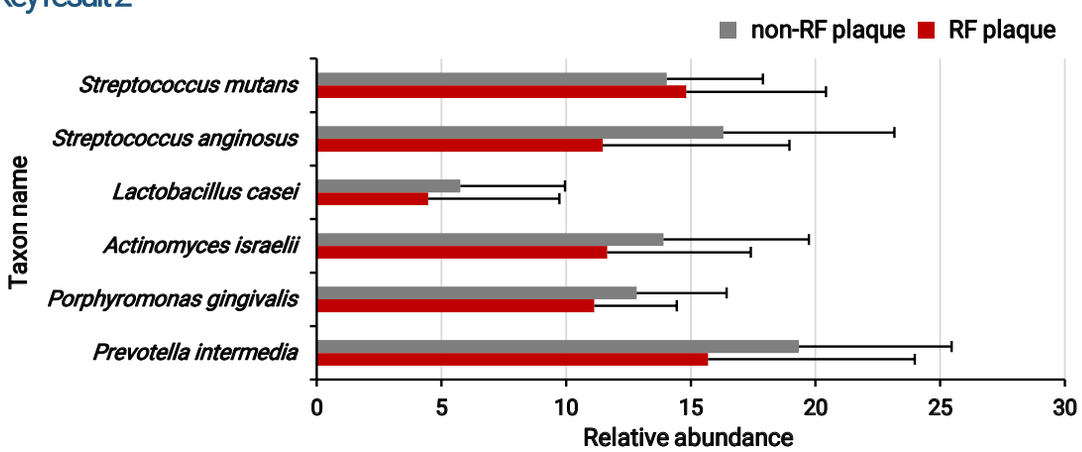

Figure 2. Comparison of the relative quantity of the 6 bacteria between RF and non-RF plaque samples (N = 10).

Plain language summary

This study aimed to compare the effectiveness of Quantitative Light-induced Fluorescence-Digital (QLF-D) with the traditional two-tone disclosure method for assessing dental plaque. Additionally, it explored the bacterial composition of red fluorescence plaque. The findings indicated a correlation between red fluorescence plaque assessed using QLF-D and blue-stained plaque from the disclosure method. However, a notable difference was observed between red staining plaque and RF plaque. Furthermore, caries bacteria, such as *Prevotella intermedia* and *Streptococcus anginosus*, were found to be more prevalent in red fluorescence plaque. These results suggest the potential of QLF-D as a valuable tool for evaluating plaque maturity in dental research.

Detection of dental plaque and its potential pathogenicity using quantitative light-induced fluorescence

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[b] Department of Health Services Research, University of Liverpool, Liverpool, UK
[c] Inspektor Research Systems BV, Amsterdam, The Netherlands

Objectives

This in vivo study aimed to identify the microbial characteristics of red fluorescent (RF) dental plaque using 16S rRNA gene sequencing and evaluate the correlations between RF plaque and the clinical symptoms of dental diseases.

Methods

This cross-sectional study was carried out with 10 adults. Before performing the sampling procedure, all subjects refrained from consuming food for 4h and performing any oral hygiene practices such as brushing, use of oral rinses, or chewing gum. After using the QLF technology (QLF-D Biluminator, Inspektor Research Systems BV, Amsterdam, The Netherlands) to obtain fluorescence images, selected 2 sites among the 12 anterior teeth per subject and collected 2 plaque samples for each site: on of RF plaque and on of non-RF plaque, the intensity of red fluorescence from the fluorescence images of each subject (Fig. 1). The mean of the red-to-green ratio (R/G ratio), indicates the relative red intensity of each site. The characteristics of the bacterial communities in the RF and non-RF plaque samples were compared by sequencing analysis.

Results

An increase in microbial diversity was observed in RF plaque compared with the non-RF plaque. There were significant differences in the community compositions between the 2 types of dental plaque (Fig. 2). Periodontopathic bacteria, such as *Prevotella, Leptotrichia, Selenomonas, Fusobacterium, Tannerella,* and *Treponema*, were significantly more abundant in the RF plaque than non-RF plaque. While *Streptococcus, Actinomyces, Lautropia,* and *Rothia* were found to be overrepresented in non-RF plaque. The fluorescence intensity of RF plaque was significantly related to the proportion of the periodontopathic bacterial community and the presence of gingival inflammation.

Conclusions

The plaque red fluorescence is associated with changes in the microbial composition and enrichment of periodontopathic pathogens, which suggests that RF plaque detected by QLF technology could be used as a risk indicator for gingival inflammation.

Key result 1

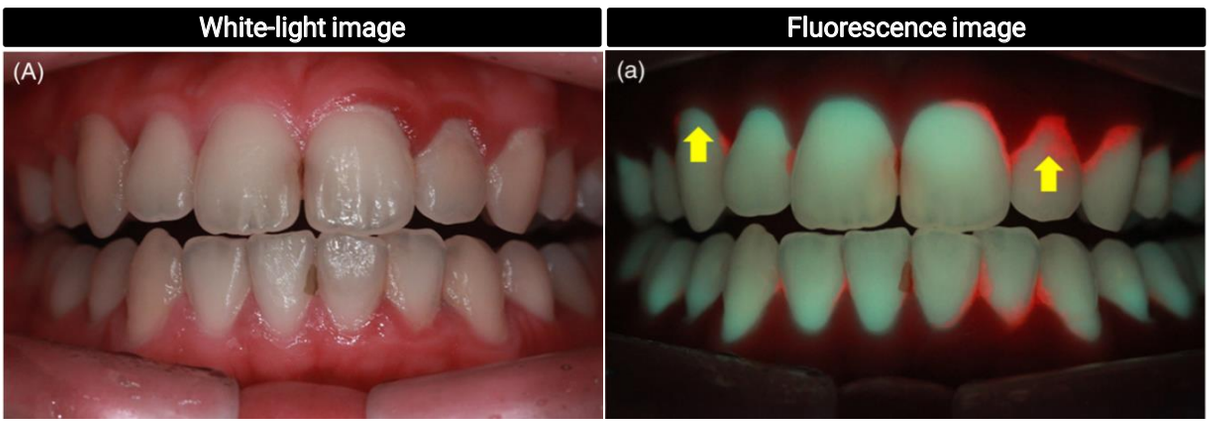

Figure 1. Representative images were obtained from the subjects in the present study. The arrows indicate sampled sites.

Key result 2

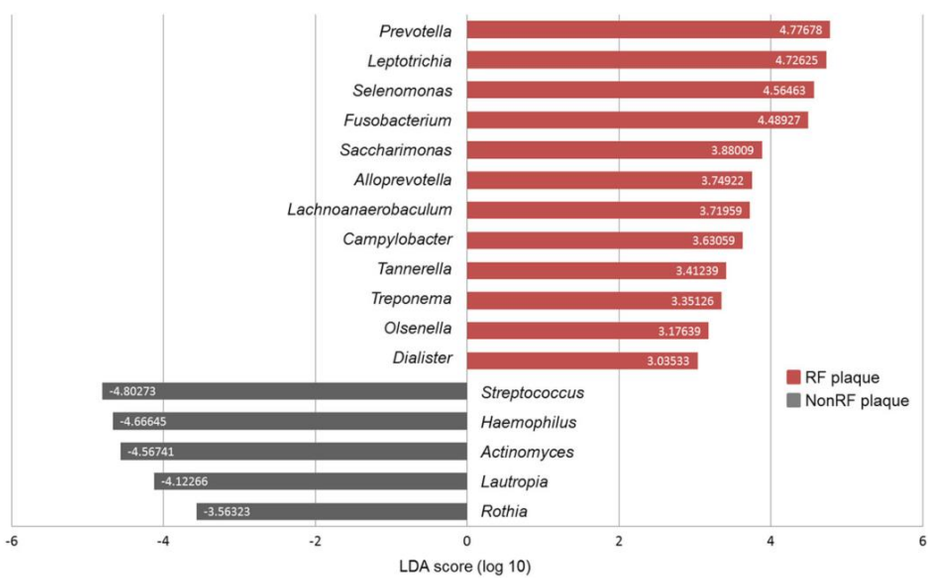

Figure 2. Linear discriminant analysis (LDA) effect size (LEfSE) analysis of bacterial taxa present in RF plaque (red bar) and non-RF plaque (gray bar) at the genus level.

Plain language summary

This study analyzed the microbial characteristics of red fluorescence plaque (RF plaque) through 16S rRNA sequencing and investigated the association between RF plaque and clinical symptoms of oral diseases. The fluorescence properties of RF and non-RF plaque were analyzed, and microbial community characteristics were compared through sequencing analysis. The results revealed that RF plaque exhibited higher microbial diversity and a greater abundance of periodontopathogenic bacteria, while non-RF plaque was dominated by different bacterial species. The fluorescence intensity of RF plaque was associated with the proportion of periodontopathogenic bacteria and gingival inflammation. These findings suggest that RF plaque detected through QLF technology can indicate gingival inflammation and highlight its association with changes in plaque microbial composition and the abundance of periodontal pathogens.

Clinical assessment of an automated fluorescent plaque index scoring with quantitative light-induced fluorescence

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Objectives

This study aimed to evaluate the clinical applicability of a new fluorescent plaque index scoring (FPI) with the Turesky modified Quigley-Hein plaque index (mQH) and its relationship with plaque maturity.

Methods

In total 69 subjects participated in this study. White-light and fluorescent images of anterior teeth were acquired using a Qraycam (AIOBIO, Seoul, Korea). FPI was obtained from fluorescent images using the proprietary software (Q-Ray v.1.39, Inspektor Research System BV, Amsterdam, The Netherlands). Teeth were stained with a two-tone disclosing agent. mQH was used to manually score the combined red and blue disclosed plaque (Combi-mQH) and blue disclosed plaque (Blue-mQH) with the white-light images. Linear relationships between FPI and Combi-mQH (or Blue-mQH) were evaluated by using simple linear regression analysis. Differences in Combi-mQH (or Blue-mQH) to FPI scores were statistically evaluated by using ANOVA with Duncan post hoc correction.

Results

The representative images of six study participants with different plaque index scores are shown (Fig 1A). FPI showed a moderate positive correlation with Combi-mQH (r = 0.66, P < 0.001) and a high positive correlation with Blue-mQH (r = 0.78, P < 0.001) (Fig 1B, C). The model explanatory power (R2) between FPI and Blue-mQH was 60.8 %, which is 16.8 % higher than the explanatory power observed with Combi-mQH (44.0 %). Both Combi-mQH and Blue-mQH increased significantly with increasing FPI scores (P < 0.001) (Table 1).

Conclusions

FPI showed a moderate positive correlation with Combi-mQH (r = 0.66, P < 0.001) and a high positive correlation with Blue-mQH (r = 0.78, P < 0.001). The model explanatory power (R2) between FPI and Blue-mQH was 60.8 %, which is 16.8 % higher than the explanatory power observed with Combi-mQH (44.0 %). Both Combi-mQH and Blue-mQH increased significantly with increasing FPI scores (P < 0.001).

Key result 1

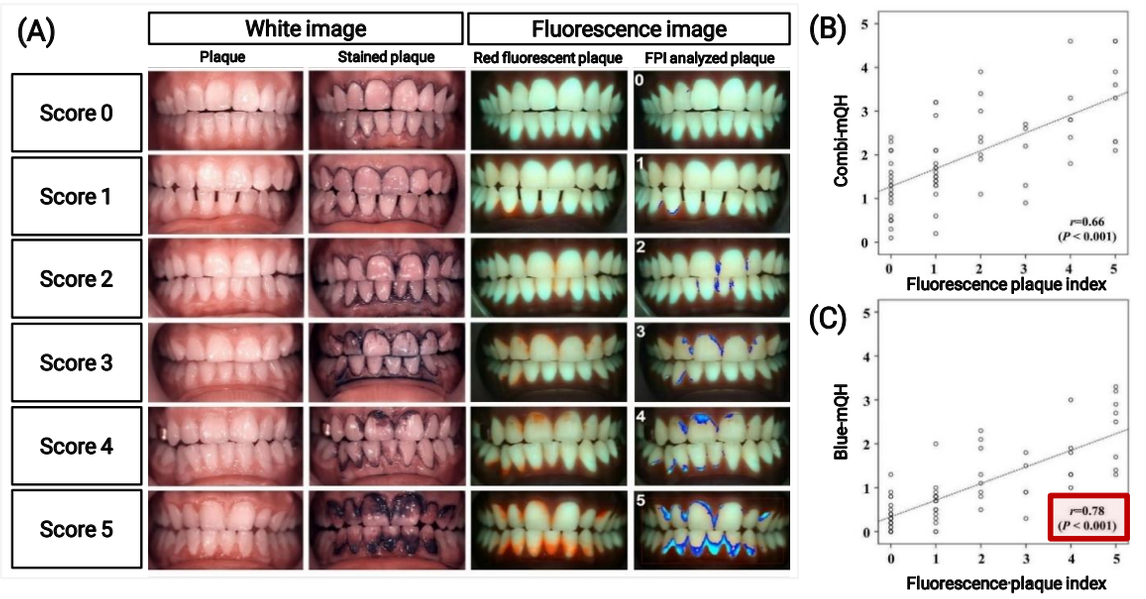

Figure 1. (A) Representative white-light and fluorescent images in accordance with fluorescent plaque index score. (B, C) Correlations and linear regressions comparing red fluorescent plaque indices (FPI) to traditional plaque indices (Combi-mQH or Blue-mQH).

Key result 2

Table 1. Distribution of the Turesky modified Quigley-Hein plaque indices of the combined red and blue disclosed plaque (Combi-mQH) and the blue disclosed plaque (Blue-mQH) according to FPI scores.

Turesky modified Quigley-Hein plaque index	Fluorescent plaque index (FPI)						*P*-value
	0 (n=24)	1 (n=18)	2 (n=8)	3 (n=5)	4 (n=6)	5 (n=8)	
Combi-mQH	1.22 (0.67)^{a}	1.70 (0.79)^{ab}	2.50 (0.90)^{bc}	1.94 (0.80)^{ab}	2.95 (0.95)^{cd}	3.33 (1.02)^{d}	< 0.001
Blue-mQH	0.36 (0.32)^{a}	0.66 (0.45)^{ab}	1.36 (0.66)^{cd}	1.08 (0.59)^{bc}	1.72 (0.71)^{d}	2.38 (0.80)^{e}	< 0.001

All values denote mean (standard deviation).
$^{a\text{-}e}$Different letters indicating significant differences in Combi-mQH and Blue-mQH according to FPI scores by ANOVA with Duncan *post hoc* correction

Plain language summary

This study evaluated the clinical applicability of a novel fluorescence plaque index (FPI) by comparing it to the Turesky modified Quigley-Hein plaque index (mQH) and investigated its relationship with plaque maturity. Sixty-nine participants were included in the study, and both fluorescence and white-light images were analyzed. FPI was obtained by using proprietary software to measure plaque from fluorescence images, while mQH was used to assess plaque from white-light images. The linear relationship between FPI and Combi-mQH (or Blue-mQH) was assessed using simple linear regression analysis. The results showed that FPI had a positive correlation with mQH, with a particularly strong association observed with Blue-mQH. Therefore, FPI proves to be a useful tool for plaque evaluation, with a notably stronger relationship observed with Blue-mQH.

Dental plaque quantitation by light induced fluorescence technology in exclusive Electronic Nicotine Delivery Systems (ENDS) users

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[j] Department of Periodontology, Medical University of Warsaw, Warsaw, Poland

Objectives

This study measures dental plaque in Electronic Nicotine Delivery Systems (ENDS) including both e-cigarettes (ECs) and heated tobacco products (HTPs) users using quantitative light-induced fluorescence (QLF) technology, comparing them with current, former, and never smokers.

Methods

This cross-sectional study compared dental plaque measurements using QLF technology (Qraycam™ Pro) among current smokers (≥10 cigarettes/day), former smokers (quit ≥6 months), never smokers, and exclusive ENDS users (quit ≥6 months). Dental plaque measurements were expressed as ΔR30 (total area of mature dental plaque) and ΔR 120 (greater plaque thickness/maturation-calculus). The Simple Oral Hygiene (SOH) score was calculated by the QLF software.

Results

A total 30 smokers, 24 former smokers, 29 never smokers, and 53 ENDS users were included. Current smokers had significantly higher ΔR30 and ΔR120 values compared to other groups ($P < 0.001$, Table 1). ENDS users showed plaque levels similar to never and former smokers ($P > 0.05$) but significantly lower than current smokers ($P < 0.01$). Although ENDS users showed a lower SOH score than smokers, this difference was not statistically significant (Fig. 1). Daily toothbrushing and mouthwash usage were significant covariates.

Conclusions

ENDS users exhibited reduced accumulation of dental plaque and calculus compared with current smokers.

Key result 1

Table 1. QLF comparisons among smokers, ex-smokers, never smokers, and ENDS (ECs and HTPs) users.

	Current Smokers	Former smokers	Never smokers	ENDS users	*P*-value
ΔR30	5.3 ± 4.39	2.13 ± 2.85	2.03 ± 2.31	2.45 ± 1.44	0.0002
ΔR120	2.13 ± 2.60	0.54 ± 1.28	0.52 ± 0.83	0.74 ± 0.79	0.0002
SOH	3.1 ± 1.97	1.5 ± 1.56	1.48 ± 1.50	1.79 ± 1.31	0.0016

Data are summarized as mean± standard deviation (SD). *P* values were calculated by ANOVA adjusted for age, gender, frequency of daily domiciliary oral hygiene and frequency mouthwash usage. SOH: simple oral hygiene.

Key result 2

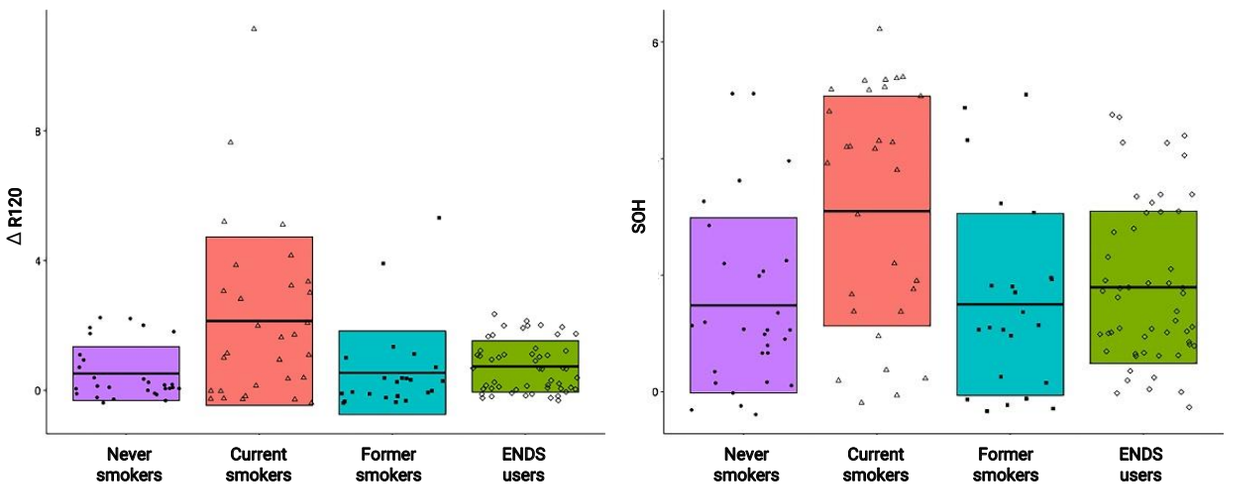

Figure 1. Comparison of ΔR120 and Simple Oral Hygiene (SOH) score among smokers, former smokers, never smokers, and ENDS (ECs and HTPs) users groups. Each dot represents the individual values of ΔR120 and SOH measurements. Box represent mean ± standard deviation (SD) of ΔR120 and SOH score for each study group.

Plain language summary

This study compared the impact of Electronic Nicotine Delivery Systems (ENDS), including e-cigarettes and heated tobacco products, on dental plaque against that of conventional cigarettes using quantitative light-induced fluorescence (QLF) technology. Participants were categorized into four groups: current smokers, former smokers, never smokers, and exclusive ENDS users. Findings indicated that ENDS users had dental plaque levels comparable to those of never and former smokers but significantly lower than those of current smokers. The results suggest ENDS may be less harmful in terms of dental plaque accumulation compared to traditional smoking, highlighting a potential dental health benefit of switching from conventional to electronic nicotine delivery systems.

Red fluorescence of Interdental plaque for screening of gingival health

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[b] Department of Periodontology, Research Institute for Periodontal Regeneration, College of Dentistry, Seoul, Republic of Korea

Objectives

Pathogenic dental plaque with deteriorated bacterial homeostasis around the gingival margin induces gingivitis. This study evaluated the applicability of red fluorescence (RF) properties of interdental plaque in screening for gingival health status.

Methods

This cross-sectional study examined 178 teeth of 40 healthy subjects who had not lost both their first and second molars in at least one quadrant. Three groups (healthy, gingivitis, and periodontitis) were identified based on the periodontal health status (bleeding on probing, probing depth, clinical attachment loss) and plaque accumulation level (plaque index) in the interdental site between the first and second molars was evaluated. This interdental plaque between the first (distal surface) and the second molar (mesial surface) was collected using dental floss. A quantitative light-induced fluorescence (QLF) technology was used to assess RF emitted from the interdental plaque. The RF properties of the interdental plaque were quantified by fluorescence intensity (R/G value) and area (%). The RF variables were compared between the groups.

Results

Analysis of fluorescence images of the floss revealed variation in both fluorescence intensity and area across different floss samples (Fig. 1). The R/G value, which indicates the fluorescence intensity of the dental plaque, was notably higher in both gingivitis and periodontitis groups compared to the healthy group. Moreover, the plaque fluorescence score, computed by multiplying the fluorescence intensity and area of the interdental plaque, had significant positive correlations with the periodontal health status (Fig. 2). This score was substantially higher in the gingivitis and periodontitis groups when contrasted to the healthy group, and was consistent between gingivitis and periodontitis groups. Further, Spearman's correlation analyses established a noteworthy relationship between the R/G value and bleeding on probing (BOP) (r = 0.49, P < 0.01), as well as between the R/G value and the visual plaque index (r = 0.59, P < 0.01) for each tooth. Additionally, when leveraging a plaque fluorescence score threshold of 33.6 for screening sites susceptible to gingivitis or associated risk factors, the sensitivity was 63.9%, and the specificity stood at 64.2%, with an AUC of 0.63–0.79 (p < 0.001), denoting its potential utility in monitoring gingival health.

Conclusions

Interdental plaque obtained by flossing and its red fluorescence quantified by QLF technology could be used as a potential indicator of gingivitis.

Key result 1

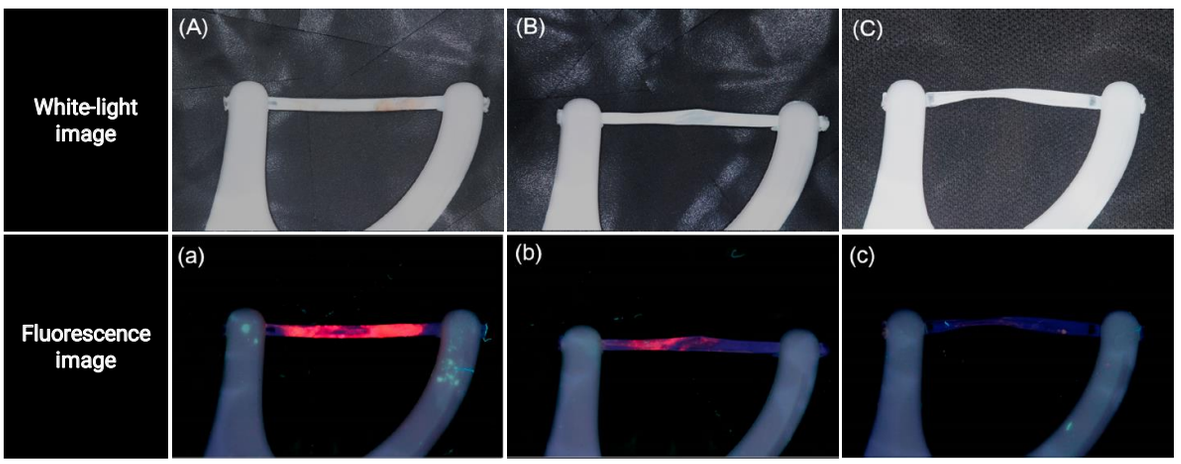

Figure 1. Interdental plaque collected on the dental floss.

Key result 2

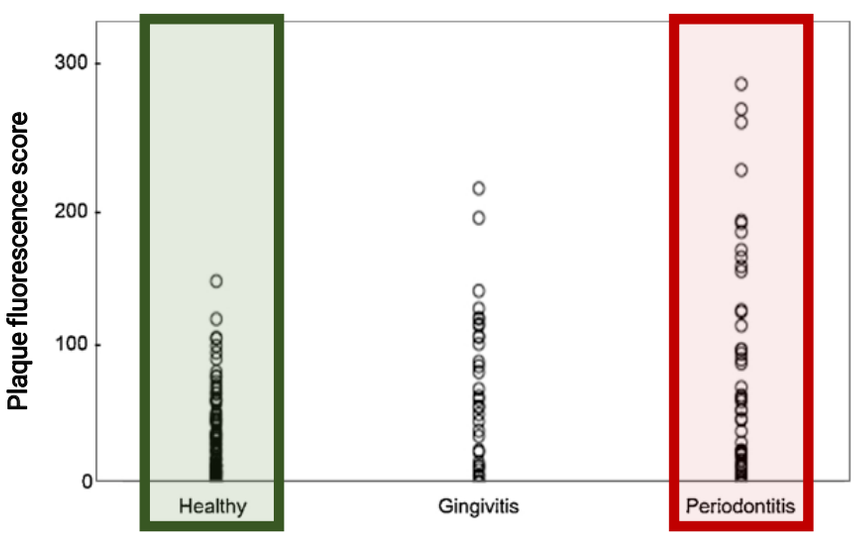

Figure 2. Scatter plots of the correlations between the periodontal health status and fluorescence score of the interdental plaque.

Plain language summary

When the balance of bacteria around the gums is disrupted, it leads to the formation of a problematic dental plaque known as periodontal disease, which can subsequently cause gingivitis, or gum inflammation. This study investigated the potential of using the red fluorescence (RF) characteristics from dental plaque as a measure to determine gum health. Among the 40 healthy participants, the RF from the plaque found between their first and second molars was measured. The findings revealed that the intensity and area of this RF were both higher in individuals with gum inflammation and periodontal disease compared to those who were healthy. This underscores the potential of the RF from dental plaque as a significant indicator for the presence of gingivitis.

Clinical assessment of oral malodor using autofluorescence of tongue coating

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Objectives

The aim of this study was to evaluate whether a new method using quantitative light-induced fluorescence-digital (QLF-D) was appropriate for the diagnosis of oral malodor by quantifying the fluorescence of tongue coating.

Methods

This study examined 103 healthy subjects who have an oral malodor as a main complaint. The levels of oral malodor were measured by organoleptic scores (OLS) and volatile sulfur compound (VSC) levels. The fluorescent tongue coating images captured by QLF-D were quantified as the integrated fluorescence score (IF score) by multiplying the intensity and area of fluorescence. The correlations between the fluorescence parameters and OLS as well as VSC levels and the diagnostic accuracy of the IF score were evaluated.

Results

From the fluorescence images of the participants' tongues, there was a noticeable variation in fluorescence intensity and area based on individual oral malodor levels (Fig. 1). Quantification of these fluorescence properties resulted in three distinct variables: area, intensity, and IF score. Upon subdividing participants based on their organoleptic scores, fluorescence variables and IF scores of the three groups varied significantly (Table 1). The group with the highest level of malodor was markedly distinct from the other groups ($p = 0.003$, $p < 0.001$, Table 1). A comprehensive evaluation of malodor assessments in relation to all fluorescence variables from the tongue was tabulated in Table 2. It was evident that all fluorescence variables had significant associations with organoleptic scores and total VSC levels. Interestingly, the fluorescence intensity had a stronger correlation with both the organoleptic score and VSC level than the fluorescence area, with the IF score recording the highest correlations. The IF score of tongue coating showed a significant positive correlation with the OLS ($r = 0.54$, $p < 0.01$) and the VSC levels ($r = 0.49$, $p < 0.01$). This score was significantly differed with the level of oral malodor ($p < 0.001$), and its AUC was 0.72 in identifying the patient with definite oral malodor (≥ OLS 2).

Conclusions

A new method quantifying tongue coating fluorescence detected by QLF-D can be used to diagnose oral malodor and assess its severity in the clinical practice.

Key result 1

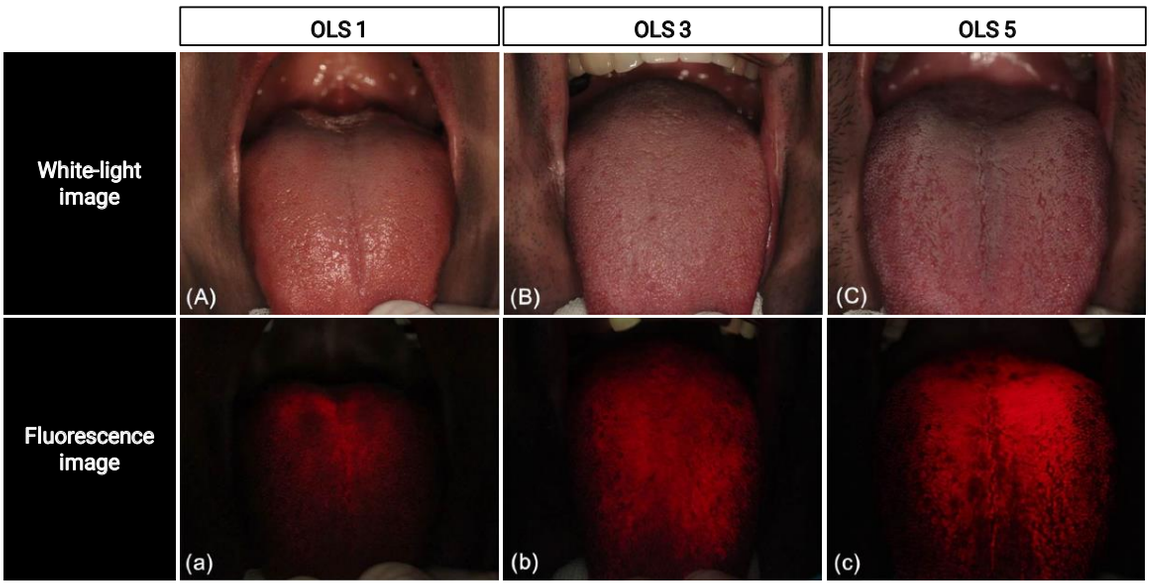

Figure 1. Examples of tongue images according to the severity level of oral malodor determined by organoleptic score (OLS).

Key result 2

Table 1. Distribution of fluorescence variables of tongue coating according to the different severity groups of oral malodor.

Severity	OLS	N	VSC level (ppb)	Fluorescence variables*		
				Intensity (*R/G*)	Area (%)	IF score
None	0-1	17	73 (17–197) [a]	2.4 (1.8–5.3) [a]	59.8 (35.6–98.3) [a]	148.5 (85.6–222.7) [a]
Slight-moderate	2-3	47	194 (2–733) [b]	2.6 (1.8–5.3) [a]	68.4 (0.61–98.4) [a]	173.0 (1.3–268.8) [a]
Strong-severe	4-5	39	533 (84–3619) [c]	2.8 (2.2–6.9) [b]	83.1 (45.7–99.2) [b]	222.1 (104.6–667.1) [b]
p-value			< 0.0001	< 0.0001	0.008	< 0.0001
Median			217	2.6	73.9	193.8

OLS: organoleptic score; IF score: integrated fluorescence score calculated by multiplying the intensity and area of the fluorescence.

R/G values represent the ratios of red pixels to green pixels in red fluorescence images of the tongue captured by the QLF-D.

Different letters within the same column indicate significant differences between groups by Bonferroni's correction for multiple analysis at α = 0.05.

* Values are the median (min–max).

Plain language summary

This study aimed to assess the utility of quantitative light-induced fluorescence-digital (QLF-D) for diagnosing oral malodor by quantifying the fluorescence of tongue coating. Among 103 participants with oral malodor complaints, fluorescence images of their tongues were captured and quantified as integrated fluorescence scores (IF scores) by combining the intensity and area of fluorescence. Significant correlations were found between the IF score and both organoleptic scores (OLS) and volatile sulfur compound (VSC) levels. Specifically, the IF score had a strong positive correlation with the OLS and VSC levels. The IF score effectively identified individuals with pronounced oral malodor. In conclusion, QLF-D-derived fluorescence quantification offers a promising method for diagnosing and gauging oral malodor severity in clinical settings.

Development of a novel tongue biofilm index using bacterial biofluorescence

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Objectives

Conventional methods for assessing tongue bacterial biofilms have low inter-examiner reliability due to visualization challenges. This study aimed to develop and assess a novel Tongue Biofilm Fluorescence Index (TBFI) for the accurate detection and objective evaluation of the quantitative and qualitative characteristics of tongue biofilms at the chairside.

Methods

Data were collected from 81 elderly individuals (n = 162 images). Qraycam captured white-light and fluorescence images of the dorsal tongue, and two examiners assessed tongue coating (TC) using the TBFI (Fig. 1). The TBFI was calculated based on biofilm intensity and coverage (0–2 scale). Inter-examiner agreement (Kappa) was compared with the Winkel's Tongue Coating Index (WTCI) and the Oho Index. Validity was evaluated through correlations with hydrogen sulfide (H_2S) and methyl mercaptan (CH_3SH) levels.

Results

TBFI demonstrated the highest inter-examiner reliability (TBFI, κ = 0.752; WTCI, κ = 0.317; Oho Index, κ = 0.496; Table 1), particularly for thickness rating (agreement rate: TBFI, 96.3%; WTCI, 76.5%; Oho Index, 79.6%). H_2S and CH_3SH concentrations showed significant positive correlations with all three indices, with the highest correlation observed between H_2S and TBFI (TBFI, r = 0.369; WTCI, r = 0.304; Oho Index, r = 0.308; $P < 0.01$). Furthermore, H_2S levels increased significantly with higher TBFI scores ($P < 0.0001$). TBFI shows enhanced reliability and validity, supporting its clinical potential

Conclusions

In conclusion, the TBFI, a novel scoring system based on bacterial biofluorescence, offers a reliable and objective method for quantifying tongue biofilms. Its superior inter-examiner agreement compared to conventional indices and its strong correlation with VSCs levels demonstrates its reliability and validity as an indicator of tongue biofilm pathogenicity. Furthermore, TBFI shows potential for facilitating real-time TC assessments, improving patient engagement, and integration into telemedicine and other clinical settings in the near future.

Key result 1

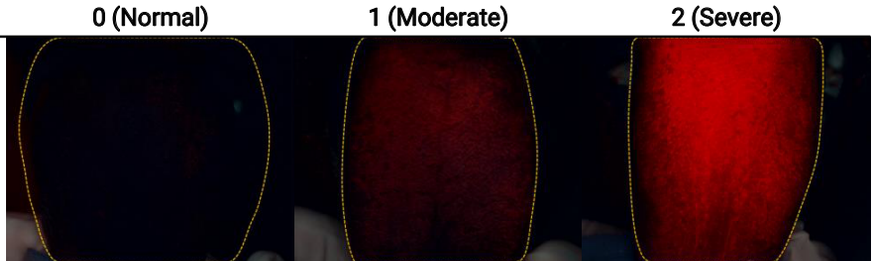
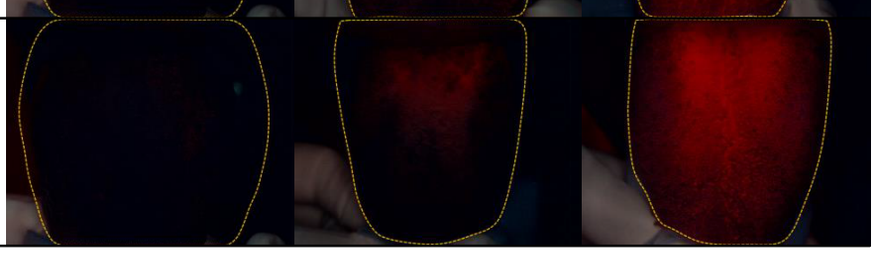
Fluorescence Score	Tongue Biofilm Fluorescence Index (TBFI)		
	0 (Normal)	1 (Moderate)	2 (Severe)
Intensity			
Coverage			
TBFI (Range: 0-4)	Intensity (0-2) × Coverage (0-2)		

Figure 1. Description and fluorescence images of the Tongue Biofilm Fluorescence Index (TBFI).

Key result 2

Table 1. Comparison of inter-rater reliability (kappa coefficient) between two examiners using different scoring systems at follow-up.

	Tongue Coating Index		
	TBFI	WTCI	Oho Index
1st Evaluation	0.778	0.291	0.394
2nd Evaluation	0.725	0.342	0.598
Mean ± SD	0.752 ± 0.027	0.317 ± 0.26	0.496 ± 0.102

TBFI: Tongue Biofilm Fluorescence Index, WTCI: Winkel's Tongue Coating Index.

Plain language summary

The study introduced a novel Tongue Biofilm Fluorescence Index (TBFI) designed to improve the accuracy and reliability of tongue biofilm assessment in elderly patients, overcoming the limitations of traditional methods. Data collected from 81 elderly individuals using Qraycam showed that TBFI provides high inter-examiner reliability and better thickness assessment compared to existing indices like the Winkel's Tongue Coating Index and the Oho Index. TBFI also demonstrated a strong correlation with volatile sulfur compounds (VSCs) levels, particularly hydrogen sulfide, indicating its effectiveness in reflecting biofilm pathogenicity. TBFI shows enhanced reliability and validity and it could enhance real-time assessments with supporting its clinical potential.

Optical detection of oral biofilm in hospitalized geriatric patients using quantitative light-induced fluorescence technology

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Department of Preventive Dentistry & Public Oral Health, BK21 FOUR Project, Yonsei University College of Dentistry, Seoul, Republic of Korea

Objectives

To determine the applicability of Quantitative light-induced fluorescence (QLF) technology for the detection and removal of pathological oral biofilm in hospitalized geriatric patients, specifically the assessment and evaluation of oral hygiene care (OHC).

Case report

An 85-year-old male patient, hospitalized for pneumonia and at high-risk for aspiration, was evaluated using Qraycam Pro (AIOBIO, Seoul, Korea), a clinical diagnostic device based on QLF technology. His oral health was observed visually and then using QLF. The oral hygiene care (OHC) was performed by an experienced dental hygienist, utilizing various methods including moisturizing, mechanical, and chemical oral biofilm control. Post OHC, the oral biofilm was reassessed with QLF. Visually, the patient's oral cavity showed dryness, a severe oral foul odor, and oral secretions combined with biofilm dried on the tooth surface and oral mucosa. However, the exact distribution and thickness of the oral biofilm on soft tissue were not discernible with a visual inspection. Using QLF, red fluorescence, indicating the presence of oral biofilm, was clearly detected on the oral mucosa (Fig. 1). After the application of OHC, which included moisturizing the oral cavity, removal of dried deposits, brushing, and application of saliva substitute, a repeated QLF examination showed a significant reduction in the red fluorescence, suggesting the removal of biofilm. However, certain areas, possibly indicative of calculus or early carious lesions, still exhibited red fluorescence post-OHC (Fig. 2).

Conclusions

QLF technology effectively detects pathological oral biofilm in geriatric patients and can serve as a reliable tool for evaluating the efficiency of oral hygiene care in hospitalized patients with extremely poor oral hygiene. While OHC was efficient in removing most of the biofilm, certain areas, like calculus or early carious lesions, remained challenging.

Key result 1

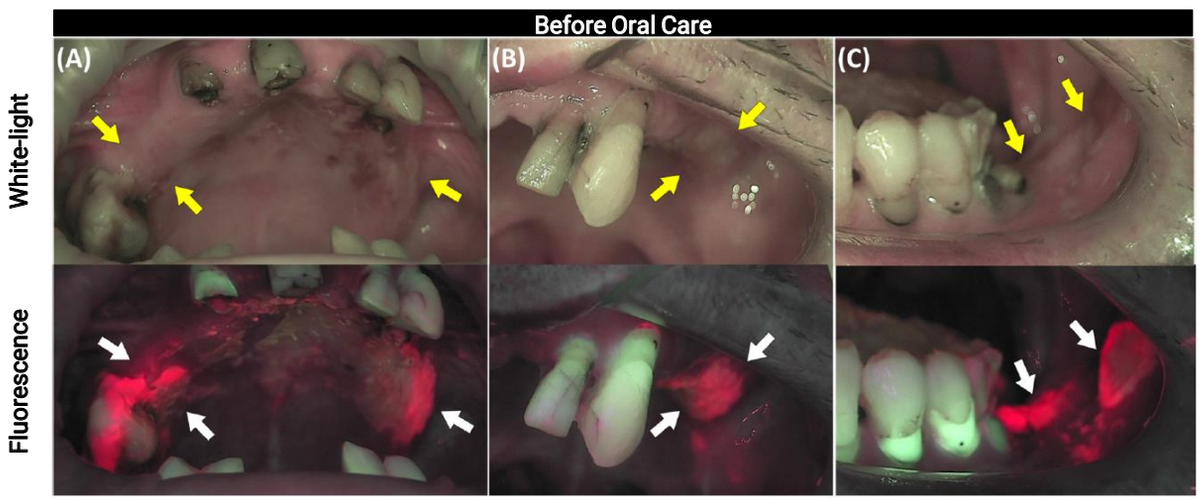

Figure 1. Representative images before oral hygiene care were obtained at the first visit. Dried up oral biofilm (yellow arrows); oral biofilm with red fluorescence (white arrows).

Key result 2

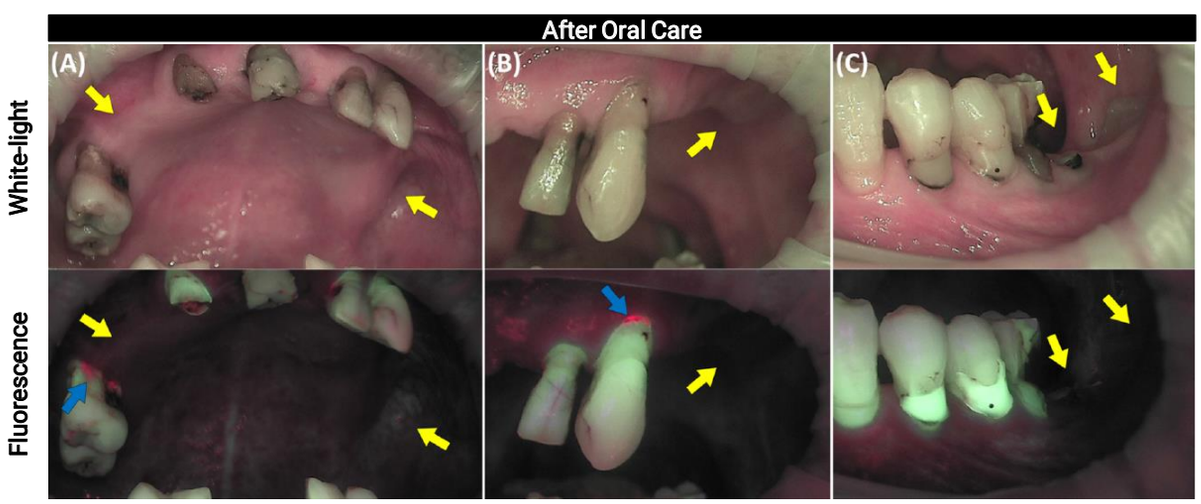

Figure 2. Representative images after oral hygiene care. Removal of dried-up oral biofilm (yellow arrows) and residual red fluorescence (blue arrows).

Plain language summary

This study aimed to assess the suitability of Quantitative light-induced fluorescence (QLF) in detecting and managing pathological oral biofilm in elderly hospitalized patients. An 85-year-old pneumonia patient's oral health was evaluated visually and with QLF technology using Qraycam Pro. Post oral hygiene care (OHC) by a dental hygienist, the biofilm was rechecked with QLF. While visual inspection revealed oral dryness and odor, it couldn't detail the biofilm's distribution and thickness. QLF, however, highlighted the oral biofilm through red fluorescence. After OHC, QLF confirmed significant biofilm reduction. QLF effectively identifies oral biofilm in elderly patients and evaluates oral hygiene care efficiency in hospitalized settings.

Real-time optical detection of endodontic infection using bacterial autofluorescence

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[b] Department of Preventive Dentistry, Academic Centre for Dentistry Amsterdam, Amsterdam, The Netherlands
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[e] Department of Electrical & Electronic Engineering, Yonsei University College of Engineering, Seoul, Korea

Objectives

For successful root canal treatment (RCT), it is essential to objectively assess the presence and activity of bacteria in the root canal system. However, current methods rely on subjective observations of root canal exudates. This study aimed to confirm whether real-time optical detection using bacterial autofluorescence can evaluate endodontic infection status by assessing the red fluorescence (RF) detected from root canal exudates.

Methods

During RCT, endodontic paper points were used to collect root canal exudates scored using conventional organoleptic tests to assess the severity of root canal infections. RF on the paper points was assessed using quantitative light-induced fluorescence (QLF) technology. RF intensity and area from the paper points were quantified, and their correlations with infection severity were assessed using their organoleptic scores. The oral microbiome composition of RF samples was compared with non-red fluorescent (non-RF) samples.

Results

The RF detection rate was nil and >98% in the non-infectious and severe groups. The RF intensity and area significantly increased with infection severity ($p < 0.001$) and showed strong correlations with organoleptic scores ($r = 0.72$, 0.82, respectively). The diagnostic accuracy for detecting root canal infection using RF intensity was good to excellent (AUC = 0.81 - 0.95) and increased with infection severity. The microbial diversity of the RF samples was significantly lower than that of the non-RF samples. Gram-negative anaerobic bacteria such as *Prevotella* and *Porphyromonas* were more predominant in RF samples.

Conclusions

Optical detection using bacterial autofluorescence can objectively evaluate endodontic infection status in real-time by assessing the RF of endodontic root canal exudates.

Clinical significance: This real-time optical technology can be utilised to detect endodontic bacterial infection without conventional incubation, allowing clinicians to determine the endpoint of chemomechanical debridement and increase the positive outcomes of RCTs.

Key result 1

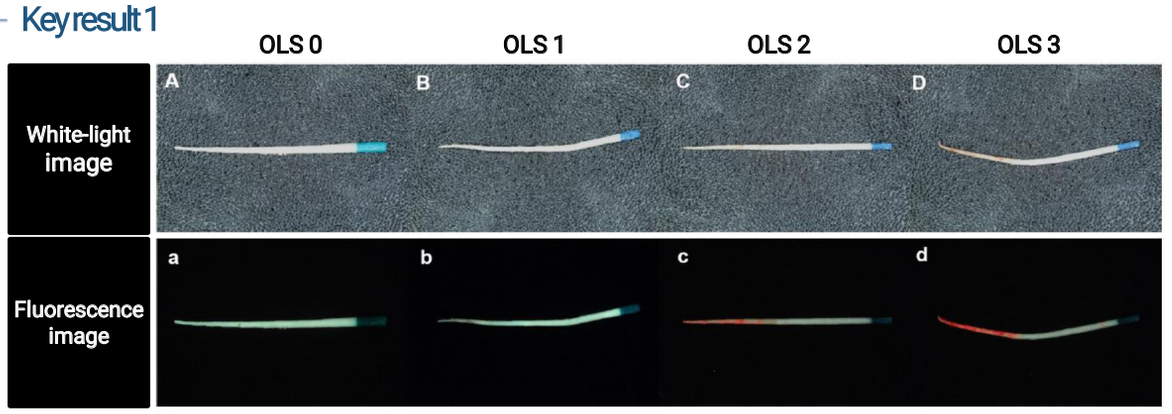

Figure 1. Representative for the collected paper points according to the organoleptic score (OLS).

Key result 2

Table 1. The area under the ROC curve, sensitivity, and specificity for red fluorescence intensity in detecting endodontic infection at each diagnostic threshold categorized by organoleptic score.

Infection severity	AUC	95% CI	p-value
OLS 0/1-3 **Slight**	0.810	0.74-0.87	<0.0001
OLS 0-1/2-3 **Moderate**	**0.917**	**0.86-0.95**	<0.0001
OLS 0-2/3 **Severe**	**0.953**	**0.90-0.98**	<0.0001

AUC, area under the ROC curve; CI, confidence interval; OLS, organoleptic score; ROC, receiver operating characteristic.

Key result 3

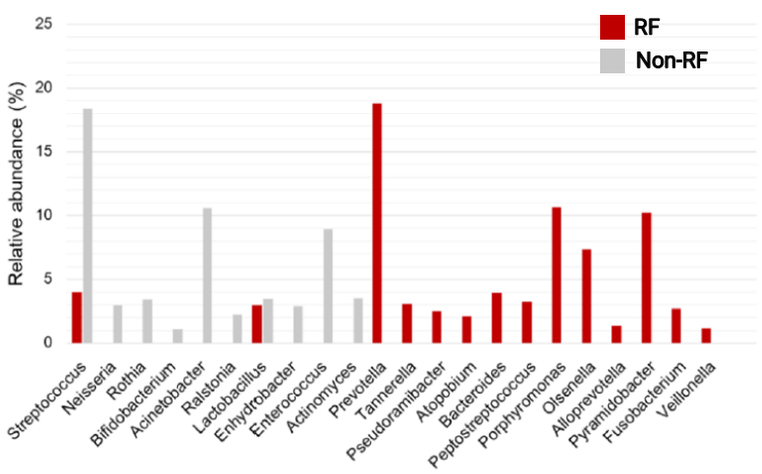

Figure 2. Relative abundance of genus-level communities identified in the RF (red fluorescence) group and non-RF samples.

Plain language summary

For successful root canal treatment (RCT), it's important to accurately understand the bacterial activity inside the root canal. Currently, we judge this by simply looking at the fluids from the canal. This study tested a new method using the autofluorescence of bacteria to see the infection status in real-time. The findings suggest that by examining the red fluorescence from the canal's fluids, we can accurately assess the infection. This method does not need the traditional process of growing bacteria in a lab and can help dentists decide when to stop cleaning and increase the success of RCTs.

The diagnostic efficacy of quantitative light-induced fluorescence in detection of dental caries of primary teeth

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[b] Oral Science Research Center, College of Dentistry, Yonsei University, Seoul, Republic of Korea
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[d] Department of Pediatric Dentistry, Kyung Hee University Dental Hospital, Seoul, Republic of Korea

Objectives

To evaluate a quantitative light-induced fluorescence (QLF) caries detection method using a portable device under clinical conditions and present a QLF scoring index (QS-index) for primary teeth.

Methods

A total of 878 tooth surfaces (proximal and occlusal) of 44 children were studied. After visual inspection and radiographic examination, images of dental caries captured with the QLF device were classified according to caries progression stages and analyzed with a specialized software. The study involved selecting the best-quality QLF images of carious lesions for analysis, which were then categorized by a single examiner, a pediatric dentist, based on QS-Occlusal and QS-Proximal levels. (Fig. 1, 2) For QS-Occlusal, the classifications were as follows: Level 0 (no fluorescence loss or red fluorescence increase in pits and fissures), Level 1 (denoting fluorescence loss and red fluorescence as a line or spot in pits and fissures), Level 2 (characterized by fluorescence loss and a glow of red fluorescence extending around pits and fissures), Level 3 (involving red fluorescence glow around pits and fissures and a dark shadow from dentin). For QS-Proximal, the classifications included: Level 0 (no dark shadow and no red fluorescence), Level 1 (irregular dark shadow but no red fluorescence), Level 2 (faint red fluorescence limited to 1/3 of the bucco-lingual width), and Level 3 (strong red fluorescence covering over 1/3 of the bucco-lingual width). Cut-off values, sensitivity, specificity, and area under the receiver operating characteristic curve (AUROC) were calculated for the QLF parameters: fluorescence loss (ΔF) and bacterial activity (ΔR). The reliability of logistic regression model to combine ΔF and ΔR was evaluated by the AUROC.

Results

Mean values of ΔF and ΔR average increased with an increase in the QS-level. There were significant differences in the QS-levels of all carious lesions ($p < .005$). QLF parameters showed a good sensitivity (0.72–0.91), specificity (0.74–0.96), and AUROC (0.861–0.940). The AUROC of logistic regression model (0.90–0.957) was higher than ΔF or ΔR average alone in all types of carious lesions (Fig. 2) Every level of the QS-index was properly defined to represent the progression of dental caries with corresponding statistical significance.

Conclusions

The reliability of QLF for dental caries detection in primary teeth was similar to or slightly higher than that of the traditional diagnostic methods of visual inspection or radiographic examination in clinical conditions.

Key result 1

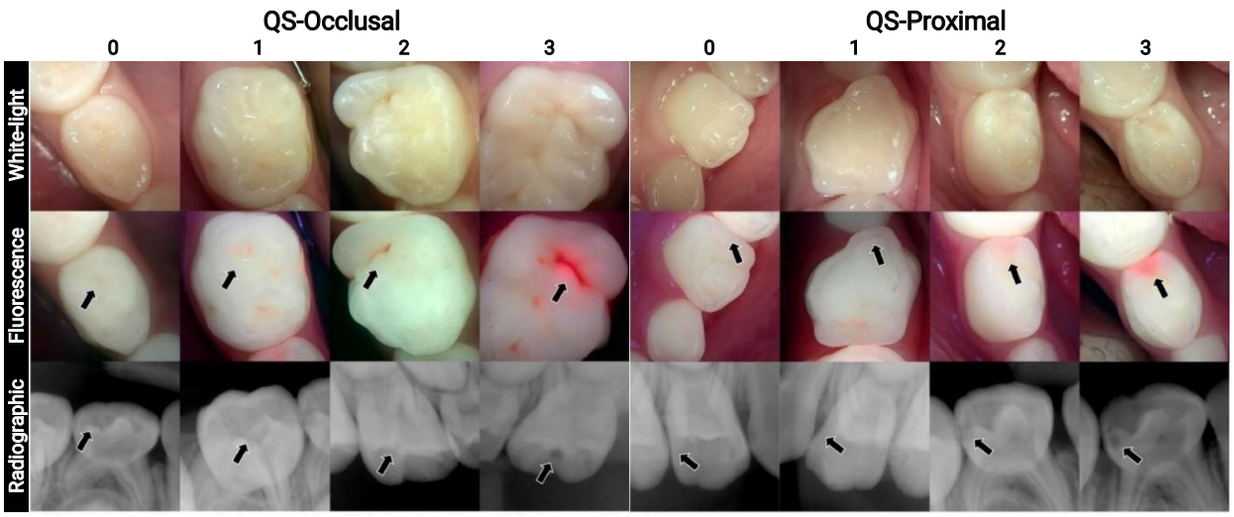

Figure 1. Quantitative light-induced fluorescence score for occlusal caries (QS-Occlusal) and proximal caries (QS-Proximal).

Key result 2

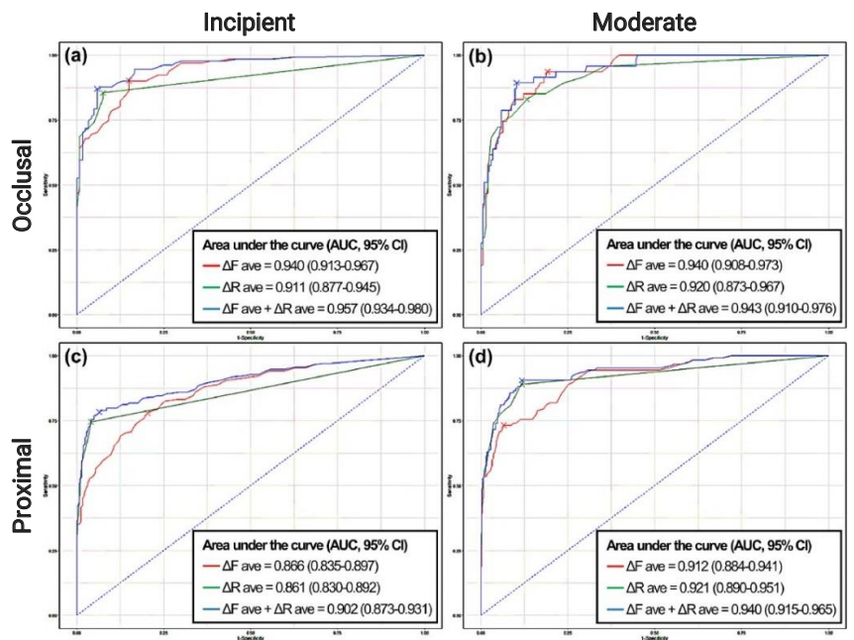

Figure 2. Receiver operating characteristic curves and corresponding AUCs of QLF parameters in dental caries of primary teeth and depth of lesions.
ΔF ave, average ΔF;
ΔR ave, average ΔR;
ΔF ave + ΔR ave, AUCs of logistic regression models for ΔF together with ΔR;
CI, confidence interval.

Plain language summary

Detecting and treating dental caries, especially in primary teeth, is vital in dentistry. Rapid progression in primary teeth necessitates early detection, commonly relying on visual inspection and radiography, which are empirical. Quantitative Light-Induced Fluorescence (QLF) technology offers precise, radiation-free caries diagnosis by detecting fluorescence changes with visible blue light. This study assesses QLF's effectiveness in diagnosing primary teeth caries, applying the QS index to represent caries progression. QLF results (ΔF or ΔR values) and the QS index efficiently depict caries progression. Despite potential challenges in obtaining quality images in children, the portable QLF device provides a safe screening method, enhancing detection efficiency when combined with traditional approaches.

A new screening method to detect proximal dental caries using fluorescence imaging

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[a] Department of Preventive Dentistry & Public Oral Health, BK21 PLUS Project, Yonsei University College of Dentistry, Seoul, Republic of Korea
[b] Department of Health Services Research, University of Liverpool, Liverpool, United Kingdom
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[d] Oral Science Research Institute, Yonsei University College of Dentistry, Seoul, Republic of Korea

Objectives

This study aimed to assess the screening performance of the quantitative light-induced fluorescence (QLF) technology to detect proximal caries using both fluorescence loss and red fluorescence in a clinical situation. Moreover, a new simplified QLF score for the proximal caries (QS-Proximal) is proposed and its validity for detecting proximal caries was evaluated as well.

Methods

This clinical study included 280 proximal surfaces, which were assessed by visual-tactile and radiographic examinations and scored by each scoring system according to lesion severity. The occlusal QLF images were analysed in two different ways: (1) a quantitative analysis producing fluorescence loss (ΔF) and red fluorescence (ΔR) parameters; and (2) a new QLF scoring index. For both quantitative parameters and QS-Proximal, the sensitivity, specificity, and area under the receiver operating characteristic curve (AUROC) were calculated as a function of the radiographic scoring index at the enamel and dentine caries levels.

Results

The QS-Proximal was determined by the degree of fluorescence loss and red autofluorescence according to the severity of the lesion, which was categorized into 4 grades (Q_0–Q_3) as follows: no dark shadow and no red fluorescence (Q_0), an irregular dark shadow but no red fluorescence (Q_1), faint red fluorescence limited to 1/3 of the buccolingual width (Q_2), and strong red fluorescence over 1/3 of the buccolingual width (Q_3) (Figure 1). For detecting dentine caries, both the Q_0/Q_1 (0.864, 95% CI: 0.810–0.919) and Q_1/Q_2 (0.826, 95% CI: 0.753–0.900) thresholds showed excellent AUROC values, whereas V_2/V_3 (0.736, 95% CI: 0.652–0.821) showed a relatively lower value (Table 1).

Conclusions

The QS-Proximal, which represents fluorescence changes, showed excellent performance in detecting proximal caries using the radiographic score as the gold standard.

Key result 1

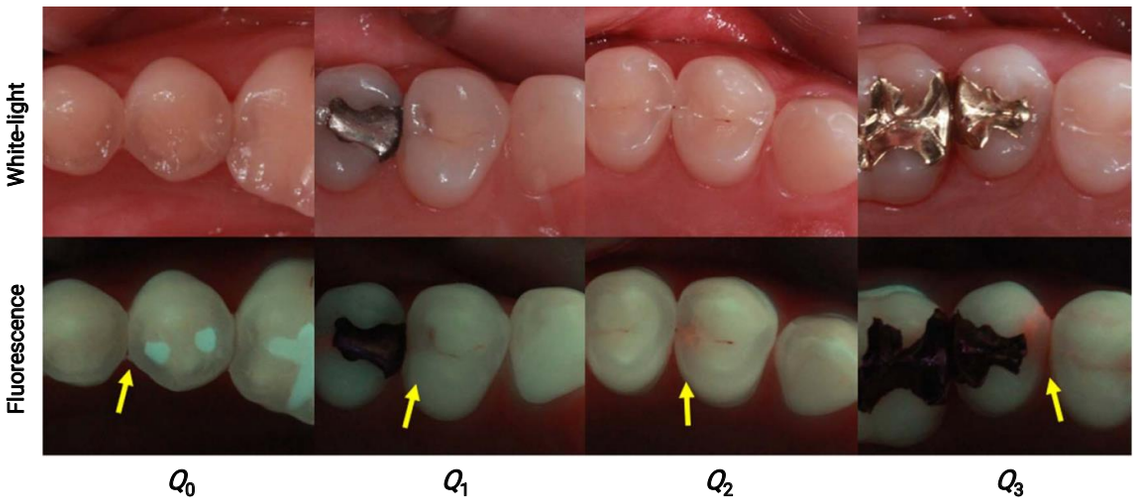

Figure 1. QLF score for proximal caries (QS-Proximal). Q_0: No fluorescence change. Q_1: An irregular dark shadow but no red fluorescence. Q_2: Faint red fluorescence limited to 1/3 of the buccolingual width. Q_3: Strong red fluorescence over 1/3 of the buccolingual width. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Key result 2

Table 1. The sensitivity, specificity, and AUROC value of the QLF score (QS-Proximal) and visual score at different cut-off thresholds (Q_0/Q_1, Q_1/Q_2) to detect proximal caries at the dentine level (R_{0-2}/R_{3-5}) measured by radiographic scores.

	QLF score (QS-Proximal)	
	Q_0/Q_1	Q_1/Q_2
Sensitivity	0.894	0.702
Specificity	0.834	0.951
AUROC (95% CI)	0.864 (0.810-0.919)	0.826 (0.753-0.900)

AUROC, area under the receiver operating characteristic curve; CI, confidence interval.

Plain language summary

Most proximal dental caries start below the proximal contact point, so they are difficult to detect visually. Another common diagnostic method, bitewing radiography (BR), showed better performance than visual inspection in detecting dentine caries on proximal surfaces. However, according to American Dental Association (ADA) guidelines, radiographic examinations should not be performed for screening purposes; they should be performed on an individual basis to minimize side effects from radiation exposure. In this study, we aimed to develop a new simplified QLF score for the proximal caries (QS-Proximal) and its validity for detecting proximal caries was evaluated as well. Both quantitative parameters (ΔF, ΔR) and the QS-Proximal which is a clinical classification system for proximal caries detection showed high clinical validity at the dentine level. It is postulated that the QLF technology can be used as a screening tool prior to radiographic examination.

Dental Caries: Permanent Teeth (Enamel Caries)

Development of a fluorescence-image scoring system for assessing noncavitated occlusal caries

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Objectives

This study aimed (1) to develop a scoring system based on a quantitative light-induced fluorescence (QLF) score for the occlusal caries (QS-Occlusal) that standardizes the fluorescence properties of noncavitated lesions from QLF images, (2) to confirm the validity and reliability of QS-Occlusal, and (3) to determine whether it is possible to replace existing clinical examinations by image evaluations based on the developed QS-Occlusal for assessing occlusal caries lesions.

Methods

This clinical study investigated 791 teeth of 94 subjects. The teeth were assessed by visual and tactile examinations using ICDAS criteria and quantitative light-induced fluorescence-digital (QLF-D) image examinations. QS-Occlusal was divided into four stages (from 0 to 3) based on the progression level of the lesion and the fluorescence loss and red fluorescence on captured QLF-D images (Figure 1). The maximum loss of fluorescence ($|\Delta F_{max}|$) and the maximum change in the ratio of red and green fluorescence (ΔR_{max}) were quantitatively analyzed by the QA2 software. The modalities were compared in terms of sensitivity, specificity, and area under the receiver operating characteristics (AUROC) curve for three different thresholds of the ICDAS codes: 0 vs 1–4 (D1), 0–2 vs 3/4 (D2), and 0–3 vs 4 (D3).

Results

At the D1 diagnostic threshold (ICDAS code 0 vs 1–4), the optimum sensitivity and AUROC (0.807) were obtained using a QS-Occlusal cutoff value of 0/1, for which a moderate specificity (0.563) was obtained. At the D2 diagnostic threshold (ICDAS code 0–2 vs 3/4), an excellent AUROC (0.929) was obtained using a QS-Occlusal cutoff value of 1/2. At the D3 diagnostic threshold (ICDAS code 0–3 vs 4), QS-Occlusal exhibited the highest sensitivity, specificity, and AUROC (0.976) (Table 1).

Conclusions

The QS-Occlusal proposed in this study can be used in the clinical detection of noncavitated lesions with an excellent diagnostic ability. This makes it possible to replace clinical examinations and intuitively evaluate the lesion severity and status relatively easily and objectively by applying this scoring system to fluorescence images.

Key result 1

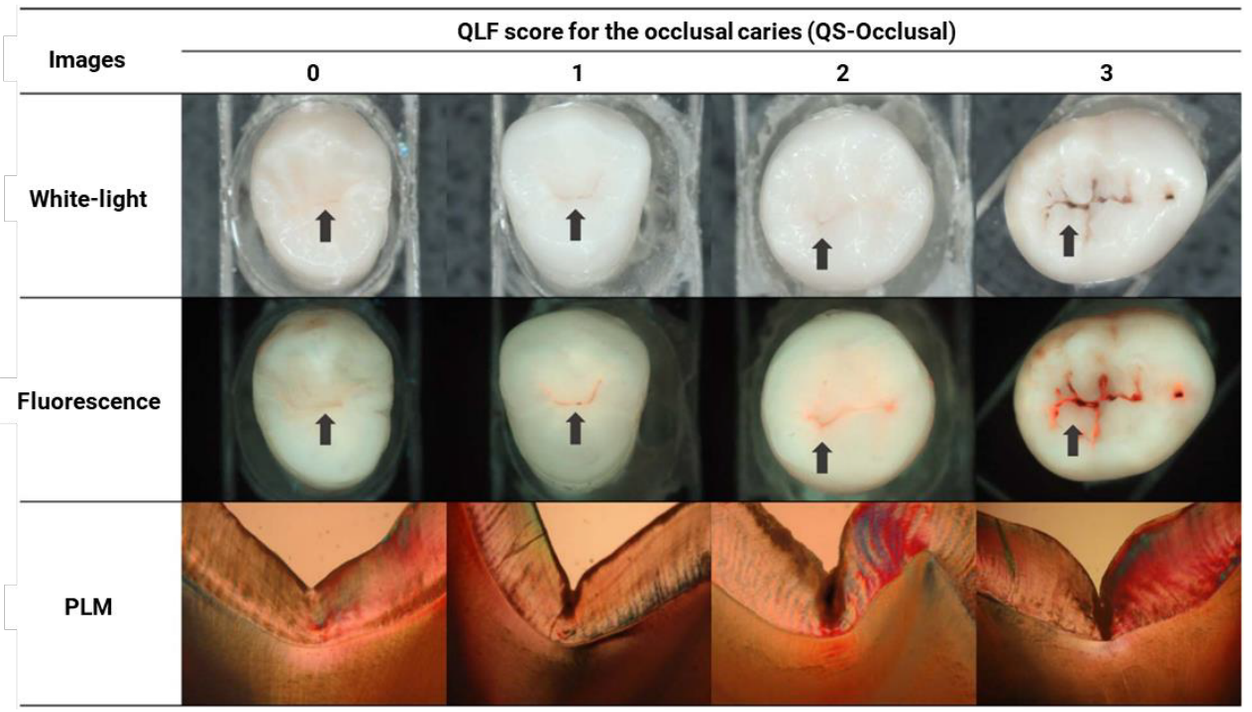

Figure 1. Representative images of occlusal surfaces according to QS-Occlusal obtained from QLF-D (white-light and fluorescence images) and polarized-light microscopy (PLM).

Key result 2

Table 1. Sensitivity, specificity, and AUROC curve of QS-Occlusal for each diagnostic division according to the lesion severity classified using ICDAS criteria.

	Diagnostic thresholds		
	D_1	D_2	D_3
Cutoff value	0/1	1/2	2/3
Sensitivity	0.895	0.912	0.977
Specificity	0.563	0.839	0.957
AUROC	0.807	0.929	0.976

D_1, 0 vs 1-3; D_2, 0-2 vs 3/4; D_3, 0-3 VS 4.

Plain language summary

Clinical signs usually appear in the visual and radiographic examinations that are commonly used for detecting caries lesions, but only after a lesion has progressed considerably into the dentin due to the anatomical structure of the lesion going downward from the pits and fissures in occlusal caries. The QLF technology is an adjunctive technique that can detect minute changes in teeth based on the tooth autofluorescence produced during irradiation with 405-nm visible blue light. In this study, the newly proposed QS-Occlusal parameter divides the caries depth into four stages according to standardized fluorescence changes detectable using QLF technology). Excellent validity and reliability were observed based on ICDAS results, which are commonly used to assess the clinical severity of caries, and on comparisons with histological test results. The findings confirm the possibility of assessing occlusal noncavitated lesions using fluorescence images.

Caries detection and quantification around stained pits and fissures in occlusal tooth surfaces with fluorescence

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Objectives

This study aimed to evaluated whether the QLF technology would be useful for detecting cariogenic discoloration (CD) based on the quantitative analysis of questionable occlusal caries due to stained pit and fissure areas, with the aim of distinguishing CD due to the process of demineralization and bacterial metabolism from noncariogenic discoloration (non-CD).

Methods

The QLF–digital Biluminator™ 2+ (QLF-D; Inspektor Research Systems BV, Amsterdam, The Netherlands) was used to evaluate the discoloration of the occlusal pit and fissure areas (Figure 1). The maximum values of fluorescence loss (ΔF_{max}) and red fluorescence gain (ΔR_{max}) were calculated using QLF images. The PLM images were histologically assessed for the presence and severity of caries lesion as follows: no enamel demineralization or a narrow surface zone of opacity (scored as 0), enamel demineralization limited to the outer 50% of the enamel layer (scored as 1), demineralization involving the inner 50% of enamel up to the DEJ (scored as 2), and demineralization involving the outer 50% of the dentine (scored as 3).

Results

62 teeth were finally analyzed. Designating all enamel and dentine lesions as disease-positive (histological score > 0) resulted in 12 teeth being sound with non-CD and 50 teeth having caries showing CD. Among the 50 lesions with CD, 43 teeth had caries within the enamel and 7 teeth had dentine caries. The $|\Delta F_{max}|$ and ΔR_{max} values were higher for deeper lesions. the optimum cutoff values of $|\Delta F_{max}|$ and ΔR_{max} were 75.0 and 105.0, respectively. Comparing the sensitivity and specificity of each QLF parameter, the sensitivity of ΔR_{max} (0.96) was higher than that of $|\Delta F_{max}|$ (0.80), while the specificity of $|\Delta F_{max}|$ (0.92) was higher than that of ΔR_{max} (0.83). The AUROC was higher for ΔR_{max} (0.94) than for $|\Delta F_{max}|$ (0.91) (Figure 2).

Conclusions

This study found significant differences in the red fluorescence parameters of non-CD and CD, with QLF being demonstrably useful for distinguishing non-CD from CD surfaces in teeth with high validity in relation to occlusal caries.

Key result 1

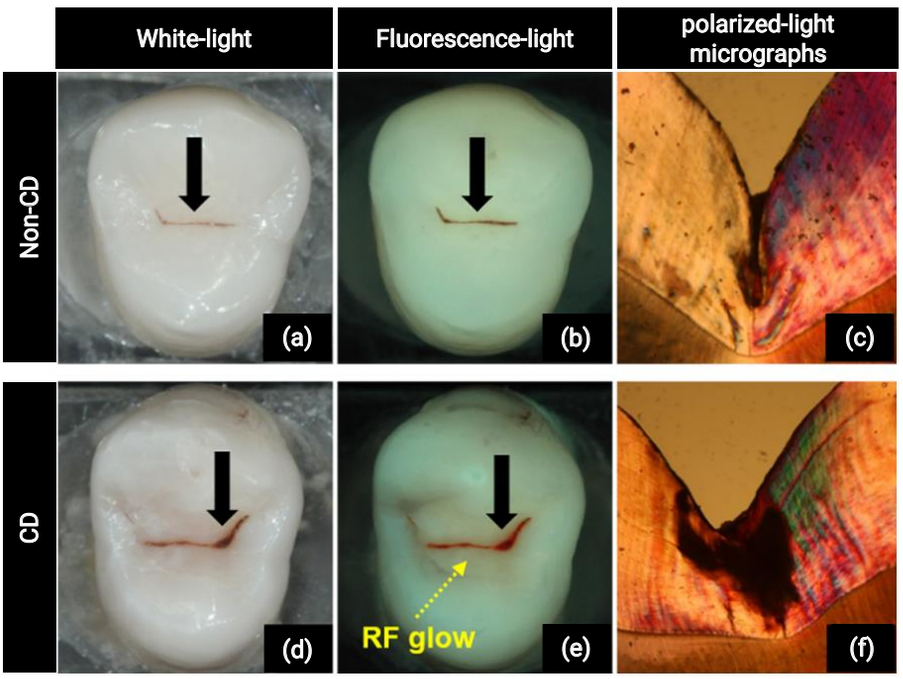

Figure 1. Images obtained using the QLF-D under different lighting conditions, and the respective polarized-light micrographs (magnification ¼ 40×). Non-CD, noncariogenic discoloration; CD, cariogenic discoloration. RF glow, red fluorescence (RF) glow around the discolored fissure. Black arrows indicate the point of sectioning.

Key result 2

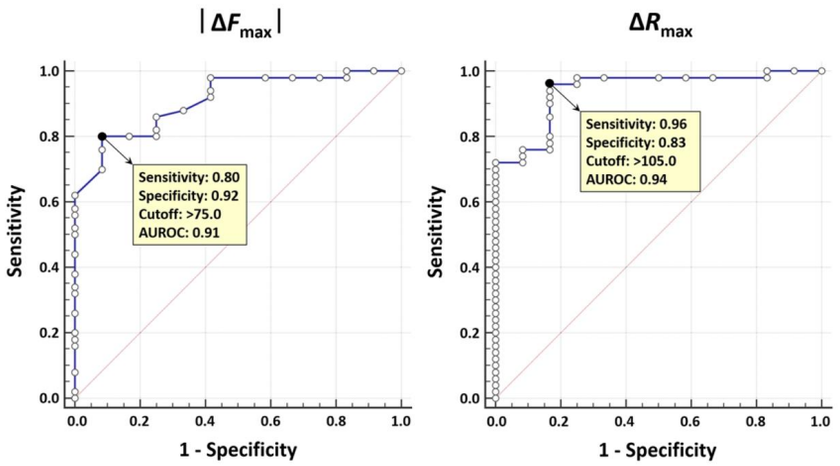

Figure 2. ROC curves of QLF parameters (ΔF_{max} and ΔR_{max}) at the enamel histological caries level to distinguish between non-CD (histological score = 0) and CD (histological score > 0).

Plain language summary

Pit and fissure discoloration is one of the factors that can affect decision-making in the diagnosis of occlusal caries, but using such discoloration as a diagnostic criterion is still controversial. most dental clinicians encounter the diagnostic dilemma of deciding whether or not they should remove discolored tissues due to the difficulty of obtaining sufficient evidence about the discoloration of pits and fissures in all clinical situations. In this study, found significant differences in the red fluorescence parameters of non-CD and CD, with QLF being demonstrably useful for distinguishing non-CD from CD surfaces in teeth with high validity in relation to occlusal caries. It can be concluded that QLF can be a useful tool for the differential diagnosis of discolored occlusal tooth surfaces. Future clinical validations may reveal that QLF technology can provide dental clinicians with meaningful information for diagnosing occlusal caries.

Dental Caries: Permanent Teeth (Enamel Caries)

Evaluation of dental caries detection with quantitative light-induced fluorescence in comparison to different field of view devices

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Objectives

This study evaluated the clinical applicability of Qraypen C® (QC) as a screening tool to detect dental caries through quantitative evaluation through fluorescence loss (ΔF) and red fluorescence (ΔR) parameters compared to the Qraycam Pro® (QP), which could be evaluated relatively precisely for the same dental carious lesion.

Methods

A total of 178teeth from 61patients were imaged using QC and QP devices and evaluated using analysis software (QA2) (Figure 1). Occlusal, secondary, and proximal dental caries were evaluated and scored according to International Caries Detection and Assessment System (ICDAS II) and X-ray criteria. Bland–Altman plots were used to compare quantitative light-induced fluorescence (QLF) parameters obtained from the different QLF devices. Sensitivity, specificity, and area under the receiver operating characteristic curve (AUROC) were calculated.

Results

Evaluation of the cut-off values and validity of the QLF parameters for diagnosing occlusal dental caries revealed an accuracy of 0.83–0.96, and an area under the receiver operating characteristic curve (AUROC) of 0.92–0.99 for the QC and 0.81–82 and 0.87–0.94, respectively, for the QP. Evaluation of the cut-off values and validity of the QLF parameters for diagnosing secondary dental caries showed an accuracy of 0.75 and AUROC of 0.90 for the QC and 0.89 and 0.82, respectively, for the QP. Evaluation of the cut-off values and validity of the QLF parameters for diagnosing proximal dental caries revealed an accuracy of 0.52–0.62, and an AUROC of 0.60–0.67 for the QC and 0.52–0.71 and 0.56–0.64, respectively, for the QP (Table 1).

Conclusions

The $\Delta F_{aver.}$ obtained from the QP showed diagnostic value mainly for screening of demineralized teeth. For teeth selected through screening, the depth of the lesion must be precisely evaluated using additional QP and radiographic imaging.

Key result 1

Table 1. Cut-of values and validity of QLF parameters for detecting occlusal, secondary, and proximal dental caries.

	Diagnostic thresholds	QLF parameters		Cut-off value	Sensitivity	Specificity	Accuracy	AUROC
Occlusal caries	D1	QC	$\|\Delta F_{aver.}\|$	12.90	0.89	0.75	0.83	0.92
		QP	$\|\Delta F_{aver.}\|$	13.40	0.91	0.68	0.81	0.87
	D2	QC	$\|\Delta F_{aver.}\|$	21.40	1.00	0.96	0.96	0.99
		QP	$\|\Delta F_{aver.}\|$	08.20	0.92	0.81	0.82	0.94
Secondary caries	D1	QC	$\|\Delta F_{aver.}\|$	13.10	0.74	0.80	0.75	0.90
		QP	$\|\Delta F_{aver.}\|$	13.90	0.96	0.60	0.89	0.82
Proximal caries	D1	QC	$\|\Delta F_{aver.}\|$	10.40	0.62	0.62	0.62	0.67
		QP	$\|\Delta F_{aver.}\|$	13.60	0.38	0.75	0.52	0.56
	D2	QC	$\|\Delta F_{aver.}\|$	14.30	0.00	0.79	0.52	0.60
		QP	$\|\Delta F_{aver.}\|$	11.00	0.57	0.79	0.71	0.64

Quantitative light-induced fluorescence (QLF), Qraycam Pro® (QP), Qraypen C® (QC).

Key result 2

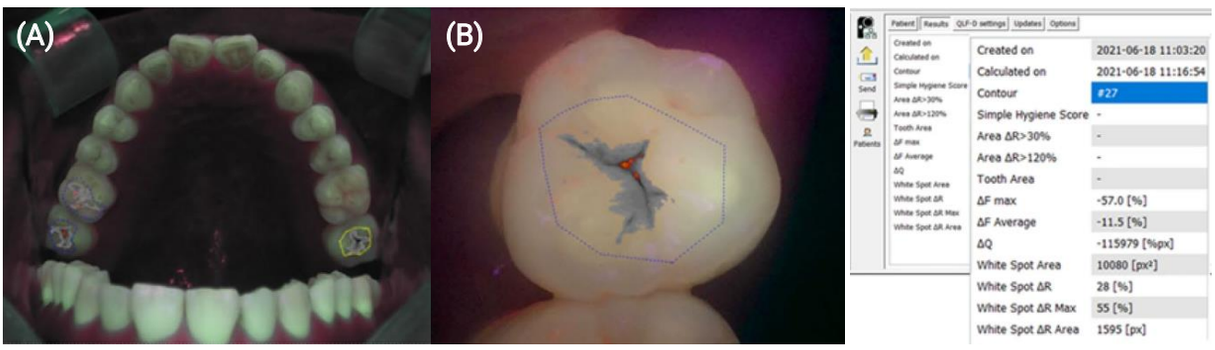

Figure 1. QA2 program provides the QLF parameters (ΔF_{max}, $\Delta F_{aver.}$, ΔR_{max}, $\Delta R_{aver.}$) of the area of interest (AOI); (A, B) Quantitative analyses of QP and QC images, respectively.

Plain language summary

The QLF technique can quantitatively evaluate minute changes in teeth based on autofluorescence that occurs when irradiated with 405 nm visible blue light. The loss of fluorescence detected in teeth was highly correlated with the loss of minerals within the lesion, which can be used to effectively detect and monitor minute changes in demineralization/remineralization in early carious lesions without cavities. Various types of devices using the QLF technology have been developed. In this study, evaluated dental caries detection ability between the Qraycam and Qraypen on the same dental caries lesions. the mean value of F ($\Delta F_{aver.}$) obtained from the Qraycam device showed diagnostic value mainly for the screening demineralized teeth. For teeth selected through screening, the depth of the lesion must be precisely evaluated using the Qraypen device and radiographic imaging.

Quantitative assessment of early caries lesion activity using novel dye-enhanced fluorescence imaging

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Objectives

This study aimed to evaluate the validity of the dye-enhanced quantitative light-induced fluorescence (DEQLF) method for assessing early enamel caries activity.

Methods

Seventy extracted human teeth with early enamel caries on smooth surfaces were included. The teeth were hydrated with distilled water for 60 s, dehydrated with compressed air for 10 s, and stained with 100μM fluorescein sodium solution for 10s. White and fluorescent images were captured using a QLF-D 2+ Billuminator. The change in fluorescence (ΔΔG) was calculated using image analysis software. Independent-sample t-tests were performed to evaluate the difference in ΔΔG between active and inactive lesions for both DEQLF and conventional quantitative light-induced fluorescence (QLF) methods. Receiver operating characteristic (ROC) curve analysis was used to assess the validity of ΔΔG for distinguishing lesion activity using the area under the ROC curve (AUROC).

Results

Among the 70 caries lesions, 33 were active and 37 were inactive (Fig. 1). Regardless of activity status, all lesions exhibited significantly darker fluorescence in the dried state than in the wet state (Fig. 1B, b). After applying the dye, active lesions showed brighter fluorescence due to dye penetration around the lesions (Fig. 1C), whereas no change in fluorescence was observed in inactive lesions (Fig. 1c). In terms of validity in distinguishing lesion activity, DEQLF-derived ΔΔG values demonstrated a moderate level of validity with AUROC of 0.72 at a cut-off value of > 1.47 (sensitivity, 0.67; specificity, 0.76; Fig. 2A). In contrast, the ΔΔG obtained from the QLF method showed lower validity compared to that of ΔΔG obtained from DEQLF, with an AUROC of 0.55 at a cutoff value of < -0.57 (sensitivity, 0.70; specificity, 0.46; Fig. 2B).

Conclusions

Applying the DEQLF method to human teeth enabled the quantitative assessment of lesion activity based on dye penetration. DEQLF-derived ΔΔG values showed significant differences based on lesion activity status and demonstrated high validity in distinguishing lesion activity.

Key result 1

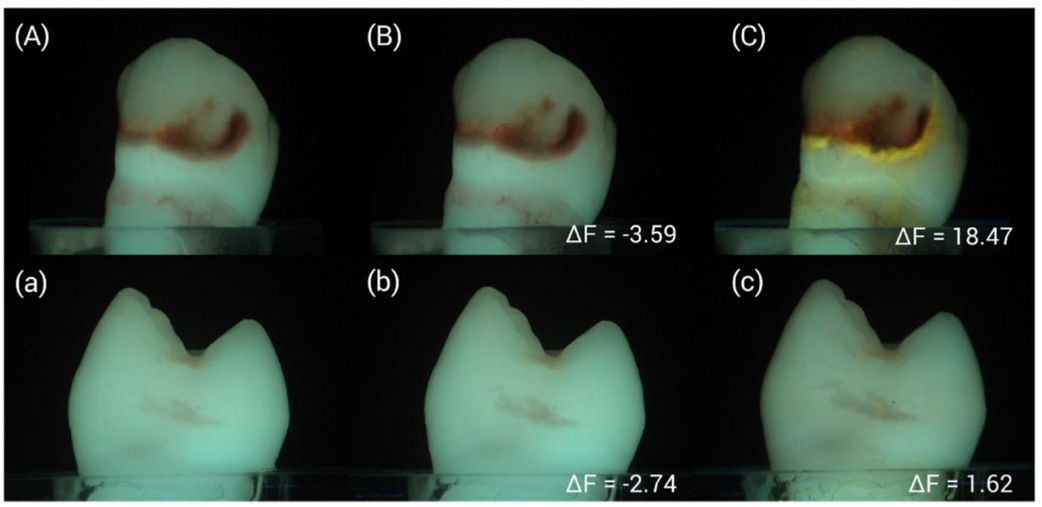

Figure 1. Representative fluorescent images of specimens with active (A-C) and inactive (a-c) caries lesions at different experimental stages: before air-drying (A, a), after air-drying (B, b), and after dye-penetration in the dried state (C, c).

Key result 2

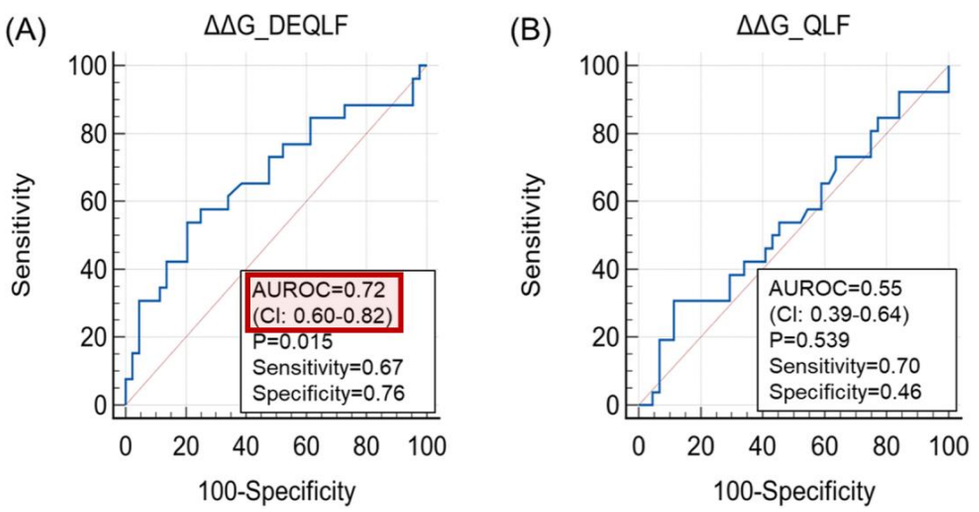

Figure 2. ROC curves of the fluorescence parameters derived from DEQLF (A) and QLF (B) for differentiating active and inactive early enamel caries lesions.

Plain language summary

This study tested the dye-enhanced quantitative light-induced fluorescence (DEQLF) method to evaluate early enamel caries activity. By analyzing 70 extracted teeth, researchers found that DEQLF could better differentiate between active and inactive caries compared to the conventional QLF method. Active caries showed significantly higher fluorescence changes (ΔΔG) than inactive ones. The DEQLF method achieved a moderate accuracy for detecting active lesions (AUROC = 0.72) with good sensitivity and specificity. This suggests that DEQLF is a promising tool for objectively assessing caries activity in clinical practice, outperforming traditional methods.

Validity assessment of a third-generation light-induced fluorescence device in detecting proximal and occlusal caries lesions: A cross-sectional study

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Objectives

The objective of this study was to evaluate the efficacy of a quantitative light-induced fluorescence (QLF) device (QrayCam Pro, AIOBIO, Seoul, Republic of Korea) in detecting and differentiating the severity of posterior proximal and occlusal primary caries.

Methods

The study included a total of 120 teeth in 60 patients (of both genders, aged between 21 and 38 years), one carious tooth and one sound tooth were selected at random in each patient. All occlusal surfaces were evaluated in accordance with the International Caries Detection and Assessment System (ICDAS), Nyvad Criteria, using the visual tactile method. Addionally, the depth of the proximal lesions was scored (0–6) using bite-wing radiography and score system was applied to record the QLF score (QS score) of the occlusal surfaces and proximal surfaces (Fig. 1). The quantitative values representing the maximum loss of fluorescence (ΔF_{max}) and the maximum change in the ratio of red and green fluorescence (ΔR_{max}) were obtained using the Q-ray Clinical software v 1.45. To assess the validity, the sensitivity, specificity, and area under the receiver operating characteristics curve (AUROC) were calculated. Spearman correlation coefficient was used to investigate the correlation between the findings of the traditional and QLF examination methods.

Results

The occlusal caries lesions, for ΔFmax, a cut-off value of less than or equal to -34 resulted in an 84% sensitivity, a 100% specificity, and an AUROC of 0.946. For ΔR_{max}, a cut-off value greater than 0 resulted in a sensitivity of 92%, a specificity of 96%, and an AUROC of 0.942 (Table 1). The proximal caries lesions, for ΔF_{max}, a cut-off value of less than or equal to -25 was found to result in a sensitivity of 88%, a specificity of 100%, and an AUROC of 0.969. For ΔR_{max}, a cut-off value of greater than 0 resulted in a sensitivity of 92%, a specificity of 100%, and an AUROC of 0.929 (Table 1).

Conclusions

This study shows that QrayCam Pro can be used as a reference and a screening tool with a good validity in early diagnosis but it's still technique sensitive and requires specific environment and criteria to achieve better diagnosis.

Key result 1

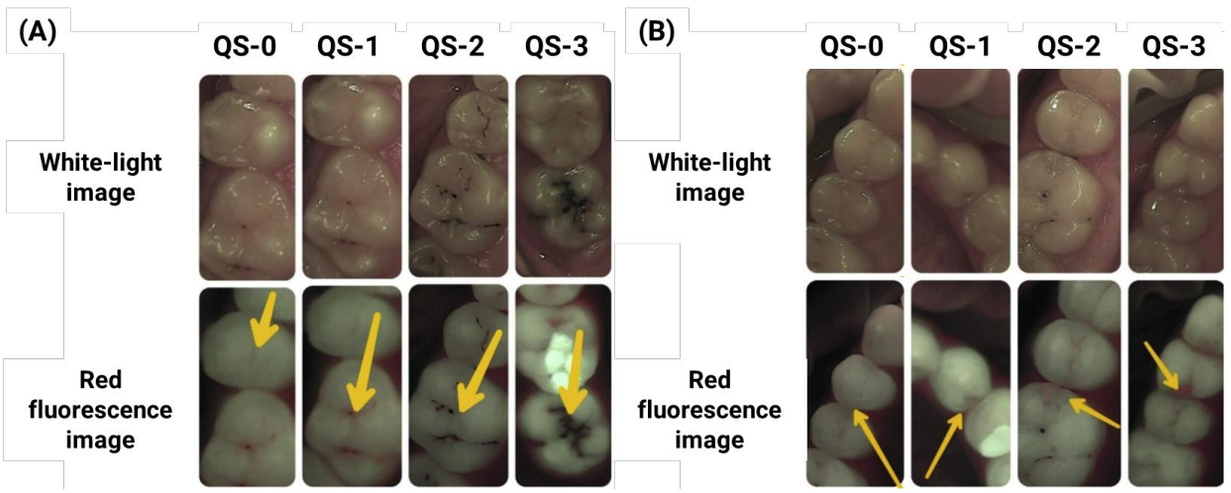

Figure 1. QS Scoring System for Occlusal and Proximal Surfaces. Occlusal score: Levels 0-3 based on fluorescence loss and red fluorescence patterns in pits and fissure (A), Proximal score: Levels 0-3 based on red fluorescence intensity and distribution across Bucco-lingual width (B)

Key result 2

Table 1. Sensitivity, specificity, and area under the receiver operating characteristic curve (AUROC) for QLF parameters in detecting occlusal caries lesions and proximal caries lesions.

	Occlusal caries lesions		**Proximal caries lesions**	
	ΔF_{max}	**ΔR_{max}**	**ΔF_{max}**	**ΔR_{max}**
Cut-off	< -34	> 0	≤ -25	> 0
Sensitivity (% 95 CI)	84 (63.9-95.4)	92 (73.9-98.8)	88 (73.2-96.7)	92 (73.9-98.8)
Specificity (% 95 CI)	100 (86.2-100)	96 (79.6-99.3)	100 (89.9-100)	100(89.9-100)
AUROC (% 95 CI)	0.946 (0.843-0.989)	0.942 (0.838-0.988)	0.969 (0.897-0.995)	0.929 (0.841-0.976)

AUROC, area under the receiver operating characteristic curve; CI, confidence interval.

Plain language summary

This study aimed to test how well the QrayCam Pro, a device that uses light-induced fluorescence, can detect and measure the severity of tooth caries on back teeth. The device measured changes in fluorescence to identify caries. Results showed it was highly accurate, with sensitivity (ability to detect caries) up to 92% and specificity (ability to correctly identify healthy teeth) up to 100%. The study concluded that QrayCam Pro provides reliable data for early diagnosis and treatment decisions, but requires proper technique and conditions for best results.

Red fluorescence intensity as a criterion for assessing remineralization efficacy in early carious lesions

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Objectives

This study aimed to evaluate the red fluorescence intensity (ΔR) measured using a quantitative light-induced fluorescence-digital (QLF-D) device as a criterion for assessing the activity of early carious lesions and predicting the efficacy of fluoride-based remineralization treatments.

Methods

A total of 44 non-cavitated carious lesions from extracted premolars and molars were classified into active (ΔR ≥ 37.55) and inactive (ΔR < 37.55) groups based on red fluorescence intensity (ΔR). Each lesion was treated with 1.23% fluoride gel for 60 seconds and stored in artificial saliva at 37˚C for 7 days, with daily saliva replacement. Changes in red fluorescence (ΔR) and fluorescence loss (ΔF) were measured at baseline and on days 1, 3, 5, and 7 using a QLF-D camera to evaluate the progression of remineralization.

Results

Active lesions exhibited a more pronounced reduction in red fluorescence emission rate (ΔR) and a steeper increase in fluorescence loss (ΔF) over time compared to inactive lesions (p < 0.001). These time-dependent changes highlight the greater responsiveness of active lesions to fluoride treatment (Fig. 1). By day 7 after fluoride application, the ΔR reduction rate in active lesions was 1.4 times higher (21.72 ± 13.86) compared to inactive lesions (15.56 ± 18.04), though this difference was not statistically significant (Table 1). The ΔF recovery rate in active lesions was 2.5 times higher (32.06 ± 16.55) compared to inactive lesions (12.83 ± 15.29), with a statistically significant difference (Table 1).

Conclusions

This study highlighted the significance of ΔR in predicting remineralization efficiency in non-cavitated carious lesions after fluoride application. It underscored the importance of accurately assessing caries activity when formulating effective treatment plans. Lesion activity, as determined by ΔR, not only influences the outcome of remineralization treatments but also provides a more objective measure for tailoring caries management strategies.

Key result 1

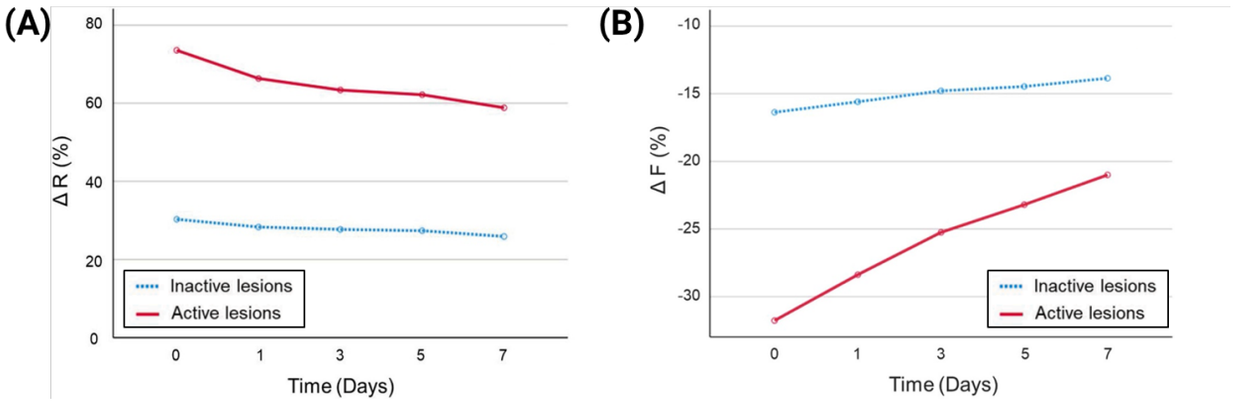

Figure 1. Change in red fluorescence emission rate (ΔR) (A) and fluorescence loss (ΔF) (B) in active and inactive lesions over 7 days.

Key result 2

Table 1. Rate of reduction of red fluorescence emission rate and rate of recovery of fluorescence loss on non-cavitated lesions according to carious lesion activity†

	Group						
	Active (N=22)	Inactive (N=22)	*p*-value		Active (N=22)	Inactive (N=22)	*p*-value
ΔR_0	73.56 ± 29.83	30.28 ± 8.80	< 0.001	ΔF_0	−31.76 ± 8.52	−16.36 ± 6.44	
ΔR_7	58.85 ± 29.08	25.89 ± 9.52		ΔF_7	−21.00 ± 5.60	−13.85 ± 5.04	< 0.001
Reduction rate	21.72 ± 14.38	15.56 ± 18.04	0.205	Recovery rate	32.06 ± 16.55	12.83 ± 15.29	

Data are presented as mean ± standard deviation.
†Carious lesion activity was classified by ΔR of 37.55.
‡*p*, all values were obtained by independent *t*-test.
ΔR_0 represents the baseline red fluorescence emission rate and ΔR7 represents the red fluorescence emission rate at 7 days after fluoride application.
ΔF_0 represents the baseline fluorescence loss and ΔF7 represents the fluorescence loss at 7 days after fluoride application.

Plain language summary

This study evaluated the use of red fluorescence intensity (ΔR) to measure the activity of early carious lesions and predict fluoride treatment effectiveness. A total of 44 non-cavitated lesions were analyzed, classified as active or inactive based on ΔR values. Changes in ΔR and fluorescence loss (ΔF) were tracked over 7 days of fluoride treatment. The findings showed that active lesions responded better, with a 1.4 times higher reduction in ΔR and a 2.5 times greater recovery in ΔF compared to inactive lesions. These results demonstrate that ΔR is a useful tool for assessing lesion activity and guiding effective caries management strategies.

Optical diagnosis of dentin caries lesions using quantitative light-induced fluorescence technology

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Objectives

This study aimed to identify the extent of dentin lesions by using Qraypen (AIOBIO, Seoul, Korea), a device that utilizes QLF technology, at the dentin level through representative case in this study.

Case report

Case:

A 29-year-old male patient visited the hospital complaining of cavities in his lower left molars. The patient had severe dentin caries beneath the inlay, and the #36 tooth had been treated several years prior. The patient complained of slight pain during chewing. Fluorescence loss and strong red fluorescence were observed under the inlay and caries lesion when the area was observed with the Qraypen. First, the patient's old restorations and severe caries were removed using only visual-tactile methods to determine the extent of the caries lesion, which extended into the bottom of the restoration. Following removal of the caries, the Qraypen produced strong red fluorescence in the suspected area. The dentin lesion, which fluoresced red and was regarded as an indicator of caries activity, was gradually removed until it reached an almost invisible state. The Qraypen was used to confirm its removal. Thereafter, the patient had restorative treatment using conventional methods. At a follow-up appointment nine months later, the patient reported being able to use the tooth without pain or discomfort.

Conclusions

The QLF technology could be applied not only to detect dentin caries but also to provide evidences for determining extent of caries removal non-invasively and objectively.

Key result

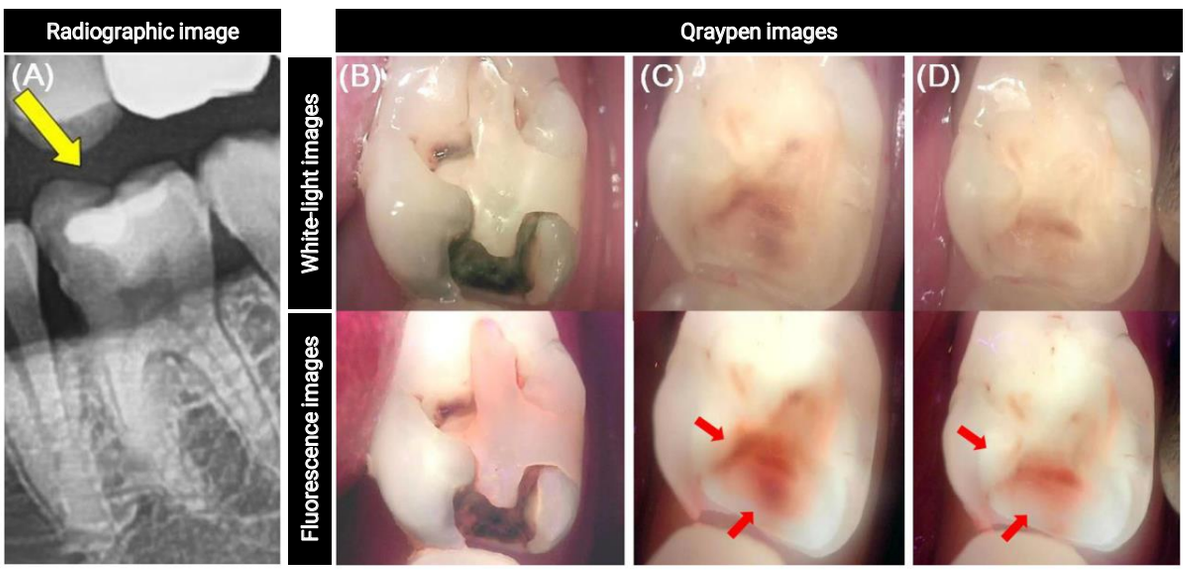

Figure 1. Radiographic image (A) and Qraypen images (B–D) at the different treatment stages; before treatment (B), after conventional caries removal (C), and after final removal of caries lesion (D).

Plain language summary

For the assessment of caries, traditional diagnostic techniques have low sensitivities of only 30% for early occlusal surface caries and 50% for dentin caries. The QLF technology relies not only on the difference in fluorescence responses between sound teeth and demineralized lesion, but also the red autofluorescence of porphyrin, a metabolite of oral bacteria. Through the case presented, we have confirmed that the red fluorescence observed from the QLF technology provides objective evidence for the diagnosis of deep caries in the dentin. Based on this case report, it suggests that the QLF technology may reduce clinical ambiguity for detection of residual caries. In conclusion, the QLF technology can be applied not only to detect dentin caries but also for provide evidence for determining extent of caries removal non-invasively and objectively.

Can red fluorescence be useful in diagnostic decision making of residual dentin caries?

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Objectives

This study aimed to investigate the usefulness of the QLF technology for diagnosing controversial cases during the detection of deep dentin caries.

Case report

Case #1 (Figure 1):

In June 2017, a 31-year-old man presented with the complaint of pain in the left mandibular first molar. The initial examination revealed fracture of an old restoration and severe caries with downward food impaction. The old restoration and caries were removed as much as possible considering the patient's pain complaint using traditional methods. The area of treatment was photographed using the Qraypen after removing the caries to assess the extent that the color and hardness of healthy dentin had been acquired. In this patient it was difficult to confirm the efficacy of endodontic treatment despite the progression of subjective symptoms and performing visual, tactile, and radiographic examinations. However, we concluded that endodontic treatment was preferable based on the Qraypen findings combined with the above-mentioned diagnostic information. The patient underwent crown restoration after the endodontic treatment, and at a 14-month follow-up he did not report any major inconveniences.

Case #2 (Figure 2):

In August 2017, a 67-year-old man presented with discomfort in the first molar on the right mandible. A traditional diagnosis revealed fracture of a restoration and caries with food impaction. Most of the existing restoration and carious lesions were removed first using traditional methods, which revealed a dark discolored dentin caries lesion. There was no red fluorescence in the section suspected of severe caries on the basis of the black color change. In addition, black discoloration was observed around and within the crack line, but with no red fluorescence. Based on the results of these examinations we decided that a minimally invasive dentistry approach was appropriate. This patient received a crown restoration without endodontic, and was using this appropriately at the 12-month follow-up.

Conclusions

Using QLF technology is more objective and accurate than other methods of determining the removal end point and detecting healthy marginal dentin for successful restoration.

Key result 1

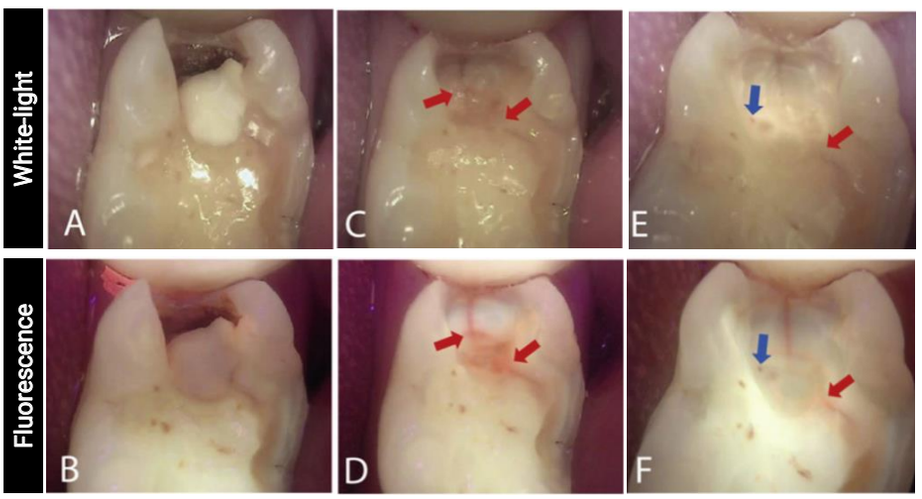

Figure 1. Initial views (A, B), after primary removal of caries (C, D), and after removal to the extent of exposing the pulp (E, F).

Key result 2

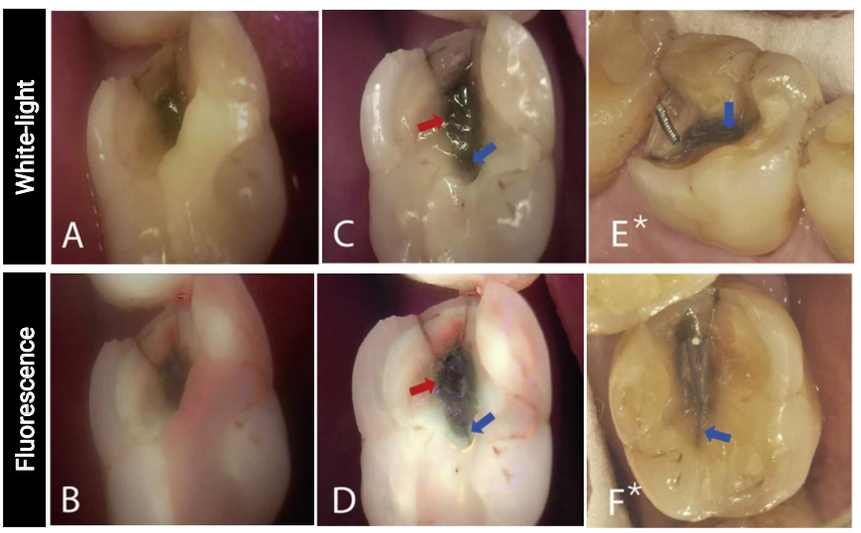

Figure 2. Initial view (A, B) and after primary removal of caries (C, D). Final removal and before restoration (E, F). Note that the black color and crack line are also visible with white light.

Plain language summary

Detecting caries at the dentin level is complex due to the requirement of a real-time assessment of the viability of the pulp. A diagnosis based on traditional visual and tactile senses can differ under the same tooth condition according to the subjective criteria used by different dentists. Additional diagnostic tools are therefore required to overcome this limitation. QLF technology based on the autofluorescence of natural teeth is a viable method for detecting residual caries. In this study, we used the Qraypen (AIOBIO, Seoul, Korea) to investigate the usefulness of the QLF technology for diagnosing controversial cases. The residual caries removal procedure using QLF technology most importantly provides objective criteria for correct clinical decision-making to determine removal end points. Applying QLF technology as an additional modality to accurately identify and ensure the caries-free dentin of the marginal area will greatly aid in obtaining successful clinical results.

Quantitative light-induced fluorescence technology for quantitative evaluation of tooth wear

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Objectives

With the QLF, relatively bright fluorescence emission can be observed clinically in regions of suspected dentin exposure on occlusal surfaces. This study aimed to determine the relationship between grinding depth and autofluorescence intensity of occlusal surfaces using QLF technology *in vitro*.

Methods

Sixteen permanent premolars were used. Each tooth was gradually ground down at the occlusal surface in the apical direction. QLF-digital and optical coherence tomography (OCT) images were acquired at each grinding depth (in steps of 100 μm). QLF images were converted to 8-bit grayscale images to calculate the fluorescence intensity. Maximum brightness (MB) values of the same sound regions in grayscale images before ($MB_{baseline}$) and phased values after (MB_{worn}) the grinding process were calculated. A retrospective analysis was conducted to determine changes in fluorescence over the remaining enamel thickness (MB_{enamel}) by calculating from 0 μm (dentin exposure point) to 600 μm at each 100 μm.

Results

Thirteen samples were included and three samples were excluded from the final analysis due to wrong OCT detection by crack lesions near the measurement points. Figure 1 shows the changes in the representative OCT and QLF-D images and the MB values following the serial tooth grinding procedure. The average MB_{worn} values of all samples showed strong correlations with grinding depth ($r = 0.994$, $P < 0.001$). There were significant differences between the average $MB_{baseline}$ and all MB_{worn} values over the 200-μm grinding depth [$P < 0.05$, Figure 2(a)]. The remaining enamel thickness and the average MB_{enamel} had a strong negative correlation ($r = -0.990$, $P < 0.001$). In addition, there were significant differences among the average MB_{enamel} values at 200-, 100-, and 0-μm enamel thickness [$P < 0.01$, Figure 2(b)]. The average rate of increase (%) of the MB_{enamel} was 4.00% for the range of enamel thickness from 600 to 200 μm, whereas this value was relatively higher in the range of enamel thickness from 200 μm to the dentin exposure point (6.51%).

Conclusions

The autofluorescence intensity of the cusps was shown to gradually increase based on the progression of mechanical occlusal tooth wear, and both parameters showed a strong correlation. In particular, the fluorescence intensity increased rapidly over the 200-μm remaining enamel thickness to the dentin exposure point. Therefore, QLF technology may be a useful non-invasive tool used to monitor the progression of tooth wear and to conveniently estimate enamel thickness.

Key result 1

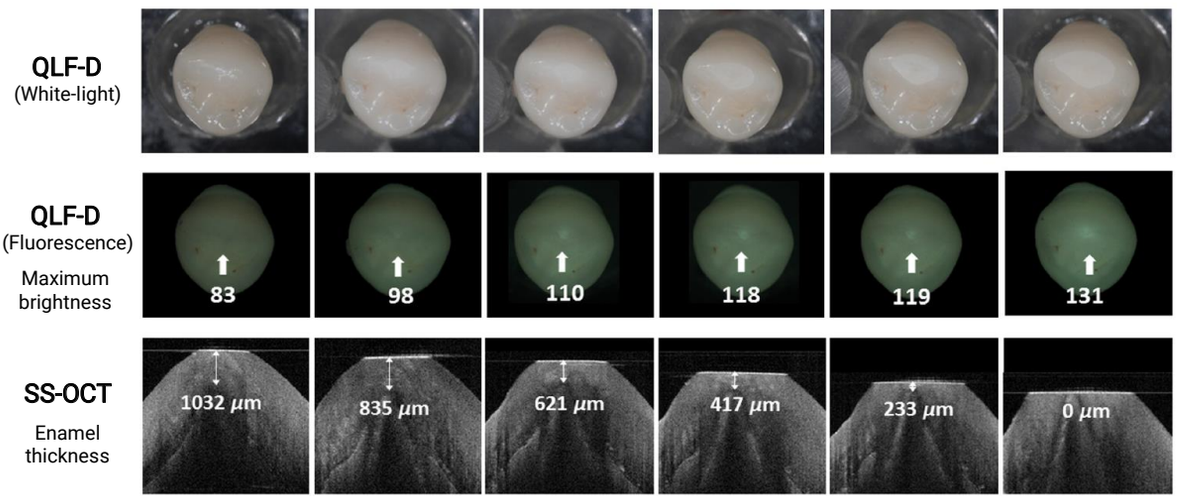

Figure 1. Representative QLF-D images, SS-OCT, MB values and the enamel thickness.

Key result 2

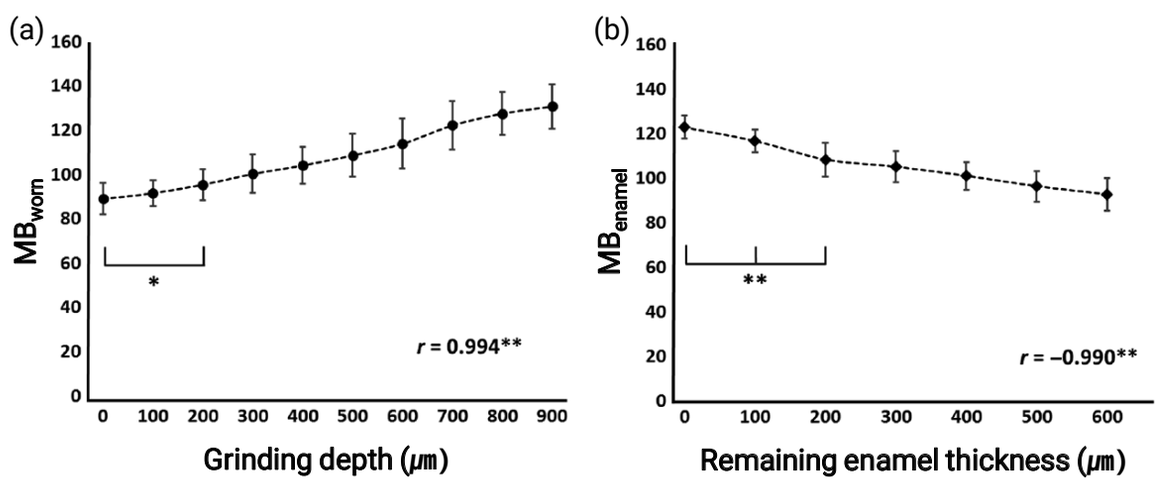

Figure 2. Changes in average MB values with (a) increasing grinding depth (MB_{worn}) and (b) remaining enamel thickness (MB_{enamel}).

Plain language summary

Tooth wear is a significant dental concern, and early detection is crucial. This study used a sensitive technology called Quantitative Light-induced Fluorescence (QLF) to investigate tooth wear and dentin exposure. It was discovered that QLF could track changes in fluorescence intensity as teeth were gradually worn down. QLF is a safe and noninvasive method that uses visible light to capture images of teeth in the oral cavity. This technology holds promise as a tool for early diagnosis and monitoring of tooth wear. It could support long-term dental care, educational efforts, and research on tooth wear trends over time. This research underscores the potential of QLF to enhance dental health management and understanding of tooth wear patterns.

Evaluation of tooth wear by estimating enamel thickness with quantitative light-induced fluorescence technology

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Objectives

Various techniques have been suggested to quantitatively assess tooth wear; most have limited clinical application. The first aim of this *in vitro* study was to predict estimate the residual enamel thickness of teeth with various degrees of wear formed in the oral cavity by using relative fluorescence, measured by QLF. The second aim was to determine relationships between the fluorescence parameters and the conventional tooth wear index (TWI) that can be used to evaluate the initial (enamel) stage of tooth wear.

Methods

Sixty-nine extracted permanent premolars and molars with initial stages of tooth wear (TWI score 1a-2: enamel wear to dentin exposure) were used. Occlusal QLF-digital images were acquired for selecting area of interest (AOI) and calculating fluorescence for occlusal tooth wear (ΔF_{wear}) of the AOI. Each specimen was cross-sectioned in the buccal-lingual direction. Enamel thickness from images obtained by stereomicroscopy and TWI of each sample was determined by the second examiner. Spearman correlation was used to determine the relationship of ΔF_{wear} with enamel thickness and TWI. ΔF_{wear} values were compared between histological scores with the Mann-Whitney *U* test.

Results

Seventy-six AOIs of 69 teeth (42 molars and 27 premolars) were included in the final analysis. Relatively higher ΔF_{wear} values were measured in samples with thinner residual enamel or higher TWI score. Figure 1 shows the representative QLF-D and stereomicroscope images after the initial ordinal grading scale for tooth wear. The samples used in this study were only from the initial enamel wear stage to the first stage after the dentin exposure (score 1a-2). Thus, there were no samples corresponding to a sound stage (score 0). The numbers of specimens for TWI scores 1a, 1b, 1c, and 2 were 10, 20, 35, and 11. Median values of ΔF_{wear} were 8.0%, 13.4%, 17.7%, and 28.6%, respectively; there were statistically significant differences between the groups according to the TWI score ($P < 0.001$) (Figure 2). In addition, ΔF_{wear} values and TWI scores were strongly positively correlated (Spearman rho = 0.753, $P < 0.001$).

Conclusions

ΔF_{wear}, calculated from changes in autofluorescence that occurred with occlusal wear, showed a strong correlation with residual enamel thickness and TWI. Therefore, QLF may enable early-stage evaluation and monitoring of tooth wear.

Key result 1

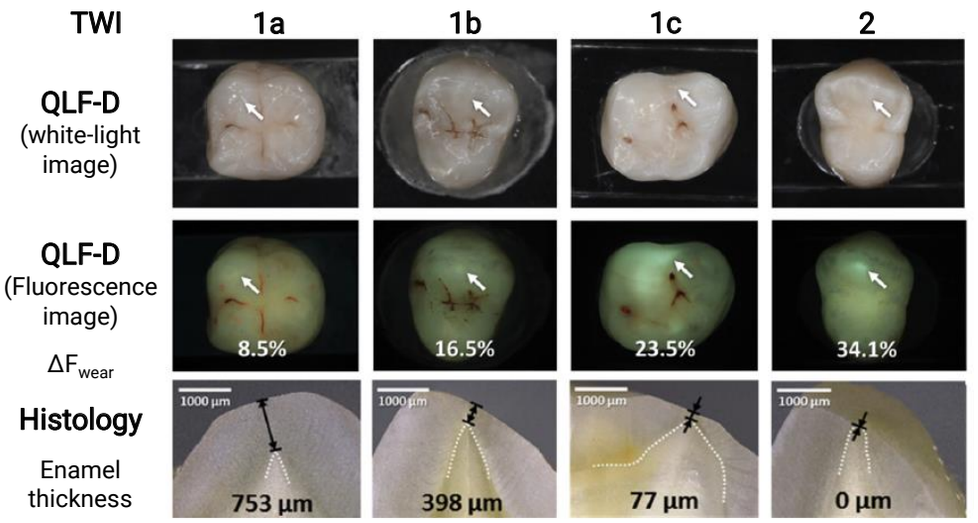

Figure 1. Representative QLF-D images, stereomicroscopic images, ΔF_{wear} values and the enamel thickness.

Key result 2

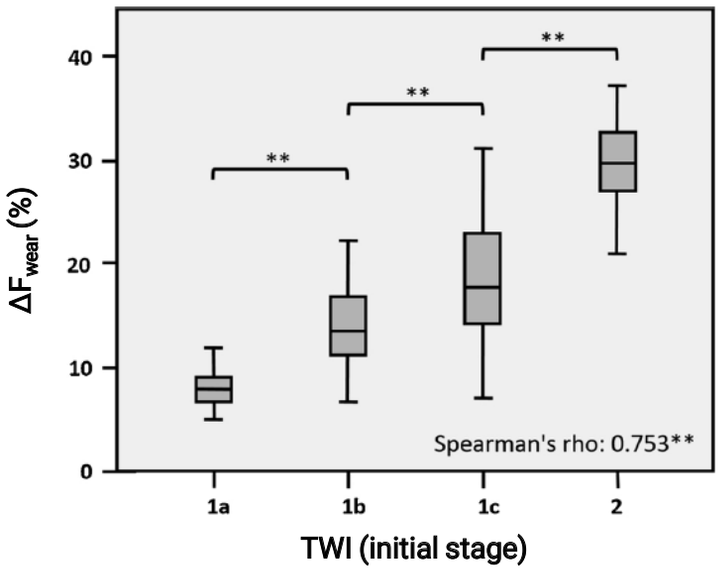

Figure 2. Box-and-whisker plots of ΔF_{wear} related to tooth wear index (initial stage).

Plain language summary

This study highlights the effectiveness of Quantitative Light-induced Fluorescence (QLF) in assessing and monitoring the early stages of tooth wear, a concern that evolves through life. Continuous monitoring and management are vital for delivering timely preventive care and determining when restorative treatment is needed. In the clinical setting, QLF offers a valuable data for obtaining fluorescence images of the entire occlusal surface of teeth. Dentists can employ QLF to easily capture and consistently observe the progression of tooth wear, especially when it arises from pathologic conditions. This technology not only aids in early detection but also facilitates ongoing observation, empowering healthcare providers to intervene promptly and make well-informed decisions to enhance dental health and patient well-being.

Detection of dentin-exposed occlusal/incisal tooth wear using quantitative light-induced fluorescence technology

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Objectives

To prolong tooth life expectancy, tooth wear resulting in dentin exposure should be detected early. However, the most objective methods are clinically limited. The first aim of this study was to provide a new method for determining traditional TWI using fluorescence parameters based on clinical QLF images. The second aim was to validate fluorescence parameters for distinguishing enamel from dentin-exposed wear.

Methods

Quantitative light-induced fluorescence (QLF) images of 73 adults (age range: 22–48 years, mean: 33.81 ± 7.71 years), including 1,949 teeth with varying tooth wear degrees, without restorations, caries, or cusp area fractures, were used to calculate the ΔF_{wear} values. Areas of interest (AOIs) were selected from QLF images (Figure 1); the ΔF_{wear} values and the tooth wear index (TWI) were calculated for each tooth. The ΔF_{wear} values were compared according to the TWI scores. The optimum ΔF_{wear} values for distinguishing enamel and dentin-exposed wear were determined using the receiver operating characteristic (ROC) analysis. All analyses were conducted using the SPSS 23.0 statistical package (SPSS Inc., USA).

Results

Among the 73 participants included in the final analysis, there were 24, 26, and 22 individuals in their 20 s, 30 s, and 40 s, respectively. Overall, 1,949 AOIs (849 anterior and 1,100 posterior teeth) were evaluated. There was a moderate positive correlation between the ΔF_{wear} values and the TWI scores (Pearson's correlation = 0.667, $P < 0.001$). The median ΔF_{wear} values for teeth with TWI scores 0, 1, and 2 (5.7%, 10.3%, and 17.0%) differed significantly ($P < 0.001$). The optimum cutoff ΔF_{wear} values were 12.1 and 14.7 in the anterior and posterior teeth, respectively; the corresponding areas under the ROC values (AUROCs) were 0.86 and 0.93 (sensitivity: 0.79 and 0.85; specificity: 0.79 and 0.85, respectively). The ΔF_{wear} cutoff values for different age groups were within a range (12.7–13.7) and showed high validity (sensitivity, specificity, and AUROC: 0.78, 0.77–0.78, and 0.87–0.88, respectively) (Table 1).

Conclusions

This study showed that the ΔF_{wear} values based on intra-oral QLF images can be used as a new standard for objective evaluation of TWI. Particularly, the validity of the ΔF_{wear} values for discrimination of dentin exposure was excellent for various tooth types and age groups. The latter suggested that QLF can be an objective and cost-effective tool for future epidemiological investigations and tele-dentistry using image data.

Key result 1

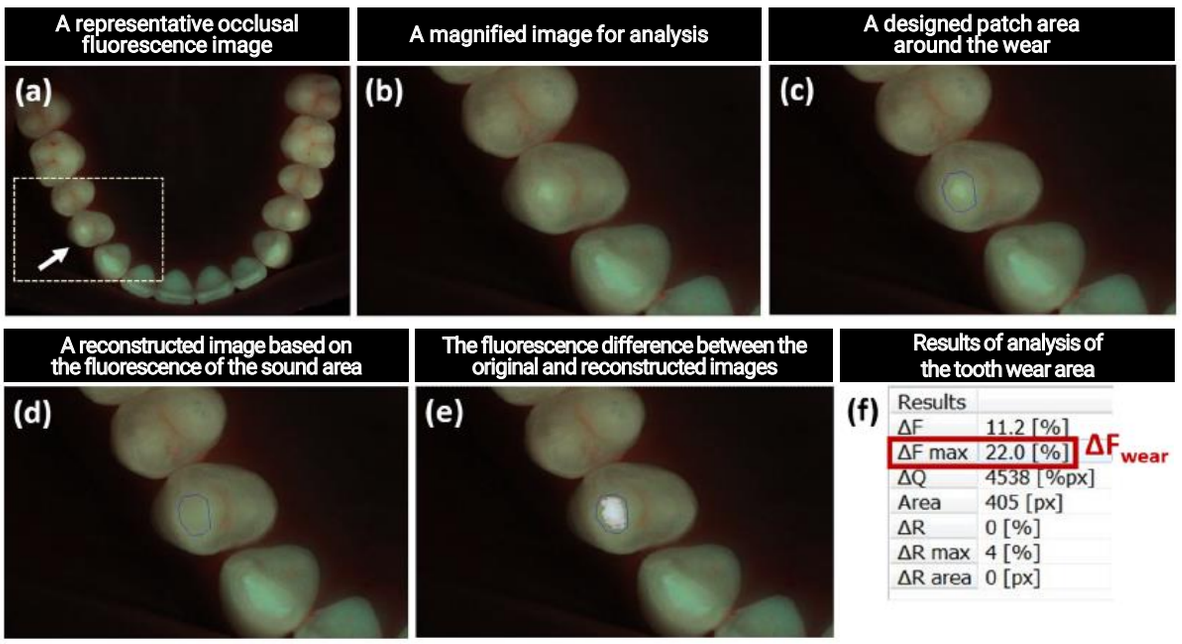

Figure 1. Fluorescence image analysis (occlusal surface images).

Key result 2

Table 1. Cut-off values and validity of ΔF_{wear} for detecting dentin exposure according to the tooth position and the age group.

		Cut-off value (ΔF_{wear})	Sensitivity	Specificity	AUROC
Tooth position	Total	13.15	0.79	0.79	0.88
	Anterior	12.05	0.79	0.79	0.86
	Posterior	14.65	0.85	0.85	0.93
Age group	20–29	12.70	0.78	0.78	0.87
	30–39	12.90	0.78	0.77	0.87
	40–49	13.70	0.78	0.78	0.88

AUROC, area under the receiver operating characteristic curve.

Plain language summary

This study successfully confirmed the potential of using Quantitative Light-Induced Fluorescence (QLF) images taken intra-orally during clinical examinations to identify tooth wear that has exposed dentin. It also showed that QLF can be used to detect dentin-exposed tooth wear and establish specific thresholds based on age groups. This means that dental professionals can now conduct precise, objective, and cost-effective investigations into tooth wear patterns and offer tele-dentistry services for tooth wear assessment. By leveraging QLF parameters, age data, and the established QLF fluorescence image thresholds, dentists can better understand and manage tooth wear in their patients. This advancement has the potential to improve dental care and monitoring, benefiting both patients and dental professionals alike.

Evaluation of residual dentin thickness using quantitative light-induced fluorescence technology

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Objectives

This study aimed to determine whether a correlation exists between residual dentin thickness and quantitative light-induced fluorescence (QLF) values and, if so, to analyze its tendencies.

Methods

Forty extracted sound human molars were assigned to filled and unfilled groups. The teeth were submerged in a mold with clear acrylic resin. Red utility wax was inserted into the pulp chamber space in the filled group to simulate vital pulp. The specimen was sectioned longitudinally to observe the inside of the pulp space. The samples were cut horizontally from the highest point of the pulp space 2 mm apart. QLF images were then taken of 2 mm, 1 mm, and 0.5 mm samples using the QLF-D Biluminator™ 2 + system. Three operators independently evaluated the QLF images, and the statistical analysis was conducted using one-way analysis of variance, Pearson correlation coefficients, and intraclass correlation coefficients.

Results

Most of the 3 mm sectioned samples revealed mixed surfaces of enamel and dentin, so these samples were excluded from the analysis to avoid errors. ΔF values were measured as negative, with the filled group showing -3.22, -7.84, and -11.52 for residual dentin thicknesses of 2 mm, 1 mm, and 0.5 mm, respectively, while the unfilled group showed 0, -6.90, and -10.14 (Table 1). There was a statistically significant difference in ΔF values based on residual dentin thickness ($P < 0.05$). Most specimens showed similar ΔF values and slopes as thickness decreased, with a slope from 1 mm to 0.5 mm in the filled group. A positive correlation was found between residual dentin thickness and ΔF values ($P < 0.05$) (Fig 1). The intraclass correlation coefficients for observations made by the three operators for the filled and unfilled groups were 0.831 and 0.917, respectively ($P < 0.05$).

Conclusions

Residual dentin thickness and ΔF values (showing a loss of fluorescence) were significantly correlated and had a highly positive correlation regardless of the QLF device operator. The results of this study are meaningful since they demonstrate that residual dentin thickness can be measured using a Q-ray device.

Key result 1

Table 1. ΔF values according to residual dentin thickness.

		Residual dentin thickness							
		Filled group				Unfilled group			
		2 mm	1 mm	0.5 mm	F(p)	2 mm	1 mm	0.5 mm	F(p)
ΔF	Mean (SD)	− 3.22 (± 4.42)	− 7.84 (± 2.40)	− 11.52 (± 3.80)	130.50 (< 0.05)*	0	− 6.9 (± 1.63)	− 10.14 (± 2.19)	596.10 (< 0.05)*
	Tukey	a	b	c		a	b	c	

Key result 2

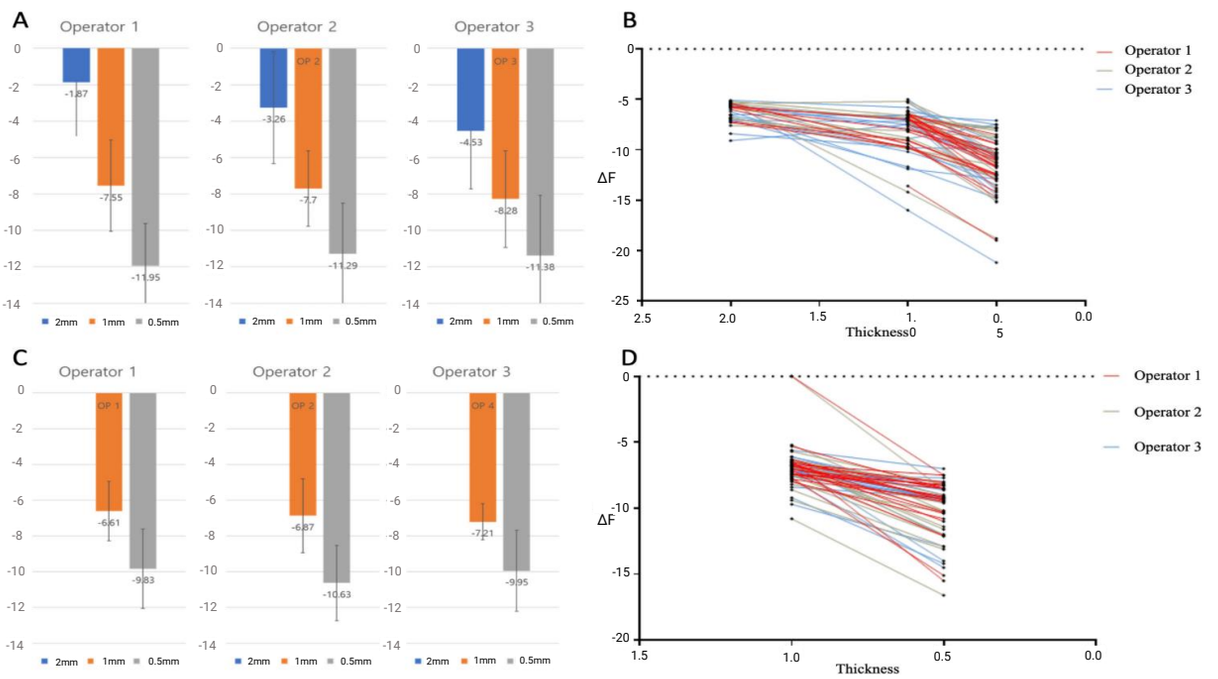

Figure 1. (A) The graph showing the average fluorescence values at each thickness of the sample with red wax. (**B)** Spaghetti plot of ΔF values of filled group according to operator. **(C)** The graph showing the average fluorescence values at each thickness. (**D)** Spaghetti plot of ΔF values of unfilled group according to operator.

Plain language summary

This study examined whether the thickness of dentin affects fluorescence values measured by a quantitative light-induced fluorescence (QLF) device. Researchers found that as the dentin layer became thinner, fluorescence values decreased significantly, showing a strong correlation between dentin thickness and QLF measurements. The results were consistent regardless of who operated the device, demonstrating reliability. This suggests that QLF devices can accurately assess dentin thickness, which is important for dental diagnosis and treatment planning.

Generational shift for clinical application of the QLF system for evaluating tooth wear

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Objectives

No study has quantitatively assessed tooth wear using a clinical quantitative light-induced fluorescence (QLF) system. This study aimed to compare fluorescence parameters (ΔF_{wear}) between the research QLF system (QLF-D) and clinical QLF system (Qraycam Pro) and evaluate the validity of both systems in detecting dentin exposure from tooth wear.

Methods

Thirty-five human molars and premolars were collected. Two blinded examiners conducted evaluations. Images from QLF-D and Qraycam Pro were captured and analyzed by the first examiner to calculate ΔF_{wear}, representing the maximum fluorescence intensity for occlusal wear. The stage of tooth wear was determined by the second examiner using the tooth wear index (TWI). The area of interest (AOI) was determined as the cusp without defects, such as caries or fractures. Only areas mutually agreed by both examiners were included in analysis. The Kruskal-Wallis test was conducted to assess differences in ΔF_{wear} between two devices. ROC analysis evaluated the validity of both systems in determining dentin exposure using AUROC.

Results

This study analyzed 38 sites from 35 teeth. While Qraycam Pro showed bright white biofluorescence and QLF-D showed darker green biofluorescence on sound tooth surfaces, both devices displayed a consistent pattern: higher TWI scores (0–2) corresponded to higher ΔF_{wear} values (Fig. 1). Median ΔF_{wear} values for TWI scores 0, 1, and 2 were slightly higher for QLF-D (6.9%, 10.3%, 24.8%) compared to Qraycam Pro (5.7%, 7.7%, 23.9%), but the differences were not statistically significant (Fig. 2). Both devices showed a significant difference in ΔF_{wear} between enamel wear (TWI 1) and dentin wear (TWI 2). ROC analysis identified thresholds for dentin exposure (18.4 for QLF-D and 18.1 for Qraycam Pro), with both devices demonstrating high accuracy (AUROC = 0.95), sensitivity (0.92), and specificity (QLF-D: 0.85, Qraycam Pro: 0.89). These findings confirm the comparable performance of Qraycam Pro and QLF-D for detecting dentin exposure from tooth wear.

Conclusions

The ΔF_{wear} values calculated using QLF-D and Qraycam Pro did not exhibit significant differences between the devices for TWI scores of 0, 1, and 2. Both devices demonstrated high diagnostic accuracy for detecting dentin exposure, with an AUROC value of 0.95. As a clinical device, the Qraycam Pro showed the same validity as QLF-D in assessing tooth wear and detecting dentin exposure. Consequently, the Qraycam Pro represents a high-performance tool for tooth wear detection with enhanced clinical practicality.

Key result 1

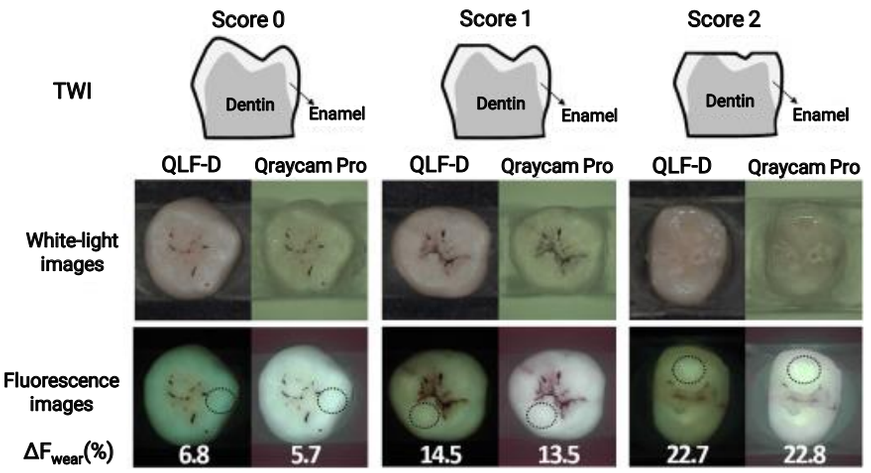

Figure 1. Representative images (white-light and fluorescence images) of QLF-D and Qraycam Pro according to tooth wear index. ΔF_{wear} values were calculated from fluorescence images. TWI, Tooth wear index.

Key result 2

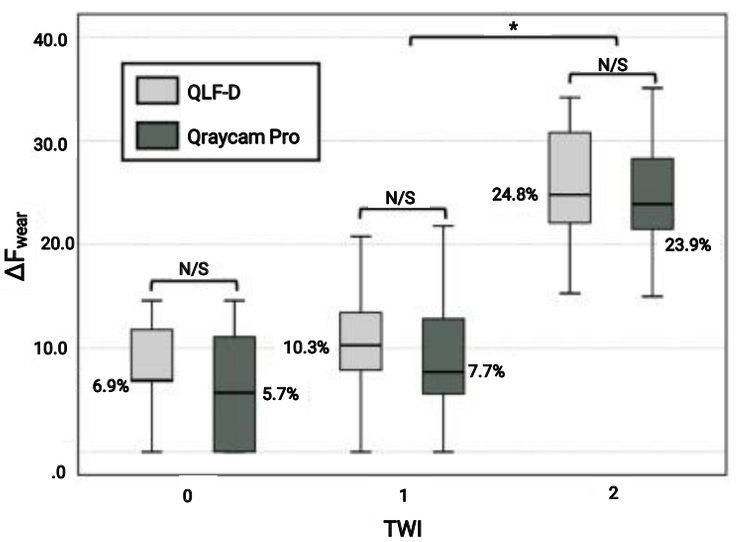

Figure 2. Box-and-whisker plots of ΔF_{wear} values from QLF-D and Qraycam Pro according to the tooth wear index (initial stage). The boxes show the lower quartile, the median (horizontal line), and the upper quartile. The asterisks indicate statistically significant differences between TWI 1 and 2 (Kruskal-Wallis test with post hoc Mann-Whitney U tests). *P< 0.001.

Plain language summary

This study compared two devices, QLF-D (research-grade) and Qraycam Pro (clinical), for measuring tooth wear using fluorescence changes (ΔF_{wear}). Both devices showed similar accuracy in detecting dentin exposure, with no significant differences in their measurements. As tooth wear increased, ΔF_{wear} values also increased for both devices. The Qraycam Pro demonstrated the same high diagnostic accuracy as the QLF-D, making it a reliable and practical tool for clinical use.

Optical diagnosis of dentin caries using quantitative light-induced fluorescence technology

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Objectives

The precise diagnosis of dental caries and determination of their severity are very important when planning for treatment. Low diagnostic power of traditional methods such as radiographic and visual-tactile examinations could increase in the ambiguity of clinical decision about some borderline lesions. This study aimed to identify the extent of dentin lesions (including the crack and secondary caries) by using Qraypen (AIOBIO, Seoul, Korea), a device that utilizes QLF technology, to diagnose deep dental caries at the dentin level.

Case report

Acute, secondary caries following crack progression:

A 55-year-old male patient visited with severe pain in his #47 tooth. The diagnosis was unclear following use of only conventional, i.e., radiographic and visual-tactile, methods. Cracks and secondary caries under the existing restoration were suspected (Figure 1A, yellow arrow). After the restoration was removed, a faint crack was observed with the naked eye (Figure 1B, blue arrows). For a more accurate diagnosis, we removed the caries lesions near the pulp and were able to detect fluorescence loss and red fluorescence along the crack (Figure 2C, red arrows). Based on the result of the Qraypen examination, it was possible to verify the presence of the crack and confirm its extension, which had progressed into the pulp. In addition, the Qraypen image was used as evidence in the process of describing the results to the patient as well as preparing the treatment plan. A follow-up appointment five months after treatment found that the tooth was clinically healthy and functioned well without any discomfort or pain.

Conclusions

Upon further examination using a device called Qraypen, which utilizes QLF technology, the dentist was able to identify fluorescence changes and red fluorescence along the suspected crack. The QLF technology helped confirm the presence of the crack and assess its extension, which had reached the pulp (inner part of the tooth). This technology could be applied not only to detect dentin caries but also to provide evidences for determining extent of caries removal non-invasively and objectivity.

Key result

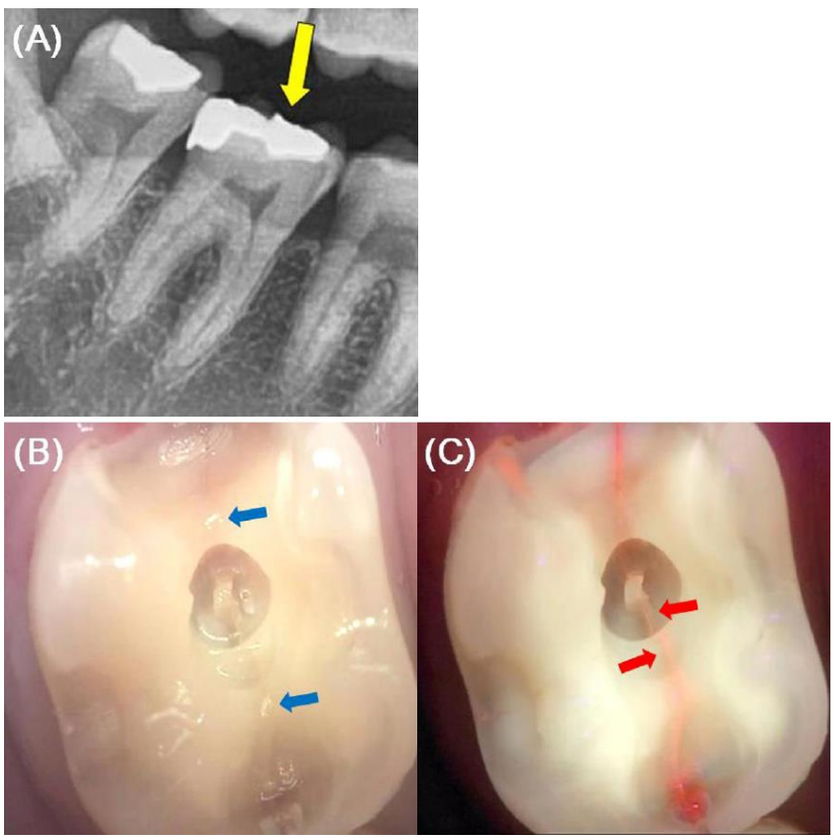

Figure 1. Representative crack images. Radiographic image (A), white-light (B) and fluorescence (c) images.

Plain language summary

This study demonstrated the effectiveness of using Qraypen, a device utilizing Quantitative Light-Induced Fluorescence (QLF) technology, to easily detect the presence and extent of a crack in a tooth. By assessing changes in fluorescence, particularly the loss of fluorescence and the appearance of red fluorescence around the crack, the device provided a clear and objective diagnosis. This is especially valuable because cracks can be challenging to identify with the naked eye. Qraypen, with its optical diagnostic capabilities, enhances the objectivity of dental diagnoses. Moreover, the QLF technology used in this approach is not only useful for detecting dentin caries but also for non-invasively and objectively confirming the presence of cracks, improving dental care and patient outcomes.

Diagnosis and management of cracked tooth by quantitative light-induced fluorescence technology

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Objectives

The aim of this case report was to describe the process of diagnosis and treatment of a cracked tooth using quantitative light-induced fluorescence (QLF).

Case report

A 43-year-old male patient visited the hospital with a complaint of cold pain on his #17 tooth. The patient had no systemic disease and a parafunctional habit of clenching. After obtaining the consent of the patient, a diagnosis and treatment plan were established. A dentist performed a conventional oral examination (visual inspection with radiography) and the QLF examination for evaluating the oral cavity by using the Qraycam (AIOBIO, Seoul, Republic of Korea), which is a third generation QLF device. Cracks and worn areas in the upper and lower occlusal surfaces were observed in white-light images (Fig. 1A and B). These were also clearly observed in the fluorescence images, due to differences in the fluorescence of the lesion (Fig. 1C and D). With tooth wear, decreased enamel thickness caused by repetitive occlusion results in strong fluorescence intensity in the form of a bright spot, as compared to that of the sound enamel (Fig. 1C and D, yellow arrow). In the fluorescence image, we observed a line showing loss of fluorescence and red fluorescence in the #17 tooth, across the occlusal plane (Fig. 1C, red arrow). There was no root fracture in the radiographic image, but a periapical lesion and bone loss were observed. we performed periodontal treatment (Fig. 2A). One month later, the patient still complained of cold, sharp pain in the #17 tooth. Based on the presence of the red fluorescent line on the cracked tooth, the possibility of recurrent pain and extraction was explained to the patient. Root canal treatment (RCT) was performed thereafter. When we opened the pulp chamber, a Qraypen (AIOBIO, Seoul, Republic of Korea), an intraoral camera type QLF device, was used to capture an image of the crack line. After opening the pulp chamber, there was no crack line visible to the naked eye (Fig. 2B, blue arrow). On the other hand, the fluorescence image obtained with the Qraypen showed that the fluorescence loss line, seen as red fluorescence, progressed to the marginal ridge, but not to the pulp floor (Fig. 2C, red arrow). After the RCT, a permanent gold crown was applied. At the end of overall treatment, a splint was placed on the maxilla. The patient has had no complaint related to this tooth for 3 years until today.

Conclusions

Clinically, use of QLF confirmed the presence of a crack before and during a root canal treatment. Therefore, it is postulated that the QLF technology could objectively facilitate the diagnosis and treatment of a cracked tooth.

Key result 1

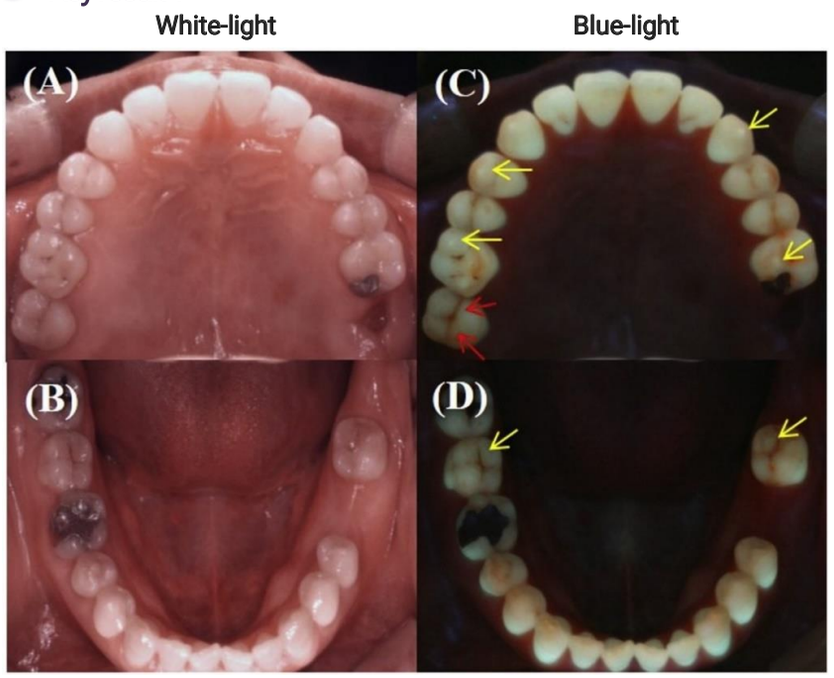

Figure 1. Multiple tooth wear (#14, #16, #23, #37, #47), loss of two teeth (#27, #36), one cracked tooth (#17), and two teeth with secondary caries (#26, #46) were diagnosed with visual inspection and Qraycam images.

Key result 2

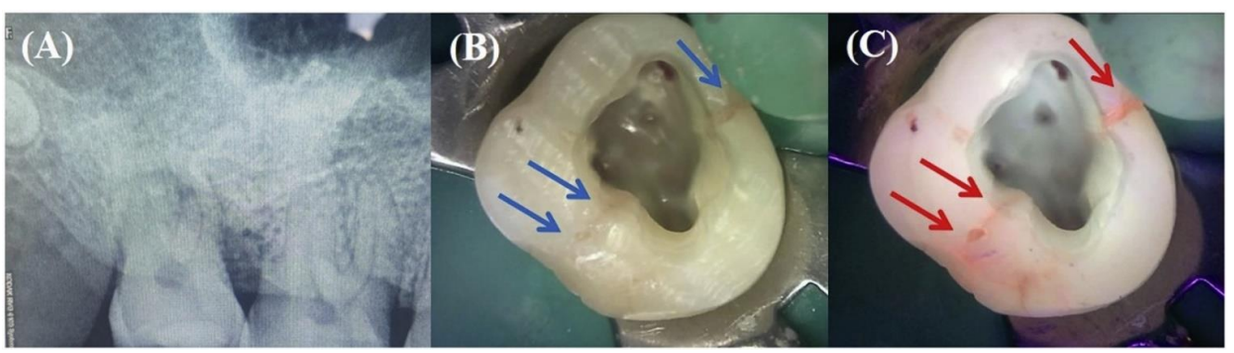

Figure 2. Radiographic image (A), white-light images (B), and blue-light images (C) taken with the Qraypen. Images taken after opening of the pulp chamber (B, C).

Plain language summary

Cracked teeth, if left untreated, can lead to tooth loss and periodontal disease. Early detection and treatment are crucial, but diagnosis can be challenging due to various factors and varying symptoms. Quantitative Light-Induced Fluorescence (QLF) technology has emerged as a less harmful alternative to X-rays for enamel crack detection. It quantifies crack depth by measuring green autofluorescence loss and identifies bacterial deposits using red autofluorescence. This technology aids in crack diagnosis and treatment, providing objective insights and helping patients understand their condition. Clinically, the use of QLF confirmed the presence of a crack before and during a root canal treatment, supporting its role in objectively facilitating the diagnosis and treatment of a cracked tooth.

The Effectiveness of a Quantitative Light-induced Fluorescent Device for the Diagnosis of a Cracked Tooth: A Case Report

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Objectives

This report describes the use of a quantitative light-induced fluorescent (QLF) device that detects fluorescence reactions with visible light (405 nm) to visually identify microscopic tooth cracks during the diagnosis and treatment of cracked teeth that caused pulp disease.

Case report

Case1:

A 55-year-old woman visited the hospital with severe cold pain in her right upper and lower teeth. A pulp sensibility test diagnosed symptomatic irreversible pulpitis in her right upper second molar (tooth #17). Visual inspection using the Qraypen C revealed no hard tissue defects in the occlusal restoration but showed red fluorescence on the distal and distopalatalsides of the gold inlay, indicating a suspected crack (Fig. 1D). After removing the occlusal restoration, crack lines were observed on the distal side, one of which extended deep along the cavity wall (Fig. 1E). QLF images confirmed the crack extended to the pulpal floor (Fig. 1F). Following root canal treatment, the pain subsided, but the tooth's prognosis remained uncertain due to the deep crack line.

Case 2:

A 42-year-old woman was referred to the university hospital because of severe pain that seemed to spread with cold and hot stimulation and continued pain during mastication of the left upper first molar (tooth #26). Clinical examination showed long-lasting and intense pain during mastication in tooth #26. The tooth also showed a hypersensitive response in the hot stimulation test. The pulp of tooth #26 was diagnosed as symptomatic irreversible pulpitis, and the pathology of the apical region was within the normal category on radiographic examination. For the treatment of symptomatic irreversible pulpitis, the patient underwent a root canal treatment. After access cavity preparation, white light and fluorescence images of the inside of the cavity were obtained using the QLF device (Fig. 2A, E). These images showed a crack progressing to the palatal side that passed deeply along the palatal wall of the access cavity. After the root canal, the patient’s symptoms disappeared. When constructing the core after the root canal filling, the adhesive resin core was constructed after removing the crack line on the palate wall by taking sequential images using the QLF device (Fig. 2B–D, F–H). The cavity of the palatal wall was prepared in the area where the red-fluorescing crack disappeared on the floor of the palatal wall (Fig. 2D, H). The core was then constructed using adhesive resin.

Conclusions

The QLF device showed a potential benefit in the diagnosis and characterization, including the location and depth, of tooth cracks.

Key result 1

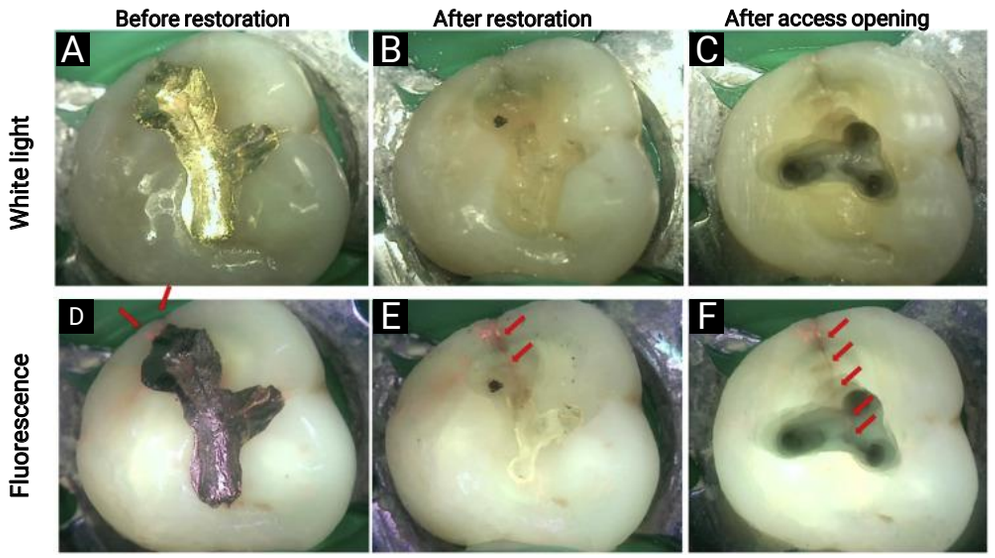

Figure 1. (*B* and *E*) The crack location is clearly visible after restoration removal. (*C* and *F*) The crack line extends from the distal side to the bottom surface of the access cavity. The *arrows* indicate the crack lines showing red fluorescence.

Key result 2

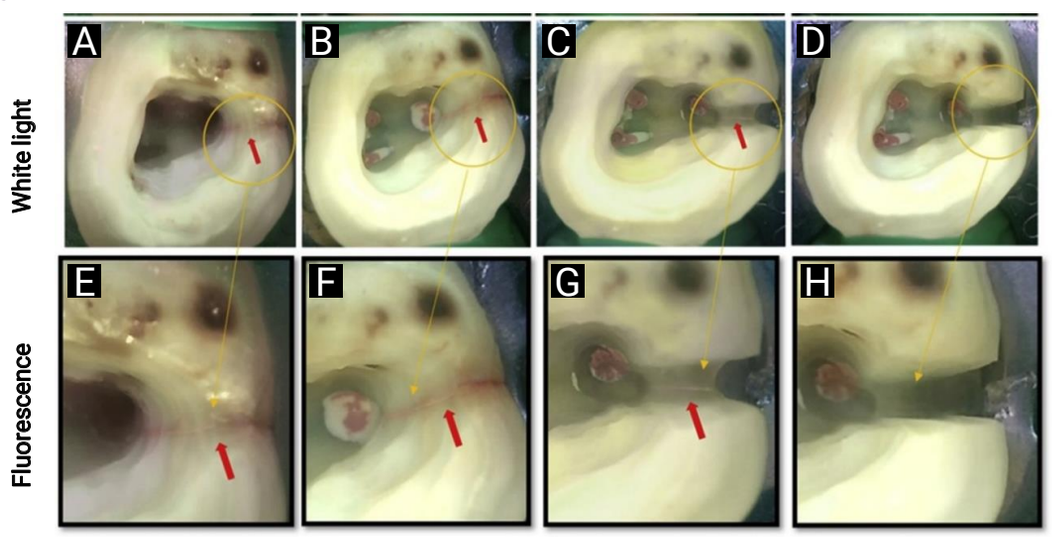

Figure 2. (A) Images showing a crack line in the palate wall. The *yellow circles* indicate the area of crack line in the palatal wall for magnification. The *arrows* indicate the tooth crack lines. Magnified fluorescence images (E and F) before, (G) during, and (H) after removing the crack line.

Plain language summary

Tooth cracks, defined as incomplete fractures in tooth structure, can lead to various clinical symptoms as they progress. Detecting these cracks is challenging, and diagnosis often relies on patient symptoms. Quantitative Light-Induced Fluorescence (QLF) technology, using visible blue light and a special filter, has potential for diagnosing tooth cracks by detecting fluorescence reactions. QLF has shown promise in detecting enamel cracks and bacterial contamination in these cracks. This case series demonstrates the effectiveness of QLF in locating and assessing tooth crack depth. While further research is needed, QLF could serve as a valuable auxiliary diagnostic tool for crack diagnosis and treatment planning.

Red fluorescence for assessing longitudinal tooth fractures

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Objectives

This study aimed to measure the autofluorescence of the extracted LFTs with endodontically treated teeth, and to determine the association between fluorescence patterns and LTF types according to AAE (American Association of Endodontics) classification. This study also aimed to identify the relationship between red fluorescence (RF) and preoperative factors detected prior to the extraction that influenced the formation of a periapical lesion adjacent to fracture.

Methods

Thirty-three extracted teeth were classified into cracked teeth, split teeth, and root fractures using LTF types. The LTF types were identified using an operating microscope. Clinical examinations were performed using the preoperative factors (tooth site, age, sex, subjective discomfort, signs and symptoms, bite test, mobility test, percussion sensitivity, palpation sensitivity, and sinus tracts) from clinical and radiographic findings (CT images and periapical radiographs). The autofluorescence emitted from each fracture was captured and quantified using a fluorescence technique. Chi-square or Fisher's exact tests and univariate and multiple logistic analyses were performed. Associations between the preoperative factors and RF were quantified using odds ratios (ORs) and 95% confidence intervals.

Results

RF was identified in 82%, 83%, and 0% of cracked teeth, split teeth and vertical root fractures, respectively ($P < 0.001$). When RF was identified on the outer tooth surface, it penetrated into the crack line; otherwise it did not penetrate into the fracture line (Figure 1). Among the examined preoperative clinical factors, differences between the presence and absence of RF were identified for sinus tract formation ($P = 0.021$), and radiographic features ($P = 0.027$). Regression analysis revealed a significant factor related to the RF, with sinus tract formation having a negative effect on RF (odds ratio [OR]=0.09). The presence of comprehensive periradicular lesions in radiography had a positive effect on RF (OR=5.04) (Table 1).

Conclusions

This study found that RF emitted from crack lines was more prevalent in cracked and split teeth as classified by the AAE. These two types originate from the crown tooth in contact with the oral cavity. However, vertical root fractures did not exhibit RF because they originated from the apical root, which did not directly contact the oral cavity. The cracks with RF also tended to appear in the radiographs alongside periodontal bone resorption adjacent to the cracks. Therefore, the RF of cracks can be used to determine the risk of comprehensive periodontal destruction surrounding cracks.

Key result 1

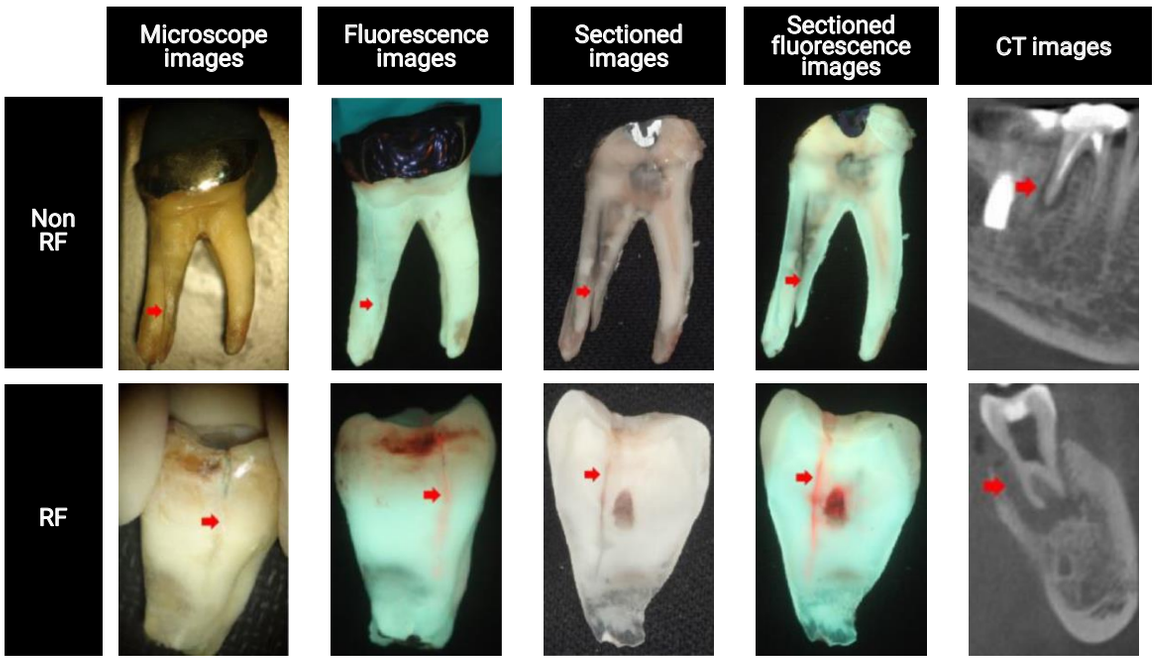

Figure 1. Representative images of LTFs exhibiting red fluorescence (RF) and non-RF LTFs.

Key result 2

Table 1. Simple and multivariate logistic regression analyses of preoperative factors affecting the emission of red fluorescence.

Preoperative Factors		Presence of red fluorescence			
		Crude OR (95% CI)	*P* value	Crude OR (95% CI)	*P* value
Sinus tract	Absence (reference)	0.09	0.03	0.09	0.03
	Presence	(0.00–0.79)		(0.00–0.79)	
Radiographic features	Periapical lesion (reference)	5.04	0.03	3.68	0.11
	Periradicular lesion	(1.13–22.50)		(0.74–18.47)	

CI, confidence interval; OR, odds ratio.

Plain language summary

The present study found a correlation between red fluorescence in teeth with longitudinal tooth factrures (LFTs) and radiographic signs of periodontal inflammation, indicating that this red fluorescence can serve as an indicator of the risk of significant periodontal damage near fractured teeth. This finding suggests that the fluorescence technique offers a straightforward clinical screening tool for detecting bacterial infection in fractured teeth. It can also help identify the patterns of alveolar bone loss associated with LTFs without the need for radiographic imaging. In essence, this method provides a valuable and non-invasive means to assess the health fractured teeth and their surrounding tissues, aiding in the timely detection of issues and potentially improving dental care outcomes for patients.

Evaluation of the clinical efficacy of quantitative light-induced fluorescence technology in diagnosing cracked teeth

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[b] Department of Preventive Dentistry & Public Oral Health, BK21 FOUR Project, Yonsei University College of Dentistry, Seoul, Republic of Korea
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Objectives

This retrospective study evaluated the clinical efficacy of quantitative light-induced fluorescence (QLF) technology for crack detection and the diagnosis of cracked teeth and assessed the possibility of a quantitative evaluation of cracks using QLF technology.

Methods

Patients who were clinically diagnosed with cracked teeth over a 1-year period were included. The QLF images of the corresponding symptomatic cracked teeth and asymptomatic contralateral teeth with crack lines were taken with Qraypen C (AIOBIO, Seoul, Korea). Fluorescence loss (ΔF), maximum fluorescence loss (ΔFmax), red fluorescence (ΔR), and maximum red fluorescence (ΔRmax) of the crack line were analyzed. The correlation between these parameters and sex, age, tooth position (1st premolar, 2nd premolar, 1st molar, 2nd molar), spontaneous pain (+/-), percussion test (+/-), cold test (++/+/-), and bite test (+/-) were statistically analyzed.

Results

A total of 66 patients were included. Twenty-four patients had asymptomatic contralateral teeth with apparent crack lines; thus, 90 teeth were analyzed. The crack lines in 84 teeth observed as red fluorescent lines on the QLF images showed ΔR values higher than the cut-off value set by the analysis program used (Fig. 1). The patient's age and the |ΔF| and ΔR values were positively correlated. However, there was no statistically significant difference in the QLF parameters between the same patient's symptomatic tooth and the contralateral tooth.

Conclusions

QLF technology is a useful assistive diagnostic device for diagnosing cracked teeth. QLF technology may enable quantifying crack line progression, but additional research is required to develop a method for directly analyzing crack line depth.

Key result 1

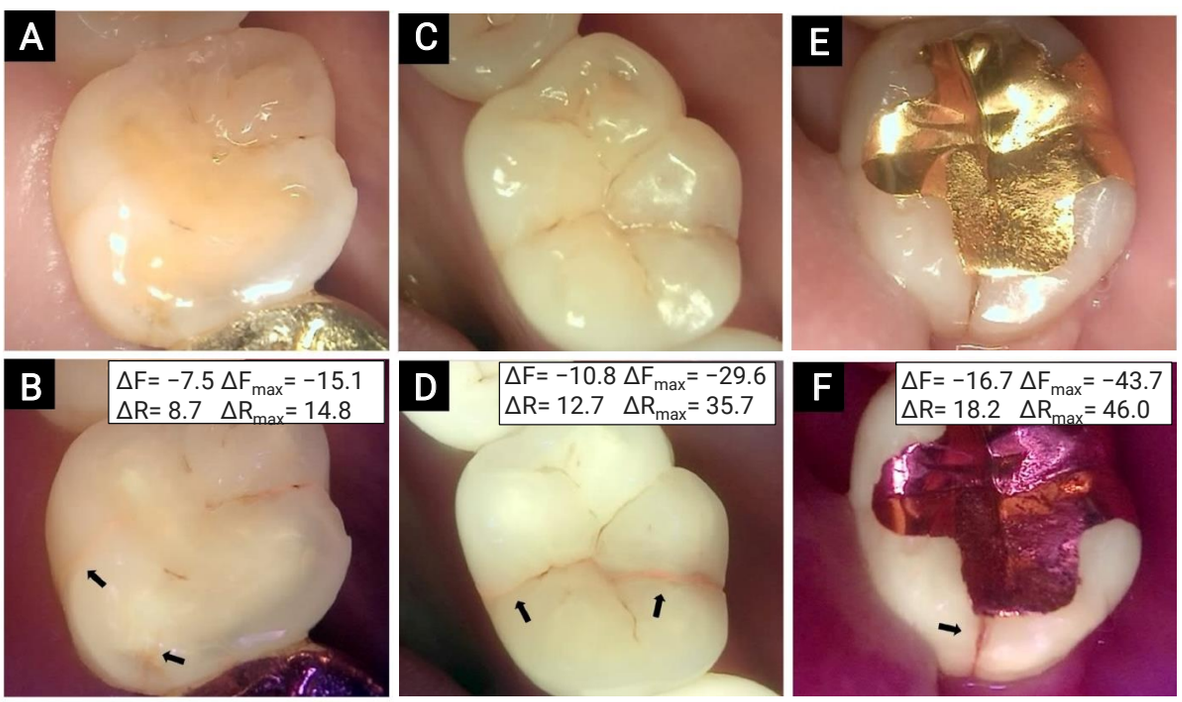

Figure 1. Arrows indicate crack lines, and QLF parameters of each tooth are shown.

Key result 2

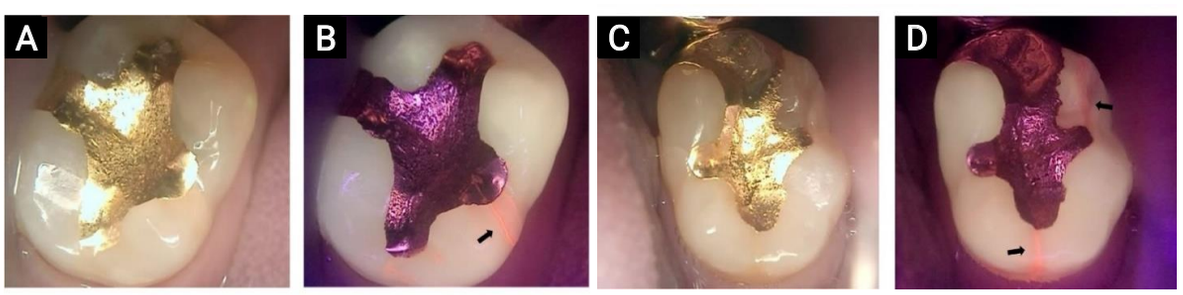

Figure 2. Representative image of additional crack lines observed in QLF image. (A) Distinct crack line was observed on the mesial marginal ridge. (B) Additional crack lines were confirmed on buccal and distobuccal cusps of the tooth, indicated by arrows.

Plain language summary

Detecting cracked teeth, which can lead to various symptoms and complications, is often challenging. Quantitative Light-Induced Fluorescence (QLF) technology, using visible blue light at 405 nm, shows potential for detecting and quantifying cracks and microbial activity. Clinical studies on QLF's efficacy in diagnosing cracked teeth are limited, and this study assesses its effectiveness and correlation with clinical symptoms. While age correlated with QLF parameters, there was no significant difference between symptomatic and asymptomatic cracked teeth in the same patient. QLF technology appears beneficial as a supplementary diagnostic tool, but further research is needed to directly analyze crack line depth.

Clinical applications of a quantitative light-induced fluorescent (QLF) device in the detection and management of cracked teeth: A case report

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Objectives

The aim of this case report was to discuss the clinical application using a quantitative light-induced fluorescent (QLF) device for the diagnosis and treatment of a cracked tooth as visualizing the tooth's crack.

Case report

A 39-year-old woman visited a dental hospital complaining of severe throbbing pain in left lower teeth during mastication. The dentist performed clinical examinations, including radiographic examinations and pulp vitality tests. Tooth #36 was diagnosed with symptomatic irreversible pulpitis. Observation of the occlusal surface with the naked eye showed that tooth #36 had a ceramic restoration with no specific findings. A visual inspection was performed on tooth #36 using a Qraypen C, an intraoral capture-type QLF device. A red-fluorescent line was observed on the distal side of the ceramic inlay in the fluorescent image (Fig. 1E), and a tooth crack in tooth #36 was, thereby, suspected. QLF Images were successively acquired while removing the old restoration of tooth #36. In the fluorescent image after removing the restoration (Fig. 1F and G), a clear crack line was observed from the distal marginal ridge of tooth #36. Root canal treatment was performed on tooth #36. Fig. 2E–G showed the fluorescent images obtained by sequentially removing the crack line as much as possible to the gingival margin after root canal filling. Fig. 2G shows that the red-fluorescent line almost disappeared at the gingival margin. Then, the upper layer of the canal filling material in the distal canal was sufficiently removed below the area where the distal crack line disappeared. Inside cavity space included the previous crack line were filled with adhesive materials (Fig. 2D and H). A full-veneer crown was recommended as the final restoration. Fluorescent images were analyzed using the software after removing the old restoration and at the gingival marginal area after the removal of the crack line. The values of ΔFmax and ΔRmax after removing the old restoration showed −17.5% and 19.9%, respectively, and those of the gingival margin after removing the crack line, showed-11.5% and 7.5%, respectively.

Conclusions

Images acquired with the QLF device can provide useful information for detecting crack lines, recording the treatment process, and restorative management of cracked teeth.

Key result 1

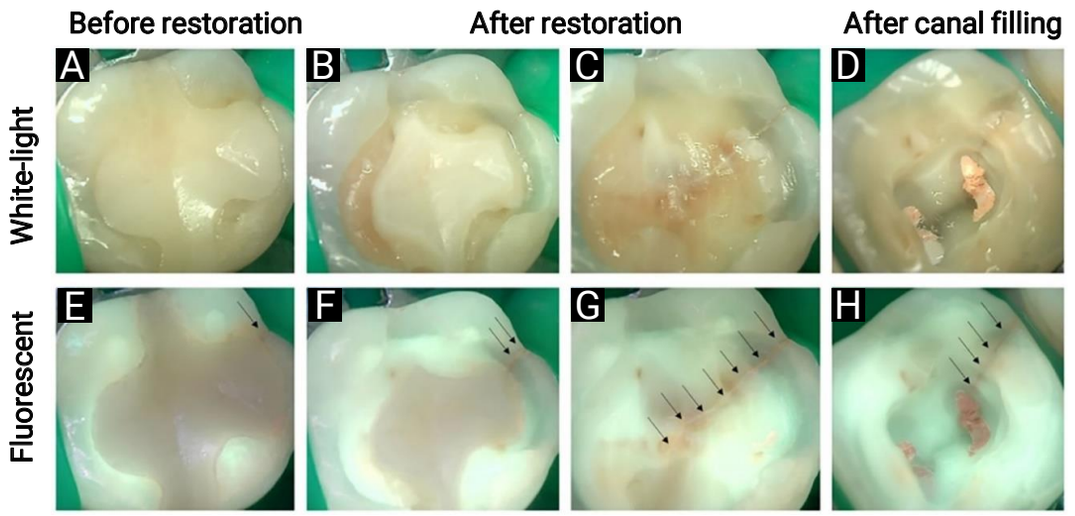

Figure 1. Fluorescent image showing distal crack line before (E) and during (F) removing restoration. Fluorescent images clearly showing crack line located inside the pulp cavity after restoration removal (G, H). The arrows indicate tooth crack lines.

Key result 2

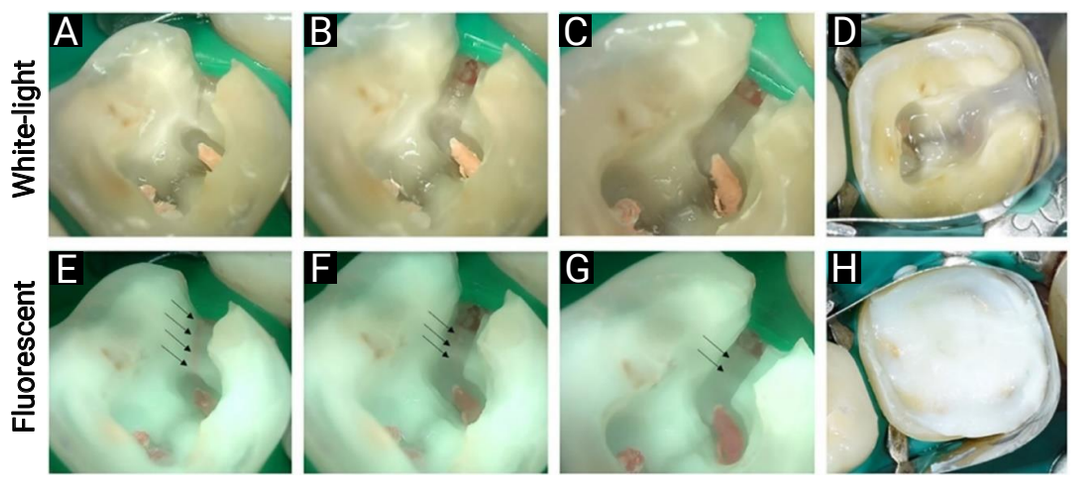

Figure 2. Images captured by Qraypen C after removing crack line. Images during core build-up (D,H) by capturing DSLR. E–G fluorescent images showed gradual disappearance of red-fluorescent line indicating the crack line. The arrows indicate the tooth crack lines.

Plain language summary

A cracked tooth is a complex issue with the potential for future fractures and microbial infection. Detecting cracks can be challenging using traditional methods. Quantitative Light-Induced Fluorescence (QLF) technology, utilizing 405 nm blue visible light, has emerged as a valuable tool for identifying tooth cracks and microbial penetration. Red-fluorescent lines in QLF images indicate crack locations and bacterial activity, offering clinicians precise diagnostic insights. In this case, Qraypen C was used for diagnosis and management, providing clear visual information about crack direction and progression. QLF images were also convenient for record-keeping and patient education. This case highlights the potential of QLF in diagnosing and guiding treatment for cracked teeth.

Investigation of validity and inter examiner agreement of quantitative light induced fluorescent images in diagnosing cracked teeth

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Objectives

This study aimed to evaluate the validity and inter-observer agreement of quantitative light-induced fluorescence (QLF) images in diagnosing cracked teeth. It also investigated the diagnostic effectiveness of two types of QLF images: natural color images and fluorescent images.

Methods

A total of 26 cracked teeth were assessed using QLF images taken before and after crack line removal. The reference standard of the crack's location was established by a trained dentist based on QLF images after removing the crack line (Fig. 1). Two examiners independently evaluated the presence of cracks in five zones (central, buccal, lingual, mesial, and distal) and later discussed their findings to reach a consensus. Agreement levels were measured using the Kappa index, and cross-comparisons were conducted based on restoration types, including gold, amalgam, and composite resin.

Results

The inter-examiner agreement was higher for fluorescent images (κ = 0.449) compared to natural color images (κ = 0.394) (Table 1). Agreement with the reference standard followed a similar trend, with fluorescent images showing a Kappa value of 0.662, while natural color images showed a much lower agreement (Kappa: 0.164). Regarding specific crack locations, mesial cracks showed the highest agreement in fluorescent images (Kappa: 0.923), while lingual cracks showed the lowest agreement in natural color images (Kappa: 0.283).

Conclusions

Fluorescent images significantly improve the accuracy and reliability of detecting tooth crack lines compared to natural color images. These findings demonstrate the diagnostic value of QLF fluorescent imaging in enhancing crack detection, particularly in areas where natural color imaging alone is insufficient.

Key result 1

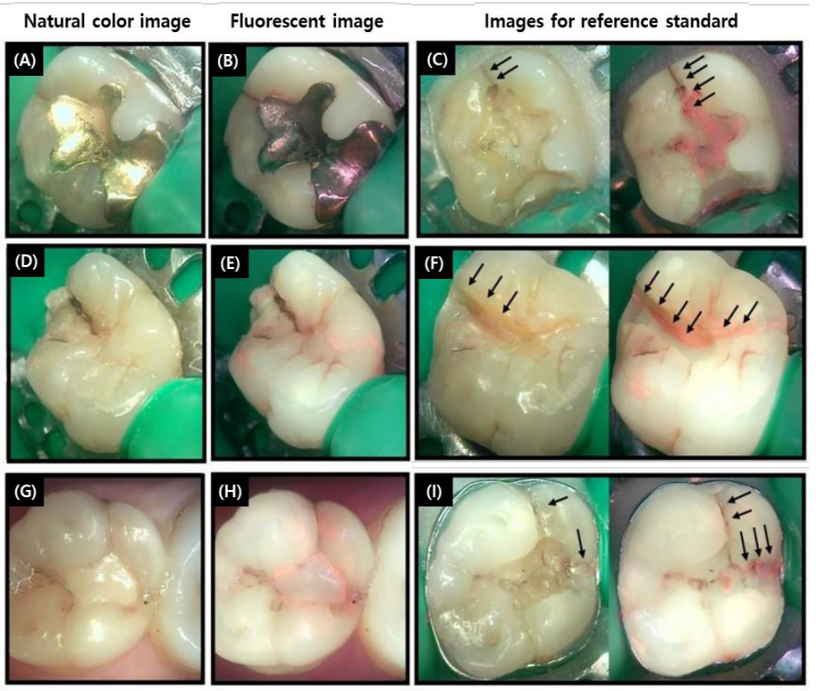

Figure 1. Three samples (A-C, D-F, G-I) showing natural color images, fluorescence images, and images for the reference standard taken using the QLF device. The reference standard of the location of the tooth's crack is established based on QLF images (C, F, I) after crack removal or restoration removal. The arrows indicate the crack lines identified within the internal tooth structure through QLF images. Examples of natural color images (A, D, G) and fluorescent images (B, E, H) were provided independently to examiners A and B.

Key result 2

Table 1. Agreement between examiners (A, B), between examiners and the reference standard, and according to crack's location (kappa value).

	Natural color image	Fluorescent image			
*Agreement between Examiner A B	0.394	0.449			
**Agreement between AB-reference standard	0.164	0.662			
	Buccal crack	**Lingual crack**	**Mesial crack**	**Distal crack**	**Central crack**
N- R	0.606	0.283	0.615	0.48	0.581
F- R	0.506	0.692	0.923	0.785	0.806

*Agreement between interpretation of examiner A and B
**Agreement between the final interpretation of examiners AB after discussion and reference standard abbreviation: N-R, agreement between the interpretation natural color image and reference standard; F- R, agreement between the interpretation of fluorescent image and reference standard.

Plain language summary

This study evaluated how well QLF images can detect cracks in teeth and compared the accuracy of two image types: natural color and fluorescent images. A total of 26 cracked teeth were analyzed, with two examiners independently assessing crack locations across five zones. The findings showed that fluorescent images more accurate and higher agreement with the reference standard than natural color images. Restoration types, such as gold and ceramic, influenced accuracy, but overall, QLF images proved effective for diagnosing tooth cracks.

Differences in the intensity of light-induced fluorescence emitted by resin composites

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Objectives

The aims of this study were to compare the intensities of fluorescence emitted by different resin composites as detected using quantitative light-induced fluorescence (QLF) technology, and to compare the fluorescence intensity contrast with the color contrast between a restored composite and the adjacent region of the tooth.

Methods

Six brands of light-cured resin composites (shade A2) were investigated. The composites were used to prepare composite discs, and fill holes that had been prepared in extracted human teeth. White-light and fluorescence images of all specimens were obtained using a fluorescence camera based on QLF technology (QLF-D) and converted into 8-bit grayscale images (Fig. 1). The fluorescence intensity of the discs as well as the fluorescence intensity contrast and the color contrast between the composite restoration and adjacent tooth region were calculated as grayscale levels.

Results

The grayscale levels for the composite discs differed significantly with the brand ($P < 0.001$): DenFil (10.84 ± 0.35, mean ± SD), Filtek Z350 (58.28 ± 1.37), Premisa (156.94 ± 1.58), Grandio (177.20 ± 0.81), Charisma (207.05 ± 0.77), and Gradia direct posterior (211.52 ± 1.66). The difference in grayscale levels between a resin restoration and the adjacent tooth was significantly greater in fluorescence images for each brand than in white-light images, except for the Filtek Z350 ($P < 0.05$) (Table. 1). However, the Filtek Z350 restoration was distinguishable from the adjacent tooth in a fluorescence image.

Conclusions

The intensities of fluorescence detected from the resin composites varied. The differences between the composite and adjacent tooth were greater for the fluorescence intensity contrast than for the colors observed in the white-light images.

Key result 1

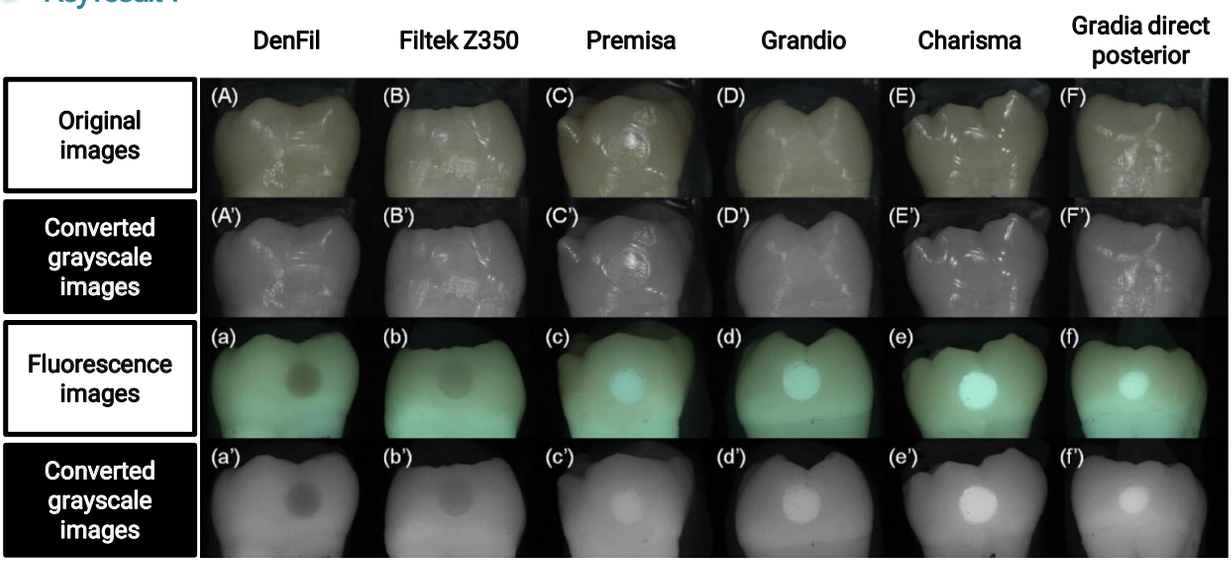

Figure 1. Images of restored teeth obtained by QLF-D.

Key result 2

Table 1. Differences in grayscale levels between each resin restoration and the adjacent region of the tooth obtained from the fluorescence images, and the difference in color obtained from the white-light images.

Brand name of resin composite	Difference in grayscale levels between a resin restoration and the adjacent region of the tooth		*p*-value*
	In white-light images	In fluorescence images	
DenFil	9.31 (6.87)	22.68 (5.14)	0.016
Filtek Z350	9.97 (4.79)	14.68 (5.02)	0.153
Premisa	11.62 (4.86)	30.36 (2.06)	<0.001
Grandio	10.41 (4.96)	35.96 (6.07)	<0.001
Charisma	8.80 (3.69)	61.26 (5.05)	<0.001
Gradia direct posterior	7.44 (4.53)	57.77 (7.93)	<0.001

The difference in grayscale levels were obtained from converted 8-bit grayscale images of the white-light and fluorescence images, and they were presented in mean (standard deviation).
**p*-values were obtained by paired t-test at α = 0.05.

Plain language summary

As technology advances, it becomes increasingly difficult to detect resin dental restorations through visual inspection alone. Changes in the fluorescence of teeth and resin restorations have recently been reported, and this property could potentially improve the detection of tooth-colored resin restorations during dental examinations. This study has two main goals: 1) to compare the fluorescence intensity emitted from various resin restorations, and 2) to compare the fluorescence intensity contrast and color differences in adjacent areas of resin restoration teeth. The results showed that different resin restorations emit different levels of fluorescence when examined using QLF-D technology. Additionally, the fluorescence of restorative composites sometimes appears brighter or dimmer than that of adjacent natural teeth. Overall, QLF-D has proven to be an excellent method for detecting restored resin restorations compared to the naked eye.

Evaluation of resin infiltration using quantitative light-induced fluorescence technology

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Objectives

To determine whether quantitative light-induced fluorescence (QLF) technology can be used to classify the colour of teeth specimens before and after resin infiltration (RI) treatment, and calculate the correlation between the ΔF value and colour difference (ΔE) in fluorescence images of the specimens obtained using a QLF–digital (QLF-D) device.

Methods

Sixty sound bovine permanent teeth specimens were immersed in demineralized solution. Two exposed windows were formed in each specimen, and RI treatment was applied to one of them. The ΔE values were obtained for the differences between a sound tooth surface (SS), an early dental caries surface (ECS) and an ECS treated with RI (RS) in white-light and fluorescence images obtained using QLF-D, respectively. The ΔF value was obtained from fluorescence images using dedicated software for QLF-D. The mean differences between the ΔE values obtained from the white-light and fluorescence images were analyzed by paired t-test. Pearson correlation analysis and Bland-Altman plots were applied to the differences between the ΔF value for ECS ($\Delta F_{SS\text{-}ECS}$) and the ΔE value between SS and ECS ($\Delta E_{SS\text{-}ECS}$), and between the ΔF value for RS ($\Delta F_{SS\text{-}RS}$) and the ΔE value between SS and RS ($\Delta E_{SS\text{-}RS}$) in fluorescence images.

Results

Significant differences were found between $\Delta E_{SS\text{-}ECS}$, $\Delta E_{SS\text{-}RS}$ and $\Delta E_{ECS\text{-}RS}$ obtained from the white-light and fluorescence images ($P < 0.001$) (Table. 1). Significant correlations between $\Delta F_{SS\text{-}ECS}$ and $\Delta E_{SS\text{-}ECS}$ ($r = -0.492$, $P < 0.001$) and between $\Delta F_{SS\text{-}RS}$ and $\Delta E_{SS\text{-}RS}$ ($r = -0.661$, $P < 0.001$) were confirmed for the fluorescence images (Fig. 1). Almost all of the values for the differences between $\Delta F_{SS\text{-}ECS}$ and $\Delta E_{SS\text{-}ECS}$ and between $\Delta F_{SS\text{-}RS}$ and $\Delta E_{SS\text{-}RS}$ fell within plus or minus 1.96 times the standard deviation from the mean of the differences in Bland-Altman plots.

Conclusions

Using QLF-D, the difference before and after RI can be classified, and the presence or absence of RI can be confirmed through fluorescence images obtained using QLF technology. QLF technology can be used to confirm the presence of RI in teeth.

Key result 1

Table 1. Comparisons of ΔE values between sound tooth surface (SS), demineralized early dental caries (ECS) and demineralized lesion treated with resin infiltration (RS) in white-light and fluorescence images.

	White-light image	Fluorescence image	*p* value †
$\Delta E_{SS\text{-}ECS}$	7.85 ± 1.67[a]	34.04 ± 5.57[a]	<0.001
$\Delta E_{SS\text{-}RS}$	3.19 ± 1.42[b]	8.61 ± 3.96[b]	<0.001
$\Delta E_{ECS\text{-}RS}$	5.18 ± 1.53[c]	26.82 ± 5.26[c]	<0.001
p value ‡	<0.001	<0.001	

$\Delta E_{SS\text{-}ECS}$ is the colour difference between SS and ECS.
$\Delta E_{SS\text{-}RS}$ is the colour difference between SS and RS.
$\Delta E_{ECS\text{-}RS}$ is the colour difference between ECS and RS.
Values with the same letter superscripts (a,b,c) are not significant in Scheffé's multiple-comparison test at α = 0.05.
† *p* value obtained from a paired t-test of ΔE values between white-light and fluorescence images.
‡ *p* value obtained from one-way ANOVA for $\Delta E_{SS\text{-}ECS}$, $\Delta E_{SS\text{-}RS}$ and $\Delta E_{ECS\text{-}RS}$.

Key result 2

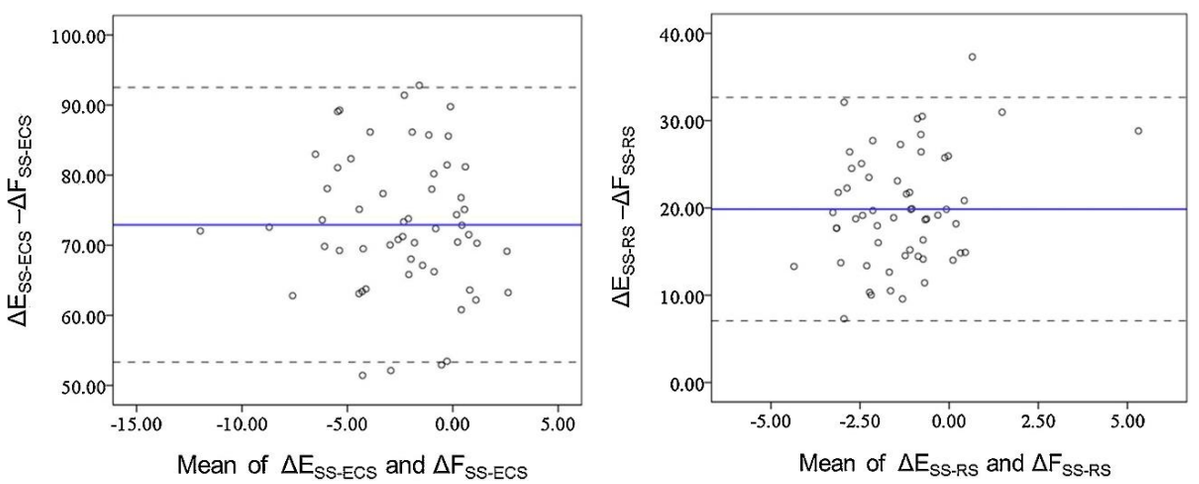

Figure 1. Bland-Altman plot. $\Delta E_{SS\text{-}ECS}$ and $\Delta F_{SS\text{-}ECS}$ obtained from QLF-D fluorescence images (A). The solid line indicates the mean difference between $\Delta E_{SS\text{-}ECS}$ and $\Delta F_{SS\text{-}ECS}$. Bland-Altman plot of $\Delta E_{SS\text{-}RS}$ and $\Delta F_{SS\text{-}RS}$ obtained from QLF-D fluorescence images (B).

Plain language summary

Resin infiltration (RI) is a preventive treatment for dental carious surfaces (ECS) that is not considered a disease. Clinicians and patients alike often question the use of RI because there are very subtle color differences compared to healthy tooth surfaces. The purpose of this study was to determine the feasibility of utilizing QLF technology to evaluate differences before and after RI treatment and to determine the correlation between ΔF values and color difference (ΔE) values in fluorescence images obtained using QLF-D. Using QLF-D, the difference before and after RI can be classified, and the presence or absence of RI can be confirmed through fluorescence images obtained using QLF technology. Therefore, QLF technology can be used as a non-destructive real-time assessment tool for RI.

Detection of residual resin-based orthodontic adhesive based on light-induced fluorescence

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Objectives

This study evaluated the fluorescence of orthodontic adhesives using quantitative light-induced fluorescence–digital (QLF-D) images, and compared differences in the color characteristics of the fluorescence between adhesive and the adjacent tooth with that under white-light illumination in specimens containing residual adhesive of various thicknesses.

Methods

Disc-shaped adhesive samples and samples comprising adhesive attached to extracted human teeth were prepared using Transbond XT, Blugloo, and Enlight, and they were ground to thicknesses ranging from 800 to 20 μm. Fluorescence and white-light images of the two types of specimens were taken with a QLF-D system. The color parameters for the fluorescence from the discs and the color difference (ΔE) between residual adhesive and the adjacent tooth were quantified in images using the CIE $L^*a^*b^*$ system.

Results

The fluorescence color values of the discs differed significantly among the three adhesive products ($P < 0.05$) (Table. 1). The ΔE values in fluorescence (ΔE_F) and white-light (ΔE_W) images for all three adhesives were lower for thinner residual adhesive specimens. The thickness of the adhesive could be perceived over a range of 50–100 μm for fluorescence images and 400–800 μm for white-light images ($\Delta E > 3.3$) (Fig. 1). ΔE_F was significantly larger than ΔE_W for all of the residual adhesives, Blugloo specimens thicker than 100 μm, and Transbond XT and Enlight specimens thicker than 50 μm ($P < 0.05$).

Conclusions

Detecting and analyzing fluorescence signals can improve the ability to detect residual adhesive on a tooth and also provide thickness information.

Key result 1

Table 1. *L**, *a**, and *b** values of the three orthodontic adhesives as observed in fluorescence and white-light images.

Adhesive	Fluorescence image			White-light image		
	*L**	*a**	*b**	*L**	*a**	*b**
Transbond XT	12.39 ± 2.83[a]	−6.23 ± 1.02[a]	2.30 ± 0.50[a]	53.17 ± 1.06[a]	−1.78 ± 0.08[a]	5.84 ± 0.25[a]
Blugloo	37.72 ± 1.01[b]	−5.20 ± 1.96[b]	13.26 ± 1.12[b]	65.56 ± 0.48[b]	−0.81 ± 0.18[b]	3.27 ± 0.32[b]
Enlight	17.89 ± 0.61[c]	−8.38 ± 0.28[c]	3.88 ± 0.31[c]	71.97 ± 0.81[c]	−2.16 ± 0.11[c]	4.87 ± 0.37[c]
P	<0.001	0.027	<0.001	<0.001	<0.001	<0.001

Data are mean ± standard-deviation values.
P values were obtained by one-way ANOVA and the Tukey post-hoc test.
[a, b] Significant differences among the three adhesives.
There was a total of 15 specimens.

Key result 2

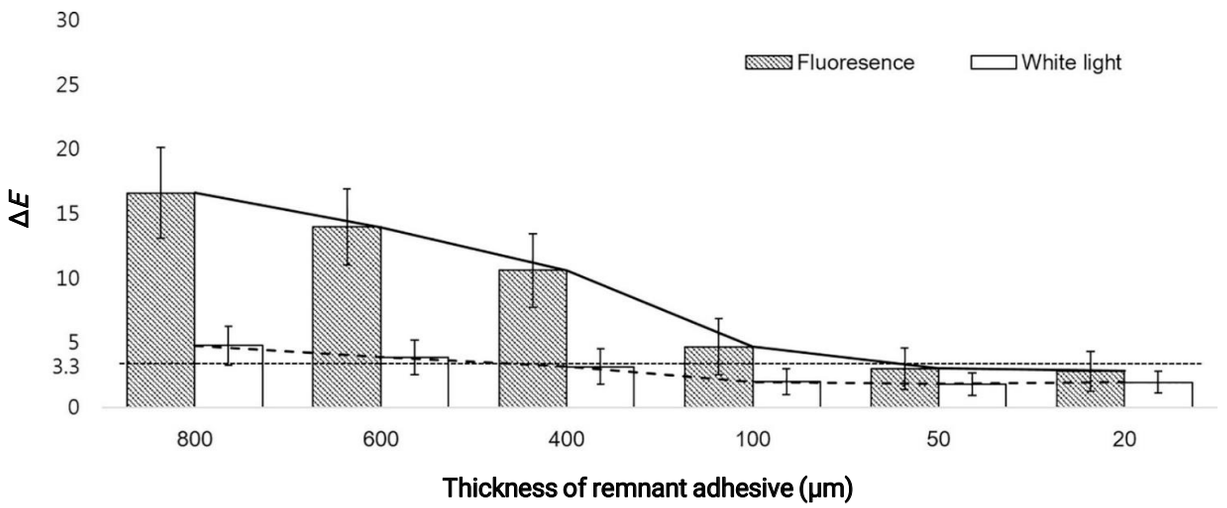

Figure 1. Change in chrominance obtained from fluorescence and white-light images for various residual-adhesive thicknesses. Data are mean and standard-deviation values for three specimens.

Plain language summary

This study used QLF-D imaging to assess orthodontic adhesive fluorescence, comparing it with white-light illumination for different adhesive thicknesses. Results showed significant differences in fluorescence color among three adhesives. Thinner adhesive had lower ΔE values in both fluorescence and white-light images, detectable at 50–100μm (fluorescence) and 400–800μm (white-light). ΔE_F exceeded ΔE_W for all adhesives, especially for thicker Blugloo (>100μm) and Transbond XT/Enlight (>50μm) specimens. In conclusion, this research showed that QLF technology is valuable for distinguishing between orthodontic adhesives and understanding their impact on tooth color. It also highlighted QLF's potential for assessing adhesive thickness, which can be useful in dental procedures involving adhesive removal.

Noninvasive detection of microleakage in all-ceramic crowns using quantitative light-induced fluorescence technology

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Objectives

The early noninvasive detection of crown microleakage is very important for tooth maintenance and preservation. A crown margin in a subgingival position combined with the obscuring effect of a ceramic crown make it difficult to diagnose microleakage using traditional methods such as visual-tactile examinations and radiography. The aim of this study was to determine the effectiveness of quantitative light-induced fluorescence (QLF) technology for diagnosing microleakage in an all-ceramic crown noninvasively.

Methods

In this study the red fluorescence glow was detected through a crown wall using the Qraycam QLF device (AIOBIO, Seoul, Republic of Korea). A 62-year-old male patient visited the hospital complaining of discomfort and teeth hypersensitivity in his upper right incisors under crown restorations.

Results

Red fluorescence inside the crown of tooth #13 was observable in the fluorescence image captured by Qraycam QLF device. Red fluorescence as well as fluorescence loss were observed on smooth and interproximal tooth surfaces in a QLF examination, which confirmed the presence of demineralized lesions in the suspected areas. Closer inspections of the removed crown indicated strong red fluorescence covering the entire inside surface of the crown wall, providing clear evidence of the presence of bacteria-induced microleakage (Fig. 1). The lesions were removed completely and the repaired crown was reattached. Thereafter, we confirmed that no further red fluorescence was observed on a fluorescence image (Fig. 2). At follow-up visits every 3 months after treatment, the tooth was healthy and well-functioning without any patient discomfort.

Conclusions

These findings indicate that QLF technology can be effectively applied to provide objective evidence for detecting microleakage and diagnosing carious lesions inside an all-ceramic crown noninvasively.

Key result 1

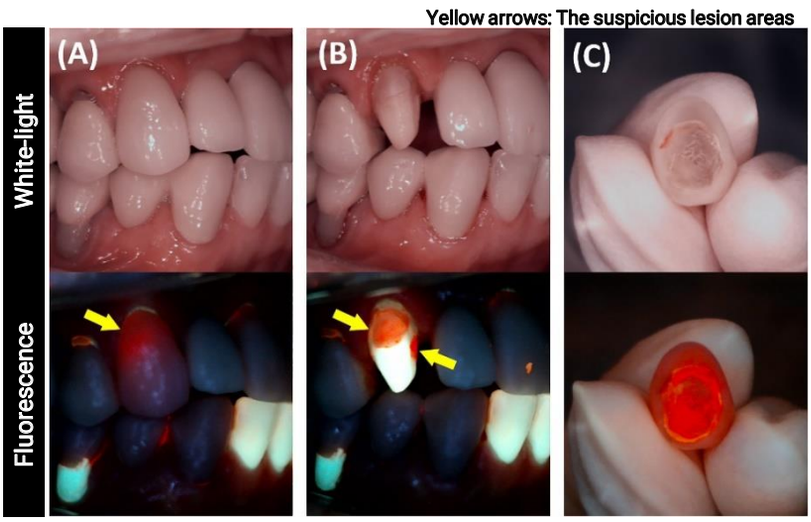

Figure 1. Images of all-ceramic crown microleakage before (A) and after (B) crown removal, and vertical images of the inside surface of the crown restoration (C). Obtained using the Qraycam device.

Key result 2

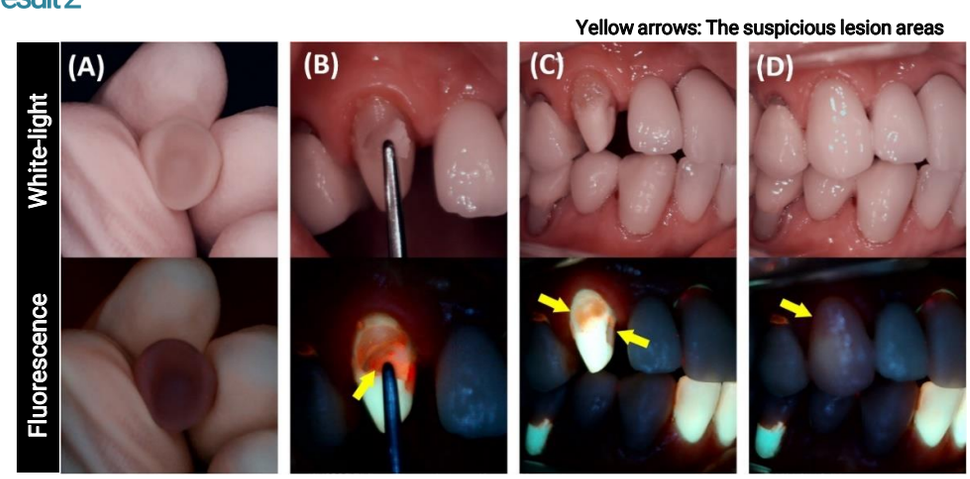

Figure 2. Qraycam images obtained at the different treatment stages: elimination of luting cement that remained inside the crown restoration (A), removal of red fluorescent tissues (B), confirmation of demineralized lesions (C), and reattachment of the repaired crown after removing carious lesions (D).

Plain language summary

Detecting microleakage in dental crowns early is crucial for maintaining and preserving teeth. It is difficult to diagnose microleakage using traditional methods such as visual-tactile examinations and radiography. This study aimed to assess the usefulness of quantitative light-induced fluorescence (QLF) technology as a noninvasive method for diagnosing microleakage in all-ceramic crowns. In this study, the Qraycam QLF device was used to identify a red fluorescence glow through the crown wall. This red fluorescence glow can be produced by bacterial microleakage and carious lesions inside the all-ceramic crown. QLF examinations enable dentists to detect microleakage in all-ceramic crowns without invasive procedures. QLF technology proves to be an effective tool for providing objective evidence in the detection of microleakage in all-ceramic crowns.

Quantitative light-induced fluorescence enables effective detection of orthodontic adhesive residues in diverse environments

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Objectives

Adhesive remnants post-orthodontic treatment might have deleterious effects on oral health, including enamel demineralization, plaque accumulation, and elevated risk of caries development. The aim of this study was to identify and characterize adhesive residues in an ex vivo environment rich in salivary microbiota using quantitative light-induced fluorescence (QLF) technology.

Methods

Disc-shaped adhesive samples with thickness ranging from 800 to 100 μm were prepared using GC Ortho, GOTO, T Orthobond, and Transbond XT and subsequently evaluated utilizing a QLF system. Bovine teeth containing GC Ortho and GOTO adhesives and isolated human premolar teeth bonded with brackets were subjected to a 10-day incubation in an artificial saliva environment. Daily imaging was conducted using QLF during incubation. Data with $\Delta R > 30\%$ and simple hygiene score (SHS) were obtained with a software for further analysis.

Results

Fluorescence intensity exhibited significant differences among the four orthodontic adhesives ($P < 0.05$)(Fig. 1). Results of incubation in artificial saliva revealed that red fluorescence surrounding the adhesive on the tooth surface was distinctly observable from day five onwards, with $\Delta R > 30\%$ and SHS levels higher than those of the control group without adhesive ($P < 0.05$)(Table. 1). Observation of fluorescence images of isolated human premolar teeth with bonded brackets indicated that red fluorescence was primarily present around the brackets.

Conclusions

Application of QLF is efficacious in identifying and demarcating adhesive residues within an environment rich in salivary microbiota.

Key result 1

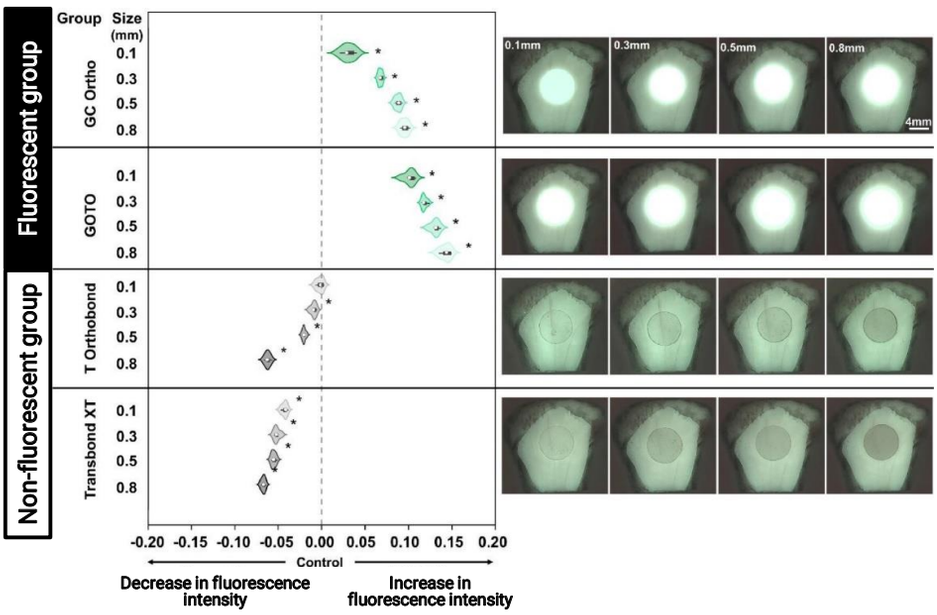

Figure 1. Fluorescence intensity variations among four orthodontic adhesives with different thicknesses under QLF imaging.

Key result 2

Table 1. ΔR > 30% values and simple hygiene score (SHS) of bovine tooth cultures containing GC Ortho and GOTO adhesives measured between days 5 to 10.

Mean value	5th day		6th day		7th day		8th day		9th day		10th day	
	ΔR	SHS	ΔR	SHS	ΔR	SHS	ΔR	SHS	ΔR	SHS	ΔR	SHS
Control	0	0	0	0	2.31	0.67	1	0.67	2.67	1.33	7.00	2.67
GC	12.67	2.16	17.33	2.83[a]	25.67	4.33[a]	32.67[a]	4.67[a]	44.17[a]	5[a]	38.17[a]	5[a]
GOTO	1	0.67	1.83	1.17	4.33	2	7.67	2.67	14.67	4.17[b]	19.67	4.5
p-value	0.27	0.06	0.11	0.008	0.05	0.03*	0.018*	0.006*	0.005*	0.003*	0.04*	0.04*

p-values were obtained by one-way ANOVA and the Dunnett post-hoc test ($p < 0.05$).
Lower case letters indicate significant differences between the control group and each of GC Ortho & GOTO on the same day from Dunnett post-hoc test.
ΔR: the area occupied by 30% increase in red fluorescence intensity compared to the fluorescence of a normal tooth surface.

Plain language summary

Adhesive remnants post-orthodontic treatment might have deleterious effects on oral health, including enamel demineralization, plaque accumulation, and elevated risk of caries development. The utilization of quantitative light-induced fluorescence (QLF) as a diagnostic instrument holds potential to enhance clinical outcomes and elevate patient satisfaction. This study aimed to detect and characterize adhesive remnants in a salivary microbiota-rich ex vivo environment using quantitative light-induced fluorescence (QLF) technology. Various orthodontic adhesives were examined, and fluorescence intensity differed significantly among them. After incubation in artificial saliva, red fluorescence appeared around the adhesive from day five onwards, with levels exceeding those of the control group without adhesive. Observation of fluorescence images of isolated human premolar teeth with bonded brackets indicated that red fluorescence was primarily present around the brackets. Application of QLF is efficacious in identifying and demarcating adhesive residues within an environment rich in salivary microbiota

Detection of pit and fissure sealant microleakage using quantitative light-induced fluorescence technology: an in vitro study

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Objectives

The aim was to evaluate the feasibility of Quantitative Light-induced Fluorescence (QLF) technology for detecting the presence and severity of microleakage in pit and fissure sealants.

Methods

The areas of interest (AOIs) were 160 pits and fissures of 40 extracted permanent teeth. Fluorescent images were acquired using a QLF device, and the maximum fluorescence loss (ΔF_{max}) of each AOI was analyzed. Following cross-sectioning and staining, histological dye penetration was scored on a scale of 0 to 3. The correlation between ΔF_{max} and microleakage depth was assessed using Spearman's rank correlation, and the diagnostic accuracy of ΔF_{max} was further evaluated by calculating the area under the curve (AUC).

Results

As the depth of microleakage in pit and fissure sealants increased, the $|\Delta F_{max}|$ value measured at the occlusal surface for areas with sealant microleakage showed increase (Fig.1). Also, the ΔF_{max} values of the microleakage areas showed a significantly strong correlation with increasing histological scores of dye penetration ($r = -0.72$, $P = 0.001$). To assess the diagnostic accuracy of the ΔF_{max} values, sensitivity, specificity, and AUC were calculated at the optimal cutoff point, based on the analysis of three diagnostic thresholds (Table 1). The AUC for ΔF_{max} demonstrated a high level of diagnostic accuracy, ranging from 0.83 to 0.91 across all diagnostic thresholds for detecting microleakage ($P = 0.001$). Specifically, when distinguishing microleakage beyond the outer half of the sealant (scores 1-3) from a lack of microleakage (score 0), a ΔF_{max} value of 10.10 yielded a sensitivity of 0.82, a specificity of 0.91, and the highest AUC value of 0.91.

Conclusions

Our study confirmed the utility of QLF technology for detecting and assessing the severity of sealant microleakage, highlighting its potential for noninvasive monitoring and improved sealant retention. Integrating QLF technology into routine dental practices could enhance sealant management and contribute to the effective prevention of secondary caries.

Key result 1

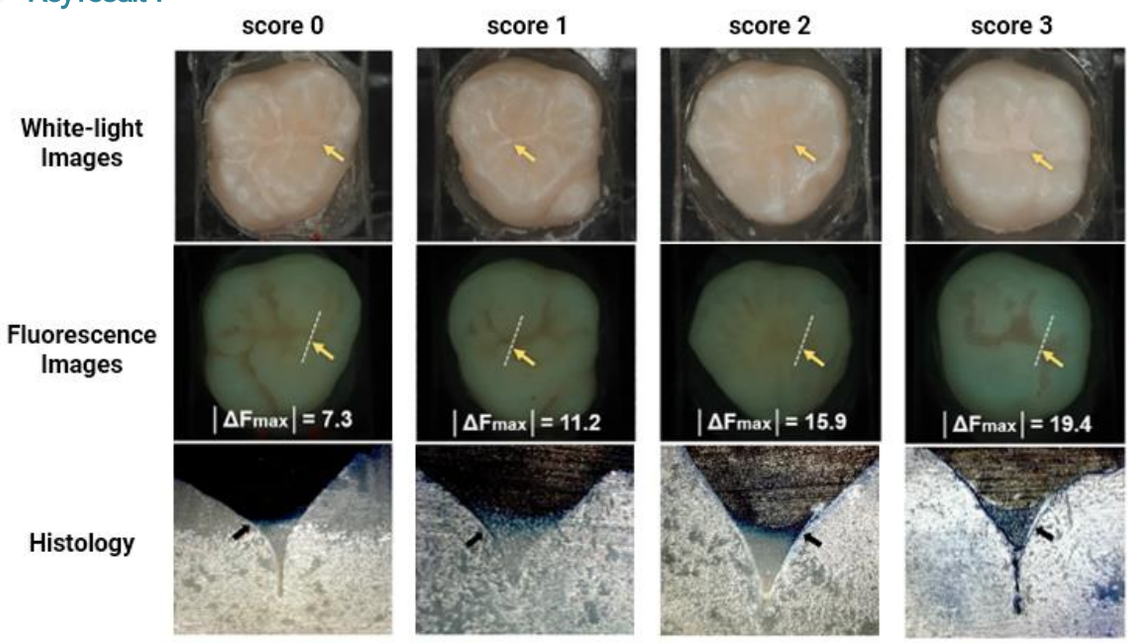

Figure 1. Representative fluorescence images and magnified microscopy images (×50) of the specimens according to the histological scores of dye penetration. Yellow arrows: analysis area; black arrows: microleakage; white dashed lines: the cross-section and analyzed regions.

Key result 2

Table 1. Area under the ROC curve, optimum sensitivity, specificity and cut-off for the $|\Delta F_{max}|$ at each diagnostic threshold measured using histological analysis.

Criteria for microleakage severity	Cut-off value of $\|\Delta F_{max}\|$	Sensitivity	Specificity	AUC	95% CI
Score 0/1-3	10.10	0.82	0.91	0.91	0.87-0.96
Score 0-1/2-3	10.22	0.95	0.68	0.89	0.84-0.94
Score 0-2/3	15.21	0.82	0.73	0.83	0.76-0.89

AUC, area under the ROC curve; CI, confidence interval; score; dye penetration histological score.

Plain language summary

This study aimed to evaluate the potential of Quantitative Light-induced Fluorescence (QLF) technology in detecting and assessing microleakage in pit and fissure sealants. Researchers analyzed 160 areas on 40 extracted permanent teeth by measuring fluorescence loss (ΔF_{max}) using QLF imaging. These measurements were compared with microleakage depth determined through dye penetration scoring. The results indicated a strong association between increased fluorescence loss and greater microleakage severity. The diagnostic analysis demonstrated that QLF could reliably identify microleakage, showing high accuracy across different thresholds. These findings suggest that QLF technology is a promising noninvasive method for monitoring sealant integrity and preventing secondary caries, offering a valuable tool for improving clinical outcomes in dental care.

Improving the competency of dental hygiene students in detecting dental restorations using quantitative light-induced fluorescence technology

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Objectives

The purpose of this study was to determine the usefulness of a quantitative light-induced fluorescence (QLF) technology in detecting dental restorations by comparing the detection ability of dental hygiene students between using conventional visual inspection alone and visual inspection combined with QLF technology.

Methods

The subjects of this study comprised 92 dental hygiene students. The students assigned to the control group only used white-light images to visually assess the mouth environment, while those in the experimental group additionally used fluorescence images (Fig. 1). Using the test results of an experienced inspector as a reference value, the agreement between the reference value and the evaluation results of the students in the experimental and control groups was evaluated using Cohen's kappa and the percentage agreement. The subjects were then classified covering three percentage ranges according to the score distribution and agreement values of the three groups were compared. The percentage agreement was calculated according to the type of dental restorations.

Results

The mean kappa value was significantly higher in the experimental group than the control group (0.70 vs 0.60, $p < 0.001$), as was the percentage agreement (80.06% vs 72.64%, $p < 0.001$). The agreement rate increased by approximately 8% when using QLF-D and visual inspection compared to using visual inspection compared to using visual inspection alone in the middle and bottom percentage groups; this was 5% higher than the increase observed in the top percentage group ($p < 0.01$, Table 1). The agreement rate also varied with the type of restoration, being significantly higher for a sound tooth or tooth-colored restoration in the experimental group ($p < 0.001$).

Conclusions

Combining QLF technology with conventional visual inspections could improve the ability to detect dental restorations and distinguish sound teeth from aesthetic restorations.

Key result 1

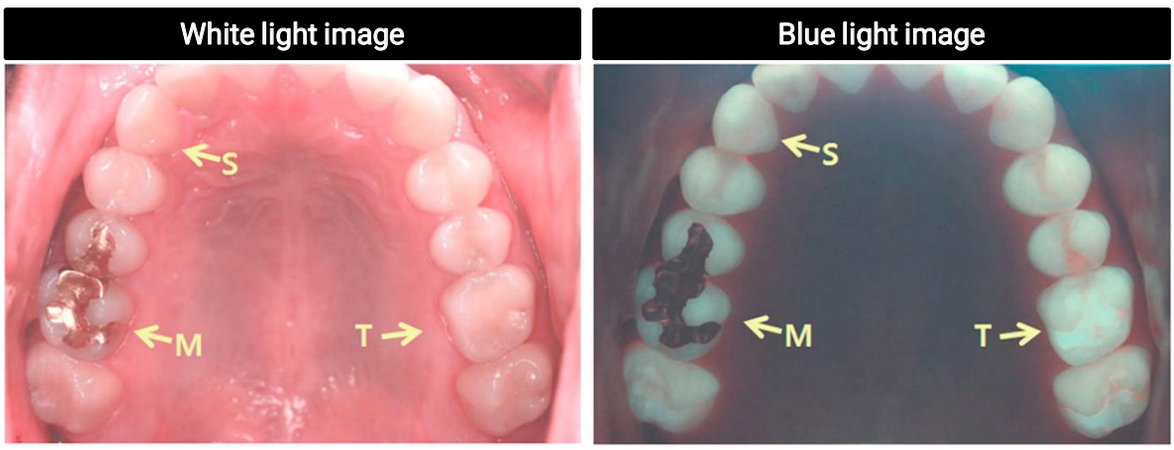

Figure 1. Examples of QLF-D images highlight the differences between the two types of images for a sound tooth (S), a metal restoration (M), and a tooth-colored restoration (T).

Key result 2

Table 1. Mean percentage agreement for detecting restorations according to three percentage groups.

Students	N	Visual inspection (%)		Visual inspection & QLF-D (%)		*p*-values*
		Mean	S.D.	Mean	S.D.	
Upper 30%	28	84.67	5.01	89.72	2.56	0.002
Middle 40%	36	72.63	3.41	80.90	2.93	<0.001
Lower 30%	28	60.63	4.15	69.34	7.27	<0.001
Total	92	72.64	10.32	80.06	9.25	<0.001

S.D.: Standard deviation.
**p*-values were calculated using an independent sample *t*-test.

Plain language summary

This study aimed to evaluate the potential of Quantitative Light-induced Fluorescence (QLF) technology in enhancing the ability of dental hygiene students to detect dental restorations. 92 students were divided into two groups: a control group that relied solely on traditional visual inspection and an experimental group that used QLF technology to detect restorations. The concordance between the students' results and those of skilled experts, used as a reference, was examined. The results revealed that the group utilizing QLF technology performed better in detecting dental restorations compared to the group relying solely on traditional visual inspection. Differences in detection were also noted depending on the type of restoration, with a particular advantage in identifying restorations related to color. In conclusion, QLF technology can aid in the accurate identification of dental restorations and differentiation from healthy teeth.

Effect of an oral health education program based on the use of quantitative light-induced fluorescence technology in Uzbekistan adolescents

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Objectives

The aim of this study was to determine whether an oral health education program using a Qscan device based on quantitative light-induced fluorescence (QLF) technology could improve the oral hygiene status and oral health literacy of adolescents.

Methods

One hundred adolescents aged 14–16 years attending a school in Tashkent city were included in this study. The participants were assigned to the following two groups using the permuted block randomization technique: (i) the control group (traditional learning) and (ii) the experimental group (Qscan device-based learning) (Fig. 1). The participants included in the experimental group received additional education and training on dental plaque removal using the Qscan device. The accumulated levels of plaque were assessed in all participants, who also completed questionnaires about their oral health status, oral health knowledge, attitude, and behavior during an 8-week period.

Results

The plaque index did not differ significantly between the two groups until the second week, but it was 68% lower in the experimental group compared to the control group (0.17 vs 0.53, $p < 0.001$) in the fourth week. This significant difference increased to 85% in the eighth week (0.07 vs 0.46, $p < 0.05$). The changes in oral health behaviors after 2 weeks differed between the two groups. In the experimental group, the knowledge and behavioral variables were improved by 28.3% and 30.7%, respectively, after 2 weeks compared to the baseline at the eighth week, while there were no significant changes in any of the behavioral variables in the control group. There were statistically significant improvements in the experimental group compared to the control group in attitude (16.7 vs 20.2, $p < 0.05$), and behavior (19.9 vs 30.5, $p < 0.05$). The difference between these two groups increased gradually, and the knowledge and behavioral variables of the experimental group improved by 56.5% and 48.8% compared to the baseline on the eighth week (Fig. 2).

Conclusions

This study has demonstrated that an oral health education program based on the use of QLF technology could be useful for improving the oral hygiene status and oral health literacy of adolescents in Uzbekistan.

Key result 1

Figure 1. Qscan device used in this study (left) and the photograph showing how to use this device in the oral health education program (right).

Key result 2

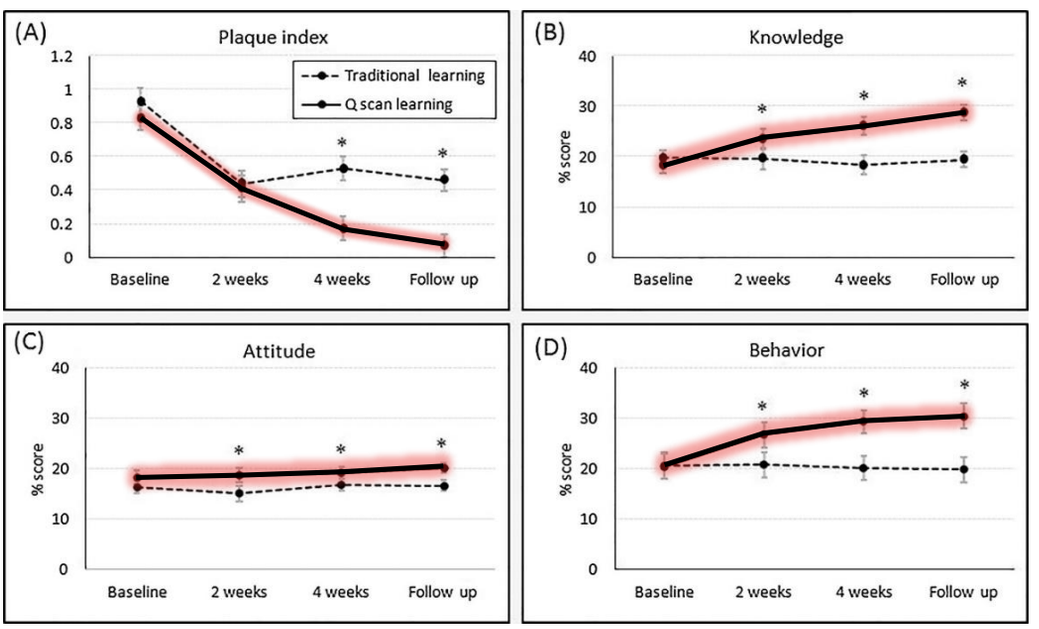

Figure 2. Oral hygiene status (plaque index) and oral health behavior variables in the two study groups. Data are median and confidence interval values. Significant differences ($p < 0.05$) are indicated by an asterisk.

Plain language summary

This study investigated whether an oral health education program utilizing Quantitative Light-induced Fluorescence (QLF) technology could improve oral hygiene status and oral health knowledge among 14-16-year-old adolescents in Uzbekistan. One hundred adolescents were divided into two groups: a control group that received traditional education and an experimental group that received education using QLF technology. The experimental group was trained on how to remove plaque formed on tooth surfaces using the QLF device. The results showed that the experimental group exhibited significant improvements compared to the control group in plaque indices, oral health knowledge, attitudes, and behaviors. Therefore, this study demonstrates that oral health education utilizing QLF technology can enhance oral hygiene status and oral health knowledge among Uzbekistani adolescents.

Comparison of the Short Time Effect of an Oral Hygiene Education in Four Sessions via Quantitative Light-Induced Fluorescence Technology Versus Disclosing Agents in Children : A Randomized, Crossover Clinical Trial

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Objectives

The aim of this study was to compare the effectiveness of Qscan plus based on quantitative light-induced fluorescence (QLF) technology and disclosing agents in oral health programs in children.

Methods

A randomized crossover study assigned 58 Korean children aged 6–11 years to start with either Qscan Plus or plaque-disclosing agents to visualize plaque during toothbrushing. The methods were switched after one month. Participants visited at baseline, post-brushing, and one-week follow-up for each method. The patient hygiene performance (PHP) index was used to assess oral hygiene status, questionnaires about oral health behavior and attitudes were completed, and QLF images of the frontal view were acquired using Qraycam Pro to analyze PHP index the simple hygiene score (SHS) and ΔR30 and ΔR120 values with a QLF-D analysis program. A total of 39 participants were analyzed using repeated-measures ANOVA, followed by the Bonferroni post hoc test with a significance level set at 0.05.

Results

The PHP score, SHS, ΔR30 and ΔR120 decreased significantly on post-brushing and follow-up compared to baseline in both methods, although there was no significant difference between the two methods (Table 1). Both methods demonstrated improvements in oral hygiene over time, as evidenced by the repeated-measures ANOVA results, which revealed statistically significant differences in PHP score, SHS, ΔR30, and ΔR120 across time points ($P < 0.001$). Responses from the questionnaire survey, indicated a significant increase in those reporting a brushing time of “3 minutes,” rising from 23.1% to 41% (Table 2). Similarly, the proportion of participants indicating “none” or “low” concern about oral hygiene decreased, while those reporting a “high” level of concern showed an increase.

Conclusions

The Qscan plus has a similar educational effect as disclosing agents, and can be used as a supplementary tool to encourage children in oral hygiene education.

Key result 1

Table 1. Variables of oral hygiene status in the two methods.

	Group	Pre-Brushing	Post-Brushing	One week later	F	*p*-value
PHP score	Qscan plus	1.58 ± 0.70	0.76 ± 0.39	1.08 ± 0.52		0.113 [a]
	Disclosing agent	1.71 ± 0.55	1.00 ± 0.43	1.20 ± 0.50		
	Time				117.216	< 0.001 [b]
SHS	Qscan plus	1.31 ± 1.78	0.49 ± 1.10	0.69 ± 1.03		0.379
	Disclosing agent	1.77 ± 1.72	0.64 ± 1.22	0.72 ± 1.02		
	Time				20.968	< 0.001 [b]
ΔR30 (%)	Qscan plus	2.05 ± 3.77	0.62 ± 1.63	0.82 ± 1.34		0.352
	Disclosing agent	2.74 ± 3.66	1.00 ± 2.53	1.08 ± 2.11		
	Time				14.620	< 0.001 [b]
ΔR120 (%)	Qscan plus	0.46 ± 1.39	0.03 ± 0.16	0.03 ± 0.16		1.000
	Disclosing agent	0.41 ± 0.88	0.05 ± 0.32	0.05 ± 0.32		
	Time				9.500	< 0.001 [b]

Each values were the mean ± SD. PHP: patient hygiene performance; SHS: simple hygiene score.
[a] *p*-values from the between-group effect of repeated-measures ANOVA at α = 0.05; [b] *p*-values from repeated-measures ANOVA, Bonferroni *post hoc* test at α = 0.05.

Key result 2

Table 2. Responses from the questionnaire survey for participants.

Question	Answer	Baseline	Post-Intervention	*p*-value
		n (%)	n (%)	
Brushing time (min)	< 2	7 (17.9)	4 (10.3)	0.02 *
	2	11 (28.2)	10 (25.6)	
	3	9 (23.1)	16 (41.0)	
	≥ 4	1 (2.6)	2 (5.1)	
	I don't know	11 (28.2)	7 (17.9)	
Degree of concern about oral hygiene	None	4 (10.3)	2 (5.1)	0.011*
	Low	21 (53.8)	16 (41)	
	High	14 (35.9)	21 (53.8)	

*$p < 0.05$, *p*-values from Fisher's exact test.

Plain language summary

This study compared the educational effects of Qscan, a quantitative light-induced fluorescence device, and plaque-disclosing agents for improving oral hygiene in children aged 6–11 years. A randomized crossover design was used, with participants alternating between the two methods. Both significantly reduced the Patient Hygiene Performance (PHP) score, simple hygiene score (SHS), and fluorescence values (ΔR30 and ΔR120), but no significant differences were found between them. Surveys showed improved brushing habits, with more children brushing for three minutes and showing greater concern for oral hygiene. Qscan is as effective as traditional methods and offers an engaging alternative for educating children on proper oral hygiene.

Explaining the Red Fluorescence Evident on the Surface of Failed Dental Implants: Case Reports

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Objectives

This study aims to understand implant failure reasons by analyzing the surface of failed dental implants using quantitative light-induced fluorescence-digital (QLF-D), targeting the red fluorescence from porphyrin metabolized by oral bacteria.

Case report

The areas of red fluorescence in QLF-D images obtained from all aspects of the fixture surface were then analyzed using quantitative analysis software.

Cases with red fluorescence:

A 51-year-old male in good general health, who is a nonsmoker, presented with a primary concern regarding periodontal disease. The dental implants were embedded in the maxillary left molar in January 2006. However, eight years post the implantation, the patient started noticing mobility in the implant and reported difficulties in chewing foods. A radiographic examination done before the implant failure indicated peri-implant radiolucency accompanied by severe bone resorption (Fig. 1A). In September 2014, due to the intense mobility, the implant was removed using forceps and then subjected to imaging under QLF-D in darkroom conditions. The white-light imaging showcased granulation tissue residue present on the implant fixture (Fig. 1B). This was contrasted by the blue-light image, where red fluorescence was evident from the abutment margin all the way down to the apex region of the implant body (Fig. 1C). Subsequent analysis of the fluorescence imagery via the QLF-D software indicated that the ΔR30 and ΔR120 areas accounted for 70% and 58.6% of the implant's surface area, respectively.

Cases with no fluorescence:

A 49-year-old male smoker presented with a root fracture in the mandibular right second molar in January 2012. Following this, a dental implant (4.8 mm in diameter and 11.5 mm in length; Osstem Implant Co.) was immediately inserted, accompanied by a guided bone regeneration procedure. By May 2012, the final restoration was delivered. However, two years post-implantation, the patient reported swelling of the gums and showed signs of fair oral hygiene. A radiograph taken during this period indicated no observable bone loss. In May 2014, upon examination, the implant was deemed to have failed and was consequently extracted. QLF-D imaging of the extracted implant showcased a clean fixture surface on the white-light image (Fig. 2B) and notably, the blue-light image did not display any fluorescence (Fig. 2C). Subsequent analysis using the QA2 software revealed that the ΔR30 area spanned just 7% of the implant surface, with no evident gradient in redness.

Conclusions

The cases presented that failed dental implant surfaces caused by peri-implantitis can be detected by the red fluorescence evident as QLF-D.

Key result 1

Figure 1. Failed implants cases with red fluorescence. A: Radiograph obtained just before the implant fell out. Implants site demonstrating bone loss caused by peri-implantitis, B: Removed implant structures (White-light image), C: Removed implant structures (Fluorescence image).

Key result 2

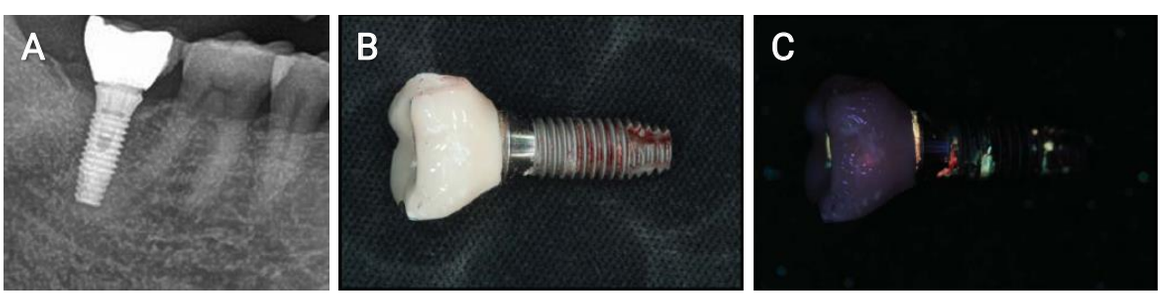

Figure 2. Failed implants cases with no fluorescence. A: Radiograph obtained just before the implant fell out. There was no peri-implant bone loss, B: Removed implant structures (White-light image), C: Removed implant structures (Fluorescence image).

Plain language summary

This study aimed to determine the potential of quantitative light-induced fluorescence-digital (QLF-D) to identify failed dental implant surfaces associated with peri-implantitis. Specifically, red fluorescence, indicative of bacterial metabolism, was evident on the surfaces of failed implants. One case showed significant red fluorescence covering a vast area of the implant surface, indicating severe bacterial activity and inflammation. In contrast, an implant from a patient with no noticeable bone loss and different clinical signs displayed minimal fluorescence. Thus, QLF-D can serve as a valuable diagnostic tool for detecting peri-implantitis, enhancing the precision and early detection of implant failure caused by this condition.

Evaluation of wound dehiscence after vertical bone graft by using quantitative light-induced fluorescence

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Objectives

To explore the potential of Quantitative light-induced fluorescence (QLF) technology in evaluating the necessity of titanium mesh removal following wound dehiscence after vertical bone augmentation in implant dentistry.

Case report

Two patients with wound dehiscence within the third week after vertical bone augmentation using autogenous particulate bone on the posterior maxilla were studied. QLF technology was applied to detect the presence of bacterial contamination by observing for red-fluorescence.

Wound Dehiscence with Red-Fluorescence on QLF View (Figure 1):

A 48-year-old male presented for implantation in the right posterior maxilla. After vertical bone augmentation using ramus cortical bone, a Neo Titanium mesh was applied and secured with mini-screws. Despite wound dehiscence observed three weeks post-op (Fig. 1A), initial monitoring showed no fluorescence on the QLF view until the sixth week. At this point, red fluorescence was detected on the grafted bone particles, indicating contamination (Fig. 1B). While there were no overt infectious symptoms, the decision was made to remove the exposed mesh and contaminated grafts. Histological assessment of the red-fluorescent grafts showed an acute inflammatory stage with neutrophil infiltration (Fig. 1C).

Wound Dehiscence without Red-Fluorescence on the QLF View (Figure 2)*:*

A 55-year-old male smoker with a history of sinus surgery and significant bone loss and sinusitis in the left posterior maxilla underwent tooth extraction and simultaneous autogenous bone graft. A titanium mesh was used for graft protection. Despite wound dehiscence occurring three weeks post-op (Fig. 2A), close monitoring with QLF over eight weeks revealed no red fluorescence, indicating no contamination (Fig. 2B). Secondary healing occurred without complications. Once verified, the mesh was removed, revealing mature lamellated bone with chronic inflammation on histology (Fig. 2C).

Conclusions

The use of QLF technology might offer a reliable method to determine the timing and extent of mesh removal in cases of wound dehiscence following vertical bone augmentation in implant dentistry. The observation of red-fluorescence can be indicative of bacterial contamination, guiding clinical decisions on the necessity of intervention.

Key result 1

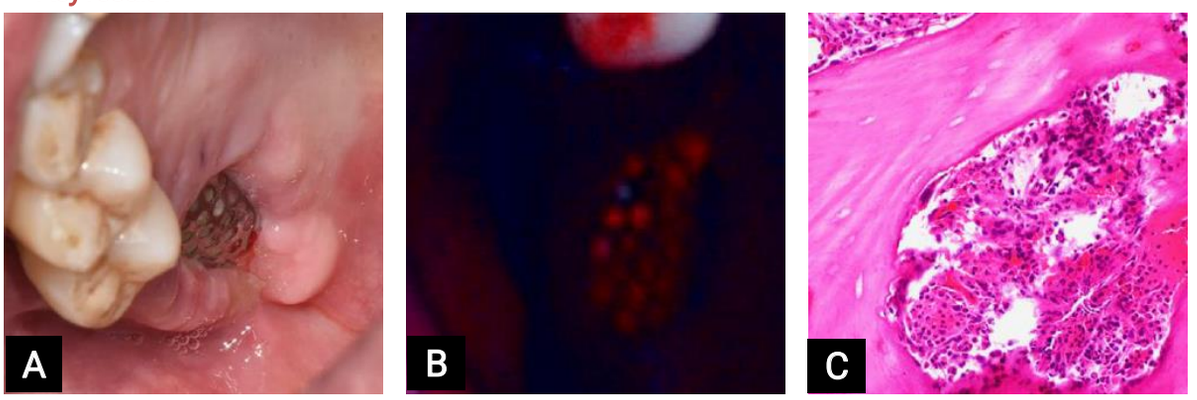

Figure 1. Patients with wound dehiscence and red-fluorescence on QLF view. A: Wound dehiscence was observed at 12 days after surgery; B: At six weeks after the operation, the red fluorescence was observed on the QLF view; C: Histology (hematoxylin and eosin stain, x200) revealed acute inflammation with dominant neutrophil infiltration into the grafted bone.

Key result 2

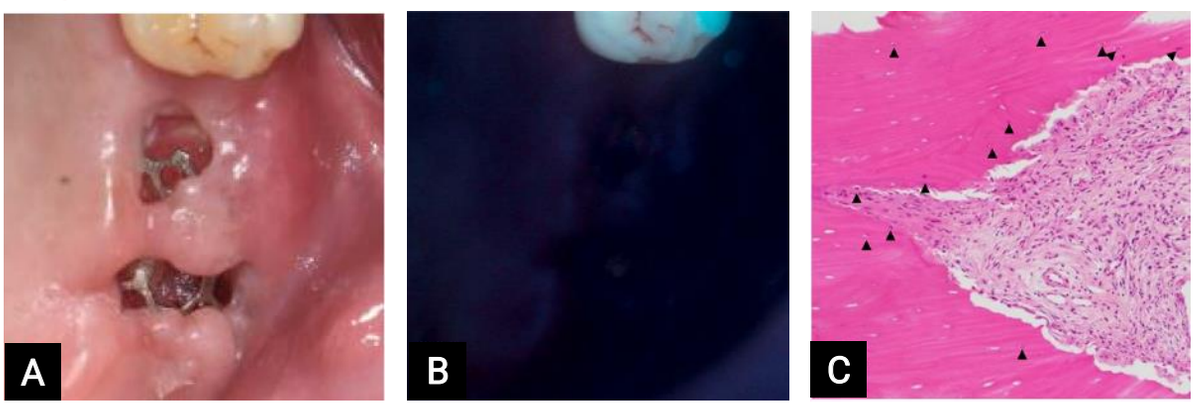

Figure 2. Patients with wound dehiscence and no red-fluorescence on QLF view. A: At eight weeks after surgery, secondary healing was observed inside the titanium mesh; B: During the eight weeks postoperative, no red-fluorescence was observed on the QLF view; C: Histology (hematoxylin and eosin stain, x100) showed a lamellated bone with osteocytes (arrow head) and chronic inflammation.

Plain language summary

This study explores the potential of Quantitative Light-Induced Fluorescence (QLF) technology in assessing the need for titanium mesh removal after wound dehiscence following vertical bone augmentation in implant dentistry. Two patients who experienced wound dehiscence three weeks post vertical bone augmentation were examined. QLF was employed to detect bacterial contamination through red fluorescence. In conclusion, QLF technology can be a valuable tool for determining the timing of mesh removal in wound dehiscence cases. Red fluorescence indicates bacterial contamination, aiding clinical decisions regarding intervention.

Histologic analysis of osteonecrosis of the jaw according to the different aspects on quantitative light-induced fluorescence images

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Objectives

The purpose of this study was to visually analyze the sequestrum in a patient with ONJ using QLF; we also aimed to evaluate the QLF results based on histologic analysis of the extracted sequestrum.

Case report

We analyzed a sequestrum from a patient with medication-related osteonecrosis of the jaw (MRONJ). quantitative light-induced fluorescence (QLF) was applied to the sequestrum. In this study, QLF demonstrated three distinct fluorescence patterns on the sequestrum: Non-red-fluorescence, hyper-red-fluorescence, and hypo-red-fluorescence (Fig. 1). The imaging of the sequestrum with white-light showed a typical appearance of ONJ, while the fluorescent imaging using QLF-D revealed dominance of hyper-red-fluorescence across the entire fragment. Additionally, distinctions between non-red-, hypo-red-, and hyper-red-fluorescence were clearly observed. Histological evaluations were performed based on the fluorescence distinctions on the QLF image. The non-red-fluorescent fragments were characterized by lamellar and sclerotic bone patterns with osteocytes occasionally present within the bony lacunae. Despite similar appearances of the non-red- and hyper-red-fluorescent fragments under regular light, further examination of the hyper-red-fluorescent fragment showed a colony of Actinomycosis and signs of osteolysis, indicating interaction between the bacterial colony and the bone tissues. On the other hand, the hypo-red-fluorescent fragment was dominated by micro-abscesses and infiltration of inflammatory cells (Fig. 2).

Conclusions

In conclusion, QLF offers the potential to provide valuable real-time insights during ONJ surgery. Specifically, it may aid in distinguishing between visually similar lamellar and infected bone tissues. By guiding the surgical process using QLF, surgeons may consider preserving the non-red-fluorescent areas while targeting the hyper- and hypo-red-fluorescent areas for removal, aiming for more precise surgical outcomes.

Key result 1

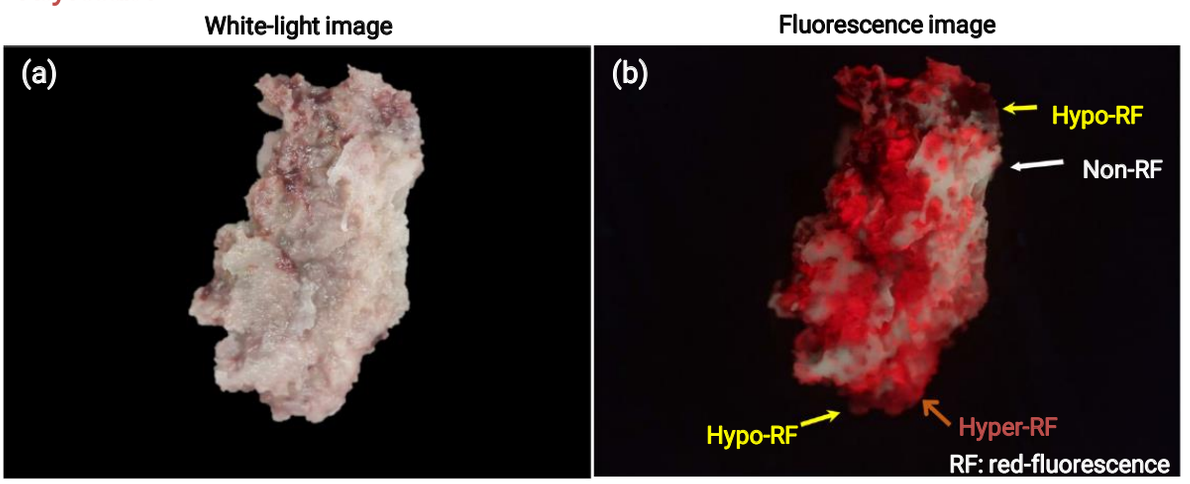

Figure 1. QLF images of the sequestrum. Although the surfaces of the sequestrum show little color difference in white-light (a), three different fluorescence types were detected by QLF (b).

Key result 2

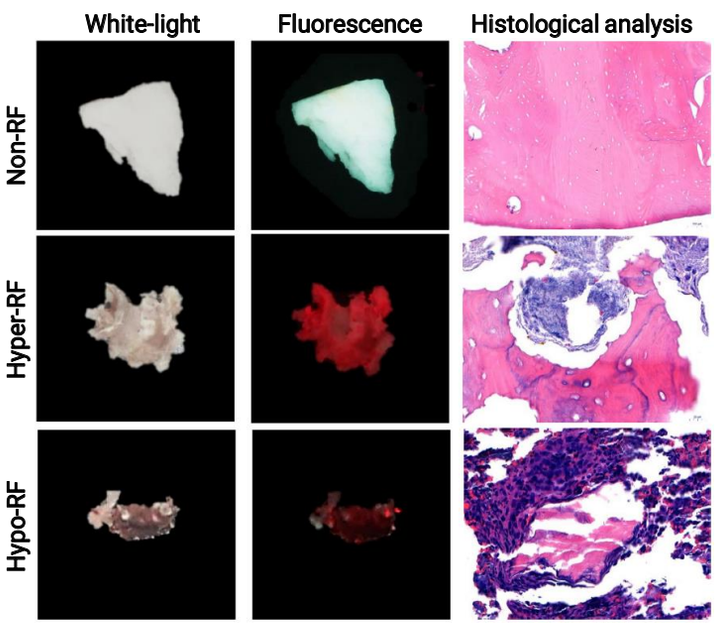

Figure 2. White-light and fluorescence images and histologic analysis according to the types of fluorescence on the fragmented sequaestrum. The non-RF fragment shows lamellar or sclerotic bone without bacterial invasion and osteolysis (upper line). Macrobacterial colony with osteolysis of bony tissue observed in the hyper-RF dominant fragment (middle line). The micro-abscess aspect with infiltration of inflammatory cells observed in the hypo-RF dominant fragment (lower line).

Plain language summary

This research aimed to develop a real-time diagnostic method for reducing the risk of recurrence after surgery for osteonecrosis of the jaw (ONJ). The study involved the analysis of bone fragments from patients with medication-related osteonecrosis of the jaw (MRONJ) using Quantitative Light-induced Fluorescence (QLF). The study's findings revealed three distinct fluorescence phenomena observed in the bone fragments when QLF was applied: non-red fluorescence, hyper-red fluorescence, and hypo-red fluorescence. Non-red fluorescence indicated healthy sclerotic and lamellar bone tissue. Hyper-red fluorescence was associated with an infectious state characterized by bacterial invasion and bone degradation. Hypo-red fluorescence predominantly represented granular tissue with inflammation, characterized by the absence of bone matrix and bacterial colonies. Based on histological analysis, the study proposes that QLF can be a valuable real-time diagnostic tool during MRONJ surgery.

Application of quantitative light-induced fluorescence technology for tooth bleaching treatment and its assessment: An in vitro study

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Objectives

This study aimed to determine the efficacy of a combination of photocatalysts—hydrogen peroxide at a low concentration (3.5%) and titanium dioxide (TiO_2)—activated at a wavelength of 405 nm using quantitative light-induced fluorescence (QLF) technology, and to quantify their tooth-bleaching efficacy using fluorescence images obtained from QLF technology.

Methods

Forty bovine incisors were extrinsically stained according to Stookey's method, and were randomly divided into four groups ($n = 10$ per group). Two bleaching solutions were prepared by mixing 3.5% H2O2 with 0.05% of anatase and rutile TiO_2 powders. These solutions were applied to the stained teeth using a microbrush and then irradiated for 15 min at either 306 or 405 nm to activate the bleaching agent. The color difference (ΔE^*) was assessed before and after every 5 min of treatment. The ΔE^* and the changes in the fluorescence loss ($\Delta\Delta F$) were obtained from white-light and fluorescence images, respectively.

Results

All of the low-H_2O_2/TiO_2 treatments caused significant tooth-bleaching efficacy after irradiation at 306 and 405 nm ($p < 0.05$). The results did not differ significantly between the two wavelengths ($p > 0.05$), but the bleaching efficacy was greater with anatase TiO_2 at 306 nm and rutile TiO_2 at 405 nm. Analysis of the fluorescence images revealed that the ΔF values increased significantly in all groups with the treatment time ($p < 0.05$). There was a statistically significant correlation between ΔE^* and the change in $\Delta\Delta F$ ($r = 0.822$, $p < 0.001$).

Conclusions

Combining low-H_2O_2/TiO_2 with QLF technology at 405 nm has an efficacy of tooth-bleaching as a less harmful and biofriendly method, while the fluorescence images obtained by QLF technology could be used to assess tooth-bleaching.

Key result 1

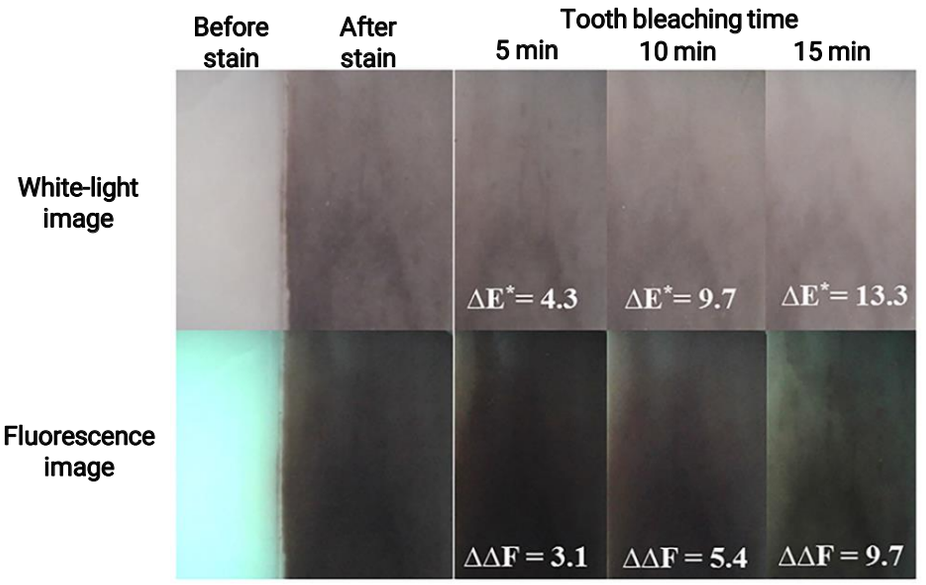

Figure 1. Representative white-light and fluorescence images obtained using the quantitative light-induced fluorescence technology presented according to the duration of tooth bleaching for rutile titanium dioxide at 405 nm. Whiteness changes are represented by ΔE^* values and changes in the fluorescence loss are represented by $\Delta\Delta F$ values. The sound and stained parts of each specimen are on the left and right, respectively.

Key result 2

Table 1. Changes in the bleaching effect (ΔE^*) for the different types of titanium dioxide (anatase and rutile) and light sources (306 and 405 nm) (n = 10 in each group).

Group	Tooth bleaching time		
	5 min	10 min	15 min
Anatase + 306 nm	5.02 ± 2.45[a]	9.86 ± 3.24[b]	15.90 ± 3.80[c]
Anatase + 405 nm	4.60 ± 2.30[a]	8.31 ± 4.05[b]	12.59 ± 5.05[c]
Rutile + 306 nm	3.15 ± 1.40[a]	7.75 ± 4.55[b]	14.63 ± 4.72[c]
Rutile + 405 nm	4.49 ± 2.62[a]	10.16 ± 5.20[b]	14.91 ± 4.83[c]

All values denote means ± standard deviations.
Different superscript letters denote statistically significant differences in ΔE^* values within or between points by two-way repeated measures ANOVA with Bonferroni post hoc test ($p < 0.05$).

Plain language summary

This study emphasized the novel concept of theragnosis in the realm of tooth bleaching. The efficacy of tooth bleaching was enhanced by amalgamating low H_2O_2/TiO_2 under 405nm. Moreover, fluorescence images were effectively utilized to assess tooth bleaching, while QLF (Quantitative Light-induced Fluorescence) technology demonstrated a dual functionality of increasing and assessing the efficacy of tooth bleaching simultaneously. In the field of tooth bleaching, QLF technology harbors the potential to realize theragnosis, presenting a novel approach that allows for real-time monitoring while concurrently elevating the therapeutic effect of bleaching treatments.

A novel model to predict tooth bleaching efficacy using autofluorescence of the tooth

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Objectives

This study aimed to confirm whether autofluorescence emitted from teeth can predict tooth bleaching efficacy and establish a novel model combining natural color parameters and tooth autofluorescence data to improve the predictability of tooth bleaching.

Methods

A total of 61 tooth specimens were prepared from extracted human molars/premolars and immersed in 35% hydrogen peroxide for 1 h for tooth bleaching. Tooth color and autofluorescence data were obtained using quantitative light-induced fluorescence (QLF) technology. Pearson correlation analyses were used to confirm the relationship between ΔLIF and autofluorescence. Intraclass correlation coefficients (ICC) were calculated to compare the conventional and new prediction models. Decision tree analysis was performed to evaluate clinical applicability.

Results

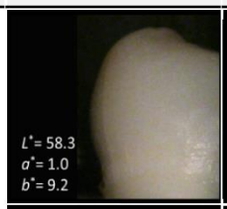
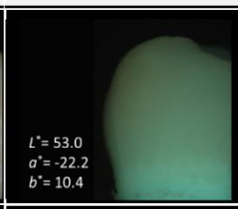
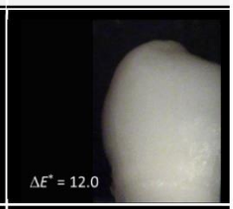
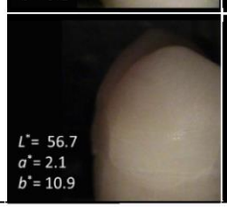
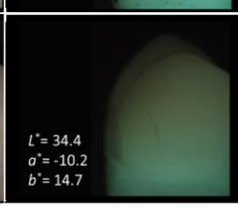
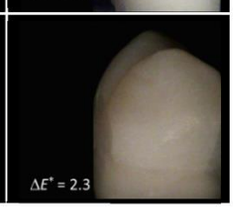
Changes in white-light and fluorescent images were observed before and after tooth bleaching (Figure 1). It was evident, even on observing with the naked eye, that the tooth color appeared bright in white light (ΔE^* = 11.79 ± 4.16), but it appeared rather darkened on fluorescence imaging (ΔE^* = 4.74 ± 1.79). In both white-light and fluorescent images, only the b^* value (the color parameters (L^*, a^*, and b^*)) showed significant relevance, and the correlation coefficient in the fluorescent image (r = −0.409, P = 0.001) was slightly higher than that in the white-light image (r = −0.337, P = 0.008). It was confirmed that as the b^* value indicating yellowness-to-blueness increased, the ΔLIF value decreased; that is, the fluorescent component of the tooth was oxidized after tooth bleaching. In the group corresponding to node 4, the WL^* value was 52.8 or less, and yellowish color (Wb^* > 5.7) was observed in the white-light image; this group showed the highest tooth bleaching efficacy (ΔE^* = 16.4 ± 4.4). In contrast, the group corresponding to node 7, which had a bright tooth color (WL^* > 52.8) and yellowish fluorescence (Fb^* > 10.5), showed the lowest tooth bleaching efficacy (ΔE^* = 7.3 ± 2.8) (Figure 2). The groups corresponding to nodes 3 and 6 were classified as having moderate efficacy of tooth bleaching, showing ΔE = 10.3 ± 3.4 and ΔE = 11.5 ± 3.2, respectively.

Conclusions

Autofluorescence of teeth could be used to predict the efficacy of tooth bleaching. The predicted efficacy of the treatment determined by the novel prediction model, which combined the use of color parameters and autofluorescence data, showed a remarkably high agreement with the actual treatment efficacy. In the decision tree analysis, the proposed natural color–fluorescence combination model was helpful in classifying the efficacy of tooth bleaching and has potential for use in clinical decision-making regarding tooth bleaching.

Key result 1

Table 1. Example images of application plan for the new prediction model based on decision tree analysis.

	Pre-bleaching		Post-bleaching
	White-light image	Fluorescent image	
Sample A			
Sample B			

*L**: 0 (black) to 100 (white); *a**: redness (+) to greenness (−); *b**: yellowness (+) to blueness (−).
Δ*E** refers to the color distance within color space.

Key result 2

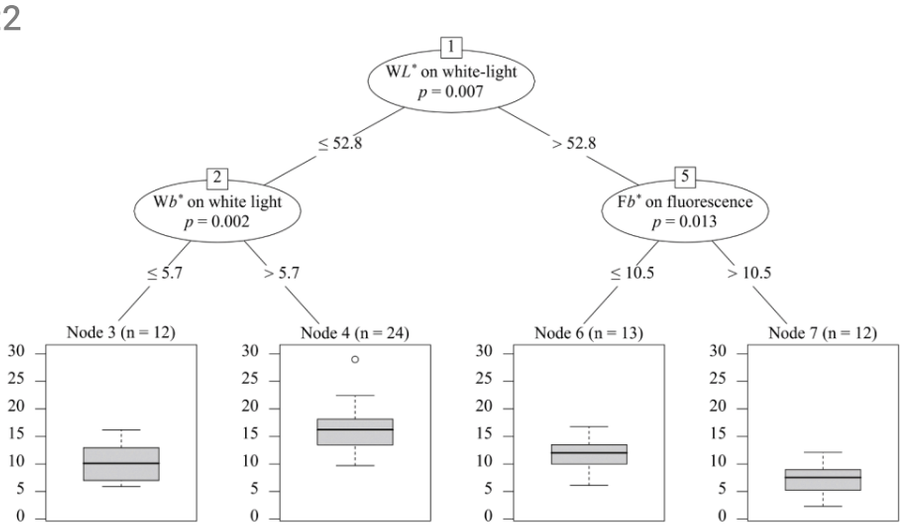


Figure 1. Decision tree analysis for applying our findings to predict tooth bleaching efficacy in clinical situations. WL* and Wb* values obtained from the white-light image; Fb* values obtained from fluorescent images.

Plain language summary

Traditionally, clinicians have predicted tooth bleaching efficacy using the naked eye to match the initial tooth color with a shade guide. However, the subjective nature of visual inspection using a shade guide makes it challenging to assess the tooth color accurately and may impair the treatment's predictability. Quantitative light-induced fluorescence-digital (QLF) technology is a clinically applicable device that can visualize the autofluorescence of teeth. In this study, we proposed a model combining the use of a tooth's color parameters and autofluorescence data-detected using clinically applicable technology-to better predict the efficacy of tooth bleaching. Our decision tree analysis showed that tooth autofluorescence data could be used for clinical decision-making regarding tooth bleaching.

Veterinary

Quantification of Canine Dental Plaque Using Quantitative Light-induced Fluorescence

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Objectives

This study aimed to evaluate Quantitative Light-induced Fluorescence (QLF™) as an alternative to the established Logan and Boyce method for determining plaque coverage of dogs' teeth.

Methods

The study assessed the inter-photographer reproducibility of Quantitative Light Fluorescence (QLF) measurements for both undisclosed and disclosed teeth. To image plaque, the right-side teeth were rinsed with water and then applied with an undiluted disclosing solution. For undisclosed teeth, dogs were divided into three groups based on the recency of their teeth brushing and were examined on four consecutive days by five different photographers. For disclosed teeth, dogs had their teeth brushed every other day, and QLF images were captured without anesthesia by three different photographers, focusing on various teeth on each side. Additionally, the study involved dogs divided into two groups to compare the effects of daily oral care chews Plaque coverage was assessed using QLF and the traditional modified Logan and Boyce method to determine their agreement in evaluating the impact of oral care chews on plaque reduction.

Results

Inter-photographer Reproducibility (Undisclosed Images, Fig. 1a): The average plaque coverage ranged from 1.2% to 41.2%. The inter-photographer reproducibility coefficient of variability was 3.21%, indicating relatively low variability in percentage plaque coverage scores between different photographers. Inter-photographer Reproducibility (Disclosed Images, Fig. 1b): The average mouth plaque values ranged from 6.5% to 38.4%. The inter-photographer reproducibility coefficient of variability was 8.5%. Comparison to Modified Logan and Boyce Method (Table 1): A product efficacy trial compared QLF to the modified Logan and Boyce scoring system. QLF images of disclosed teeth showed an average reduction in plaque accumulation of 19.12% when dogs received an oral care chew compared to no chew. This result was similar to the results obtained using the modified Logan and Boyce method, which showed an average reduction of 22.13%.

Conclusions

This study found that Quantitative Light-induced Fluorescence (QLF) is a reliable and accurate method for assessing plaque coverage in dogs' teeth, both in conscious and anesthetized conditions.

Key result 1

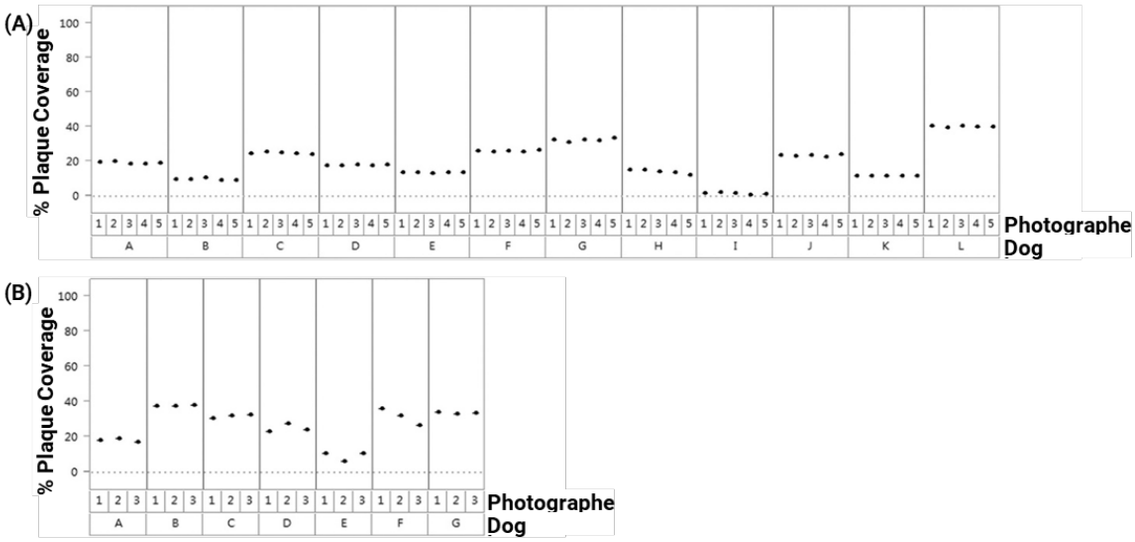

Figure 1. Inter-photographer repeatability of 5 photographers taking images of undisclosed (A), and disclosed (B) teeth of conscious dogs. Variability chart of percentage plaque coverage (whole mouth average: maxillary third incisors, maxillary and mandibular canines, and third and fourth premolars).

Key result 2

Table 1. Comparison of QLF to modified Logan and Boyce for measuring the difference n percentage plaque reduction between dogs fed an OC chew compared with no chew.

	Percentage mean plaque coverage (95% confidence intervals)			
Data type	**OC chew**	**No Chew**	**Plaque Reduction (%)**	***P* value**
Modified Logan and Boyce	9.79 (8.83, 10.75)	12.57 (11.54, 13.59)	22.13 (12.64, 31.62)	<0.001
QLF disclosed	54.78 (51.72, 57.85)	67.73 (64.48, 70.98)	19.12 (14.09, 24.14)	<0.001
QLF undisclosed	10.35 (7.03, 13.66)	32.97 (29.48, 36.46)	68.62 (58.96, 78.27)	<0.001

Abbreviations: QLF, Quantitative Light-induced Fluorescence; OC. Oral care.

Plain language summary

This study aims to evaluate whether Quantitative Light-induced Fluorescence (QLF) technology can serve as an alternative method to the established Logan and Boyce approach for assessing plaque on dogs' teeth. The study is divided into two main parts. Firstly, it investigates how effectively different photographers can use QLF to measure plaque on both concealed and visible teeth in dogs. Additionally, it tests the impact of daily oral care chews on plaque accumulation in 26 dogs, utilizing both QLF and the Logan and Boyce method for assessment. The findings of this study suggest that QLF is an effective and accurate method for assessing plaque on dogs' teeth, applicable in both conscious and anesthetized conditions. It yielded similar results to the Logan and Boyce method when teeth were visible but exhibited more pronounced differences when teeth were concealed. In conclusion, this research supports the reliability and suitability of QLF for plaque assessment on dogs' teeth across different conditions.

Veterinary

Assessment of dental plaque coverage by Quantitative Light-induced Fluorescence (QLF) in domestic short-haired cats

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Objectives

Dietary means of reducing plaque and calculus deposits are frequently sought for the maintenance of oral health in cats and dogs. In the development of such products sensitive, reliable, reproducible methods of measuring plaque and calculus are key. The aim of this study was to assess Quantitative Light-induced Fluorescence (QLF™) for the detection of dental plaque coverage in cats compared to the modified Logan and Boyce technique.

Methods

The techniques were utilized in a crossover study, which compared two diets for their effect on plaque deposition in a cohort of 24 adult cats. with each cat receiving two different diets: a control diet (Royal Canin Feline Selective 40 Protein Preference) and a dental efficacy diet (Royal Canin Oral Care 30). The diets adhered to nutrient guidelines. Plaque was assessed using a clean mouth model after professional dental cleaning, and QLF imaging was conducted. Intra-operator and inter-operator repeatability assessments were performed. Anesthesia was administered for dental procedures, and QLF images were captured under blue light before and after plaque disclosure. Plaque coverage was analyzed using QLF-D software, with a baseline reference added to disclosed plaque images. Plaque was also scored using the modified Logan and Boyce method. Statistical analyses, including variance component estimation and comparison of QLF to plaque scores, were conducted. The study aimed to detect a 15% difference in plaque accumulation with at least 90% power in a two-way crossover study.

Results

Analysis of the effect of diet on plaque coverage by both the modified Logan and Boyce technique and QLF showed significant effect of feeding regime (p = 0.024 and $p \leq 0.0001$, respectively) with good agreement between the techniques in the percentage reduction of plaque accumulation. A within study assessment of QLF demonstrated excellent intra-operator repeatability (coefficient of variation 2.2%). Similarly, inter-operator reproducibility was also good (coefficient of variation 2.3%) (Fig. 1). A retrospective analysis, using the data to estimate the sample size required for at least 90% power to detect a 15% difference between treatments in a two-way crossover study, established that 10 cats would be sufficient for plaque measurement by QLF, while assessment by the modified Logan and Boyce method required over 30 cats (Fig. 2).

Conclusions

QLF was determined to be a reliable, reproducible method for the assessment of plaque deposition in cats and requires fewer subjects for the detection of differences between treatment effects compared to the modified Logan and Boyce method.

Key result 1

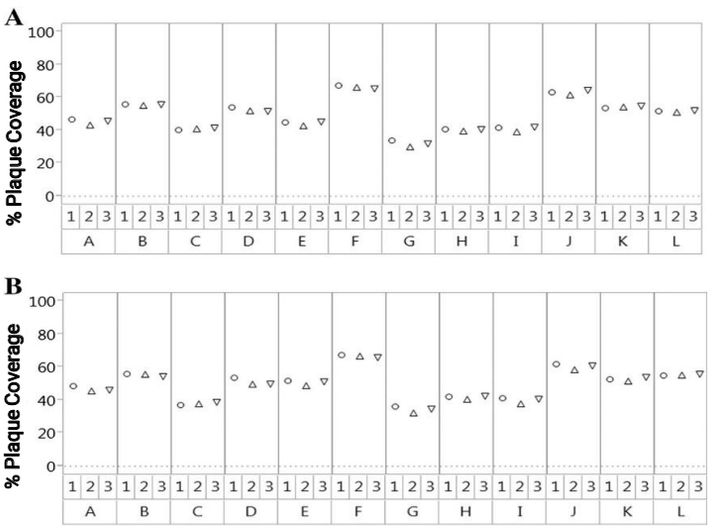

Figure 1. Inter-operator reproducibility: Variability chart showing whole mouth average percentage plaque coverage (A) and weighted mouth average percentage plaque coverage (B) as determined by QLF triplicate images of disclosed teeth in 12 cats taken by three independent operators.

Key result 2

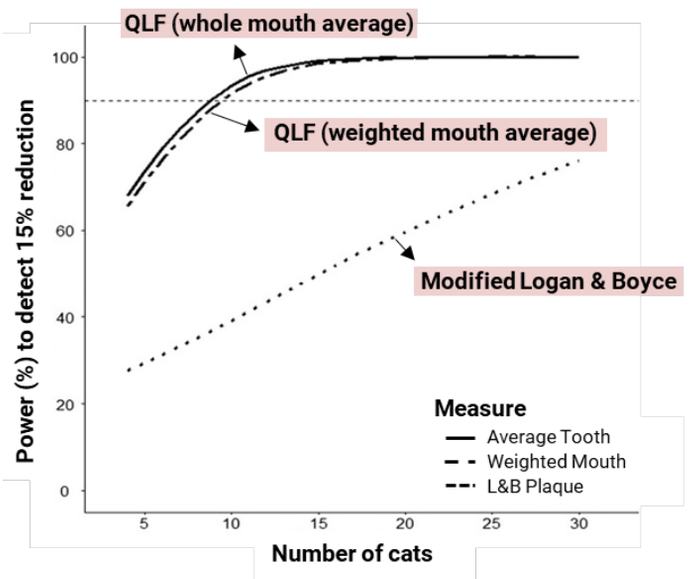

Figure 2. Retrospective power analysis demonstrating the number of cats required to detect a 15% reduction in plaque accumulation between two treatments in a two-way crossover trial.

Plain language summary

This study aimed to assess Quantitative Light-induced Fluorescence (QLF™) for detecting dental plaque in cats. They used both methods in a crossover study with 24 adult cats testing different diets. Results showed that QLF is a reliable, reproducible method for plaque assessment in cats, requiring fewer subjects to detect treatment differences compared to the modified Logan and Boyce method. The diets significantly affected plaque coverage, with good agreement in plaque reduction between the techniques. Plaque measurement by QLF demonstrated excellent intra-operator repeatability and inter-operator reproducibility. QLF has the advantage of requiring fewer cats for the detection of differences between treatment effects compared to the modified Logan and Boyce method of plaque measurement.

Veterinary

Validation of Quantitative Light-Induced Fluorescence for Quantifying Calculus on Dogs' Teeth

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Objectives

The objective of this study was to determine whether quantitative light-induced fluorescence (QLF™) is a suitable tool to quantify the amount of calculus on the buccal surface of dogs' teeth following the removal of disclosed plaque by tooth brushing.

Methods

The amount of calculus on the teeth of 26 miniature schnauzers was measured, using QLF and a calculus index method (Warrick-Gorrel), during a 28-day phase crossover study comparing feeding a daily dental chew versus providing no daily chew. For Warrick-Gorrel method, the coverage score ranged from 0 to 4, where 0 was no observable calculus, 1 coverage on less than 24% of buccal tooth surface, 2 coverage on 25% to 49%, 3 coverage on 50% to 74%, and 4 coverage on greater than 75% of the buccal surface. The thickness score ranged from 1 to 3, where 1 was defined as thin (<0.5 mm), 2 moderate thickness (0.5-1.5 mm), and 3 thick (>1.5 mm). The quantity of calculus on each tooth was determined in 2 ways: (1) the coverage from each of the 3 areas of the tooth were summed within each tooth (termed "coverage"), and (2) for each of the 3 areas scored per tooth, the coverage score was multiplied by the thickness score and the 3 scores summed to provide an overall tooth score (termed "coverage × thickness"). The software provided with the QLF camera was used to define the area of red fluorescence on the tooth surface at various fluorescence intensities in relation to the total tooth area (%ΔR) with the ΔR30 used in the analysis. The overall percentage of calculus coverage in the mouth was calculated in 2 ways: (1) the average percentage calculus across the teeth, termed "average mouth" and (2) the total calculus on the teeth divided by the total area of all the teeth and multiplied by 100 to determine the overall percentage calculus in the mouth, termed "weighted mouth."

Results

Analysis of data from 612 teeth (17 dogs, 18 teeth per dog, 2 phases) using both Warrick-Gorrel and QLF methods revealed significant differences in calculus accumulation between dogs receiving a standard diet and those supplemented with a daily dental chew. Quantification of calculus using the Warrick-Gorrel method showed a 43.8% reduction in calculus buildup, with 95% confidence interval of 27.3 to 60.3 ($P < .001$). With QLF, the percentage reduction in calculus accumulation was 65.8% (58.1-73.4, $P < .001$). A retrospective sample size analysis showed that fewer dogs were required for QLF analysis compared to the Warrick-Gorrel method.

Conclusions

This study demonstrated that QLF is a sensitive and precise method for quantification of calculus on dogs' teeth. It removes the subjective element of human examiners and has greater accuracy and reduced variability through the continuous nature of the data.

Key result 1

Figure 1. Example QLF images of an individual dog's maxillary third and fourth premolars and first molar teeth following the removal of disclosed plaque by tooth brushing.

Key result 2

Table 1. Means and Differences, with 95% Confidence Intervals, in the Quantity of Calculus on the Teeth of Dogs Receiving a Daily Dental Chew for 28 Days Compared to Just the Commercial Diet.[a]

Measure	Means (95% Confidence Intervals)				*P* Value
	No Chew	Chew	Difference	Percent reduction from "No Chew"	
Warrick-Gorrel coverage × thickness	5.7 (4.9-6.5)	3.2 (2.4-4)	2.5 (1.6-3.4)	43.8 (27.3-60.3)	<.001
Warrick-Gorrel coverage	5.0 (4.3-5.7)	3.1 (2.4-3.7)	1.9 (1.2-2.7)	38.5 (23.7-53.3)	<.001
QLF average mouth (%)	26.4 (23.5-29.3)	9.0 (6.2-11.9)	17.3 (15.3-19.4)	65.8 (58.1-73.4)	<.001
QLF-weighted mouth (%)	20.1 (17.9-22.2)	7.0 (4.9-9.2)	13.0 (11.4-14.7)	64.9 (56.6-73.1)	<.001

Abbreviation: QLF, quantitative light-induced fluorescence.
[a]Table shows the differences in results when the amount of calculus was determined using the Warrick-Gorrel method (both coverage and coverage*thickness) and QLF (both average mouth and weighted mouth).

Plain language summary

Periodontal disease is common in dogs, initiated by bacterial attachment to tooth surfaces, leading to plaque buildup and inflammation. Calculus, a mineralized form of plaque, doesn't cause the disease directly but worsens it by providing a surface for bacterial attachment. Professional cleaning is required to remove calculus, but regular tooth brushing or chewing can help prevent its formation. Various methods assess plaque and calculus, with quantitative light-induced fluorescence (QLF) being a promising tool for quantifying calculus on dogs' teeth after plaque removal. The study demonstrates that Quantitative Light-induced Fluorescence (QLF) is effective in quantifying calculus on dogs' teeth after plaque removal. It outperforms the traditional Warrick-Gorrel method, possibly due to its ability to detect natural bacterial fluorescence. Additionally, QLF shows promise in quantifying conscious dogs' calculus, as demonstrated for plaque measurements.

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Oral Biofilms (10)

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