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Quantitative evaluation of fluorescence intensity according to degree of occlusal tooth wear using QLF

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Quantitative evaluation of fluorescence intensity according to degree of occlusal tooth wear using QLF

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Abstract

Quantitative evaluation of fluorescence intensity according to degree of occlusal tooth wear using QLF

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As the quality of life improves and life expectancy increases, the number of teeth retained by the elderly population is increasing. Since tooth wear is irreversible over a lifetime, the prevalence of tooth wear increases with age. Tooth wear has become a common symptom in all ages and is becoming an important issue to be managed early on in order to maintain healthy dentition over the long term. However, tooth wear is symptomless and it is already late when patients feel it. Therefore, it is important to prevent the pathological wear before it progresses. The method of evaluating the degree of tooth

wear has been mainly used to calculate the index according to the visual characteristics. Widely used methods in dentistry are Smith and Knight's Tooth wear index (TWI). Various indices that indicate the degree of wear have been newly developed and supplemented, but there has been no significant change in the fact that index values are subjective. When measuring wear while looking directly at the teeth, there is a risk that the measurement results will vary depending on the subjective opinion of the evaluator. Quantitative light-induced fluorescence (QLF) is a typical optical technology for detecting auto fluorescence in teeth using light at a wavelength of 405 nm. When QLF is applied to the tooth, normal enamel emits green fluorescence, but in dentin it emits brighter fluorescence than enamel. The purpose of this study is to evaluate the physical properties of human teeth with real abrasion.

In this study, dental collections were performed on patients aged 20 years or older who visited Yonsei University College of Dentistry. A total of 102 teeth were used in this study among the collected teeth by selecting only those teeth that were not exposed to dental caries, restorations and dimensions. A total of 102 tooth specimens were numbered and tooth wear index (TWI) was measured from 0 to 3 for each tooth. To evaluate the dentin exposure of teeth used in this study, swept-source optical coherence tomography (SS-OCT) system was used. For fluorescence studies to be used in this study, all specimens were placed so that the tooth occlusion plane was level with the ground, and then the QLF-D was placed perpendicular to the occlusal plane. All photographed images were quantitatively calculated using software. All fluorescence images were converted to 8-bit grayscale images. In order to calculate the difference in the degree of abrasion relative to

the normal region of each tooth, the difference between the most abrasive region and the normal region on the occlusal surface of each tooth was calculated as a percentage (ΔG).

When assessing the reliability of the 5 examiners for examination of visual tooth wear index, QLF tooth wear index (QTWI) showed 0.743 of intra-examiner reliability and 0.778 of inter-examiner reliability, which are substantial agreement. However, Kappa values of conventional TWI showed 0.695 of intra-examiner reliability and 0.545 of inter-examiner reliability, which are over moderate agreement but lower than those of QTWI.

When tooth wear was divided into TWI values from 0 to 3, the intensity of fluorescence increased significantly as the degree of wear increased. The change in fluorescence intensity (ΔG) at the abrasion site showed a strong positive correlation with the degree of abrasion according to TWI ($\rho = 0.77$, $P < 0.001$). When the actual dentin exposure of the abraded teeth was evaluated by OCT, the fluorescence intensity of the abraded area compared to the normal area was increased as the dentin was exposed ($P < 0.001$).

As a result, it was confirmed that the intensity of fluorescence expressed in the teeth increases with increasing wear. The results of the study confirmed the possibility of QLF technology as an evaluation tool of tooth wear. If clinical validity is confirmed at a later date, QLF technology can be used as a promising tool to objectively evaluate and monitor wear.

Keywords: tooth wear, diagnosis of tooth wear, auto fluorescence of tooth, quantitative light-induced fluorescence (QLF)

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Ⅰ. INTRODUCTION

Dental attrition is the loss of tooth surface slowly over a long period of time due to friction caused by continuous contact with opposing teeth or other dental materials, which is different from loss of tooth tissue caused by caries or trauma. Tooth wear can be classified into attrition, abrasion, and erosion according to the physical and chemical factors acting on the teeth (Hattab and Yassin, 2000). Among these, attrition is caused by the physical contact and friction of the structure of the oral cavity such as bruxism, clenching and chewing. There is a feature that a flat facet is formed on the occlusal surface, or the enamel surface or cusp is fractured. On the other hand, abrasion shows a state of being worn by physical factors caused by external substances such as chewing of rough foods, nail biting, brushing, prosthesis, etc. Abrasion is observed in the notch of the worn enamel area. Occurrence occurs differently depending on the cause. In the case of abrasion caused by ingestion of rough foods, exposed dentin dents are observed in a wide range of dentitions, and in some dentitions, when abrasion is observed, abutment teeth of abraded teeth are often restored with stronger restorations. Incorrect brushing also results in a dented area of the cervical area (Addy and Shellis, 2006). Erosion means that the surface of the tooth is damaged due to corrosion by acidic external chemical factors. As the intake of acidic foods and carbonated beverages increases, erosion also increases, which is characterized by flattening and smoothing as the teeth lose their original shape (Kaidonis, 2012; Lussi, et al., 2006).

As quality of life improves and life expectancy increases, efforts to keep your natural teeth as long as possible have increased the number of teeth in the elderly population (Lee, et al., 2012; Smith and Knight, 1984). Since tooth wear is irreversible over a lifetime, the prevalence of tooth wear increases with age (Van't Spijker, et al., 2009; Wetselaar, et al., 2016). Therefore, abraded teeth occupy a large part in the retained teeth of the elderly population, and this ratio will continue to increase (Donachie and Walls, 1995). In recent years, the intake of acidic foods and changes in dietary culture have also increased the incidence of tooth wear in children and adolescents over age (Sirimaharaj, et al., 2002). In addition, bruxism and clenching due to emotional states such as stress and anxiety in modern society are also affecting the increase of tooth wear incidence in young group (Tsiggos, et al., 2008). In conclusion, tooth wear has become a common symptom in all ages and has become an important issue to be managed early to maintain healthy dentition over the long term.

The tooth wear goes to the stage of life-long physiological phenomenon, or pathological wear where the patient becomes uncomfortable and painful when the degree becomes worse (Hattab and Yassin, 2000). At this time, the dentin of the tooth is exposed, and the chewing sensation is felt, and the cusp is lost and the chewing efficiency is lowered. In addition, the length of the crown is reduced, which causes various inconveniences, accompanied by a decrease in vertical dimension during occlusion. However, tooth wear is symptomless and it is already late when you feel it. (Banerji and Mehta, 2016). Restorative treatment is needed to restore irreversibly worn teeth, but this does not directly remove the cause of wear and can lead to various complications depending on various factors (Mehta, et al., 2012). Therefore, it is important to identify and prevent risk factors before pathological wear (Lussi and Carvalho, 2014).

The method of evaluating the degree of tooth wear has been mainly used to calculate the index according to the visual characteristics. This qualitative tooth wear index (TWI) is based on clinical features such as the degree of abrasion of enamel, residual enamel, and dentin exposure (Lopez-Frias, et al., 2012). Widely used methods in dentistry are Smith and Knight's Tooth wear index (TWI). This is a way to classify the degree of wear in five grades with the degree of wear of the enamel, the exposure of the dentin, and the degree of wear of the teeth. Basic erosive wear examination(BEWE) (Bartlett, et al., 2008) was used to evaluate abrasion due to corrosion. Tooth wear evaluation (TWES) (Wetselaar and Lobbezoo, 2016) proposed by Wetselaar was used to complement the Smith and Knight method for evaluating wear through crown length measurement. In addition, studies using various existing TWI methods have been actively conducted (Bardsley, 2008).

Various indices that indicate the degree of wear have been newly developed and supplemented, but there has been no significant change in the fact that index values are subjective. To date, a large number of studies have measured tooth wear as a method of directly observing a patient's teeth with eyes, a method of evaluating photographs taken in the oral cavity, a method of casting with the impression of a tooth, and a casting method (Mehta, et al., 2012). However, when measuring wear while looking directly at the teeth, there is a risk that the measurement results will vary depending on the subjective opinion of the evaluator (Paesani, et al., 2014). In addition, even if the patient presents a numerical value of tooth wear, the patient has difficulty in accurately grasping his or her condition through qualitative numerical value. In the case of photographs taken in the oral cavity, the patient can identify his or her mouth, but there is a limit to understanding the degree of wear of the enamel or the degree of exposure of the dentin through the photograph. In addition, casting causes inconvenience to the patient because the impression should be made, and it is difficult to accurately assess the dentin exposure because cast color does not distinguish the color of the teeth.(Paesani, et al., 2014).

In order to overcome the limitations of existing qualitative methods, a variety of objective wear assessment methods have been continuously studied and developed (Al-Omiri, et al., 2010). Such methods include OCT, profilometry, CAD / CAM, radiation, and ultrasound (Ahmed, et al., 2017; Algarni, et al., 2016; Ganss, et al., 2000; Sindi, et al., 2015). Optical coherence tomography (OCT) is a non-destructive optical method for observing tomography of human tissue, and is widely used in the field of dentistry. This technology is capable of observing the internal structure by the scattering signal in the tissue when the light is irradiated in the near infrared region (Jones, et al., 2006). Therefore, the shape of the enamel and the dentin exposure can be confirmed. However, it is difficult to observe if there is a crack in the teeth, and there are insufficient disadvantages in understanding the wide penetration depth structure. There are also factors to overcome such as time consuming, high cost, low image resolution (Hsieh, et al., 2013). And other methods also have problems such as time consuming, high cost, low image resolution.

On the other hand, many researches have been conducted to objectively evaluate the condition of teeth using the fluorescence characteristic of teeth in the dental field (Walsh and Shakibaie, 2007). The teeth exhibit different fluorescence depending on the type and condition of the tissue, and dentin in particular emits brighter fluorescence than enamel (Hartles and Leaver, 1953). Quantitative light-induced fluorescence (QLF) is a typical optical technology for detecting autofluorescence in teeth using light at 405 nm wavelength (Heinrich-Weltzien, et al., 2003). When the blue visible light of this technology is irradiated on the teeth, normal enamel expresses green autofluorescence, but fluorescence changes are present in the lesion or in other parts. Previous studies have reported that as the wear of the enamel layer of the occlusal surface increases, the fluorescence that is expressed increases (Kim, et al., 2017). However, previous studies have evaluated the artificially formed wear in a controlled environment, and no studies have evaluated the fluorescence properties of teeth with actual wear. Therefore, this study aims to evaluate the fluorescence properties of human teeth with real abrasion.

Since QLF technology can evaluate the difference of autofluorescence in enamel and dentin, it is expected to be used as an objective measurement tool of tooth wear.

The purpose of this study was to classify human teeth with real abrasion according to the existing tooth wear classification method and to evaluate their respective fluorescent properties.

In addition, this study quantitatively evaluates the fluorescence intensities of the areas where wear is suspected on the occlusal surfaces of the teeth, to confirm the difference of autofluorescence by wear depth and to confirm the feasibility of QLF technology as a differential diagnosis tool of tooth wear.

Ⅱ. MATERIALS AND METHODS

2.1. Research materials

2.1.1. Collection of teeth

Prior to using the extracted tooth, we received the approval of the study (IRB No. 2-2015-0032) from the Institutional Review Board for Clinical Research of the Yonsei Dental Hospital, Yonsei University. Tooth collection was performed on patients aged 20 years or older who visited Yonsei University College of Dentistry. Patients were instructed on the purpose of the study and on the method of study prior to extraction. The teeth were collected from participants who signed voluntary participation and signed the agreement.

A total of 102 teeth were used in this study among the collected teeth, only the teeth without dental caries, restorations, and pulp exposures were selected. Immediately after removal of the teeth, the residual tissue and other attachments around the teeth were removed with a manual scaler, and toothbrushes. Prior to the preparation of the specimens, frozen samples were stored at -20 ° C (Francescut, et al., 2006).

2.1.2. Preparation of tooth samples

In order to equalize the height of the tooth specimen to be used in the study, 1.5 cm was measured from the highest point of the occlusal cusp of the tooth, and the root area exceeding 1.5 cm is cut by a diamond discs (NTI-Kahla GmbH, Germany) and low speed handpieces (Lasungmedice, Korea). In order to fix the cut tooth horizontally to the ground, the tooth root was placed in an acrylic block (20 × 12 × 8 mm) using a resin for orthodontic appliance (Ortho-Jet, Land Dental Mfg. Co., Inc., USA). The remaining resin residue in the polymerization process and the root protruding beneath the acrylic block were removed by polishing the bottom of the acrylic block using 400 grit of abrasive paper (SiC Sand Paper, R & B Inc., Daejeon, Korea).

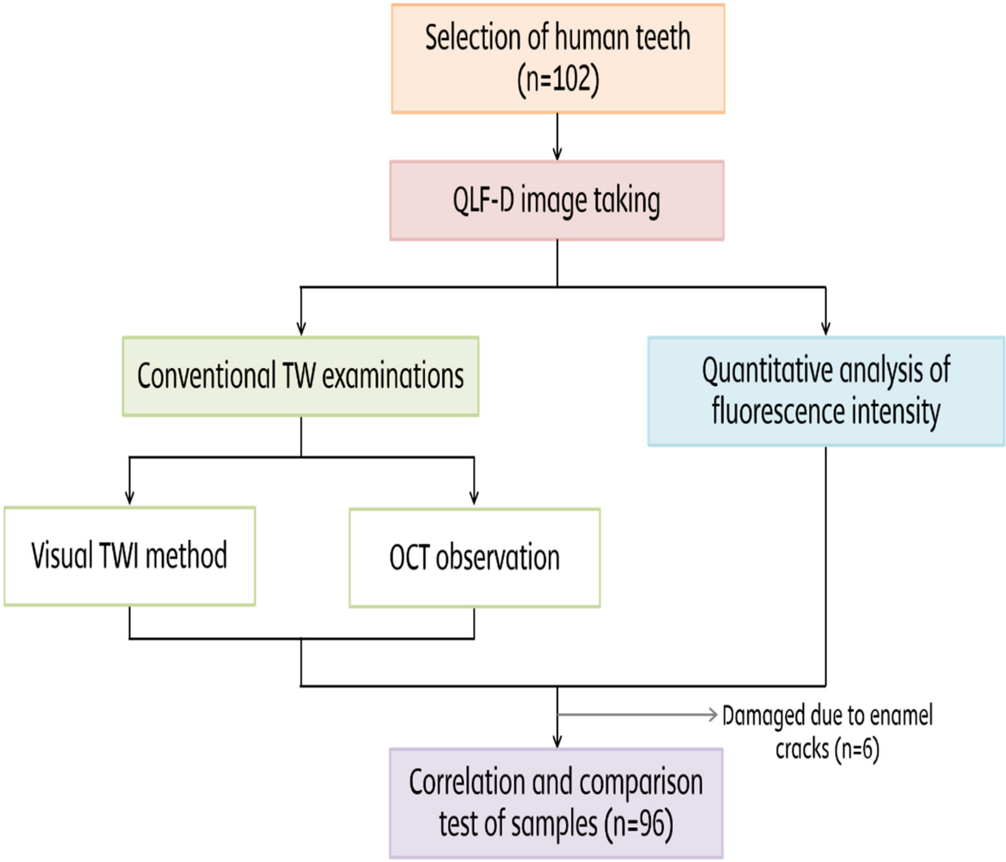

Figure 1. Flow chart of study procedure

2.1.3. Acquisition of QLF images

For the fluorescence studies to be used in this study, white light and fluorescence images of all specimens were used with QLF-D (Biluminator ™, Inspektor Research Systems BV, Amsterdam, The Netherlands). The images were taken using separate software (C3 v1.25, Inspektor Research Systems BV, Amsterdam, The Netherlands) included with the QLF system. The camera was set to the shooting conditions shown in Table 1, and images were taken without the external light according to the manufacturer's recommendation. At this time, the teeth were placed so that the occlusal surface was level with the ground, and then the QLF-D was placed perpendicular to the occlusal surface (Figure 2).

Table 1. Image acquisitioning condition of QLF-D

	White-light	Fluorescent-light
Shutter speed	1/60 s	1/50 s
Aperture value	11.0	9.5
ISO speed	1600	1600
Pixel size	2592×1728	2592×1728

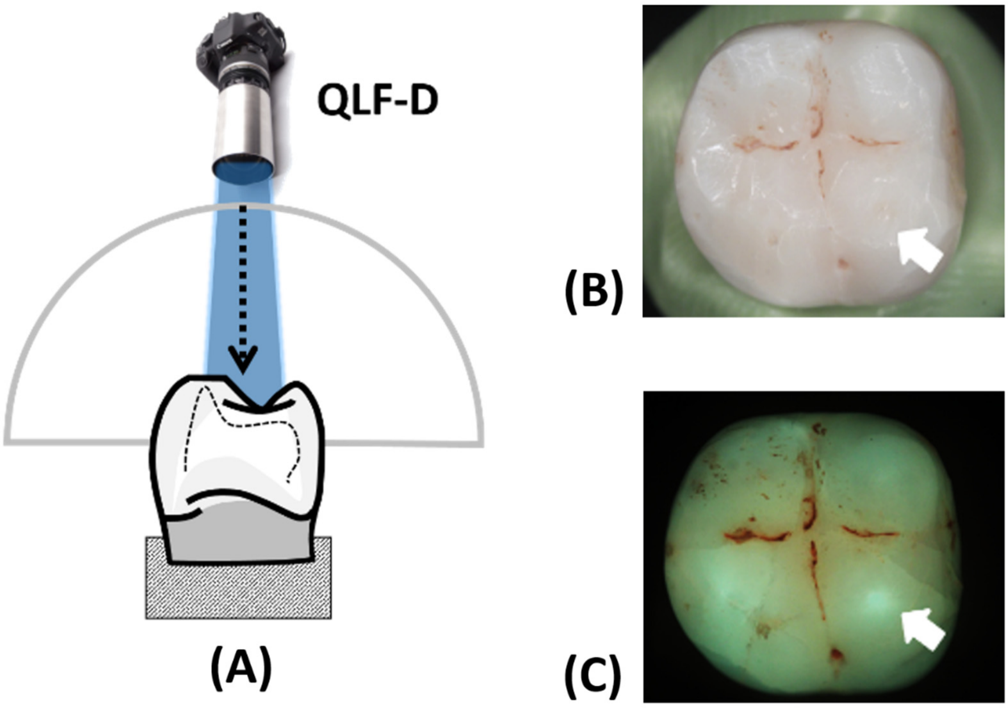

Figure 2. QLF-D image taking position (A) and the obtained images taken under different lights (B: White-light, C: Fluorescent-light)

2.2. Visual examinations of tooth wear (TW)

2.2.1. Conventional tooth wear index (TWI)

Prior to the evaluation of this study, an arbitrary identification number was assigned to a total of 102 tooth specimens, and the evaluator randomly selected the tooth specimens for the evaluation. The tooth wear index (TWI) of Smith and Knight, which is traditionally used as a gold standard in tooth wear testing, was used (Smith and Knight., 1984). The evaluator read the preceding article on TWI prior to the evaluation and conducted the evaluation after several repetitions and the reproducibility (Cohen's Kappa) of the evaluation became over 0.8. In this study, only teeth with a TWI code of less than 4 were evaluated because pulp exposed teeth were excluded. Since only the occlusal wear was measured, codes were assigned to each tooth according to Smith and Knight's criteria for occlusal surface description (Table 2).

To investigate the reliability of conventional criteria, a total of 5 dentists participated the study examination. Before the assessment, the examiners got instruction on the study flow and the conventional TWI method. In the main assessment, the examiners conducted the evaluation twice time for calculating the intra-examiner reliability.

Table 2. Tooth wear index (TWI) from Smith and Knight about descriptions of only occlusal aspects

Code	Extent	Description
0	No evidence of wear	No loss of enamel surface characteristics
1	Enamel wear	Loss of enamel surface characteristics
2	Dentine wear	Loss of enamel exposing dentine for less than one-third of the surface
3		Complete loss of enamel, or exposure of secondary dentine

2.2.2. Fluorescent tooth wear assessment

After completion of conventional TWI examination, each examiner assessed fluorescent images of tooth wear. All examiners took the instruction of the principle of QLF technology and fluorescence properties of worn teeth before the examination. The QLF tooth wear index (QTWI) was used on this assessment session. The classification criteria focused on both wear faucets on white-light images and bright fluorescence on fluorescent-light images (Figure 3). The examiners firstly saw the occlusal surfaces of tooth samples, then compared the QLF images and made a decision of QTWI codes.

QTWI (QLF tooth wear index)

Code 0 **Sound**	• Fluorescence of cusp is same as surroundings
If wear facets of enamel surfaces appear on white images or visual inspection, move to over code 0 and observe the fluorescence changes on fluorescence images	
Code 1 **Initial wear**	• **Slightly brighter** fluorescence **limited to cuspal areas**
Code 2 **Moderate wear**	• **Clear fluorescence changes** appearing **a strongly brighter** in or over cuspal areas with **imprecise margin of facets and no cusp discoloration**
Code 3 **Advanced wear**	• **Strong bright** fluorescence **with distinct margin of facets and cusp discoloration**

* Dot lines represent wear facets of enamel surfaces and arrows represent worn areas according to each wear facets

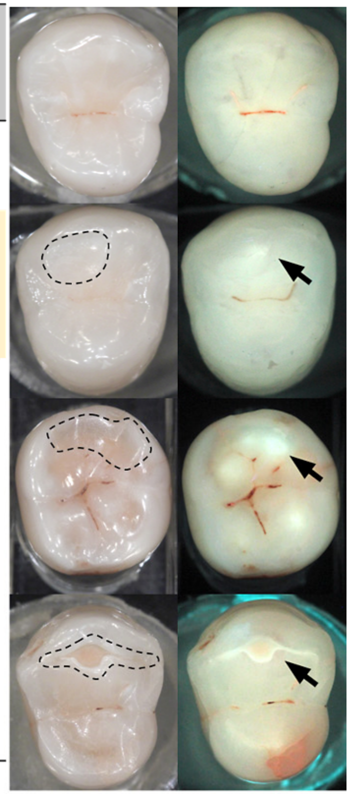

Figure 3. Newly developed QLF tooth wear index (QTWI) descriptions using fluorescence changes on occlusal aspects

2.3. Histological evaluation using optical coherence tomography (OCT)

To evaluate the dentin exposure of teeth used in this study, a swept-source optical coherence tomography (SS-OCT) system (prototype, LG Electronics, Seoul, Republic of Korea) with Santec HSL-20-100L laser ; center wavelength 1,310 ± 50 nm) (Figure 4). After positioning the tooth specimen perpendicular to the OCT probe, the probe was continuously moved from the mesial to distal part of the tooth specimen and the tooth section was continuously observed. The distance between the enamel surface and the dentinoenamel junction (DEJ) was observed. When the enamel surface is thinnest, dentin exposure was judged in the images observed.

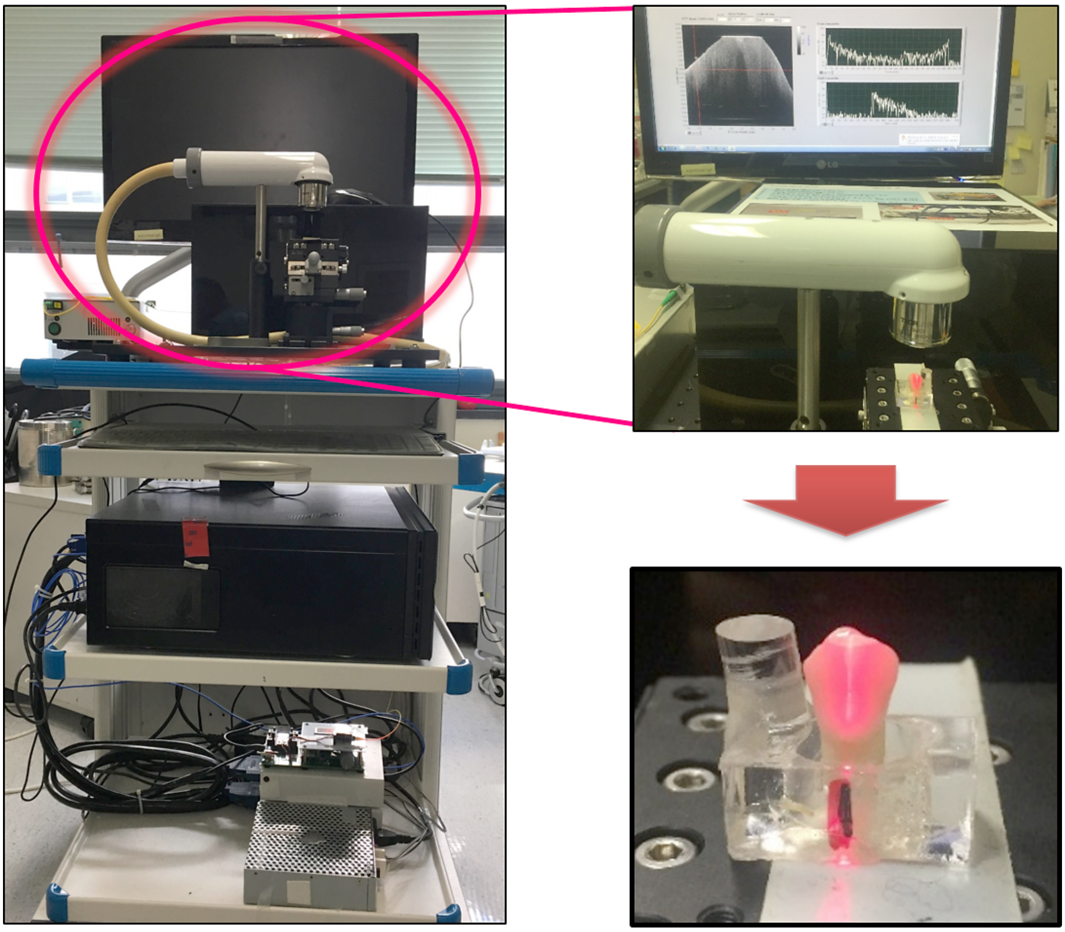

Figure 4. Swept source optical coherence tomography (SS-OCT)

2.4. Quantitative analysis of fluorescence intensity

All photographed images were quantitatively calculated using software (ImageJ v1.51o, National Institutes of Health, NIH, Bethesda, MD, USA). All fluorescence images were converted to 8-bit grayscale images to analyze fluorescence intensity at the grayscale level. The area of interest (AOI) was defined as the area of wear (AOI_{worn}) and the region of normal structure (AOI_{sound}) around the wear area in the white light image. The stored patch was applied to 8-bit grayscale images and the maximum grayscale values of AOI_{worn} (G_{worn}) and AOI_{sound} (G_{sound}) were calculated (Figure 5). The difference (ΔG) of fluorescence intensity was calculated by substituting the following equation to calculate the difference in the degree of wear compared to the normal region of each tooth by percentage.

$$\Delta G\ (\%) = \frac{G_{worn} - G_{sound}}{G_{sound}} \times 100$$

- ΔG = difference of grayscale between worn and sound area
- G_{worn} = maximum grayscale of worn area (AOI_{worn})
- G_{sound} = maximum grayscale of sound area (AOI_{sound})

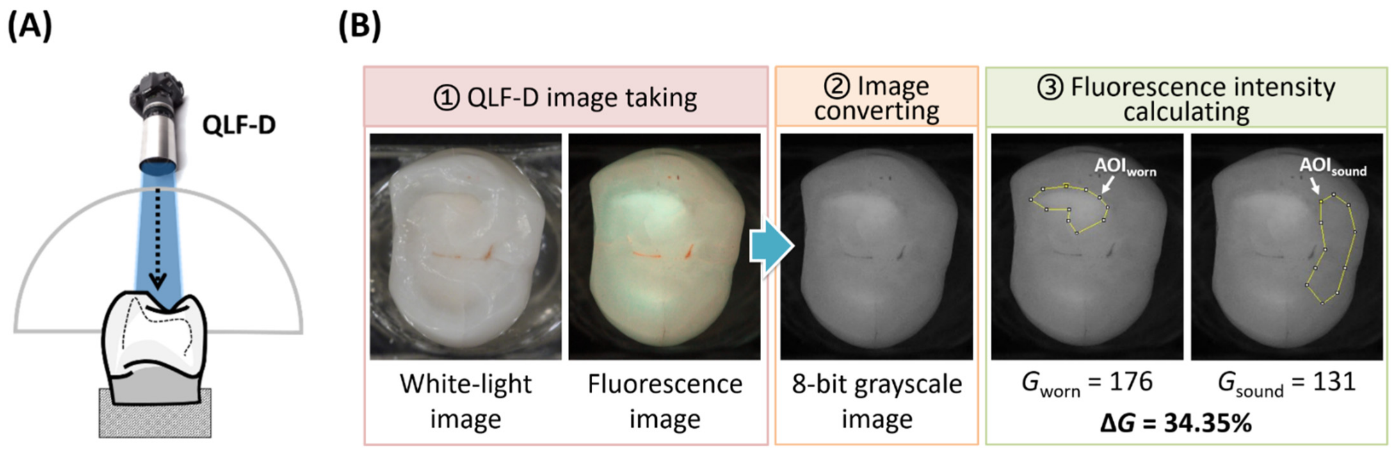

Figure 5. Fluorescent image processing to calculate the ΔG value and representative images of each step (A) a quantitative light-induced fluorescence-digital (QLF-D) and (B) quantitative analysis process. AOI, area of interest; G_{worn}, the maximum grayscale value in the worn area; G_{sound}; the maximum grayscale value in the sound area; ΔG, the difference in the fluorescence intensity between worn and sound area.

2.5. Statistical analysis

Statistical analysis was performed using a statistical package for the social science version 23.0 (SPSS Inc., Chicago, IL, USA) at a significance level of 0.05.

Prior to the statistical analysis, the gold standard was used to evaluate the dentin exposure assessed by TWI and OCT performed by the prospective evaluation. For the calculation of inter- and intra-examiner reliability, Cohen’s Kappa test was used. The Kruskal-Wallis test was performed to determine the significance of the fluorescence intensity variable according to TWI. The difference in fluorescence intensity according to dentin exposure was confirmed using the Mann-Whitney test. The correlation between the depth of tooth wear and fluorescence was calculated by Spearman's rank correlation test.

Ⅲ. RESULTS

Of the 102 teeth used in this study, a total of 96 teeth (55 molars and 41 premolars) were used for final analysis. Six teeth that were not able to obtain the image of the cut surface due to the cracking of the tooth enamel during OCT were excluded.

3.1. Visual examinations of tooth wear (TW)

3.1.1. Visual tooth wear index (TWI)

The tooth wear index of Smith and Knight was used to evaluate the entire tooth. As a result, there were 13 normal code 0 teeth, 40 code 1 teeth (enamel wear), 35 code 2 teeth (dentin exposure less than 1/3 of occlusal surface), and 8 code 3 teeth (dentin exposure more than 1/3 of occlusal surface) (Table 3). This result was used for a gold standard on reliability test.

Table 3. Distribution of worn tooth examined using conventional methods

Type of wear from OCT results	Tooth wear index				
	Code 0	Code 1	Code 2	Code 3	Total
Dentine unexposed teeth	13	39	5	-	57
Dentine exposed teeth	-	1	30	8	39
Total	0	40	35	8	96

3.1.2. Reliability of tooth wear classification

Comparing the gold standard, Cohen's kappa values of conventional TWI and QTWI were obtained. The result showed that both intra- and inter-examiner reliability values of QTWI were higher than those of conventional TWI (Table 4). Mean intra-reliability of QTWI was 0.745 and higher than conventional TWI (0.695). However both of them showed substantial agreement. In terms of inter-examiner reliability, Kappa value of QTWI (0.778) was also higher than conventional TWI (0.545). QTWI showed substantial agreement, on the other hand, conventional TWI was moderate agreement.

Table 4. Intra- and inter-examiner reliability values of conventional TWI and QTWI

Type of reliability	N	Type of assessment	
		Conventional TWI	QTWI
Intra - examiner reliability	5	0.695 (0.113)	0.743 (0.055)
Inter - examiner reliability	5	0.545 (0.141)	0.778 (0.063)

All data is mean value (standard deviation)

3.1.3. Optical coherence tomography (OCT) observation

The dental specimens were divided into 57 dentine unexposed teeth and 39 dentine exposed teeth in the optic section of OCT. In TWI results, one of the 40 teeth evaluated as code 1 was actually exposed to dentin, whereas 5 of 35 code 2 teeth were not exposed to dentin (Table 3, Figure 6).

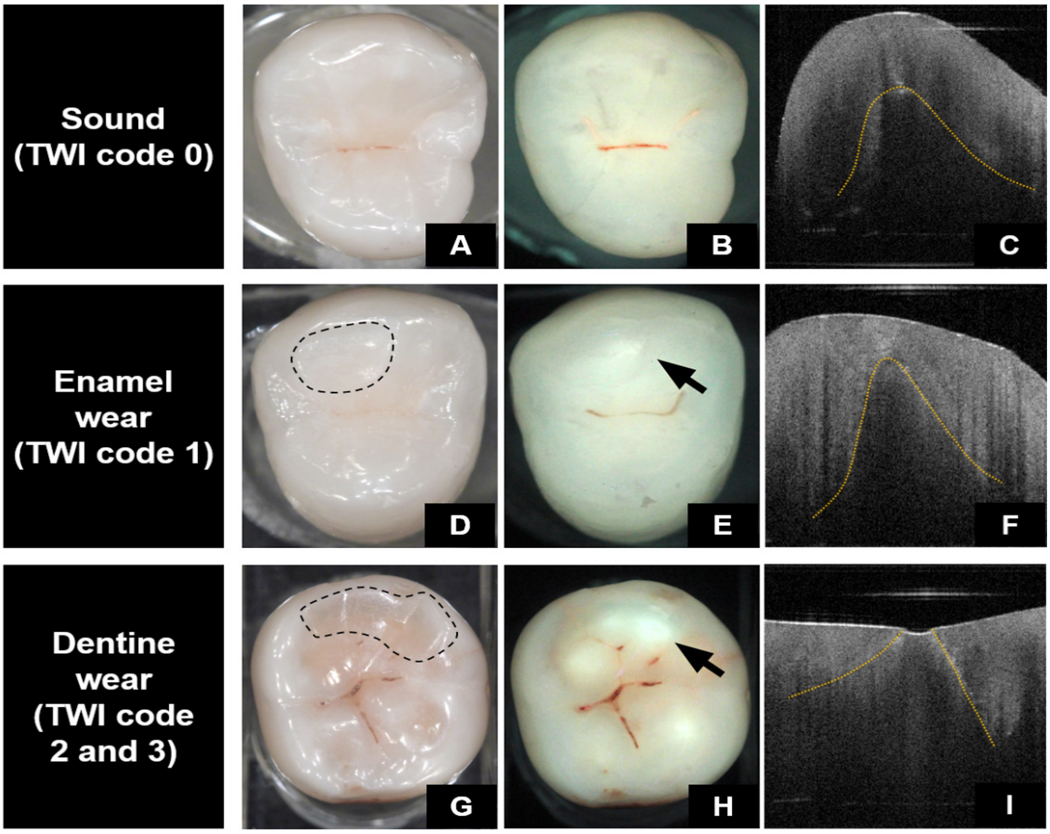

Figure 6. Representative images of tooth wear under white-light of QLF-D (A, D, G) and blue-light illumination (B, E, H), and the respective OCT images (C, F, I). Dashed line and arrow indicate the wear faucet and the AOI, and dotted line represents the dentinoenamel junction (DEJ).

3.2 Quantitative analysis of fluorescence intensity

3.2.1. The change in fluorescence intensity according to TWI

When tooth wear was classified by depth in TWI, the intensity of fluorescence increased significantly with increasing depth of wear (Figure 7, Table 5). The change in fluorescence intensity (ΔG) at the abrasion site showed a strong positive correlation with the depth of abrasion according to TWI ($\rho = 0.77$, $P < 0.001$). In the case of the teeth classified as code 0, ΔG of the suspected wear area increased by 5.38% at maximum compared with the surrounding normal area. The ΔG of the enamel worn teeth (code 1) was 13.29%, which was significantly different from code 0 ($P < 0.001$). The fluorescence intensities of the dentin abrasive codes, code 2 and code 3, increased by 29.23% and 44.40%, respectively, and their ΔG values were significantly higher than those of code 0 and code 1, which had enamel. However, there was no significant difference in fluorescence intensity between code 2 and code 3.

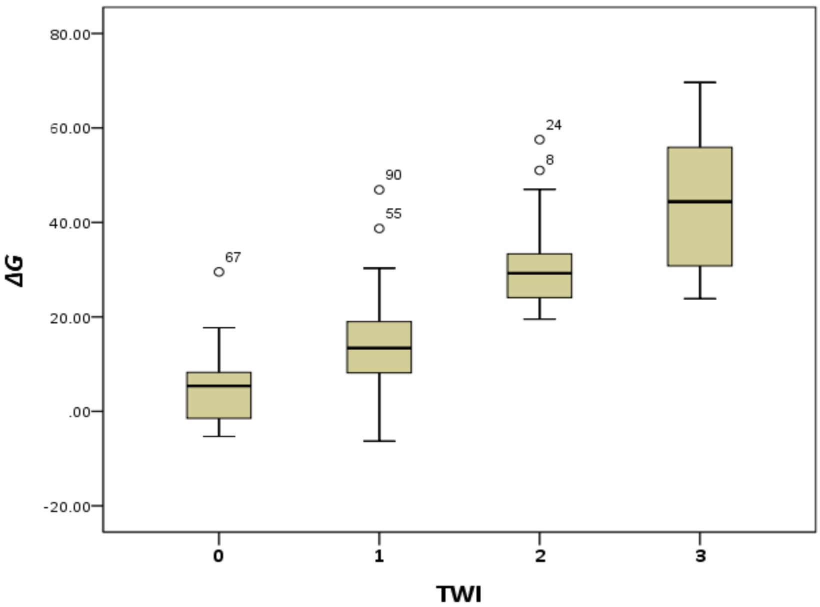

Figure 7. Comparison of Δ*G* values according to the tooth wear index (TWI)

Table 5. Distribution of Δ*G* related to the tooth wear index (TWI)

TWI code	N	Δ*G* (%)
0	13	5.38 [a] (-2.10 to 8.77)
1	40	13.29 [b] (8.07 to 19.40)
2	35	29.23 [c] (23.40 to 33.33)
3	8	44.40 [c] (28.95 to 57.80)
P		<0.001

Data are median (first quartile to third quartile) values.
Different letters within the same row indicate significant intergroup difference by the Kruskal-Wallis test and the Mann-Whitney test with Bonferroni post-hoc correction.

3.2.2. The change in fluorescence intensity according to dentin exposure

When the actual dentin exposure of the abraded teeth was evaluated by OCT, the fluorescence intensity of the abraded area compared to the normal area was increased as the dentin was exposed (Figure 8, Table 6). The enamel remained teeth showed a maximum increase of 12.35% fluorescence whereas the ΔG of the dentine exposed teeth was 30.93%, which was significantly different from that of enamel teeth (P<0.001). Furthermore, the range of ΔG during the step from the enamel remained tooth to the dentine exposed tooth showed from 20.43% to 34.26 (Table 7).

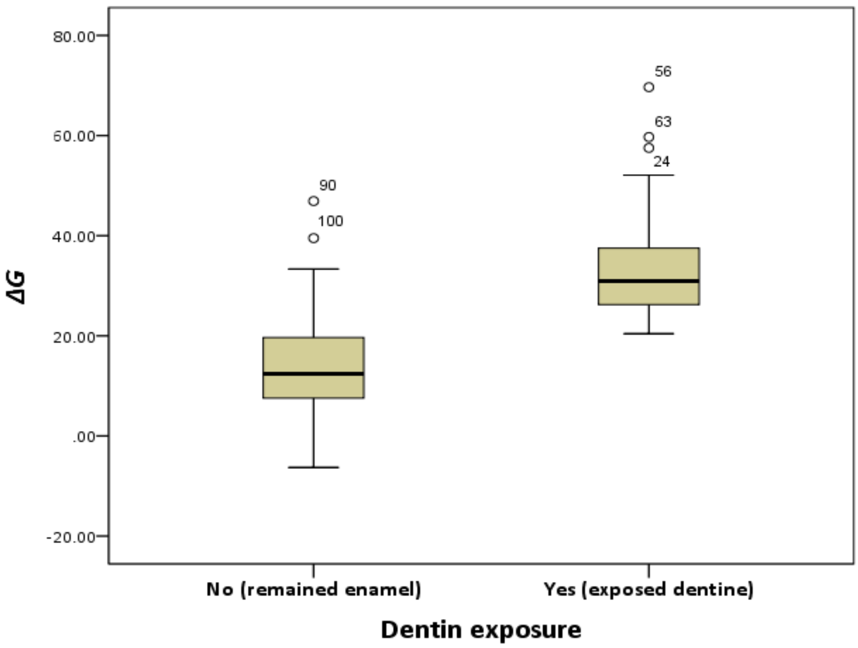

Figure 8. Comparison of Δ*G* values according to the existence of dentine exposure from OCT results

Table 6. Difference in Δ*G* related to the existence of dentine exposure from OCT results

	Type of wear (*N*)		*P*
	Enamel remained teeth (57)	Dentine wear teeth (39)	
Δ*G* (%)	12.35 [a] (7.55 to 19.66)	30.93 [b] (25.93 to 38.71)	<0.001

Data are median (first quartile to third quartile) values.
Different letters within the same column indicate a significant difference between groups by the Mann-Whitney test.

Table 7. Δ*G* value during the step from the enamel remained tooth to the dentine exposed tooth

ΔG (%)	Status of tooth wear
$\Delta G < 20.43$	Enamel remained tooth
$20.43 < \Delta G < 34.26$	The step from the enamel remained tooth to the dentine exposed tooth
$\Delta G > 34.26$	Dentine exposed tooth

Ⅳ. DISCUSSION

In this study, we evaluated the degree of wear by collecting extracted teeth without any caries or restorations on the occlusal surface using conventional methods which is TWI index of Smith and Knight. The TWI index is an index that evaluates the degree of wear and is the most widely used, intuitive, and easy to evaluate and analyze existing wear studies. TWI is divided into code 0 (normal tooth), code 1 (tooth enamel worn out), code 2 and 3 (tooth worn to dentin). Since then, QLF technology has been used to evaluate whether the difference in fluorescence expressed in teeth is useful for distinguishing the degree of wear of occlusal surfaces. As the TWI value increased, the change in the fluorescence intensity of the worn area increased with a strong positive correlation coefficient of 0.77 (ρ=0.77), indicating a significant difference in fluorescence intensity between the groups (Table 4, $P < 0.001$). However, there was no significant difference in fluorescence intensity between code 2 (wear to dentin, less than 1/3 of area) and code 3 (wear to dentin, more than 1/3 of area). In previous studies, the difference between code 2 and code 3 in the TWI index is differentiated by the area of wear rather than the depth of wear (M.K. Al-Omiri, et al., 2010). However, although the difference was not statistically significant, the fluorescence intensity increased as the dentin exposure area increased. However, if we analyze the fluorescence area rather than the fluorescence intensity, we could easily distinguish it. As a result, it was confirmed that the intensity of fluorescence expressed in the teeth increases with the increase of wear.

The exposed dentin is depressed and discolored or the color of the original dentin is thicker than enamel, resulting in a yellowish or brownish appearance (F.J. Lopez-Frias, et al., 2012). The dentin exposure is often used as an indicator of dental wear, because dentin exposes the clinical symptoms, and since the abrasive is abraded after the dentin is exposed compared to the enamel. The total number of teeth used in this study was 96 teeth. Among them, 43 teeth were exposed to dentin by TWI analysis. The number of dentin was greater than that of the actual exposed teeth when the cut surface of the tooth was observed with OCT as a golden standard. This is consistent with previous studies in which classification of dentin exposure by visual examination was different from histological analysis (C. Ganss, et al., 2006). Originally, TWI was developed to confirm dentin exposure and has been widely used as a useful method, but The visual inspection showed a disadvantage that accuracy was lowered due to the subjectivity of the evaluator (D. Bartlett, et al., 2011). On the other hand, in the fluorescence analysis of QLF, the fluorescence increase in the enamel-worn teeth compared to the normal region was 13.29%, and the fluorescence increase in the dentin exposed teeth was 30.93%. There was a significant difference between the two abraded teeth, and the fluorescence difference according to the dentin exposure could be confirmed more accurately than the TWI (Table 5, $P < 0.001$). These results are the same as the results of previous studies reported that the fluorescence intensity at the time of dentin exposure in the stepwise formed artificial wear model increases sharply. Because dentin contains more fluorophore than enamel, it expresses up to 4 times brighter fluorescence (RL Hartles, et al., 1953). The QLF technology used in this study detects dentin exposure It seems to be useful.

We needed a gold standard to determine if the wear rate was correct with QLF. Initially, the tooth was directly cut. However, if the tooth is directly cut, the specimen may be damaged during the cutting process, and there is a possibility that the cut surface of the cut part represents an entire tooth. In this study, OCT was used to confirm the incisal surface of the tooth for use as a gold standard instead of direct cutting. All sections of the tooth were scanned in real time using OCT and the thinnest portion of the enamel was found. However, in the case of enamel wear, it was difficult to distinguish between physiological wear and pathological wear by OCT observation. Long-term follow-up studies are needed to evaluate the rate of tooth wear, which may be a key factor in distinguishing between these. We found that the fluorescence intensity increased by 4.00% as the residual enamel thinner 100 μm when the abrasion was formed stepwise from the abrasion-free steady state as the baseline in the previous study (S.K. Kim, et al., 2017). When the rate of progression of physiological wear was considered to be about 15 μm for premolars and 29 μm for molar teeth per year (P. Lambrechts, et al., 1989), the change in fluorescence intensity of QLF was associated with the speed of tooth wear progress and the pathological condition of tooth wear. In addition, the conventional TWI has the disadvantage that it is impossible to diagnose and monitor the initial wear. Therefore, the QLF technology (M. Ando, et al., 2003), which can quantify the minute fluorescence change according to enamel thickness, It is necessary to evaluate the initial state.

The intensity of tooth fluorescence calculated from 0 (black) to 255 (white) according to the brightness when transforming fluorescence image obtained from QLF equipment into 8-bit grayscale image distinguishes between normal enamel, wear of tooth surface and resin filled for restoration. It has already been reported (B.R. Kim, et al., 2016). Therefore, in order to evaluate the degree of wear in this study, the fluorescence intensity was calculated as grayscale levels, and the micro-change according to the wear depth was quantitatively calculated by calculating the difference from the normal region. However, in the previous study, the absolute value of the area to be assessed was calculated to observe a simple comparison or change trend. However, in this study, the brightness of the normal and the abrasion area was calculated as a ratio, as a percentage. It will be easy for the patient to understand the wear and the degree of wear of the tooth as well as the dentist by introduction of fluorescence only in the actual clinical scene intuitively.

In modern age, lifespan has increased and dietary habits such as eating habits and drinking a lot of carbonated beverages have changed, so that not only the elderly but also young people have more tooth wear than before (Sirimaharaj. et al., 2002). Before tooth problems occur, most patients do not realize that their teeth are worn. Prosthetic treatment is often needed because wear and tear are abrupt enough to recognize the worn condition, often resulting in aesthetic and functional problems. This may lead to an increase in dental costs for the patient and may cause discomfort compared to natural teeth. For this reason, it is most effective to recognize and prevent tooth wear at the early stage, considering that paradigm for the management of wear teeth is changed to prevent the occurrence of abrasion as much as possible before prosthetic treatment (B. Loomans, et al., 2017). As far as we know, this is the first study to evaluate real abrasive teeth that were not artificially worn in the laboratory by QLF technology. Experimental results have shown that it is possible to use the fluorescence intensity of QLF technology to quantitatively measure and monitor tooth wear.

To keep a tooth healthy for a long time, it is important to recognize and prevent it at the beginning of wear. In order to accurately diagnose tooth wear at an early stage, it is necessary to develop a new diagnostic method that is more advanced than the conventional method. The method presented in this paper also shows that it is effective to diagnose the wear condition more accurately at the beginning. QLF is not only harmless to the human body, but also noninvasive and fast, it can capture images in real time and store them as images. In addition, the cost and time required for shooting and analysis can be reduced, the patient can be easily seen and recognized, and the advantage of comparatively analyzing the degree of abrasion objectively by quantitatively analyzing accumulated images over a long period of time have. Therefore, it can be used as a new auxiliary diagnostic tool by replacing the conventional TWI and evaluation equipment. If we compare the etiology and age of various abrasive teeth and confirm clinical validity, QLF technology can be a useful tool for evaluating and monitoring wear. In the future, if more data and analysis are made, it will be possible to diagnose the abrasion condition more accurately in an objective and quantitative manner at the beginning.

In addition, it is important to understand the cause of abrasion in order to prevent the occurrence of abrasion. As mentioned before, attrition, abrasion, and erosion are the causes of abrasion. Nowadays, tooth wear is the most common and increasing trend (Van't Spijker A, et al., 2009). Therefore, to prevent this, it is necessary to periodically check the condition of the wearer's teeth and to improve eating habits to reduce intake of acidic or carbonated beverages. In particular, when wear occurs, it should be recognized at the beginning and efforts should be made to prevent further progress. In addition to improving the eating habits at the time of initial wear, there is fluoride application in dentistry (S. B. Mehta, et al., 2012). Progressive restorations may require aesthetic or functional problems, pain, discomfort, unstable occlusion, continuing progression, risk of dimensional exposure, and so on (S. B. Mehta, et al., 2012). Oral splints may be required for patients with irritable or rickety habits. Patients with systemic disease with bulimia or gastroesophageal reflux disease require prescription (Mehta SB, et al., 2012).

Ⅴ. CONCLUSION

The purpose of this study was to classify human teeth with real abrasion according to the existing tooth wear classification method and to evaluate their respective fluorescent properties.

The results of this study showed that QLF method increased reliability of tooth wear examination and distinguish the degree of wear significantly. Therefore, QLF technology could be regarded as a useful tool for evaluation of tooth wear.

Further conclusion of this study are below;

1. The result from that the 5 examiners assess tooth wear using visual classification criteria showed higher reliability values (intra-, 0.743; inter-reliability, 0.778, respectively) of QLF tooth wear index (QTWI) than those of conventional TWI (intra-, 0.695; inter-reliability, 0.545, respectively).

2. In the result of quantitative analysis, the changes in the fluorescence intensity of teeth evaluated by QLF were significantly increased as wear progressed with a strong correlation comparing the degree of tooth wear (ρ = 0.77, P <0.001). Also, the difference of fluorescence (ΔG) showed a maximum increase of 12.35% fluorescence in enamel remained teeth group and 30.93% in the dentine exposed teeth group with being significantly different from that of enamel teeth (P<0.001).

In conclusions, the results of this study confirmed the possibility of QLF technology as an evaluation tool of tooth wear. If clinical validity is confirmed at a later date, QLF technology can be used as a promising tool to objectively evaluate and monitor wear.

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ABSTRACT (in Korean)

QLF 를 이용한 치아의 교합면 마모 정도에 따른 형광 강도의 정량적 평가

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이 영 동

삶의 질이 향상되고 평균 수명이 늘어남에 따라 노인 인구의 보유치아 수가 증가하고 있다. 치아 마모는 일생에 걸쳐 비가역적으로 진행되기 때문에 연령이 증가할수록 그 유병률 또한 증가하는 특징이 있다. 전체 연령에서 치아 마모는 일반적인 증상이 되었으며, 건강한 치열을 장기적으로 유지하기 위해서 조기에 관리해야 할 중요한 사항이 되어가고 있다. 하지만 치아 마모는 증상이 없어서 본인이 이를 느끼는 때가 되면 이미 늦은 경우가 많다. 따라서 병적 마모가 진행되기 이전에 예방하는 노력이 중요하다. 치아 마모 정도를 평

가하기 위한 방법은 시각적으로 보이는 특징에 따른 index를 주관적으로 산출하는 방법이 주로 사용되어 왔다. 치의학 영역에서 널리 사용되어온 방법은 Smith와 Knight의 Tooth wear index(TWI)이다. 마모의 정도를 알려주는 각종 index들은 새로 개발되고 보완되어 왔지만 index 값을 주관적으로 매긴다는 점에는 큰 변화가 없었다. 치아를 직접 보면서 마모를 측정할 경우 평가자 개인의 주관에 따라 측정 결과가 달라질 위험이 있다. Quantitative Light-induced Fluorescence(QLF)는 405 nm 파장의 빛을 이용하여 치아의 자가형광(auto fluorescence)을 탐지하는 대표적인 광학 기술이다. QLF를 치아에 조사하면 정상 법랑질은 녹색의 자가형광을 발현하지만 상아질에서는 법랑질보다 더 밝은 형광을 발현한다. 본 연구는 실제 마모가 존재하는 사람 치아의 형광학적 특성을 평가해보고자 한다.

본 연구에서 치아 수집은 연세대학교 치과대학병원에 내원한 만 20세 이상의 환자를 대상으로 하였다. 수집된 치아 중 치아 우식, 수복물 및 치수의 노출이 없는 치아만을 선별하여 총 102개의 치아를 본 연구에서 사용되었다. 총 102개의 치아 시편에 번호를 부여한 후 각각의 치아에 대해 tooth wear index (TWI)를 0에서 3까지 측정하였다. 본 연구에 사용된 치아의 상아질 노출 여부의 평가에는 swept-source optical coherence tomography (SS-OCT) system 을 사용하였다. 본 연구에 사용될 형광 검사를 위해 모든 시편에 대해 치아 교합면이 지면과 수평이 되도록 위치시킨 후 QLF-D를 교합면

과 수직이 되도록 놓고 촬영을 하였다. 촬영된 모든 사진은 이미지는 소프트웨어를 사용하여 정량적으로 계산하였다. 모든 형광 이미지는 8 - bit grayscale 이미지로 변환하였다. 각 치아 별 정상 부위 대비 마모된 정도의 차이를 계산하기 위해 각 치아의 교합면 상에서 가장 마모가 심한 부위와 정상 부위의 차이값을 percentage로 산출하였다.(ΔG)

시각적 분류 기준을 사용하여 5명의 평가자들의 신뢰도 분석을 하였을 때, QLF 기술을 이용한 치아 마모 분류 방법(QTWI)는 평가자 내 일치도가 0.743, 평가자 간 일치도가 0.778로 우수한 일치율을 보였다. 기존의 치아 마모 분류(TWI)의 평가자 내, 평가자 간 일치율이 0.695, 0.545로 중등도 이상의 일치율을 보였으나 QTWI와 비교하였을 때, 낮은 일치율을 보였다.

치아 마모를 0에서 3까지의 TWI 값으로 구분하였을 때, 형광의 강도는 마모의 정도가 증가할수록 유의하게 증가하였다. 마모 부위의 형광 강도의 변화(ΔG)는 TWI에 따른 마모의 정도와 강한 양의 상관 관계를 보였다($\rho=0.77$, $P<0.001$). OCT를 통해 마모 치아의 실제 상아질 노출 여부를 평가하였을 때, 정상 부위와 비교한 마모 부위의 형광 강도는 상아질이 노출됨에 따라 증가하였다($P<0.001$).

결론적으로, 마모가 증가함에 따라 치아에서 발현되는 형광의 강도가 함께 증가하는 것을 확인하였다. 연구 결과를 통해 QLF technology가 치아 마모의

평가 도구로서의 가능성을 확인하였다. 추후 임상적 타당도가 확인된다면, QLF technology는 마모를 객관적으로 평가하고 모니터링하는데 유망한 (promising) 도구로 활용이 가능할 것이다.

핵심되는 말: 치아 마모, 마모 진단, 치아 자가형광, quantitative light-induced fluorescence (QLF)