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# Inter-rater agreement among multiple examiners for the assessment of plaque scores between quantitative light-induced fluorescence-digital and two-tone disclosing solution-stained digital images

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ABSTRACT

*Background:* To utilize plaque scoring indices as objective measures, a certain standard of intra-rater and inter-rater agreement must be met. Achievement of high consistency among several examiners in the assessment of images from Q-ray cam (for quantitative light-induced fluorescence-digital imaging) and digital single-lens reflex camera of stained tooth surfaces might enable more efficient undertaking of large epidemiological studies and oral tests.

*Methods:* Second-year dental hygiene students and registered dental hygienists 40 examiners were randomly selected, all of whom provided informed consent. Multiple examiners assessed plaque scoring indices from the two types of images of the same 30 patients. The images were observed on a computer monitor, and the area with dental plaque was assessed using the Patient Hygiene Performance Index. The intra-class correlation coefficient was determined to evaluate the agreement among examiners and test methods for dental plaque Q-ray cam and digital single-lens reflex camera measurements were compared using a Bland-Altman plot. The intra-class correlation coefficient was analyzed using SPSS version 24 software (SPSS Inc., Chicago, IL, USA), and the exploratory graph was analyzed with MedCalc.

*Results:* Agreement among 40 examiners was excellent with an intra-class correlation coefficient of 0.990 when the Q-ray cam was used. The intra-class correlation coefficient for the registered dental hygienists group was 0.987 and that for the dental hygiene students group was 0.980.

*Conclusions:* The study was high agreement in the assessment of Q-ray cam images and digital single-lens reflex camera images of stained dental plaque by multiple examiners, confirming that the two methods are validated both independently and with high mutual agreement.

## 1. Introduction

Dental plaque refers to the microorganisms in oral biofilms, attached to the tooth surface, and is one of the causes of various oral symptoms and diseases, such as dental caries and periodontal diseases [1]. Visual detection of dental plaque is difficult; therefore, plaques are stained with disclosing solutions or tablets [2]. When a two-tone disclosing solution is used, new dental plaques are stained red, whereas relatively older dental plaques are stained blue, according to their pH [3,4]. However, disclosing solutions also stain surrounding areas, such as the soft and hard tissues inside and outside the mouth, causing discomfort for both the patient and practitioner. Quantitative light-induced fluorescence-digital, a new imaging technology which uses a digital camera, has been validated as a tool for visually detecting dental plaques [5,6]. Quantitative light-induced fluorescence-digital enables the evaluation of quantity and distribution of dental plaques by assessing the red fluorescence of endogenous porphyrin produced by oral bacteria, thereby saving time and reducing patient discomfort [7].

Plaque-scoring Indices are generally used to assess patients' oral hygiene and oral self-care status [1]. To utilize plaque scoring indices as objective measures, a certain standard of intra-rater and inter-rater agreement must be met [8]. In most studies that assessed the validity and reliability of plaque indices, the agreement of the results was assessed after one examiner repeatedly tested the same sample or two

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examiners assessed the same patient [5,6,9]. However, large-scale regional or national level epidemiological surveys [10,11] require a method with high reliability coefficient for multiple examiners for the assessment of oral hygiene.

Plaque scoring indices reportedly have a high agreement between clinical and photographic examinations by two examiners [12]. Achievement of high consistency among several examiners in the assessment of images from Q-ray cam (for quantitative light-induced fluorescence-digital imaging) and digital single-lens reflex camera of stained tooth surfaces might enable more efficient undertaking of large epidemiological studies and oral tests.

This study aimed to investigate the inter-rater agreement among several examiners in the assessment of Q-ray cam images of tooth surfaces and digital single-lens reflex camera images of tooth surfaces with dental plaque stained with a two-tone disclosing solution.

## 2. Materials and methods

### 2.1. Participants

Among the participants who participated in the dental hygiene training at S College between August 2017 and June 2018, those who consented to participate after having understood the purpose and methodology of this study were enrolled. The minimum sample size required was computed using the G*Power 3.1 program. At a significance level (α) of 0.05, power (1-β) of 0.8, and effect size of 0.5, the minimum sample size was computed to be 51; nonetheless, we increased the sample by 10% and recruited 56 participants. After screening the dental images of all 56 participants, the images of 30 participants were selected for testing the inter-rater agreement [13]; four teeth (upper central incisors and upper lateral incisors), which were the most clearly observed, were selected as the target teeth. The images of participants who underwent dental restoration procedures in the target teeth and poor-quality images of the target teeth were excluded.

The minimum sample size was computed for assessing the inter-rater agreement using the MedCalc program (type 1 error = 0.05, type 2 error = 0.20, correlation coefficient = 0.5). The computed sample size was 29. Assuming a 25% withdrawal rate, 40 examiners were selected. Twenty second-year dental hygiene students of S College and 20 registered dental hygienists were randomly selected, all of whom provided informed consent. The registered dental hygienists and dental hygiene students were divided into groups and were the examiners in this study for the assessment of inter-rater agreement. The mean clinical career of the registered dental hygienists was 4.65 years (1–10 years). Examiners independently assessed two types of images of 30 participants. This study was approved by the research ethics committee at S College (IRB2-7008167-AB-*N*-01-201706-HR-003-01).

### 2.2. Method

#### 2.2.1. Q-ray cam and digital single-lens reflex camera imaging

The target teeth were photographed using a Q-ray cam and a digital single-lens reflex camera. Q-ray cam (Co., AIOBIO, Seoul, Republic of Korea) imaging used the following parameters: Resolution (image size), full high-definition [1920*1080 pixels]; shutter speed, auto [1/30–1/30000 s]; aperture, Auto [F1.2–360]; sensor-object distance, 2.3Mpixel Image Sensor. Digital single-lens reflex camera (Nikon D, Tokyo, Japan) photography used the following imaging parameters: Resolution (image size), [S 2902*2000 pixels (6 megabyte)]; shutter speed, 1/160 s, aperture, F32; ISO, 200; White Balance, Auto; Magnification, 1:3; photography mode, manual; sensor-object distance, Nikon AF-S Micro NIKKOR 85 mm 1:3.5 G ED.

First, the Q-ray cam was connected to a desktop computer, and the cheek was retracted using a cheek retractor to take the photographs. Next, the dental plaque was stained with a two-tone disclosing solution and a photograph was taken with the digital single-lens reflex camera using the same method. The images were stored with a serial number instead of names to protect personal information.

#### 2.2.2. Inter-rater assessment method

Before assessment, all examiners were provided with a detailed test guideline. The guideline contained Q-ray cam images of tooth surfaces and digital single-lens reflex camera images of the same tooth surfaces stained with a two-tone disclosing solution. The boundaries of the test area of the target teeth were demarcated with dotted line to minimize unnecessary measurement error. If any dental plaque was observed in the test area, the examiners were instructed to mark 1 for yes.

Multiple examiners assessed plaque scoring indices from the two types of images obtained from the same 30 participants. The images were observed on a computer monitor (LG LED monitor, Seoul, Republic of Korea) with the following settings: Resolution (pixels in XY, VGA/HD/4 K/8 K), high-definition [1920*1080 pixels], size, 22 in.; contrast ratio, 1000:1 (DFC 5,000,000:1); back light source, Blue; lighting condition room, illuminated by a light-emitting diode. The area with dental plaque was assessed using the Patient Hygiene Performance index [14].

#### 2.2.3. Plaque scoring index

Inter-rater agreement was examined using the Patient Hygiene Performance index in this study. The Patient Hygiene Performance index is used to assess microbial biofilm by dividing a tooth surface longitudinally into the proximal, distal, and middle thirds, and again subdividing the middle third horizontally into the incisal, middle, and gingival thirds (Fig. 1) [14].

#### 2.2.4. Test using the Q-ray cam

The Q-ray cam guideline provided to the examiners, in accordance with the Patient Hygiene Performance index, instructed them to mark 1 if red fluorescence was observed on the divided segments of the test teeth and 0 if no red fluorescence was observed.

#### 2.2.5. Assessment with the two-tone disclosing solution

Two-tone disclosing solution stains dental plaques with two different colors according to the period of their generation [3,4]. Testing with the two-tone disclosing solution was performed 1 week after the Q-ray cam photography [5] (Fig. 2). The guideline provided to the examiners instructed them to mark 1 for red staining, 2 for blue staining, 3 for red and blue staining, and 0 for no staining on visual observation of the divided segments of the test teeth according to the Patient Hygiene Performance index (Fig. 3).

### 2.3. Statistical analyses

The null hypotheses of this study were as follows: First, the plaque scoring by multiple examiners will show a low inter-rater agreement for the assessment of Q-ray cam and digital single-lens reflex images. Second, 20 examiners of the registered dental hygienists group and 20 examiners from the dental hygiene students group will show different

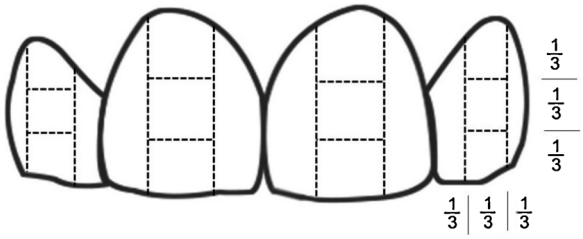


**Fig. 1.** Patient Hygiene Performance Index.
The Patient Hygiene Performance index is used to assess microbial film.

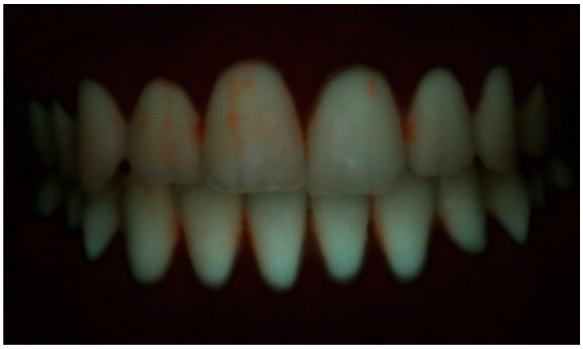

**Fig. 2.** Q-ray cam image.
Representative Q-ray cam images used in the assessment.

**Fig. 3.** Image of two-tone disclosing solution image.
Representative images of tooth surfaces stained with the two-tone disclosing solution used in the assessment.

inter-rater agreement for plaque scoring indices. Third, the two methods used to measure plaque scoring will differ in their inter-rater agreements.

The intra-class correlation coefficient was determined to evaluate the agreement among examiners and the test methods for examination of dental plaques. A two-way random effects model was used in which the examiners were considered as a random effect. An intra-class correlation coefficient of < 0.50 was defined as poor, 0.50–0.74 as moderate, 0.75–0.89 as good, and ≥0.90 as excellent, according to the criteria suggested by Portney and Watkins [15]. Measurements of Q-ray cam and digital single-lens reflex camera images were compared using Bland-Altman plot. Bland-Altman plots illustrate the differences in measurements graphically, and the inter-rater agreement is considered high if the difference values were clustered around the mean value. The intra-class correlation coefficient was analyzed using SPSS version 24 software (SPSS Inc., Chicago, IL, USA), and the exploratory graph was analyzed with MedCalc.

## 3. Results

### *3.1. Inter-rater agreement for the Patient Hygiene Performance Index using the Q-ray cam and two-tone disclosing solution*

The intra-class correlation coefficient and 95% confidence interval for assessing inter-rater agreement for dental plaque are as follows: Inter-rater agreement among the 40 examiners was excellent with an intra-class correlation coefficient of 0.990 (95% confidence interval: 0.984–0.994) when the Q-ray cam was used. The intra-class correlation coefficient for the registered dental hygienists group was 0.987 (95% confidence interval: 0.979–0.993) and that for the dental hygiene students group was 0.980 (95% confidence interval: 0.968–0.989) (Table 1).

Agreement among the 40 examiners for images with digital single-lens reflex camera after two-tone disclosing solution staining for dental plaques was also excellent with an intra-class correlation coefficient of 0.992 (95% confidence interval: 0.987–0.996) (Table 2).

**Table 1**
Agreement of Patient Hygiene Performance Index using the Q-ray cam.

| | | Q-ray cam | |
|---|---|---|---|
| Group | N | ICC | 95% CI |
| RDH | 20 | 0.987 | 0.979-0.993 |
| DHS | 20 | 0.980 | 0.968-0.989 |
| Entire | 40 | 0.990 | 0.984-0.994 |

RDH, registered dental hygienist; DHS, dental hygienist student; ICC, intra-class correlation coefficient; CI, confidence interval.

**Table 2**
Agreement of Patient Hygiene Performance Index using DSLR images with two-tone disclosing solution.

| | | Disclosing solution | | Red | | Blue | |
|---|---|---|---|---|---|---|---|
| Group | N | ICC | 95% CI | ICC | 95% CI | ICC | 95% CI |
| RDH | 20 | 0.988 | 0.981-0.994 | 0.980 | 0.969-0.989 | 0.986 | 0.977-0.992 |
| DHS | 20 | 0.979 | 0.967-0.989 | 0.962 | 0.940-0.979 | 0.974 | 0.958-0.986 |
| Entire | 40 | 0.992 | 0.987-0.996 | 0.985 | 0.976-0.992 | 0.990 | 0.984-0.994 |

RDH, registered dental hygienist; DHS, dental hygienist student; ICC, intra-class correlation coefficient; CI, confidence interval.

To graphically compare the Patient Hygiene Performance indices measured using the Q-ray cam and digital single-lens reflex camera, the Bland-Altman plots of dental hygienists and dental hygiene students groups were compared. The results indicated high agreement between the two groups as the difference values clustered around the mean of the two groups (Fig. 4).

### *3.2. Comparison of methods for the Patient Hygiene Performance Index using the Q-ray cam and two-tone disclosing solution*

The intra-class correlation coefficient and 95% confidence interval for assessing method comparison for dental plaque are shown in Table 3.

To graphically compare the Patient Hygiene Performance indices measured using the Q-ray cam and digital single-lens reflex camera, the Bland-Altman plots of dental hygienists and dental hygiene students groups were compared. The results indicated high agreement between the two measurement methods as the difference values clustered around the mean of the two measurements (Fig. 5).

## 4. Discussion

Most plaque examination methods use fluorescent dyes or disclosing agents to distinguish plaque from the tooth; however, the quantitative light-induced fluorescence-digital does not need any additional disclosing procedure [7]. Therefore, it is suitable for use in patients fitted with orthodontic appliances or in those who underwent dental restorations and are concerned about discoloration [16,17].

Evaluation of measurement errors is a process to examine the validity of measured values in a clinical study [18] A study is deemed significant if it has an inter-rater agreement of ≥0.75 [15]. In studies that evaluated the intra-examiner reliability of plaque scoring indices by quantitative light-induced fluorescence-digital, the inter-class correlation coefficient of 1 or 2 examiners was 0.823 [5] and 0.995 [6], which showed a high level of intra-examiner reliability; moreover, the inter-examiner reliability was 0.980, which was considered high. Additionally, the intra-examiner reliability of plaque score evaluated by the two-tone disclosing solution method was 0.952 [6].

This study selected 40 examiners, which is considered large for an epidemiological study [13]. According to our results, there was

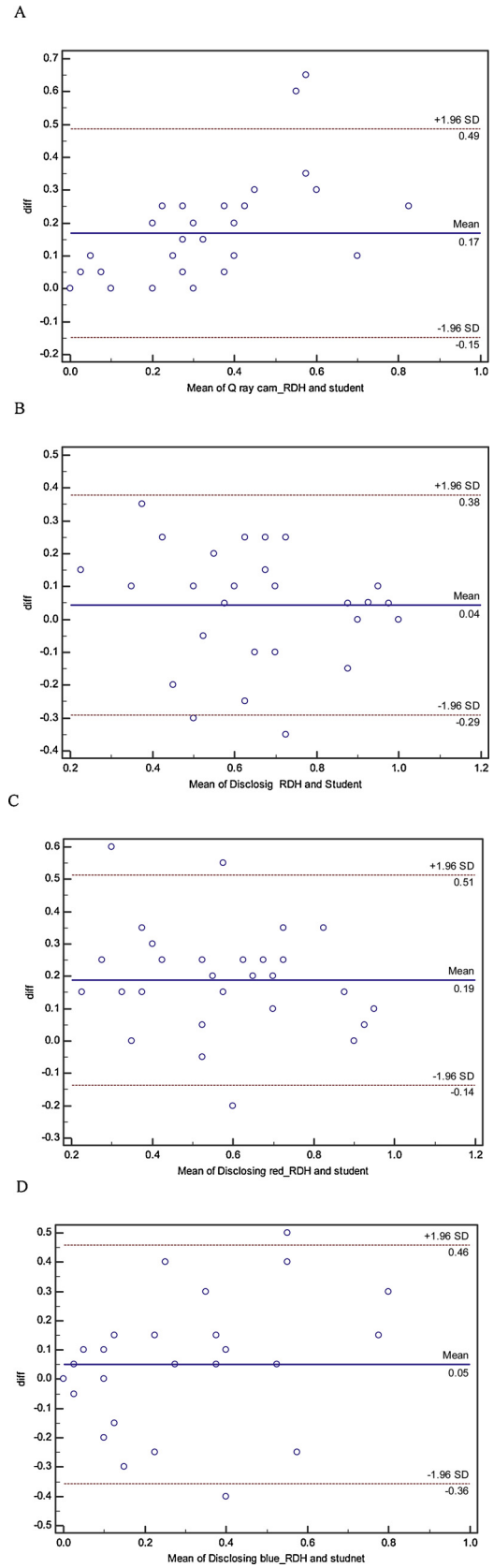


**Fig. 4.** Bland-Altman plot of the Patient Hygiene Performance Index agreement between the registered dental hygienist and dental hygiene student groups.
The difference values were clustered around the mean of the two measurements. (A) Q-ray cam; (B) Two-tone disclosing solution; (C) Red disclosing solution; (D) Blue disclosing solution.

**Table 3**
Agreement of Patient Hygiene Performance Index using Q-Ray Cam and DSLR images with two-tone disclosing solution.

| | | Q-ray cam and Disclosing solution | |
|---|---|---|---|
| Group | N | ICC | 95% CI |
| RDH | 20 | 0.961 | 0.935-0.976 |
| DHS | 20 | 0.955 | 0.949-0.960 |
| Entire | 40 | 0.978 | 0.976-0.981 |

RDH, registered dental hygienist; DHS, dental hygienist student; ICC, intra-class correlation coefficient; CI, confidence interval.

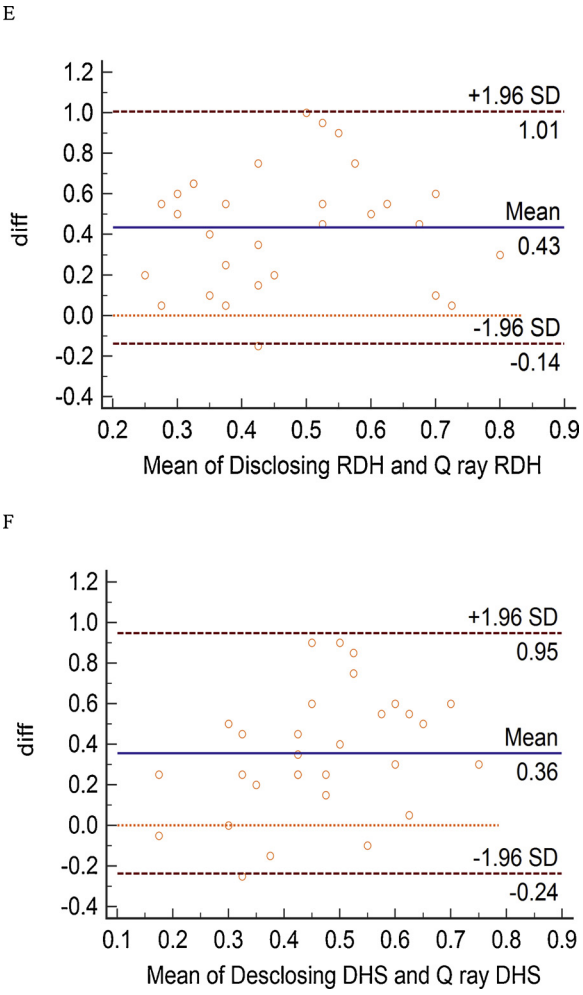


**Fig. 5.** Bland-Altman plot of the Patient Hygiene Performance Index agreement between the Q-ray cam and digital single-lens reflex camera.
The difference values were clustered around the mean of the two measurements. (E) Registered dental hygienist group; (F) Dental hygiene student group.

excellent agreement for the Patient Hygiene Performance indices measured using images from Q-ray cam and digital single-lens reflex camera among 20 examiners each in the registered dental hygienists and dental hygiene students groups (Table 1). In addition, there was excellent agreement among the 40 examiners of the registered dental hygienist and dental hygiene student groups (Tables 1 and 2). Additionally, we found excellent agreement among 20 relatively skilled examiners of the registered dental hygienist group and 20 examiners of the dental hygiene student group. These results were congruent to that reported by Shaloub and Addy [19] who examined inter-rater agreement for plaque area among 15 examiners for eight patients, wherein the results were similar among more experienced examiners and less experienced or inexperienced examiners.

Previous studies which compared the use of quantitative light-induced fluorescence-digital and disclosing solution reported significant positive correlation between the plaque scoring indices by 1 or 2 examiners with quantitative light-induced fluorescence-digital and the plaque scores assessed by disclosing solution [20,21]. In addition, another study reported a significant correlation between the plaque scores measured across the surface of all maxillary and mandibular teeth with quantitative light-induced fluorescence-digital and Patient Hygiene Performance index [22]. Although the examiners in previous studies directly examined patients' oral cavity, this study is meaningful because a high agreement was found in the results of assessment of Q-ray cam and digital single-lens reflex camera images of stained dental plaques by multiple examiners.

Multiple examiners in this study showed a high level of inter-rater agreement only with image-based remote radiation. Moreover, this method reduces the time and cost needed to evaluate plaque scoring and can also be used regardless of the location of the tooth or the number of participants. In addition, this study confirmed that Patient Hygiene Performance indices measured using Q-ray cam images have excellent consistency, irrespective of the examiners' experience and skills. Although inter-rater agreement is usually calibrated during the training of assessors in a clinical study [23], this study confirmed high agreement despite the use of a written guideline summarizing the criteria and images instead of directly performing the calibration.

However, this study has the following limitation. The inter-rater agreement was only evaluated for four upper anterior teeth because of various imaging limitations. Nevertheless, the assessment method described herein can probably be applied to other teeth by adjusting the photography conditions, according to the requirements of the study or survey. In future, the use of technology which will accurately photograph the entire tooth surface, with provisions for data transfer, would enable more efficient use of this method.

## 5. Conclusion

This study was high agreement in the assessment of Q-ray cam images and digital single-lens reflex camera images of stained dental plaque by multiple examiners, confirming that the two methods are validated both independently and with high mutual agreement.

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## Declaration of Competing Interest

The authors declare that there are no conflicts of interests.

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