Validation of quantitative light-induced fluorescence-digital (QLF-D) for the detection of approximal caries in vitro

Hae-Youn Ko a, Si-Mook Kang a, Hee Eun Kim b, Ho-Keun Kwon a, Baek-Il Kim a,*

aDepartment of Preventive Dentistry & Public Oral Health, Oral Science Research Institute, Brain Korea 21 PLUS Project, Yonsei University, College of Dentistry, 50 Yonsei-ro, Seodaemun-Gu, Seoul 120-749, Republic of Korea
bDepartment of Dental Hygiene, College of Health Science, Gachon University, Incheon, Republic of Korea

ARTICLE INFO

Article history:
Received 2 January 2015
Received in revised form
14 February 2015
Accepted 17 February 2015

Keywords:
Approximal caries
Caries detection
Quantitative light-induced fluorescence-digital
International Caries Detection and Assessment System
Radiography

ABSTRACT

Objectives: Detection of approximal caries lesions can be difficult due to their anatomical position. This study aimed to assess the ability of the quantitative light-induced fluorescence-digital (QLF-D) in detecting approximal caries, and to compare the performance with those of the International Caries Detection and Assessment System II (ICDAS II) and digital radiography (DR).

Methods: Extracted permanent teeth (n = 100) were selected and mounted in pairs. The simulation pairs were assessed by one calibrated dentist using each detection method. After all the examinations, the teeth (n = 95) were sectioned and examined histologically as gold standard. The modalities were compared in terms of sensitivity, specificity, areas under receiver operating characteristic curves (AUROC) for enamel (D1) and dentine (D3) levels. The intra-examiner reliability was assessed for all modalities.

Results: At D1 threshold, the ICDAS II presented the highest sensitivity (0.80) while the DR showed the highest specificity (0.89); however, the methods with the greatest AUC values at D1 threshold were DR and QLF-D (0.80 and 0.80 respectively). At D3 threshold, the methods with the highest sensitivity were ICDAS II and QLF-D (0.64 and 0.64 respectively) while the method with the lowest sensitivity was DR (0.50). However, with regard to the AUC values at D3 threshold, the QLF-D presented the highest value (0.76). All modalities showed to have excellent intra-examiner reliability.

Conclusions: The newly developed QLF-D was not only able to detect proximal caries, but also showed to have comparable performance to the visual inspection and radiography in detecting proximal caries.

Clinical significance: QLF-D has the potential to be a useful detection method for proximal caries.

© 2015 Elsevier Ltd. All rights reserved.

* Corresponding author. Tel.: +82 2 2228 3070; fax: +82 2 392 2926.
E-mail address: drkbi@yuhs.ac (B.-I. Kim).
http://dx.doi.org/10.1016/j.jdent.2015.02.010
0300-5712/© 2015 Elsevier Ltd. All rights reserved.
1. Introduction

As it was realized that dental caries process is dependent on the balance between pathological factors and protective factors, and that caries progresses when the pathological factors predominate while the caries can be arrested or reversed when the protective factors predominate, the treatment principles for caries lesions gradually shifted towards preventive treatment of enamel lesions where the lesions can have an opportunity to reverse.\(^1\)\(^-\)\(^3\) In order to implement the preventive therapy, caries lesions need to be detected at their early stage. However, early detection of caries can be difficult, especially approximal caries, due to their anatomical position. It was found that 75% of approximal lesions are in the contact area and 25% are beneath the contact area, which makes visual detection complicated.\(^4\) Hence, approximal lesions are normally detected when the weakened marginal ridges break down and become cavitated.\(^5\) Therefore, it is likely to underestimate the number of approximal carious lesions with visual examination only. Radiographic examination is another common method for detection of approximal lesions, yet it has been known that radiographic examination often detects caries lesions at advanced stage, which have already passed the scope of remineralization interventions. Furthermore, the use of ionizing radiation, which exposes patients to risk, leads into consideration of alternative methods for detection of approximal lesions.

Since the performance of visual examination in detection of early approximal caries lesions is inadequate, enhanced visual scoring systems have been developed. One of them is International Caries Detection and Assessment System (ICDAS), which has been reported by number of studies that it is an accurate and reproducible method to detect early lesions and also to detect longitudinal changes in lesions.\(^6\)-\(^8\) The ICDAS is also theoretically applicable to approximal smooth surfaces,\(^9\) and the use of ICDAS for approximal caries has been evaluated in a few studies.\(^10\)-\(^11\)

Another potential method for approximal caries detection is a newly developed device called quantitative light-induced fluorescence-digital Biluminator\(^\text{TM}\) (QLF-D). This device is an upgraded version of the first product, the QLF device (Inspektor\(^\text{TM}\) Pro, Inspektor Research Systems BV, Amsterdam, The Netherlands), with a modified filter set (D007; Inspektor Research Systems BV, Amsterdam, The Netherlands), and the principle of this device is based on auto-fluorescence of teeth. When a tooth with demineralization is excited by a visible light of 405 nm from the QLF, there is loss of fluorescence from the demineralized part, and the QLF is able to detect and quantify the change in demineralization.\(^12\)-\(^13\) and early studies have shown that this device has high sensitivities and specificities.\(^12\)-\(^14\)-\(^15\) Other than quantitatively detecting mineral loss, the QLF is also able to detect endogenous porphyrins produced by oral bacteria and present as red fluorescence, and the detected red fluorescence is found to be associated with caries risk.\(^16\)-\(^17\) The QLF-D is upgraded to enhance these characteristics of the QLF. Since the results of the previous studies can be interpreted in terms of QLF only, there is a need to investigate the ability of the QLF-D in detecting caries lesions.

In order to assess performances of detection methods, clinical studies are ideally required. However, it is difficult to conduct such clinical studies because there are many confounding factors to be considered and the extraction of teeth is required for the gold standard. Therefore, the present study was conducted in vitro. The aims of the study were to assess the ability of the QLF-D in detection of approximal caries at different stages, compared with histology examination, and to compare its performance with those of other detection methods such as ICDAS and digital radiography.

2. Materials and methods

2.1. Sample selection

A total of 100 permanent molar and premolar teeth without enamel hypoplasia or dental fluorosis were selected from a pool of extracted permanent human teeth from Yonsei University, with ethical approval from the Institutional Review Board for Clinical Research in Yonsei Dental Hospital (IRB 14-0067). Prior to the extraction, informed and written consent was obtained from all the study participants. After teeth were extracted, they were immediately collected in specimen jars containing distilled water first, and then the teeth were carefully cleaned of soft tissues and calculus, and frozen at \(-20 \degree C\) until used.\(^18\)

Before the teeth were examined using different detection methods, the stored teeth were unfrozen, and selection of teeth was performed. Proximal surfaces with extensive cavities involving more than half of the proximal surface were excluded. Each tooth was given an identification number that was maintained throughout the study.

2.2. Preparation of simulation pairs

Pairs were formed with marginal ridges in contact to simulate the oral relationship with resin (Ortho-jet, Lang Dental Mfg. Co., Inc., USA) in putty (DuoSil Putty set, Bukwang, Busan, Korea), and they were stored individually in containers of distilled water. Each sample was removed from the container, scored and replaced in the container.

2.3. Examiner standardization

All the examinations were performed by one calibrated dentist. The examiner was experienced in the use of QLF-D for caries detection and quantification. For the ICDAS, the examiner had a 90-min training session through the e-learning program prior to the examination. The training for radiographic scoring involved discussion of the radiographic scoring system with a dental professional who was specialized in radiology, and if there was any uncertainty, it was discussed to consensus.

2.4. Detection methods

Three caries detection methods were applied. ICDAS II, digital radiography, and quantitative light-induced fluorescence-digital Biluminator\(^\text{TM}\) (QLF-D).
2.4.1. ICDAS II
The proximal sites of each simulation pair was examined using air syringe and a WHO probe, and the lesions were recorded according to the ICDAS II criteria.\(^\text{19}\) The code (0) refers to sound, the code (1) to first visual change in enamel, the code (2) to distinct visual change in enamel when viewed wet, the code (3) to localized enamel breakdown due to caries with no visible dentine, the code (4) to underlying dark shadow from dentine with or without localized enamel breakdown, the code (5) to distinct cavity with visible dentine, and the code (6) to extensive distinct cavity with visible dentine.

2.4.2. Digital radiography
A pilot study was undertaken in order to ensure the quality of the radiographs. Optimal current, voltage, exposure time, and projection geometry were determined, and a special holder was constructed. The holder arranged the cone to be at a distance of approximately 3 cm from the simulation pairs of teeth and 5 cm from the sensor. Following the pilot study, digital radiography (DR) was performed with the holder using the dental X-ray machine (Kodak 2200 Intraoral X-ray System, Eastman Kodak Co., Rochester, NY, USA) at 60 kV and 7 mA and exposure time of 0.096 s.

The radiographs were then viewed by using software (PIViewSTAR; Infinitt, Seoul, Korea) on an 18 in. computer screen under the same lighting conditions at a standard distance. Simulating clinical situations, brightness and contrast could be adjusted. The lesions on radiographs were classified according to the following score.\(^\text{20}\) The code (0) refers to no radiolucency, the code (1) to radiolucency restricted to the outer half of the enamel, the code (2) to radiolucency involved inner half of enamel, up to (including) DEJ, the code (3) to radiolucency confined to outer half of dentine, and the code (4) to radiolucency involved inner half of dentine with/without apparent pulpal involvement.

2.4.3. Quantitative light-induced fluorescence-digital (QLF-D)
The pairs were dried with a cotton wool roll to remove excessive water and imaged by the QLF-D (Fig. 1). The images were captured from occlusal, buccal and lingual aspects of the specimens under darkroom conditions, where all the lights in the room were turned off, using proprietary software (C3 v1.16, Inspektor Research Systems BV, Amsterdam, The Netherlands) at the following setting: shutter speed of 1/20 s, aperture value of 13.0, and ISO speed of 1600. The distance between the specimen and the QLF-D was 10 cm, and the angle between them was maintained to 90° when proximal lesions were captured from buccal and lingual aspects.

The QLF-D images taken in the standardized condition were then analyzed using the QLF-D software (QA2 v1.21, Inspektor Research Systems BV, Amsterdam, The Netherlands). As three different view images were taken for each specimen, an analysis patch from software was drawn on each view image. The patch surrounded the lesion including all the borders, and mineral loss was automatically calculated as \(\Delta F\) (%) at 5% fluorescence loss threshold. From these three different measurement \(\Delta F\) values for each lesion, the highest value was taken for further analysis.

Before the teeth were sectioned for the histological examination, intra-examiner reliability was assessed for all the methods. The recordings for visual inspection and the acquired images taken under DR and the QLF-D were repeated with a 7-day intermission among the different modalities.

2.5. Histology
After completion of all the assessments, all teeth were prepared for histological assessment. The teeth were sectioned buccolingually to a 2 mm thick specimen using a microtome (TechCut 4TM, Allied High Tech Products, Inc., CA, USA). The specimens were then ground with silicon carbide paper (800 grit, SiC Sand Paper, R&B Inc., Daejeon, South Korea) to a thickness of 200 \(\mu\)m, and photographed at magnifications of 40 and 100 for histological examination with Polarized Light Microscope (PLM, CX31-P, Olympus, Tokyo, Japan). The histological score was assigned according to the following classification. The code (0) refers to no enamel demineralization or a narrow surface zone of opacity, the code (1) to enamel demineralization limited to the outer 50% of the enamel layer, the code (2) to demineralization involving the inner 50% of the enamel, up to the enamel-dentine junction, the code (3) to demineralization involving the outer 50% of the dentine, and the code (4) to demineralization involving the inner 50% of the dentine.

2.6. Statistical analysis
To evaluate reproducibility of all the methods including the novel device, intra-examiner reliability was assessed using

---

**Fig. 1** – Interproximal simulation model with the QLF-D at applied angulations.
intra-class correlation coefficient (ICC). Sensitivity and specificity were calculated for each diagnostic method at enamel threshold (D1) and dentine threshold (D3). At D1, all enamel and dentine lesions were regarded as disease positive, and at the D3 sound surfaces and enamel lesions were classified as disease negative while dentine lesions were regarded as caries. For the ICDAS II and DR, the cut-off point of D1 was between 0 and 1, and the cut-off point of D3 was between 2 and 3. For the ΔF values of the QLF-D, as there was no scale available for detecting proximal lesions, the ROC analysis was performed by comparing the ΔF scores against histological scores in order to determine the cut-off limits. The optimal cut-off limits were established when the combination of sensitivity and specificity was maximum (Med Calc 12.7.0.0., Mariarke, Belgium). The detection methods were analyzed by Receiver Operating Characteristics (ROC) statistics to obtain areas under receiver operating characteristic curves (AUROC) at D1 and D3. The significance level for all the statistical tests was set at \( \alpha = 0.05 \) (PASSW statistics ver.18.0, SPSS, Chicago, IL, USA).

### 3. Results

As 5 damaged teeth were discarded, 95 teeth were included for analysis. Histological examination revealed that 19 surfaces were sound, 62 surfaces had caries within enamel (D1, D2), while 14 surfaces had caries in dentine (D3, D4). Table 1 presents the agreement between histological status and all the modalities. Agreement of DR with histology was the highest for sound (90%) and enamel lesion (58%). Agreements of ICDAS II and QLF-D with histology were the highest for dentine lesion (64% and 64%). Among the agreed surfaces of QLF-D for enamel lesions, the viewing direction which showed the highest agreement with histology was lingual direction (16/33), followed by buccal direction (13/33), and occlusal direction (4/33). For dentine lesions, buccal direction showed the greatest agreement (5/9), followed in rank order by lingual direction (3/9), and occlusal direction (1/9). Fig. 2 shows examples of images of QLF-D, DR, and histology for the specimens with enamel and dentine caries.

Before sensitivity and specificity were calculated for the detection methods, ROC curve analysis was performed to find the optimum ΔF threshold values for enamel and dentine lesions. The optimal cut-off values for ΔF scores were \( \Delta F \leq -13.8 \) for sound, \( -13.8 < \Delta F \leq -28.3 \) for enamel lesion, and \( \Delta F > -28.3 \) for dentine lesion.

Sensitivity, specificity, and AUC values for ICDAS II, DR, and QLF-D at two diagnostic thresholds (D1 and D3) are presented in Table 2. At D1 threshold, the ICDAS II presented the highest sensitivity (0.80) while the DR showed the highest specificity (0.89); however, the methods with the greatest AUC values at D1 threshold were DR and QLF-D (0.80 and 0.80 respectively). At D3 threshold, the methods with the highest sensitivity were ICDAS II and QLF-D (0.64 and 0.64 respectively) while the method with the lowest sensitivity was DR (0.50). However, with regard to the AUC values at D3 threshold, the QLF-D presented the highest value (0.76), followed in rank order by DR (0.72) and ICDAS II (0.66).

As the experiment was performed by a single examiner, the intra-examiner reliability was assessed for all the modalities using ICC, and the values showed excellent reliability for all the detection methods (Table 3).

### 4. Discussion

When a new detection device is developed, it is required to accurately examine the device compared to the established methods. For proximal caries detection, visual examination and radiography have been the conventional diagnostic methods. The sensitivity and specificity of the visual examination for proximal surfaces with cavities were reported to be 0.29 and 0.89, which increased to 0.36 and 0.98 when aided with radiography.1 Although slightly increased when combined with radiography, the sensitivity and specificity values still indicate that the combination of visual examination and radiography is deficient for detecting proximal cavitated lesions.

The QLF has been shown to be a sensitive, valid, and reproducible detection method, and it has been reported that the device enables not only the detection of early caries but also longitudinally monitoring the progression or regression of the lesions.21 These abilities of the device are based on auto-fluorescence of tooth. When there is a lesion, less fluorescence is emitted from tooth because the lesion actually blocks the excitation light of the device and also the back-scattered fluorescence from dentine, which is necessary for producing fluorescence.13 This phenomenon results in a reduction of fluorescence, and this device is able to detect and quantify the contrast in fluorescence between the lesion and the sound area.13 There have been several previous studies that evaluated the QLF on proximal caries, and one of the earliest study found a strong correlation between the readings of QLF and lesion depths derived from the histopathological examination with the coefficient value of 0.84, and also with microradiography with the coefficient value of 0.87.15 Another in vitro previous study reported that the QLF could be used to

<table>
<thead>
<tr>
<th>Table 1 – Agreement between the detection methods and gold standard histology.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Histology</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>S</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>D</td>
</tr>
</tbody>
</table>

S, sound; E, enamel lesion; D, dentine lesions.
detect interproximal caries lesions at the D2 and D3 level when applied from buccal and lingual directions.22 Although the potential of the QLF as the proximal caries detection device has been observed in vitro, there has not been any clinical study to validate the performance of QLF in vivo. The QLF-D, the newly developed device used in the present study, is based on the same principle but with an enhanced light source and filter system. The present study was performed in order to evaluate the performance of the QLF-D in detecting proximal caries. Thus, simulation pairs were formed of extracted teeth, and 95 surfaces in total were examined using the QLF-D that provides mineral loss in %, and the QLF-D was validated against histological gold standard, and compared with ICDAS II and DR.

As results, relatively high sensitivity and specificity at both enamel and dentine thresholds were observed for the QLF-D in this study (Table 2, Fig. 2). When compared to the previous study where high sensitivity and specificity values of 0.83 and 0.98 were obtained for the QLF in detecting dentine lesions, the values of the present study were found be slightly lower.15 However, since the previous study evaluated the performance of the QLF on free proximal surfaces, the differences seem to be reasonable, confirming the good performance for the QLF-D. The present study’s results regarding the AUC analysis also showed that the QLF-D was the method with the greatest AUC values at both thresholds. Although there was no distinctive difference between the AUC values of the QLF-D and those of the conventional methods of this study, ICDAS II and DR, the comparable AUC values along with the relatively high sensitivity and specificity at both thresholds suggest the

### Table 2 – Sensitivity, specificity, area under receiver operating characteristics (AUROC) curve of caries detection methods at enamel and dentine histological thresholds.

<table>
<thead>
<tr>
<th>Method</th>
<th>ICDAS II</th>
<th>Digital radiography</th>
<th>QLF-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy enamel</td>
<td>0/1</td>
<td>0/1</td>
<td>ΔF &lt; 13.8</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.80</td>
<td>0.71</td>
<td>0.75</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.68</td>
<td>0.89</td>
<td>0.84</td>
</tr>
<tr>
<td>AUROC (95% C.I.)</td>
<td>0.74 (0.64–0.83)</td>
<td>0.80 (0.71–0.88)</td>
<td>0.80 (0.70–0.87)</td>
</tr>
<tr>
<td>Carious enamel</td>
<td>2/3</td>
<td>2/3</td>
<td>ΔF &gt; 28.3</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.64</td>
<td>0.50</td>
<td>0.64</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.68</td>
<td>0.94</td>
<td>0.88</td>
</tr>
<tr>
<td>AUROC (95% C.I.)</td>
<td>0.66 (0.56–0.76)</td>
<td>0.72 (0.62–0.81)</td>
<td>0.76 (0.66–0.84)</td>
</tr>
</tbody>
</table>

*AUROC, area under the ROC curve; C.I., confidence interval.*

### Table 3 – Intra-examiner agreement obtained for the methods in detecting proximal caries.

<table>
<thead>
<tr>
<th>Method</th>
<th>ICDAS II</th>
<th>Digital radiography</th>
<th>QLF-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICC (95% C.I.)</td>
<td>0.94 (0.91–0.98)</td>
<td>0.88 (0.76–0.94)</td>
<td>0.78 (0.59–0.89)</td>
</tr>
</tbody>
</table>

*ICC, intraclass correlation coefficient; C.I., confidence interval.*

Fig. 2 – (A) White light image of premolar with suspected carious area, (B) QLF-D image showing demineralized areas, (C) radiographic image not showing demineralized areas, (D) the same proximal surface scored as enamel carious lesion by the histological assessment, (E) white light image of premolar with cavitated lesion, (F) QLF-D image showing demineralized areas, (G) radiographic image showing demineralized areas within enamel, (H) the corresponding histological image scored as dentine lesion. Arrows indicate the caries lesions.
potential of the QLF-D for the effective proximal caries detection method.

Diagnostic performance of the traditional detection methods, i.e. visual examination and DR, were also evaluated. The AUC values presented that the overall performances of all the detection methods were similar. More specifically, visual inspection using ICDAS II was the most sensitive method for detecting enamel carious lesions, and also at dentine threshold along with the QLF-D. Meanwhile, DR showed the highest specificity at both enamel and dentine thresholds. These results could be compared to the results of the previous study where ICDAS II was found to be the most sensitive method and the digital radiography and the conventional radiography presented the highest specificity, while similar ranges of AUC values were also obtained for ICDAS II, conventional radiography, and digital radiography.23 However, the sensitivity of the ICDAS II reported by the previous study was higher than that of the present study at both enamel and dentine level.23 Considering the previous study was performed on free proximal surfaces, it can be assumed that there is a possibility of the values being over-estimated whereas the results of the present study reflect the actual clinical situation where there is limited visibility to proximal surfaces. This study evaluated the DR only rather than the conventional film radiography. Although DR has been recently introduced, DR has advantages over conventional radiography including reduced radiation exposure, elimination of dark room processing, ability to manipulate images, and ready storage and communication.24 However, the problem with use of ionizing radiation, which exposes patients to risk, cannot still be resolved, leading into a need to search for other detection methods.

This study was the first study to suggest the optimal cut-offs for the QLF-D for detecting proximal caries at different stages. There was a previous study that developed the preliminary QLF index for clinical management of early occlusal caries.25 Although the QLF clinical index consisted of the three different ranges of QLF scores in relation to treatment decisions, each treatment decision could also be considered as the appropriate treatment for sound, enamel and dentine caries.25 Thus, although the cut-off values determined in this study were to distinguish the extent of caries, they were still comparable to the cut-off values of the QLF clinical index. According to the clinical index, when the QLF score for a lesion is between 12 and 23, fissure sealant or PRR are suggested for treatments, and when it is higher than 23, class 1 restoration is the suggested treatment decision.25 The absolute cut-off values determined in this study were slightly lower as they were 13.8 for distinguishing between sound and enamel caries and 28.3 for distinguishing between enamel and dentine caries. It could be assumed that the differences between the cut-off values were due to the differences in the devices since the previous study used the QLF while the present study used the upgraded QLF-D. Moreover, the differences in the origin of lesions could be another reason because occlusal caries and proximal caries have relatively different histopathological features, in addition to their different locations. Even though the clinical index was validated clinically and can be practical and easy to approach in terms of suggesting treatment decisions, it would be restricted to guiding dentists decide appropriate treatment plans for occlusal caries. However, since the index of this study was validated histologically, it has a potential to help dentists diagnose more accurately and also monitor caries lesions by providing them quantitative information about the extent of caries.

In this study, the QLF-D images were captured from occlusal, buccal and lingual directions for each lesion, and after the severity of lesion was analyzed as three different ΔF values from the three view images, the highest ΔF value was taken for further analysis. As results, more lesions were found from buccal or lingual than occlusal directions, which was in agreement with the previous study’s finding where the viewing direction from either buccal or lingual was superior to viewing from occlusal.22 The results may be attributed to the presence of thick marginal ridges preventing the QLF-D from detecting the loss of fluorescence from occlusal direction. Also, when the lesion was located in close proximity of the marginal ridges, it seemed to be detected well from occlusal direction. However, it was hard to find out the effect of the distance between the marginal ridge and the coronal part of the lesion on detection ability of the QLF-D in this study, necessitating further studies in this matter.

Since the study was performed by a single trained examiner, the intra-examiner reliability was checked throughout the study. The ICC values showed all the modalities had excellent reproducibility (Table 3). Reproducibility of ICDAS II and the DR could be compared to the finding of the previous study where children were examined with different detection methods.26 They reported of 0.864 for the reproducibility of the ICDAS II, which was lower than that found by the present study, and 0.889 for that of the radiography, which was in accordance with that of the present study. The lower value of the ICDAS II reported by the previous study may be due to the fact that the study evaluated detection devices in children in vivo, which made visual examination difficult. Meanwhile, the QLF-D also showed high intra-examiner reliability (Table 3), indicating that the automated method was effective in producing similar results at different times. However, as this study relies in only one examiner for all methods, it may be difficult to interpret the results in generalization. Therefore, further study with various examiners is necessary. In addition, although the present study was in vitro study which validated the detection methods versus the histological gold standard, there can be a limitation in translating the results into the clinical situation; hence it is required to assess the novel technology in vivo. When an experiment is performed in vivo, it should always be considered that there are factors affecting the validity of the QLF-D including presence of plaque and stain,27 which necessitates thorough cleaning for accurate examination for the QLF-D.

Approximal caries diagnosis is difficult due to the anatomical position of the lesions. As visual examination is the most affected detection method by the anatomical position of the lesions, the radiography has been the mainstay for proximal caries detection method. Nevertheless, the radiography is often not able to distinguish between cavitated lesions and lesions with an intact surface,28 which can result in undesired treatments based on incomplete examination. These drawbacks of the conventional methods led into searching for a potential accurate and non-invasive detection method. Within
the limitation of this study, it was showed that the QLF-D system was able to detect the approximal caries lesions at different stages, and its performance was comparable to those of the conventional detection methods. However, as this device is able to generate quantitative measurement data regarding caries extent based on its automated analysis, there is a potential for the QLF-D to overcome the subjectivity of the visual examination and incomplete examination of radiography. Moreover, considering that the QLF-D is in a form of SLR digital camera, the image taking process would take less than a minute even for three different viewing images, which is not any longer than the amount of time spent for visual inspection and radiography. In addition, the analysis process is also an automated process, which only takes a couple of seconds upon drawing a analysis patch around the suspected lesion area. Thus, based on the suggested cut-off values from this study, the use of the QLF-D would enable dental professionals to correctly identify demineralization at different stages in a relatively short period of time, determine appropriate treatment decisions and monitor, but also help patients understand their oral health status through the numerical values and become motivated for improvement. Furthermore, its accuracy, speed, and portability would allow remote assessment and delivery of dental services for critical communities.

5. Conclusion

This study assessed the performance of the novel technology based method QLF-D in detecting proximal caries compared to the traditional methods, and the performance of the newly developed QLF-D in detecting proximal caries was similar to those of the traditional methods. Although, having relatively high sensitivity and specificity at both enamel and dentine caries and providing quantitative data regarding the extent of caries based on the proposed cut-off values indicates that the QLF-D has the potential for an effective detection method that would help not only managing caries from early stage but also avoiding unwanted operative treatment. When this device complements the traditional methods, it will help dental professionals to determine accurate clinical diagnosis and make appropriate treatment plan.

Acknowledgements

This research was supported by Basic Science Research Programme through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2013R1A1A2062505).

REFERENCES


