

Comparison of Laser Fluorescence Devices' Diagnostic Validity in Occlusal Caries of Primary Teeth

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Objective: To compare the diagnostic validity of laser fluorescence devices in occlusal caries of primary teeth.

Methods: 48 examination sites were classified into five groups according to the ICDAS-II criteria and measurements were taken using diagnostic devices according to each manufacturer's instructions. All examination sites were analyzed using Micro-CT and classified into three groups based on caries depth (no radiographic transparency, radiographic transparency limited to enamel, radiographic transparency extending to dentin). ROC curve analysis was performed to calculate sensitivity and specificity and to determine the optimal cut-off value for caries progression.


Results: All laser fluorescence devices showed an increasing trend in measurement values as the ICDAS-II code increased. DIAGNOdent showed significant differences between Code 1 and Code 2, and between Code 2 and Code 3. DIAGNOdent pen showed significant differences between all groups except between Code 0 and Code 1. SmarTooth showed significant differences between Code 1 and Code 3, and between Code 3 and Code 4 and above.

Conclusion: ROC curve analysis results indicated that for enamel caries diagnosis, the accuracy was highest with DIAGNOdent, followed by SmarTooth, and then DIAGNOdent pen. For dentin caries diagnosis, the accuracy was highest with SmarTooth, followed by DIAGNOdent pen, and then DIAGNOdent. However, all three devices demonstrated high accuracy in diagnosing occlusal caries in primary teeth. The cut-off values for primary teeth differed from the manufacturer's instructions based on permanent teeth. It is believed that using appropriate cut-off values could make these devices a supplementary method for caries diagnosis.

Keywords: smartooth, early caries detection, sensitivity and specificity, diagnostic accuracy

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Received May 27, 2025, Revised June 23, 2025,

Accepted June 24, 2025

Introduction

Traditional dental caries diagnosis methods include visual inspection, radiography, and explorer probing. Visual diagnosis of early caries may vary between dentists. Absence of objective evidence can lead to distrust in dental care. Explorer probing may transfer caries-causing microorganisms to healthy tooth structure. It can damage the enamel surface accelerating caries progression. Some reports suggest explorer probing is unhelpful for caries diagnosis [1-3]. Radiography

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poses radiation exposure risks and may be rejected by patients. Research has developed more objective diagnostic methods.

One method is DIAGNOdent[®] (KaVo Biberach, Germany; DD) developed by Lussi et al. [4]. DIAGNOdent[®] employs laser fluorescence technology utilizing a 655 nm wavelength diode laser that penetrates tooth structure and elicits fluorescence emissions in the near-infrared range. When the laser light encounters carious tissue, fluorescence occurs through multiple mechanisms: structural changes in tooth tissue, such as porosity from demineralization, produce fluorescent emissions of different wavelengths, while bacterial metabolites, particularly porphyrins produced by cariogenic bacteria, contribute to increased red fluorescence in carious areas. The device detects these porphyrin derivatives with high sensitivity and can identify lesions deep in fissures due to enamel's transparency in the near-infrared range. The laser is directed through an optical fiber to specific locations on the tooth surface, and the device measures fluorescence intensity through infrared detection fibers, displaying results as numerical values ranging from 0 to 99 [1,4-9]. Using the same principle, DIAGNOdent[®] pen (KaVo Biberach, Germany; DDpen) was released in 2005 for proximal caries detection. SmarTooth (SmarTooth, Seoul, Korea; ST) was released in Korea in 2023 as a digital oral diagnostic device utilizing similar laser fluorescence principles. Unlike DIAGNOdent devices that use sapphire probes, SmarTooth employs an acrylic optical sensor and integrates with smart devices through a mobile application, allowing for data storage, analysis, and tracking of caries progression over time.

DD manufacturer states for pits and fissures: sound tooth structure shows values 0-5. Outer half enamel caries shows values 6-14. Inner half enamel caries shows values 15-20. Dentin caries shows values above 21. DDpen manufacturer states for occlusal surfaces: sound tooth structure shows values 0-12. Enamel caries shows values 13-24. Dentin caries shows values above 25 [10]. For ST: values 0-10 indicate sound tooth structure. Values 11-20 indicate enamel caries.

Values above 21 indicate dentin caries.

These cut-off values are applicable to permanent teeth and criteria for diagnosing caries in primary teeth have not been established. Research on the accuracy of ST in diagnosing dental caries is limited.

This study aims to compare measurements of these three devices on primary teeth occlusal surfaces with ICDAS-II criteria. It will determine optimal cut-off values for caries diagnosis by calculating sensitivity and specificity.

Materials and Methods

1. Materials

1) Tooth

This study was conducted with approval from the Institutional Review Board (IRB) of Dankook University Dental Hospital (DKUDH IRB 2024-08-002). Maxillary and mandibular primary first and second molars were collected from patients who visited the Department of Pediatric Dentistry at Dankook University Dental Hospital from August 2024 to October 2024. Forty eight measurement sites were included in the study. The specimens were stored in physiological saline solution under refrigeration until immediately before the caries assessment (Table 1).

2) Laser fluorescence devices

Diagnostic devices employing laser fluorescence principles were utilized, consisting of the following three instruments (Fig. 1).

Table 1. Subjects participated in this study

Number of tooth surfaces (%)	48 (100)
Maxillary teeth	24 (50)
Mandibular teeth	24 (50)
1 st primary molar	25 (52.1)
2 nd primary molar	23 (47.9)



Figure 1. Laser fluorescence devices used in this study. (A) DIAGNOdent[®]. (B) DIAGNOdent[®] pen. (C) SmarTooth.

3) Micro-CT

A Skyscan 1176 (Bruker microCT, Kontich, Belgium) was used to determine the depth of caries in each tooth specimen.

2. Methods

1) Specimen preparation

Prior to conducting examinations using laser fluorescence devices, calculus removal was performed using an ultrasonic scaler, followed by polishing of the tooth surface using a low-speed handpiece and ICB brush. A plastic mold measuring 17.0 mm in width, 17.0 mm in length, and 12.0 mm in height was fabricated using a 3D printer. The teeth were embedded in acrylic resin with the crowns exposed.

2) ICDAS assessment through visual examination

The ICDAS-II codes were determined for 48 locations to be measured by the devices through visual examination (Table 2). In this study, ICDAS-II codes 4 through 6 were classified as the Code 4 and above group (Code 4+), dividing all teeth into five groups (Code 0, Code 1, Code 2, Code 3, Code 4+).

3) Laser fluorescence examination

Three devices were used for laser fluorescence examination: DIAGNOdent® (KaVo Biberach, Germany; DD), DIAGNOdent® pen (KaVo Biberach, Germany; DDpen), and SmarTooth (SmarTooth, Seoul, Korea; ST). All measure-

ments were performed by a single calibrated examiner to eliminate inter-examiner variability. Prior to the study, the examiner underwent training sessions with each device according to the manufacturer's protocols to ensure measurement consistency. Calibration was performed according to the manufacturers' instructions. Measurements were taken by contacting the probe to the tooth surface at various angles. The highest value was recorded.

4) Caries depth evaluation using Micro-CT

Each embedded tooth was scanned using Micro-CT. The X-ray source was operated at 90 kV, and the X-ray detector used a 12-bit CCD camera coupled with fiber-optic coupling connected to an 11 mega-pixel (4,000×2,670) scintillator. Three-dimensional reconstruction of the acquired images was performed using Nrecon (Bruker, Kontich, Belgium), and analysis was conducted using Dataviewer (Bruker, Kontich, Belgium), FastStone Photo Resizer 4.4 (FastStone Soft, USA), and FastStone Image Viewer 8.0 (FastStone Soft, USA). Each tooth was classified as having no radiolucency (pR₀), radiolucency limited to the enamel (pR₁), or radiolucency extending to the dentin (pR₂). The optimal cut-off values were determined by calculating sensitivity and specificity compared with the measurements of the diagnostic devices. In this study, the measurement with the highest sum of sensitivity and specificity was calculated as the optimal cut-off value.

3. Statistical analysis

Statistical analysis was performed using IBM SPSS 27.0. Kruskal-Wallis test was used for comparative analysis of measurements according to ICDAS-II classification, with Mann-Whitney U test with Bonferroni correction as post-hoc analysis. ROC curve analysis was performed to determine the optimal cut-off values through comparison of sensitivity and specificity.

Table 2. ICDAS II codes and criteria

0	Sound
1	First visual change in enamel
2	Distinct visual change in enamel
3	Localized enamel breakdown (without clinical visual signs of dentinal involvement)
4	Underlying dark shadow from dentin
5	Distinct cavity with visible dentin
6	Extensive distinct cavity with visible dentin

Table 3. Laser fluorescence readings and mean ranks among three groups classified by ICDAS-II in primary dentition

ICDAS-II	Number (%)	DD		DDpen		ST	
		Reading (Mean ±SD)	Mean Rank	Reading (Mean ±SD)	Mean Rank	Reading (Mean ±SD)	Mean Rank
Code 0	6 (12.5)	2.67 ±0.52	4.50 ^a	0.50 ±0.84	6.25 ^a	2.50 ±0.55	7.50 ^a
Code 1	7 (14.6)	5.00 ±2.45	13.57 ^a	1.29 ±1.38	9.57 ^a	3.00 ±2.52	10.07 ^a
Code 2	10 (20.8)	7.10 ±5.57	17.30 ^b	6.40 ±8.54	18.45 ^b	7.30 ±6.07	18.55 ^{a,b}
Code 3	10 (20.8)	19.20 ±7.60	30.25 ^c	20.30 ±11.56	30.35 ^c	17.40 ±8.32	27.65 ^b
Code 4 and higher	15 (31.3)	57.20 ±35.16	38.57 ^c	58.73 ±35.30	38.90 ^d	61.67 ±36.78	39.90 ^c

P: Kruskal-Wallis test (α=0.05), ^{a,b,c}Mann-Whitney's U test as post-hoc test.

DD: DIAGNOdent®, DDpen: DIAGNOdent® pen, ST: SmarTooth.

^{a,b,c}Same superscript letters in the columns indicate non significantly different by the Mann-Whitney's U test.

Results

1. Assessment of diagnostic devices using laser fluorescence principles according to ICDAS classification

The measurements of caries diagnostic devices classified according to ICDAS-II criteria are shown in the following table (Table 3). All caries diagnostic devices showed a tendency for measurement values to increase as the ICDAS-II code values increased. DD showed significant differences between Code 1 and Code 2, and between Code 2 and Code 3 ($p < 0.05$). DDpen showed significant differences between all groups except between Code 0 and Code 1 ($p < 0.05$). SmarTooth showed significant differences between Code 1 and Code 3, and between Code 3 and Code 4 and above groups ($p < 0.05$).

2. ROC curve analysis

The ROC curve analysis for enamel caries showed that the AUC values were highest in the order of DD (0.886), ST (0.882), and DDpen (0.864) (Fig. 2, Table 4).

For dentin caries, the ROC curve analysis indicated that the AUC values were highest in the order of ST (0.960), DDpen (0.932), and DD (0.928) (Fig. 3, Table 4).

3. Optimal cut-off values

Sensitivity and specificity were calculated according to the manufacturer's instructions. Optimal cut-off values were determined. The corresponding sensitivity and specificity were obtained. Cut-off values for distinguishing enamel caries were 10 for DD, 10 for DDpen, and 9 for ST. Cut-off values for

distinguishing dentin caries were 21 for DD, 13 for DDpen, and 18 for ST. Cut-off value for enamel caries in DD was higher than the manufacturer's instruction. Cut-off value for dentin caries matched the manufacturer's instruction. Cut-off values for both enamel and dentin caries in DDpen and ST were lower than manufacturer's instruction (Table 5).

Discussion

ICDAS examination is highly reliable for dental caries. It has high intra- and inter-examiner reliability. It demonstrates strong histological correlation [11-13]. In this study, agreement probability between ICDAS examination and enamel caries was 72.2%. The agreement probability with dentin caries was 85.7%. Higher ICDAS code values corresponded to higher measurement values for DD, DDpen, ST in primary teeth.

Measurement value differences among devices result from probe material and diameter variations. Takamori et al. [14] found that DDpen produced higher values than DD. DD and DDpen use sapphire probes and ST uses an acrylic optical sen-

Table 4. Area under the ROC curve of DD, DDpen, ST

Threshold	DD	DDpen	ST	p-value
pR ₁	0.886	0.864	0.882	0.001*
pR ₂	0.928	0.932	0.960	0.001*

Pairwise comparison of ROC curves (* $p < 0.05$). DD: DIAGNOdent[®], DDpen: DIAGNOdent[®] pen, ST: SmarTooth, pR₁: enamel caries, pR₂: dentin caries.

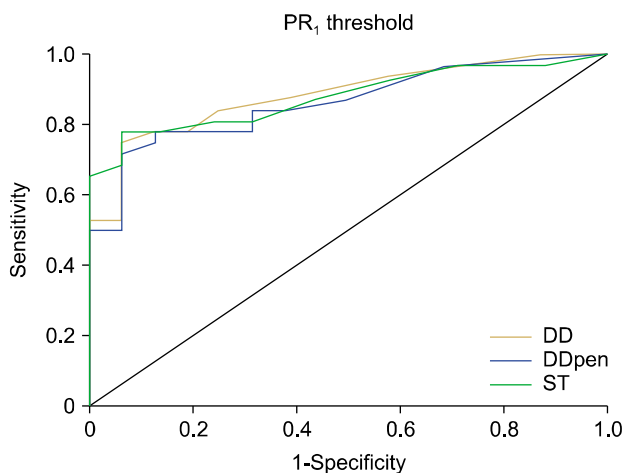


Figure 2. Receiver operating characteristics curves of DD, DDpen, ST at pR₁ threshold (enamel caries). DD: DIAGNOdent[®], DDpen: DIAGNOdent[®] pen, ST: SmarTooth.

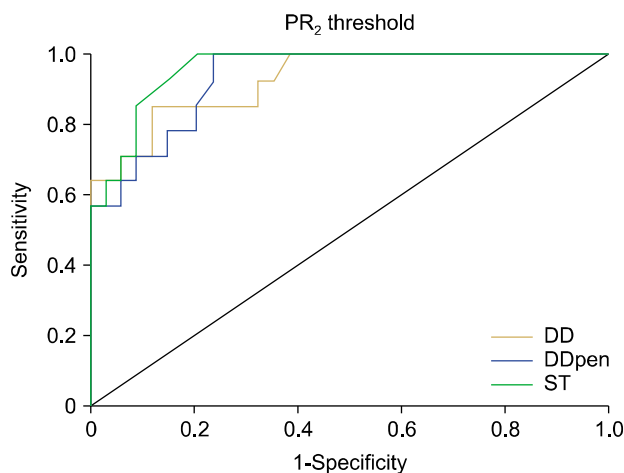


Figure 3. Receiver operating characteristics curves of DD, DDpen, ST at pR₂ threshold (dentin caries). DD: DIAGNOdent[®], DDpen: DIAGNOdent[®] pen, ST: SmarTooth.

Table 5. Sensitivities and Specificities at different cut-off values suggested by manufacturer and the result of this study in primary dentition

	pR ₁ threshold			pR ₂ threshold		
	Cut-off	Sn	Sp	Cut-off	Sn	Sp
DD	6 ^a	0.84	0.75	21 ^a	0.86	0.88
	10 ^b	0.75	0.94	21 ^b	0.86	0.88
DDpen	13 ^a	0.66	0.95	25 ^a	0.71	0.85
	10 ^b	0.66	0.94	13 ^b	1	0.76
ST	11 ^a	0.72	0.94	21 ^a	0.93	0.85
	9 ^b	0.78	0.94	18 ^b	1	0.79

DD: DIAGNOdent[®], DDpen: DIAGNOdent[®] pen, ST: SmarTooth, pR₁: enamel caries, pR₂: dentin caries, Sn: Sensitivity, Sp: Specificity.

^aManufacturer's suggestion, ^bOptimal cut-off maximizing sum of sensitivity and specificity in this study.

sor [15]. Sapphire probes have high light transmittance and strength according to the manufacturer. ST and DDpen probes have a single optical sensor with 1.0 mm diameter. The DD probe has a 1.4 mm diameter with ten 40 µm optical fibers [10,16]. DDpen transmits excitation and absorption light through a single pathway. DD uses independent pathways [14]. DD's smaller head allows easier examination. Pen-type devices have lower reproducibility due to probe breakage risk [17]. ST mitigates this by allowing acrylic optical sensor length adjustments. The different optical characteristics between acrylic and sapphire materials may contribute to variations in diagnostic performance observed in this study. However, given the limited research on SmarTooth's diagnostic performance, these findings require validation through larger clinical studies.

Dental caries occurs from demineralization and remineralization imbalance. Early enamel-limited caries detection allows non-invasive treatments like fluoride application rather than invasive tooth preparation [1,18,19]. ICDAS-II Code 3 shows localized enamel breakdown without visible dentin. Code 4 presents visible dentin caries [11,20-22]. Codes 3 and 4 indicate a high likelihood of dentin caries progression. DD and DDpen showed significant differences between Code 2 and 3. DDpen and ST showed significant differences between Code 3 and Code 4 or higher.

Diagnostic accuracy is assessed by ROC curve area (AUC). Larger AUC indicates higher accuracy. AUC values are categorized: non-informative (AUC=0.5), less accurate (0.5<AUC<0.7), moderately accurate (0.7<AUC<0.9), highly accurate (0.9<AUC<1), perfect (AUC=1) [23,24]. Enamel caries diagnosis accuracy was highest for DD, then ST, DDpen. For dentin caries, ST was highest, then DDpen, DD. All devices showed AUC above 0.7 for enamel caries diagnosis. AUC for dentin caries diagnosis exceeded 0.9.

Primary teeth cut-off values differ from permanent teeth due to morphological and histological differences [25,26].

Primary teeth have thinner enamel providing less masking of fluorescent light. Primary teeth have amorphous enamel and lower mineral content. Primary enamel's porosity increases light scattering, reducing fluorescence signals. Lussi and Francescut [3] reported these factors do not substantially affect cut-off values.

Studies report varying sensitivity and specificity for enamel/dentin caries detection on primary teeth occlusal surfaces using DD and DDpen [25,27,28]. Çınar et al. [25] found DDpen sensitivity significantly higher than DD for shallow enamel caries. No significant difference existed for deeper caries. Cut-off value, sensitivity, and specificity variations across studies may result from measurement location differences, storage solutions, methods, duration [29-33].

ST integrates with smart devices through a dedicated application. The separation of measurement and monitoring devices facilitates assessment. Data storage tracks caries progression. Laser fluorescence devices may enhance non-cavitated initial caries and secondary restoration caries diagnosis [34,35]. Numerical values and color-coded indicators help caries prevention and patient education [36-38].

Study limitations include several factors that may affect clinical applicability. First, this in vitro study was conducted under controlled laboratory conditions that differ significantly from the actual intraoral environment. Clinical factors including saliva, ambient lighting conditions, tooth surface staining, and plaque accumulation can substantially influence laser fluorescence measurements. Additionally, the positioning and angulation of probes in the oral cavity may be more challenging than in laboratory settings, potentially affecting measurement reproducibility. Second, the sample size of 48 measurement sites was relatively small, and power analysis was not performed to determine adequate sample size for detecting clinically meaningful differences between devices. Larger sample sizes would enable more precise sensitivity and specificity calculations.

Conclusion

In this study, the occlusal caries detection ability of three laser fluorescence-based caries diagnostic devices was compared. The results indicated that higher ICDAS codes corresponded to higher measurement values from the devices, demonstrating a strong correlation with visual examination findings. For enamel caries diagnosis, the accuracy was highest in the order of DIAGNOdent[®], SmarTooth, and DIAGNOdent[®] pen. For dentin caries diagnosis, SmarTooth showed the highest accuracy followed by DIAGNOdent[®] pen and DIAGNOdent[®]. All three devices exhibited high accuracy in diagnosing occlusal caries in primary teeth. Utilizing laser fluorescence-based diagnostic devices as a supplementary method for caries detection in primary teeth may enhance diagnostic accuracy.

Acknowledgement

This study was supported by research funding from SmarTooth Co., Ltd.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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References

- Hibst R, Paulus R, Lussi A. Detection of occlusal caries by laser fluorescence: basic and clinical investigations. *Med Laser Appl* 2001;16:205-13.
- Lussi A. Validity of diagnostic and treatment decisions of fissure caries. *Caries Res* 1991;25:296-303.
- Lussi A, Francescut P. Performance of conventional and new methods for the detection of occlusal caries in deciduous teeth. *Caries Res* 2003;37:2-7.
- Lussi A, Hibst R, Paulus R. DIAGNOdent: an optical method for caries detection. *J Dent Res* 2004;83:80-3.
- Kienle A, Hibst R. Light guiding in biological tissue due to scattering. *Phys Rev Lett* 2006;97:018104.
- Koenig K, Hibst R, Meyer H, Flemming G, Schneckeburger H. Laser-induced autofluorescence of carious regions of human teeth and caries-involved bacteria. *Dent Appl Lasers* 1993;2080:170-80.
- Kwaśny M, Bombalska A. Applications of laser-induced fluorescence in medicine. *Sensors (Basel)* 2022;22:2956.
- Fyrestam J, Bjurshammar N, Paulsson E, Johannsen A, Östman C. Determination of porphyrins in oral bacteria by liquid chromatography electrospray ionization tandem mass spectrometry. *Anal Bioanal Chem* 2015;407:7013-23.
- Buchalla W, Attin T, Niedmann Y, Niedmann PD, Lennon AM. Porphyrins are the cause of red fluorescence of carious dentine: verified by gradient reversed-phase HPLC. *Caries Res* 2008;42:223.
- Lee C, Lee D, Kim J, Yang Y. Comparison of diagnostic validity between laser fluorescence devices in proximal caries. *J Korean Acad Pediatr Dent* 2018;45:426-35.
- Kim HJ, Noh HS, Kim S, Jeong TS. Literature review of international caries detection and assessment system II to oral examination for children. *J Korean Acad Pediatr Dent* 2011;38:202-9.
- Park K, Kim D, Lee D, Kim J, Yang Y, Kim J. Evaluation of caries status among adolescents in Jeonju city with WHO basic methods, international caries detection and assessment system II (ICDAS-II). *J Korean Acad Pediatr Dent* 2016;43:382-90.
- Kim HE. Review on international caries detection and assessment system. *J Korean Soc Dent Hyg* 2014;14:609-15.
- Takamori K, Tanaka Y, Iwasaki M, Shirakawa T. In vivo comparison between measurement from two fluorescence-based devices of occlusal and smooth surface caries in primary and permanent teeth. *Pediatr Dent J* 2012;22:50-4.
- Rams TE, Alwaqyan AY. In vitro performance of DIAGNOdent laser fluorescence device for dental calculus detection on human tooth root surfaces. *Saudi Dent J* 2017;29:171-8.
- Lussi A, Hellwig E. Performance of a new laser fluorescence device for the detection of occlusal caries in vitro. *J Dent* 2006;34:467-71.
- Moriyama CM, Rodrigues JA, Lussi A, Diniz MB. Effectiveness of fluorescence-based methods to detect in situ demineralization and remineralization on smooth surfaces. *Caries Res* 2014;48:507-14.
- Kim JG. Strategies for the prevention of dental caries as a non-communicable disease. *J Korean Acad Pediatr Dent* 2023;50:131-41.
- Kim JG, Kim YJ, Kim YS, Baik BJ. In vitro comparison of various diagnostic methods of occlusal carious lesions. *J Korean Acad Pediatr Dent* 2001;28:613-9.
- Wong A, Subar PE, Young DA. Dental caries: an update on dental trends and therapy. *Adv Pediatr* 2017;64:307-30.
- Zeller G, Young DA, Novy B. The American dental association caries classification system (ADA CCS). In: Zandona AF, Longbottom C, eds. *Detection and assessment of dental caries: a clinical guide*. Cham: Springer; 2019:57-67.
- Young DA, Novy BB, Zeller GG, Hale R, Hart TC, Truelove EL; American Dental Association Council on Scientific Affairs;

- American Dental Association Council on Scientific Affairs. The American Dental Association caries classification system for clinical practice: a report of the American Dental Association Council on Scientific Affairs. *J Am Dent Assoc* 2015;146:79-86.
23. Song SW. Using the receiver operating characteristic (ROC) curve to measure sensitivity and specificity. *Korean J Fam Med* 2009;30:841-2.
 24. Fan J, Upadhye S, Worster A. Understanding receiver operating characteristic (ROC) curves. *CJEM* 2006;8:19-20.
 25. Çinar C, Atabek D, Odabaş ME, Olmez A. Comparison of laser fluorescence devices for detection of caries in primary teeth. *Int Dent J* 2013;63:97-102.
 26. Lussi A, Megert B, Longbottom C, Reich E, Francescut P. Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. *Eur J Oral Sci* 2001;109:14-9.
 27. Sürme K, Kara NB, Yilmaz Y. In vitro evaluation of occlusal caries detection methods in primary and permanent teeth: a comparison of CarieScan PRO, DIAGNOdent Pen, and DIAGNOcam Methods. *Photobiomodul Photomed Laser Surg* 2020;38:105-11.
 28. Luczaj-Cepowicz E, Marczuk-Kolada G, Obidzinska M, Sidun J. Diagnostic validity of the use of ICDAS II and DIAGNOdent pen verified by micro-computed tomography for the detection of occlusal caries lesions—an in vitro evaluation. *Lasers Med Sci* 2019;34:1655-63.
 29. Bahramian H, Argani P, Baghalian A. Comparison of different diagnostic techniques in detecting smooth surface caries in primary molars using the histological gold standard: an in vitro study. *Photodiagnosis Photodyn Ther* 2020;31:101867.
 30. Lussi A, Hack A, Hug I, Heckenberger H, Megert B, Stich H. Detection of approximal caries with a new laser fluorescence device. *Caries Res* 2006;40:97-103.
 31. Mendes FM, Siqueira WL, Mazzitelli JF, Pinheiro SL, Bengtson AL. Performance of DIAGNOdent for detection and quantification of smooth-surface caries in primary teeth. *J Dent* 2005;33:79-84.
 32. Francescut P, Zimmerli B, Lussi A. Influence of different storage methods on laser fluorescence values: a two-year study. *Caries Res* 2006;40:181-5.
 33. Kaul R, Kaul V, Farooq R, Wazir ND, Khateeb SU, Malik AH, et al. Cut off values of laser fluorescence for different storage methods at different time intervals in comparison to frozen condition: a 1 year in vitro study. *J Conserv Dent Endod* 2014;17:124-8.
 34. Akarsu S, Karademir SA. In vitro comparison of ICDAS and DIAGNOdent pen in the diagnosis and treatment decisions of non-cavitated occlusal caries. *Odovtos Int J Dent Sci* 2019;21:67-81.
 35. Sichani AV, Javadinejad S, Ghafari R. Diagnostic value of DIAGNOdent in detecting caries under composite restorations of primary molars. *Dent Res J (Isfahan)* 2016;13:327-32.
 36. Kim M, Lee SY, Cho YS. The effect of oral health education for the elderly using QscanTM. *J Korean Soc Dent Hyg* 2015;15:555-63.
 37. Lim SY, Lee K, Choi BJ, Lee JH. Parents education of oral hygiene using QLF-D in patients for special health care needs. *J Korean Dis Oral Health* 2017;13:99-103.
 38. Lee J, Kim S, Jeong T, Shin J, Lee E, Kim J. Effectiveness of oral health education program using home-using portable device for children. *J Korean Acad Pediatr Dent* 2019;46:301-9.