Evaluation of residual dentin thickness using Quantitative Light-Induced Fluorescence

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Abstract

Evaluation of residual dentin thickness using Quantitative Light-Induced Fluorescence

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The aim of this study is that to find out whether correlation between residual dentin thickness and Quantitative light-induced fluorescence (QLF) values exists and to analyze its tendency. Because there are no previous studies on the relationship between residual dentin thickness and QLF value, this study aims to examine the characteristics of the relationship in detail.

Sample teeth were assigned from the Human Derivatives Bank of Yonsei University Dental Hospital. Forty extracted sound human molars were obtained. Calculus and periodontal tissue attached to the root surface were removed. Twenty teeth were assigned to ‘Unfilled’ group and ‘Filled’ group, respectively. Using 3D printer, forty resin molds (11 x 11 x 14 mm) were produced, and the roots of the teeth were submerged in clear acrylic resin. Specimen was sectioned longitudinally to visualize the inside of the pulp space. For each sectioned specimen, I set the reference point at the highest point of the pulp space to measure the distance of the residual dentin thickness. After setting the reference point, each specimen was cut horizontally with a low speed precision diamond saw so that the residual thickness of dentin would be 3mm from the reference point. Then, the QLF images were taken on each of the sectioned surface. In Unfilled group, 3mm, 2 mm, 1 mm, 0.5 mm specimen were made. As for Filled group, 2 mm, 1mm, 0.5 mm sections were made while 3mm specimen was omitted. In Filled group, red utility wax was inserted into the empty pulp chamber to reproduce the actual pulp chamber which is filled with blood. After taking all the images, Q-ray software was used to analyze the intensity of fluorescence, and this process was repeated by 3 different operators in each group to determine if the results are stable regardless of the person analyzing. For statistical analysis, One-Way ANOVA analysis, Pearson Correlation Coefficient, and Intraclass Correlation Coefficient were performed.

In Unfilled group, mean ΔF values for 2 mm, 1 mm, 0.5 mm residual dentin thickness were zero, -6.90, -10.14, respectively. In Filled group, mean ΔF values for 2 mm, 1 mm,

0.5 mm residual dentin thickness were -3.22, -7.84, -11.52, respectively. In both groups, there was significant difference ($p<0.05$) among ΔF values of the three different residual dentin thickness. ΔF values of Filled group increased by a relatively constant value when compared to those of Unfilled group. Correlation analysis showed positive correlation between residual dentin thickness and ΔF. The results were 0.94 for Unfilled group and 0.77 for Filled group, and these values signify the highly positive correlation ($P < 0.05$) that exists between the two factors. Intra-class correlation coefficients of Unfilled group and Filled group show 0.917 and 0.831 ($P < 0.05$).

Residual dentin thickness and ΔF value that shows the loss of fluorescence are significantly correlated. ΔF value and residual dentin thickness have highly positive correlation regardless of the operator using the Q ray device. This study shows that residual dentin thickness can be measured using Q-ray device. The clinician can utilize the ability of Q-ray device to measure residual dentin thickness in order to prevent irritation of the pulp caused by unnecessary preparation of teeth. Based on the findings of this study, it is expected that pulpal irritation due to excessive iatrogenic preparation of teeth can be prevented.

Keywords : Quantitative light-induced fluorescence; QLF; residual dentin thickness; pulp health; Pulp status

Evaluation of residual dentin thickness using Quantitative Light-Induced Fluorescence

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I. Introduction

The dental pulp is a complex organ in which the microcirculation and sensory nerves are encased in a rigid structure of dentin and enamel, creating a low compliance environment (Kim and Dorscher-Kim, 1989). Among the organs in the body, organs with low compliance are those that play highly important functions, such as the brain and spinal

cord. Such human physiology enables to protect the functions of important organs from external stimuli. As for teeth, hard tissues such as dentin and enamel serves as protective barriers that encase internal pulp from mechanical and chemical stimulation as well as external irritants such as bacteria. In order to maintain the normal vitality of pulp, preserving the hard tissue barrier is essential.

But during clinical procedures such as caries removal or crown preparation, protective hard tissues of the tooth can be destroyed excessively iatrogenically, inducing pulp injury or pulp exposure (Bergenholtz, 1991). This progressed pulp injury causes pulp hyperemia, which leads to inflammatory state and thus pulpitis. However, pulpitis can be resolved when appropriate treatment and removal of the cause, but if not, the inflammation of the pulp continues to lead to pulp necrosis, resulting in the inevitable root canal treatment.

The hard tissues of teeth, enamel and dentin, have high strength but can be damaged by various irritants (Caldwell, et al., 1957) such as dental caries, most commonly caused by the accumulation of biofilm in the oral cavity, and wear due to attrition or frictional contact against apposing enamel or harder restorative materials like porcelain. In addition, hard tissue damage such as cracks or fractures may occur from small or large traumatic external forces. Through treatment, damaged hard tissues are removed and reconstructed, and in this process, it can be said that leaving hard tissues in a healthy state as much as possible is an essential factor in maintaining normal vitality of pulp tissue.

The residual dentinal thickness, from the depth of the cavity preparation to the pulp, is

the single most important factor in protecting the pulp from insult(Stanley, 1981). The safety depth according to residual dentin thickness after cavity preparation is described as the effective depth(ED). Effective depth means the minimum thickness of healthy tooth structure, especially dentin, required to separate the caries lesion and pulp tissue. It is known that when ED is 2 mm, it shows healthy reparative action, unhealthy reparative reaction at 0.8~2 mm, and pulpal reaction such as hypersensitivity and pulpitis at 0.3~0.8mm(Murray, et al., 2002). Although the detailed thickness varies, most studies report that a pulpal reaction occurs when the residual dentin thickness is smaller than 2mm. While the conventional concept of treatment was to completely remove and reconstruct affected and damaged hard tissues, the recent treatment paradigm shifts to minimally invasive management, such as selective caries removal. The concept of selective caries removal is based on ‘the development of adhesive bioactive/bio-interactive restorative materials’ and ‘the adverse effects that a good peripheral seal of the adhesive restorative material to prepared cavity walls have on the viability of remaining bacterial and their cariogenicity(Banerjee, et al., 2017).

When pulp exposure occurs in the preparation process, procedure such as direct pulp capping and partial pulpotomy are used as vital pulp therapy to maintain pulp vitality. However, it can be considered that the difference in prognosis between calcium hydroxide and Mineral Trioxide Aggregates, which was used previously, is still a controversial part, such as the lack of sufficient data and the need for a longer term follow up(Schwendicke, et al., 2016). Consequently, preventing iatrogenic pulp exposure is important.

Inexperienced practitioners are more likely to cause iatrogenic pulp exposure due to lack of experience.

Along with the development of materials, there has also been the development of diagnostic instruments. Autofluorescence, called ‘primary fluorescence’, is the fluorescence found in natural substances. Human tooth also fluoresces under irradiation with ultraviolet light. Because the fluorescence intensity of carious enamel is weaker than that of non-carious enamel, the measurement of fluorescence can be applied to examine the carious portion(Matsumoto, et al., 1999). The diagnostic device using such autofluorescence is Quantitative Light induced Fluorescence (QLF).

QLF is a technology that assists in diagnosing dental caries and observes caries progress by irradiating visible light with a wavelength of 405 nm to the teeth and measuring the degree of fluorescence loss due to dental caries. When 405 nm of blue visible light is irradiated, green auto-fluorescence is generated in sound teeth and reflected after transmitting to dentino-enamel junction. Sound teeth exhibit 100% fluorescence and show a bright image, but when minerals in the teeth area lost through caries progression, light scatters from the lesion, and fluorescence is also lost. This loss can be quantified as fluorescence loss (△F). The value △Q, obtained by multiplying △F by the area of the lesion measured at the outermost part of the enamel, means the volume of the entire lesion. Currently, by adding a digital filter to QLF, the green fluorescence of healthy tooth structure is recognized as the original color of the tooth, and red

fluorescence emitted by microorganisms is emphasized to aid the visual judgment in the clinic. In fact, when light is irradiated on the teeth, normal teeth are identified as white or ivory while caries lesions are identified as gray or dark red (김백일, 2011).

By using the technology of QLF, more analytical data can be obtained on the condition of teeth and oral hygiene, and research is also underway to detect pathological and physiological changes in teeth using QLF. Kim et al.(Kim, et al., 2019) conducted a research to quantify tooth wear using QLF. As the enamel thickness decreased due to increased wear, the value of ΔF_{wear} tended to increase. This is to take advantage of the fact that dentin that emits natural fluorescence at 405nm and enamel that transmits it at 405nm gradually increases the value of fluorescence as dentin is exposed as the enamel due to wear decreases. Also Keiko NAKATA et al. (Nakata, et al., 2009) also designed tooth model to quantify erosion using QLF. They constructed an enamel erosion model in vitro and analyzed the relationship between the mineral loss of enamel and the QLF value. As analyzing the correlation between ΔF and the demineralization depth of enamel, it was reported that the correlation coefficients were 0.91, showing a strong positive correlation.

As shown above, until now, QLF has focused on patient caries detection, screening, and preventive education, but its usage is more actively being involved during actual clinical procedures, and is used for analysis of mineral loss such as enamel wear and erosion. According to Ando et al.(Ando, et al., 2003), when there is an intact enamel in the upper part, it is reported that the actual fluorescence underestimation tends to occur due to the

decrease in fluorescence radiance. For this reason, case reports using detection of residual infect dentin after removing the upper enamel have been reported. The relationship between enamel thickness and mineral loss and QLF has been reported. However, studies on the relationship between dentin thickness and QLF are rare.

The aim of this study is that to find out whether correlation between residual dentin thickness and Quantitative light-induced fluorescence values exists and to analyze its tendency. Because there are no previous studies on the relationship between residual dentin thickness and QLF value, this study aims to examine the characteristics of the relationship in detail.

II. Materials and Methods

1. Specimen Preparation

This study was approved by the Institutional Review Board of Yonsei University Dental Hospital (approval number: 2-2020-0042). The sample teeth were assigned from the Human Derivatives Bank of Yonsei University Dental Hospital. Then, teeth with the following conditions were excluded : dental caries, restorations, and enamel or dentin hypoplasia. Consequently, forty extracted sound human molars were obtained. The attached calculus and periodontal tissue were removed by curettage and soaking the tooth in the 6% sodium hypochlorite solution.

Forty Resin molds (11 x 11 x 14 mm) were produced using 3D printer (Nextdent 5100, Nextdent BV, Soesterberg, Netherlands), and the roots of the teeth were submerged in the mold with clear acrylic resin (Ortho-Jet®, Lang Dental Manufacturing Co., Wheeling, USA). Each specimen was sectioned in a longitudinally using a disc to see the inside pulp space. In the section area, I set the reference point at the highest point of the pulp space to measure the distance of the residual dentin thickness. After setting the point where the thickness of residual dentin from the reference point to dentin becomes 3mm, each specimen was cut horizontally using a low speed precision diamond saw (TOPMET Metsaw-LS, R&B, Daejeon, Korea). And then the QLF images were taken on the sectioned surface. The same procedure was repeated for the 2 mm, 1 mm, 0.5 mm

sections (Fig. 1).

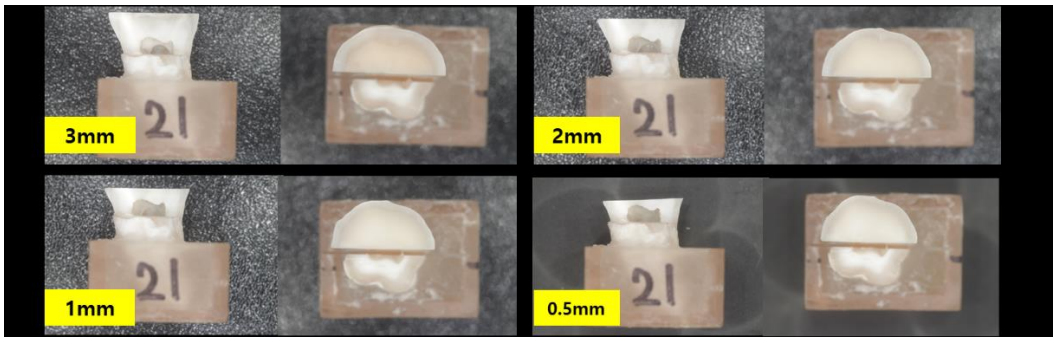

Figure 1. Sectioned sample images (white-light images) of specimens by thickness.

To evaluate the effectiveness of QLF with regard to the environment in the pulp chamber, forty teeth were divided into 2 groups, 20 for ‘Unfilled group’ and 20 for ‘Filled group’ each. Unfilled group was the group with empty pulp chamber, and Filled group was the group with simulated red color of vital pulp. The empty pulp space in Unfilled group has a limit in representing the actual oral environment. In addition, there is a possibility that the color of blood contained in normal pulp affects the data value. Therefore, in order to replicate the real pulpal color, a red utility wax (Utility wax, Atria Co., Seoul, Korea) was inserted into the pulp chamber and the QLF images were taken (Fig. 2).

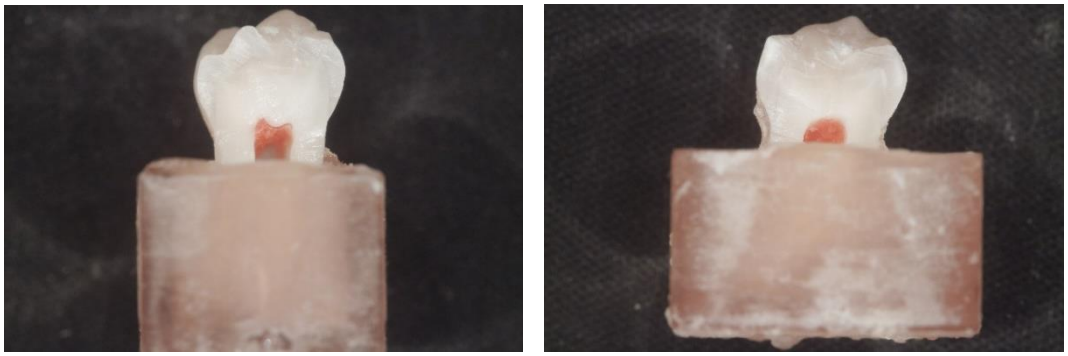

Figure 2. White-light images of specimens that replicating the pulp status by inserting the red utility wax into the pulp chamber.

2. QLF Image Acquisition

The QLF images were taken on each specimen in the two directions that longitudinal way and perpendicular section by using QLF-D Biluminator™ 2+ system (Inspektor Research Systems BV; Amsterdam, Netherlands).

The images were taken sequentially for one shot; an image from a digital camera in the white light, a fluorescence image in the blue light of a specific wavelength. The condition of the shooting of the white light and blue light were as follows.

- White light : ISO 1600, Shutter Speed : 1/60s, Aperture value : 8.0, Image size : Small fine, White balance : Manual
- Blue light : ISO 1600, Shutter Speed : 1/60s, Aperture value : 5.6, Image size : Small fine, White balance : Daylight

3. QLF Image Analysis

After taking all the images, Q-ray software (Q-Ray™ version 1.36, Inspektor Research Systems BV, Netherlands) was used to analyze the intensity of fluorescence, and this process was repeated by 3 different operators to see if the results are stable regardless of the person analyzing. First, the operator draws a boundary on the area to be analyzed. The area includes the highest pulp point. The blue border means the normal standard where the dentin is thick enough and the red border means excluded. When all the setting is finished, ΔF shows the average fluorescence loss inside the selected area compared to the normal standard (Fig. 3).

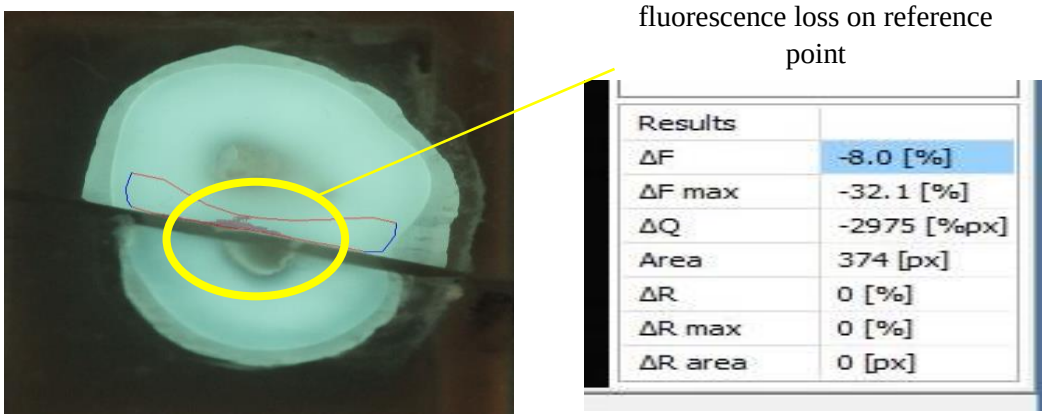

Figure 3. Quantitative light-induced fluorescence (QLF) image analysis process. The analysis area contains the reference point on top of the pulp space. The blue line indicates the sound reference area, whereas the red line indicates the deactivated area.

4. Calibration of the Analysis Procedure

In the section surface, there may be points that are thinner than the point I set, through the discussion among the evaluators, the following shape areas were set to exclude areas where the degree of fluorescence loss may be higher (Fig.3). In the both groups, after discussion 3 operators conduct QLF image analysis.

5. Statistical Analysis

All statistical analyses were conducted with the Statistical Package for the Social Sciences (SPSS) version 25.0 (SPSS Inc.; Armonk, NY, USA) with a significance level of 0.05. One-Way ANOVA analysis with Tukey's post-hoc test and Pearson Correlation Coefficient was performed between residual dentin thickness and ΔF values to determine the relationship between residual dentin thickness and relative fluorescence intensity in each sectioned surface. In addition, Intraclass Correlation Coefficient was measured to assess reliability among three operators Unfilled group and Filled group. The Bland-Altman graph were performed using for GraphPad Prism version 9.0.0 for Windows (GraphPad Software, San Diego, CA, USA) by setting operator 1 as main operator for analyzing agreement with other operators. In order to examine the significance of the difference between Unfilled group and Filled group, Independent sample t-test was conducted.

III. Results

1. Unfilled group

Most of the 3 mm sectioned samples revealed mixed surface, with the presence of both enamel and dentin. To avoid errors in the analysis, 3 mm sectioned images were excluded.

Table 1. ΔF values related to residual dentin thickness of Unfilled group.

		Residual dentin thickness			
		2mm (n=55)	1mm (n=60)	0.5 mm (n=60)	F(p)
ΔF	Mean	0	-6.90	-10.14	596.10(<0.001)*
	(SD)	0	1.63	2.19	
	Tukey	a	b	c	

SD = standard deviation, p*<0.05

The fluorescence value in each specimen represents a negative value. At 2 mm, most of the data showed a value of zero, and the degree of fluorescence loss increased for 1 mm section. ANOVA analysis shows that the differences among 3 groups are statistically significant. Mean values of ΔF for 2 mm, 1 mm, 0.5 mm residual dentin thickness are zero, -6.90, -10.14, respectively. Significant change of ΔF was observed when residual dentin thickness is below 1 mm, and most of the data for 2 mm section showed value of zero (Table 1).

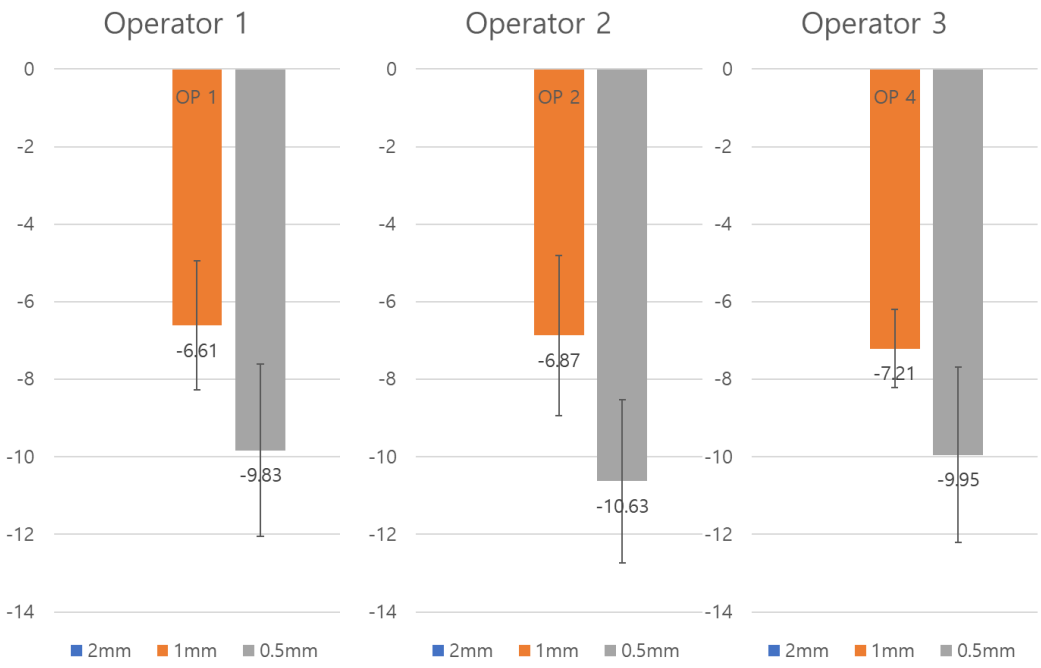

Figure 4. The graph showing the average fluorescence values at each thickness (2 mm, 1 mm, 0.5 mm).

Figure 4 shows the average values of sections of different thickness analyzed by 3 operators in Unfilled group. Overall, the average value was found within the similar ranges, and as the residual dentin thickness decreases, ΔF value tends to increase.

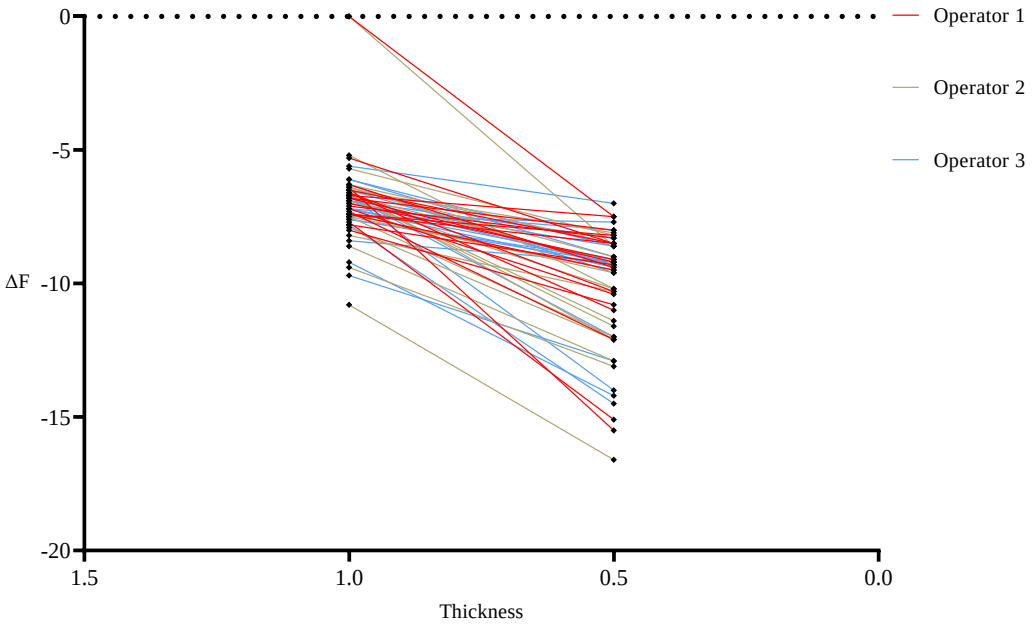

Figure 5. Spaghetti plot of ΔF values of Unfilled group according to operator at 1 mm, 0,5 mm thickness.

The tendency of ΔF values as the thickness decreases is shown in Figure 5. This plot indicates ΔF values of all specimens analyzed by 3 operators. The zero values at 2 mm thickness are excluded. Most specimens have similar values and slopes as the thickness decreases.

Correlation analysis shows positive correlation between thickness and ΔF. In this group, the value was 0.94 which means the two factors have highly positive correlation (Table 2). ΔF values at each residual dentin thickness of all samples of Unfilled group are shown in Figure 6.

Table 2. Correlation between residual dentin thickness and ΔF in Unfilled group.

	Thickness	ΔF
Thickness	1	.94*
ΔF	.94*	1

p*<0.05

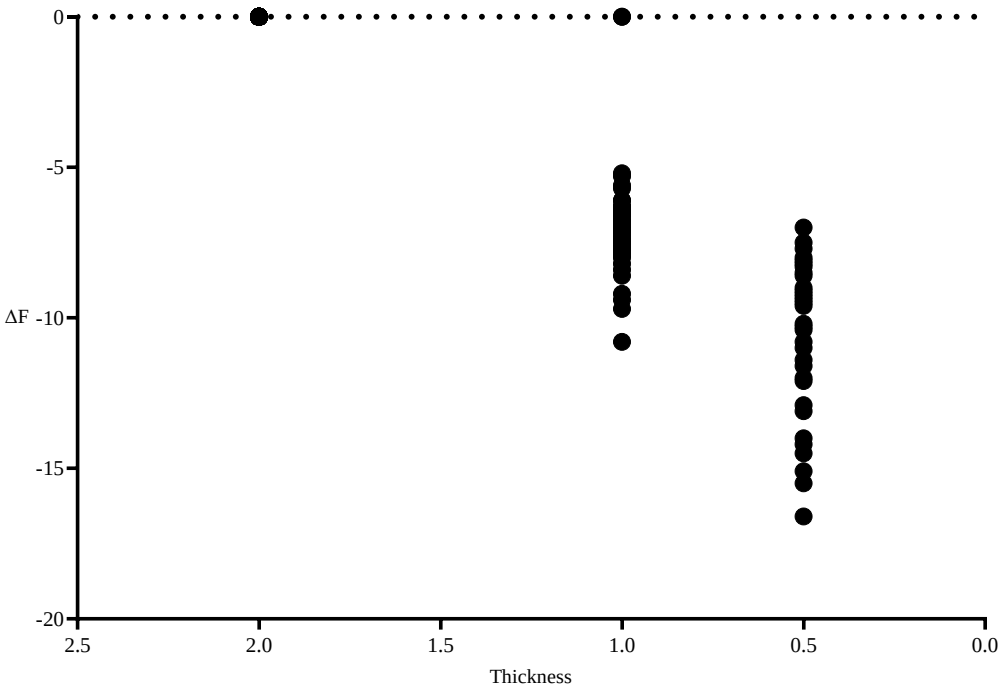

Figure 6. A scatter plot of ΔF values of Unfilled group according to the residual dentin thickness.

Consistency value by Intra-class correlation analysis which shows how much the data is consistent among operators was 0.92 (Table 3).

Table 3. Intraclass correlation coefficient among 3 operators. Variables: 3 operators

	Unfilled group	
	ICC(2,3)	95%CI
Single measures	0.917	0.875-0.948
Average measures	0.971	0.955-0.982
p	<0.001*	

p*<0.05

Figure 7 shows Bland-Altman plot of agreement of 2 and 3 with the main operator 1, respectively.

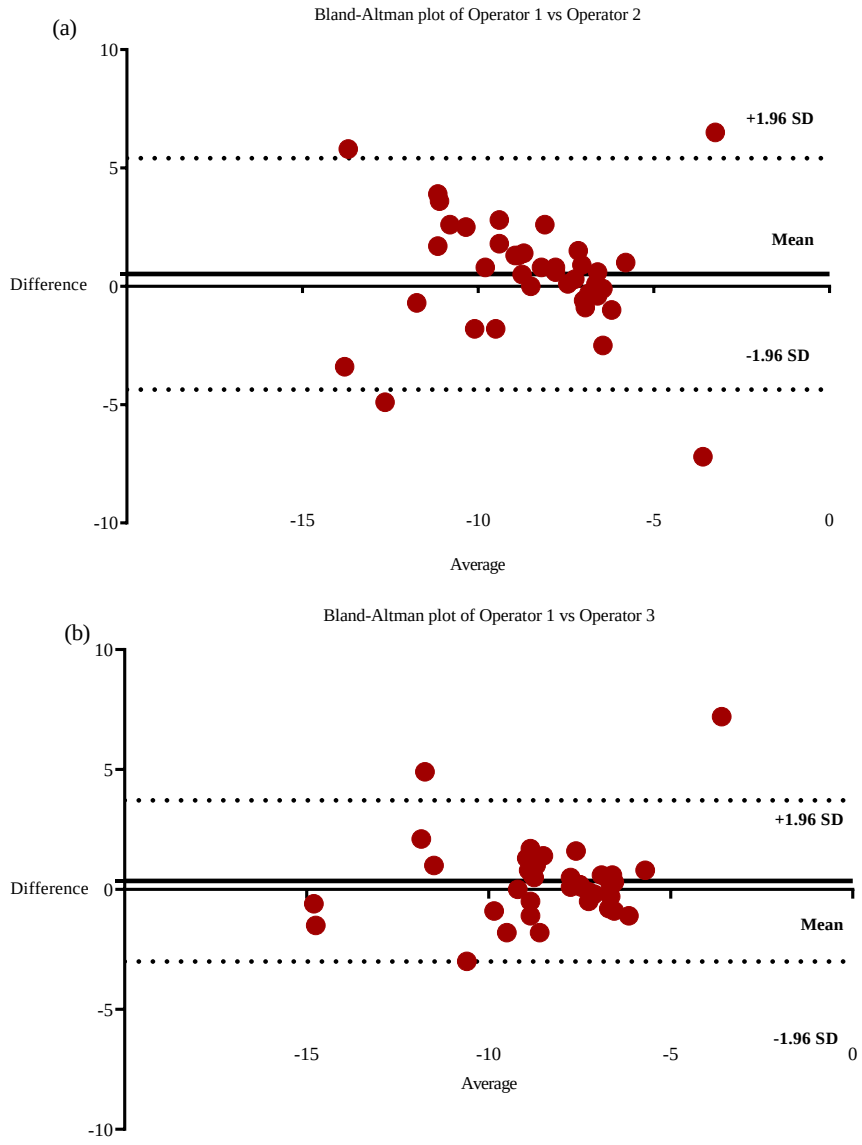

Figure 7. Bland-Altman plot shows agreement between Operator 1 and 2(a), Operator 1 and 3(b) in Unfilled group.

2. Filled group

As in Unfilled group, only the results 2 mm, 1 mm, 0.5 mm were analyzed and ΔF shows the negative values. When compared with the Unfilled group, the overall values were increased by 1 or more. Table 4 shows the one-way ANOVA results of the Filled group. Mean values of ΔF for 2 mm, 1 mm, 0.5 mm residual dentin thickness are -3.22, -7.84, -11.52.

Table 4. ΔF values related to residual dentin thickness of Filled group.

		Residual dentin thickness			
		2 mm (n=60)	1 mm (n=60)	0.5 mm (n=60)	F(p)
ΔF	Mean (SD)	-3.22 4.42	-7.84 2.40	-11.52 3.80	130.50 (<0.001)*
	Tukey	a	b	c	

SD = standard deviation, p*<0.05

Figure 5 shows the average values of each thickness of the 3 operators in Filled group. ΔF of the 3 operators showed an overall similar standard deviation.

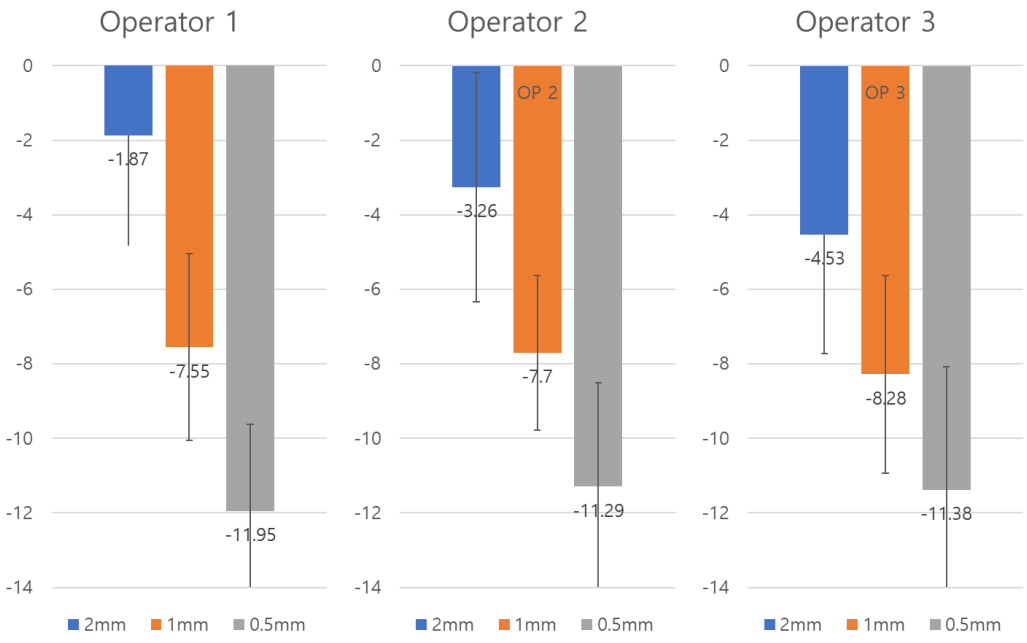

Figure 8. The graph showing the average fluorescence values at each thickness of the sample with red wax (2 mm, 1 mm, 0.5 mm).

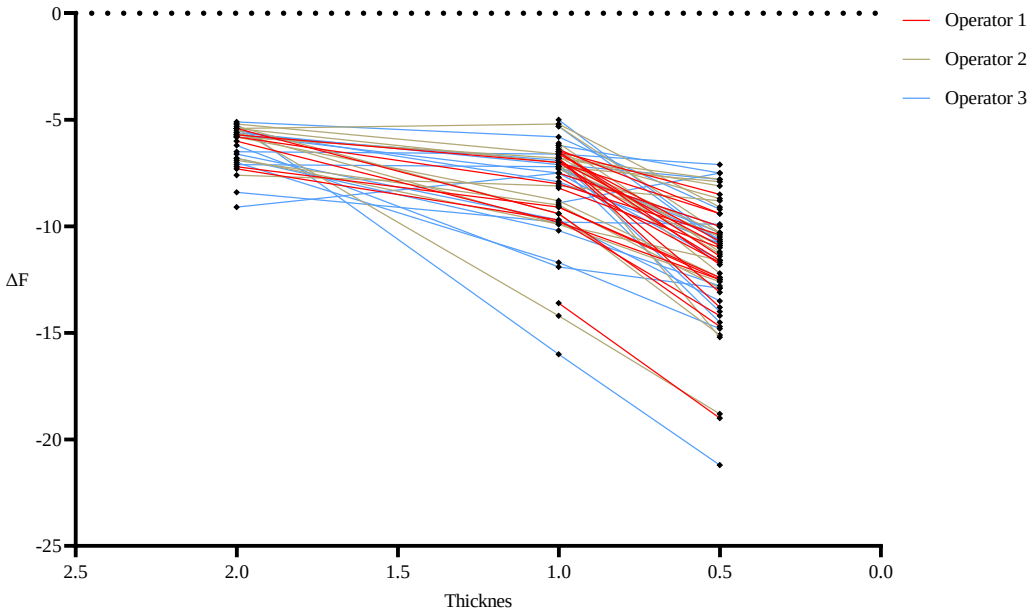

Figure 9. Spaghetti plot of ΔF values of Filled group according to operator at 2mm, 1 mm, 0.5 mm thickness.

The tendency of ΔF values of filled group as the thickness decreases is shown in Figure 9. The zero values at 2 mm thickness are also excluded. Most specimens have similar values and slopes as the thickness decreases. The slope from 1mm to 0.5mm shows a more rapid decline than the slope from 2mm to 1mm.

Correlation analysis also shows positive correlation between thickness and ΔF. The value was 0.77 and was slightly lower than Unfilled group. However, it can also be said that there is a strong positive correlation between thickness and ΔF (Table 5).

Table 5. Correlation between residual dentin thickness and ΔF in Filled group.

	Thickness	ΔF
Thickness	1	.77*
ΔF	.77*	1

p*<0.05

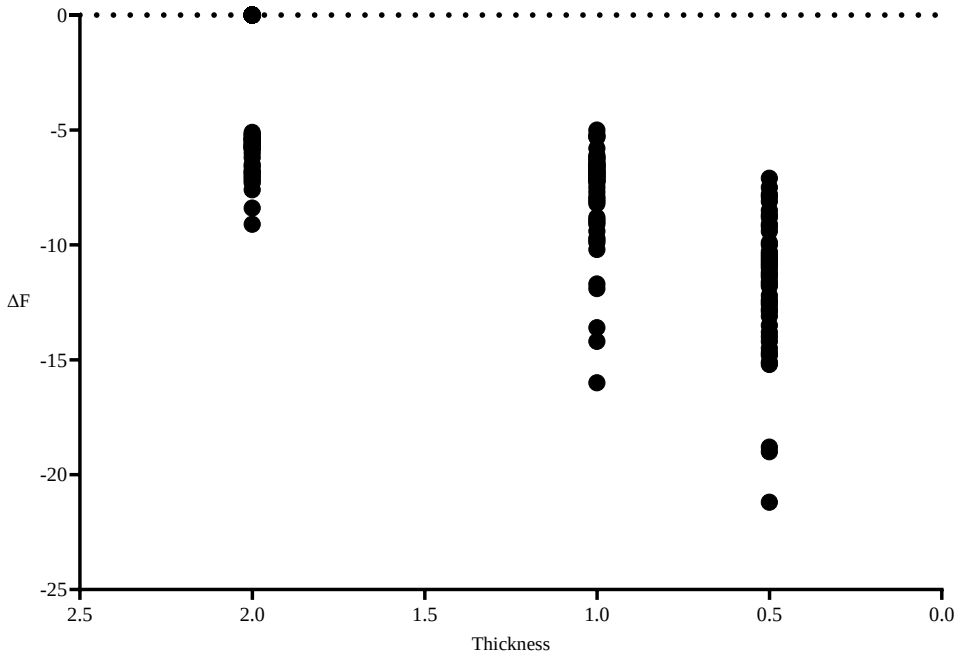

Figure 10. A scatter plot of ΔF values of Filled group according to the residual dentin.

The Intra-class correlation among three operators in Filled group showed a value of 0.83 (Table.6).

Table 6. Intraclass correlation coefficient among 3 operators. Variables: 3 operators.

	Filled group	
	ICC(2,3)	95%CI
Single measures	0.831	0.753-0.889
Average measures	0.936	0.901-0.960
P	<0.001*	

p*<0.05

Figure 11 shows Bland-Altman plot of agreement of 2 and 3 with the main operator 1, respectively.

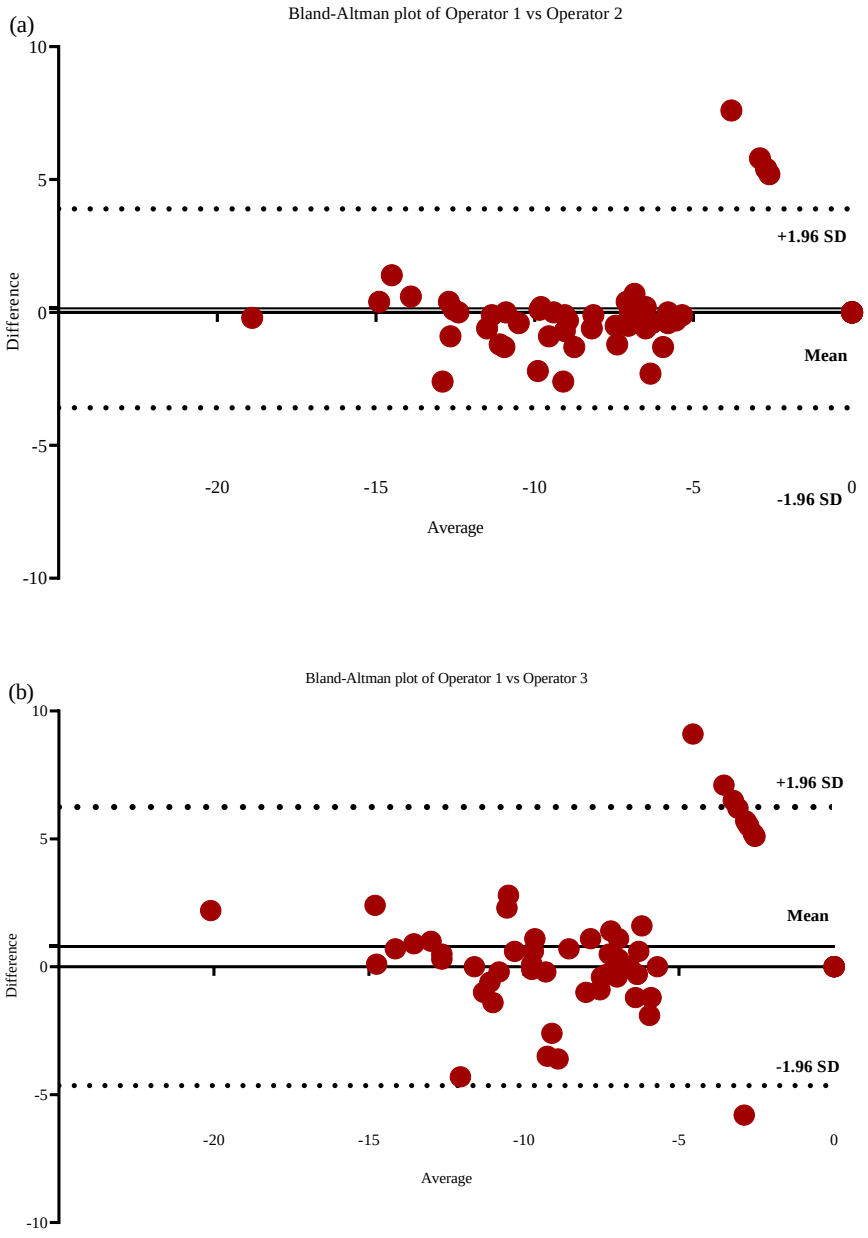

Figure 11. Bland-Altman plot shows agreement between Operator 1 and 2(a), Operator 1 and 3(b) in Filled group.

3. Comparison between Unfilled group and Filled group

Compared to Unfilled group, Filled group shows uniformly increased mean values in all thicknesses, even considering the errors of the experimental procedures (Fig.12). To analyze that there was a significant difference between two groups, Independent sample t-test was conducted. The results of Independent sample t-test were significantly different in all thickness (Table 7).

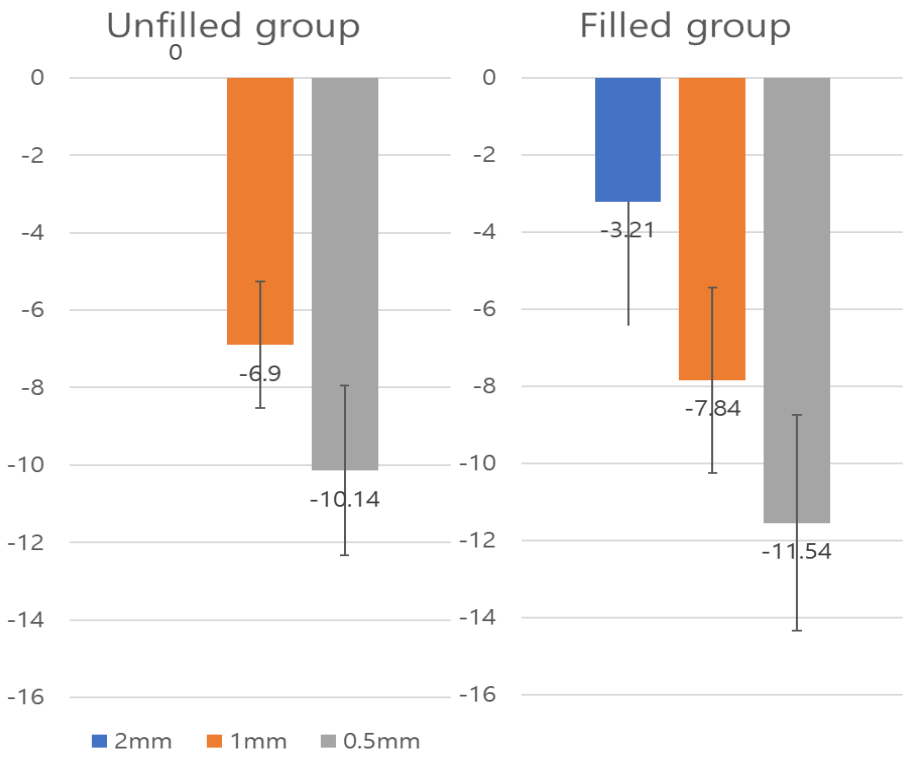

Figure 12. The graph showing the average fluorescence values at each thickness between Unfilled group and Filled group.

Table 7. Independent sample t-test between Unfilled group and Filled group.

	Group	*N*	Mean(*M*)	*SD*	*t*(*p*)
2 mm	Unfilled	55	0	0	7.74(<0.001)*
	Filled	60	-3.21	3.22	
1 mm	Unfilled	60	-6.90	1.63	2.52(0.013)*
	Filled	60	-7.84	2.40	
0.5 mm	Unfilled	60	-10.14	2.19	3.05(0.003)*
	Filled	60	-11.54	2.80	

SD = standard deviation, p*<0.05

IV. Discussion

This study attempted to find out whether there is correlation between residual dentin thickness and QLF values and to analyze, its tendency in order to establish a database that can be applied to clinical procedure. This study shows the possibility that QLF technology, which has been used in the conventional preventive aspect, can be actively applied to actual clinical procedures. In addition, because there was no previous experiment on the relationship between residual dentin thickness and QLF, it can be said that this study has the significance as a database and evidence for the fact that the degree of fluorescence loss varies according to the thickness of the dentin.

QLF techniques are already proven to have a lot of effectiveness as a diagnostic device. IA Pretty(Pretty, 2006) describes that QLF has been used to detect a range of lesion types. For occlusal caries, sensitivity has been reported at 0.68 and specificity at 0.70, and this compares well with other systems. Correlations of up to 0.82 have also been reported for QLF metrics and lesion depth. Smooth surfaces, secondary caries and demineralization adjacent to orthodontic brackets have all been examined. As such, a study was conducted to find out the dentin thickness using QLF, which was verified as a diagnostic device.

Before entering this experiment, various models were used to create a model to see the change in the amount of fluorescence according to the residual dentin thickness. Disc-shaped models were considered at first, but the current QLF analysis program requires the process of setting the fluorescence amount, which is the standard for the normal

fluorescence amount. Because of this analysis method, area with sufficient thickness and the area to be thinner should be included simultaneously in the analyzed area within the same model. Therefore, the disk shape that the entire specimen becomes thinner, has a point that it is difficult to be used for experiments in terms of current equipment. However, a natural tooth model, in which the internal pulp space is protected by the external hard tissue, is difficult to measure the actual residual thickness of dentin. Therefore, in order to make it possible to measure as much as possible and to create a model that includes both the normal and the thinning area, a model was produced that sectioned longitudinally at first and then decreases the thickness in the horizontal direction.

In the results of the Unfilled group, there were no significant ΔF values in the 2 mm section. This can be interpreted that normal fluorescence is detected when residual dentin thickness is thicker than 2 mm. When the residual dentin thickness is less than 2 mm, the fluorescence amount falls below the normal value, but it is difficult to regard this as a loss of fluorescence due to damage of tooth structure by demineralization. The thickness boundary for generating a substantially sufficient amount of fluorescence can be predicted to be 2 mm thick. Since the pulp chamber was left empty, the effect of the actual pulp was ignored, but the tendency of the fluorescence loss according to the residual dentin thickness can be understood. Dentin can express a normal amount of fluorescence at a thickness of about 2 mm or more, but when the thickness is less than 2 mm, the amount of fluorescence tends to decrease. In addition, as the thickness decreases, there is a strong positive correlation between the residual dentin thickness and ΔF value. Table 2 shows the

correlation degree. In the Pearson Correlation Coefficient, value 1, 0 and -1 means positive relationship, no relationship and negative relationship, respectively. As a result, it can be interpreted that as the thickness decreases below 2 mm, the fluorescence disappears. This is a result that correlates with the effective depth mentioned in introduction. Further research will be needed to fully understand this. If the ΔF value on the QLF image of the residual dentin in clinical situation during an actual preparation starts to increase from 0, it can be interpreted that to the remaining dentin thickness is 2 mm or less.

In order to simulate the actual clinical situation where the tooth being treated contains vital pulp, red utility wax was placed in the empty pulp chamber for Filled group. Through pilot study, it was decided that red utility wax was suitable for this experiment because it showed the least amount of fluorescence among the candidate materials (ink, dye, wax), reflecting on the fact that blood does not show fluorescence. However, while actual human blood does not show fluorescence at 405 nm, a pilot study revealed that the presence of blood decreases the brightness of the converted QLF image to further increase the change in ΔF value. Therefore, in order to check how much influence this point will have, the implementation of Filled group was planned. Due to the difficulty of placing actual blood inside the longitudinally sectioned specimen, a pilot study was conducted to replace blood with a reddish material to reproduce it as much as possible. Most of the red materials contains dyes, and these dyes contain fluorescent materials, but the red utility wax showed the least fluorescence compared to the dyes used in the pilot study and showed the fluorescence expression similar to that of blood. So red utility wax was chosen as an

internal material of the pulp space.

In the planning stage of Filled group, the expected result was that in the group of the same method, it would not affect the result value or show a certain amount of change. Looking at the results of Filled group, one can see that the value of ΔF increases to a certain level considering the errors of the procedures. This result means that empty pulp chamber does not affect fluorescence intensity of dentin itself. However, the presence of actual blood in the pulpal chamber causes ΔF value of the QLF image to be measured higher than that of Unfilled group. Based on Table 8, it can be judged that the presence of wax inside the pulp chamber, which is the difference between the two groups, is a factor indicating a significant difference in the ΔF value. Therefore, it seems that the situation of Filled group can be a clearer criterion for actual clinical situations such as cavity preparation. For further study of the relationship between the residual dentin thickness and the degree of fluorescence loss, it is necessary to insert a material in the pulp chamber rather than to empty the pulp chamber. The material needs to be able to reproduce pulp and does not show fluorescence, which is likely to show more accurate results.

In figure 5 and figure 9, we can see the tendency of the specimen except for the value indicating 0. Although there is a difference between the specimens, it seems that the data and slopes within the same range are similar. It can be seen that there is a possibility that ΔF and the residual dentin thickness have a certain regularity. In order to minimize the bias for this, the value of 0 was excluded from the graph because it is not known whether the actual value of 0 is 2mm. In order to clarify the regularity, it seems that additional studies

on more various thicknesses are needed.

Currently, much progress is being made to make QLF device easy to carry, simple to use, and convenient. Despite the advancement, QLF devices are not used much due to the complexity of analyzing the images. In order to analyze the QLF images captured at 405nm wavelength, those images must undergo a separate analysis process to view data such as loss of fluorescence on the tooth. However, in this process, the image on the program is analyzed not by analyzing the actual fluorescence, but by analyzing the color value of the image showing the fluorescence. Therefore, it is necessary to set a normal fluorescence amount as a reference point in the analysis process. As shown in Figure 3, a reference area and an inactive area are indicated with blue and red lines. This is because dentin exhibits a constant fluorescence value, and the ΔF value above a certain thickness is 0. However, as the thickness of dentin gradually decreases, it will show a loss of fluorescence in the same environment. In the specimen of this study, the outer layer, corresponding to the primary dentin, will have a sufficient thickness of dentin, and in the central dentin, the thickness of the dentin remaining up to pulp chamber will gradually decrease and each value of fluorescence amount will be different. Due to the limitations of the QLF analysis program, there is a concern that bias may be present in the analysis and in interpretation of result for this study. To minimize this bias, several operators performed the analysis process on the same specimen to evaluate the degree of precision because reliable reproducibility in the analysis process is essential for diagnosis and treatment in the future clinical procedure. The intraclass correlation coefficient of this study showed about 92%, 83% agreement

between the three operators which indicates relatively consistent value of the ΔF at a given certain thickness regardless of the operator. The intraclass correlation coefficient of this study has 'good' reliability according to the guideline(Koo and Li, 2016).

Figure 7 and Figure 11 show the degree of agreement in this study more visually. Since the Bland-Altman analysis is a method of expressing the degree of agreement between the two evaluations, operator 1 was set as the main operator for both the Unfilled and Filled groups. Operator 1 is the evaluator who performed both unfilled and filled group analyzes. It can be seen that each of the 20 specimens shows a high degree of agreement except for some. In both groups, the error of the result value was slightly higher in the case of teeth due to cracks and teeth with cracks among the causes of tooth extraction used in the specimen.

In order to be used as a diagnostic model, 'accuracy' and 'precision' are essential. When looking at the results of the ICC of Unfilled group and Filled group, the degrees of agreement for both experimental groups are higher of more than 80% in both groups. In terms of precision, the high value of degree of agreement is enough to support the effectiveness of QLF device as a diagnostic tool. However, in the aspect of 'accuracy', the reliability is slightly inferior because red utility wax contains fluorescent dyes while blood does not.

The QLF device has been further developed in recent years. One of the limitations of this study is the heavy weight and poor mobility of QLF-D biluminator used for taking

the images. Qraycam (AIOBIO, Seoul, Republic of Korea) and Qraypen(AIOBIO) have been developed to improve convenience. However, their utilization in clinical practice has not yet been frequent because it is difficult to perform both photographing and analysis simultaneously. In addition, improvement of limitations of the analyzation program mentioned above and the image quality improvement of the simplified equipment are expected to be necessary. In this study, since only a few residual dentin thickness was evaluated, additional studies on various thickness would have to be conducted in order to obtain information about a more specific relationship between the residual dentin thickness and ΔF value. Furthermore, in order to apply the diagnostic model in the dentin-pulp area using QLF, in vitro studies using an advanced model that reproduces the actual pulp environment and in vivo studies should be performed for applying it to the actual clinical process.

V. Conclusions

In conclusion, residual dentin thickness and ΔF value that shows the loss of fluorescence are significantly correlated. Regardless of the person using the Q-ray device, ΔF value has a highly positive correlation with residual dentin thickness. The result of this study is significant because it demonstrates that one can measure residual dentin thickness using Q-ray device. Based on the findings of this study, it is expected that pulpal irritation due to excessive iatrogenic preparation of teeth can be prevented.

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Abstract (In Korean)

정량광형광기법을 사용한 잔존 상아질 두께 평가

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본 연구의 목적은 와동 형성 후 남은 잔존 상아질의 두께와 정량광형광기법(Quantitative Light-induced Fluorescence, QLF)의 분석값 과의 사이에 상관 관계가 있는 지 경향성을 알아보고, 임상에서 활용할 수 있도록 이들의 특성에 대해 자세히 알아보는 것에 있다.

연구에 사용된 표본 치아는 연세대학교 치과대학병원 인체유래물은행을 통해 분양을 받았으며 치아우식증, 수복물, 법랑질 저형성증, 상아질 저형성증을 가진 치아는 제외되었다. 결과적으로 얻어진 총 40개의 인간의 건전한 발거치를 6%의 차아

염소산나트륨(NaOCl)에 24시간 동안 보관한 후 치주큐렛을 이용하여 치주조직과 치석을 제거하였다. 이후 ‘Unfilled’ 그룹과 ‘Filled’그룹으로 나누어 각각 20개씩 배정하였다.

시편은 3D 프린터를 이용하여 제작한 40개의 레진 몰드(11 x 11 x14 mm)에 투명한 acrylic resin으로 치근이 잠기도록 하여 표본을 제작하였다. 제작된 표본을 치아 장축 방향으로 중앙에서 종단하여 치수강을 노출시킨 후 단면에서 가장 높은 치수부위를 기준점으로 설정하였다. 이후 기준점에서 상아질 두께가 3 mm가 되는 지점에서 치아를 low speed precision diamond saw를 이용하여 횡단하였다. 이후 절단된 평면을 QLF 이미지를 촬영하였으며 같은 방법으로 2 mm, 1 mm, 0.5 mm 두께에서 절단 및 촬영을 진행하였다. Filled 그룹에서는 Red utility wax를 비어 있는 치수강 내에 넣은 후 2 mm, 1 mm, 0.5 mm에서 Unfilled 그룹과 같은 방식으로 절단 및 촬영을 진행하였다. 촬영된 이미지는 Q-ray 소프트웨어를 통해 형광량 분석을 실시하였으며 분석의 결과가 평가자 간에 차이가 있는지 알아보기 위해 Unfilled 그룹과 Filled 그룹 모두 3명의 평가자가 각각 같은 표본의 이미지 분석을 실시하였다. 통계분석을 위하여 one-way analysis of variance와 Pearson Correlation Coefficient, Intraclass Correlation Coefficient, Bland-Altman graph를 시행하였다.

두 그룹 모두에서 표본의 치수강까지의 잔존상아질 두께가 줄어들수록 형광량 소실 값을 나타내는 ΔF 정도는 증가하였다. ANOVA 분석 결과 2 mm, 1 mm, 0.5 mm에서 값의 차이는 모두 통계적으로 유의차를 보였다. Unfilled 그룹에서는 평균값은 2 mm, 1 mm, 0.5 mm에서 0, -6.90, -10.14 를 보였으며 Filled 그룹에서는 평균값은 2 mm, 1 mm, 0.5 mm에서 -3.22, -7.84, -11.52 을 나타냈다. Filled 그룹의 ΔF 평균값은 Unfilled 그룹에 비해 상대적으로 일정한 증가량을 보였다. Pearson 상관계수 분석에서 잔존 상아질 두께와 ΔF 사이에 양의 상관관계를 보였다. Unfilled 그룹은 0.94, Filled 그룹은 0.77 의 값을 보였다. 급내 상관계수 분석에서는 Unfilled 그룹에서 0.92, Filled 그룹에서 0.83을 나타내며 이는 평가자 간의 약 92%, 83% 정도의 일치도

를 보이는 것을 의미한다.

결론적으로, 형광량의 소실도를 나타내는 ΔF 값은 잔존 상아질의 두께와 유의미한 연관성을 보인다. ΔF는 잔존 상아질 두께와 강한 양의 상관관계를 나타내며, 측정값은 QLF 장비를 이용하는 평가자 간의 높은 일치도를 보여주었다. 이를 토대로 QLF 장비를 통해 잔존 상아질 두께에 대한 평가가 가능할 것으로 생각되며 이는 치아의 불필요한 삭제로 인한 치수의 자극을 방지할 수 있을 것으로 기대된다.

핵심 되는 말 : 정량광형광기법(Quantitative Light-induced Fluorescence); QLF; 잔존 상아질 두께; 치수 생활력; 치수 상태;