

Quantitative Micro-CT Evaluation of Microleakage in Composite Resin Restorations

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Abstract

One of the most important and basic test of dental restorative materials is the evaluation of microleakage into the tooth-restorative interface. There are many techniques to test microleakage, but most of them have several disadvantages.

Recently developed microtomography(micro-CT) can provide the three dimensional image and information about the internal component in non-destructive way, therefore using micro-CT, it is possible to evaluate microleakage exactly in quantitative manner.

The purpose of this study is to find a new method for quantitative and non-destructive evaluation of microleakage in composite resin restorations using micro-CT and to compare the new method with conventional dye penetration method. Thus, microleakages of two kinds of dentin bonding systems were evaluated with above two methods.

40 extracted sound human premolars were randomly divided into two groups consisting of 20 samples and restored accordingly.

Group 1 : Class V resin restorations with Adper™ Singe Bond

Group 2 : Class V resin restorations with Adper™ Promp™ L-pop.

The Filtek™ Supreme was applied to the Class V cavities of all teeth. After that, 10 teeth from each group were applied to evaluation of microleakage using micro-CT, and other 10 teeth from each group were using conventional dye penetration method.

The conclusions of this study were as follow:

1. Using micro-CT, Group 1 showed significantly less microleakage than Group 2 and there was statistically significant difference($p < 0.01$) between two groups.
2. Using conventional dye penetration method, Group 1 leaked less than Group 2 and there was statistically significant difference($p < 0.01$) between two groups.
3. The difference between two groups is more evident in the method using micro-CT.
4. In all two methods, microleakage appeared more into the cavities to dentinal margins than enamel margins.

Key words : Microleakage, Micro-CT, Dye penetration, 3D image

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I. INTRODUCTION

One of the most important and basic test of dental restorative materials is their marginal integrity along the tooth restorative interface. The clinically undetectable passage of bacteria, fluids, molecules, or ions between the cavity wall and the applied restorative material has been defined as microleakage^{1,2)}. The inability of a restorative material to adapt or adhere tightly to dental hard tissue is what creates the gaps allowing microleakage to occur. Some of the sequelae of microleakage include tooth discoloration, accelerated deterioration of restorative materials, recurrent caries, pulp pathology and postoperative tooth sensitivity³⁻⁷⁾. There are many techniques to test microleakage. These include the use of dye penetration method, scanning electron microscope(SEM)⁸⁾, bacterial studies⁹⁾, electro-chemical method¹⁰⁾, fluid filtration and clearing technique¹¹⁾, and chemical and radioactive tracers¹²⁾.

Among them, dye penetration method is generally used for assessment of microleakage because it is easy to be used and scored with. But there are critical disadvantages in the dye penetration method. It is the destructive method as sectioning both teeth and the restorative materials, and a few 2D sectional surface images are evaluated as the whole microleakage of the tooth. Other methods are also impossible to analyze the exact portion or quantity of microleakage.

Therefore, in recent days, there were so much efforts of 3 dimensional quantitative evaluation of microleakage following the advance of computer systems and 3-dimensional analysis programs.

Recently developed microtomography(micro-CT) can provide the 3 dimensional image and information about the internal component with non-destructive way¹³⁻¹⁵⁾. Because of these properties, so many studies with micro-CT were performing in many kinds of fields including dentistry.

Micro-CT is a combination of tomographical reconstruction and x-ray microscopy¹⁶⁾. The micro-CT setup is similar to the commercially produced tomography systems for medical purposes, but in micro-CT, the object rotates instead of rotation of X-ray source or CCD camera. During rotation of the object, radiations are collected on CCD camera and after

that, the accepted shadow image is stored in computer. Special software package provides all system control and 3D reconstruction from 2D shadow projections. Results of reconstruction - set of thin virtual slices through the object - can be shown as a sequence of cross sections or combined into realistic 3D-image onto computer screen. Hence, using micro-CT, the 2D or 3D images of internal components of the object can be seen non-destructively up to μm units. And the image of particular density portion can be obtained by controlling X-ray source or reconstruction process¹⁷⁾. Moreover, by using computer program in micro-CT software, volume, surface, and mineral density of particular density portion can be analyzed¹³⁻¹⁵⁾.

Accordingly, there is capability of assessing microleakage of composite restoration using micro-CT, but there were few research about that at recent.

Santis RD et al.¹⁸⁾ reported that the quality of the dentin-adhesive-composite interfaces was evaluated by using the dual energy absorption X-ray micro-CT investigation technique with the synchrotron beam light and by reinforcing the visualization of silver nitrate leakage dentin-DBS interface. But in that study, there were some kinds of limits. For examples, the 'sectioned' tooth specimen were named as 'non-destructive' samples, and only the quality of the interfaces was evaluated for explaining general pattern of microleakage such as portion, shape, and quantity. In addition, these facilities are rather complicated and expensive and are not accessible for most researchers.

Cho and Shin¹⁹⁾ evaluated microleakage in class V resin restorations with micro-CT, but there were some kinds of errors in experimental process. In that study, the Ag particles were evaluated after the restored resin were removed with bur in low speed dental handpiece. But during resin removal, Ag particles might be removed also. And 3D images were obtained by the way of direct drawing on computer monitor as seeing 2D images.

Therefore, the purpose of this study is to find a new method for quantitative and non-destructive evaluation of microleakage in composite resin restorations using micro-CT, and to compare the new method with conventional dye penetration method. So microleakage of two kinds of dentin bonding sys-

tems(one-bottle system and self-etching system) were evaluated by using the new method(using micro-CT 3D image) and conventional dye(methylene blue) penetration method.

II. MATERIALS AND METHODS

1. Tooth selection & Preparation

Forty extracted caries-free human premolars were obtained from Seoul National University Dental Hospital. They were stored in saline solution until date of use. The root surfaces of the teeth were scaled to remove any remaining tissue and polished with pumice. Class V cavities(2.3mm diameter, 1.5mm depth) were prepared on the buccal surfaces at the cemento-enamel junction, half of the finishing lines within dentin, and the carvosurface walls finished to a butt joint. #8 round burs in a high speed dental hand-piece with copious water spray were used to prepare the cavities. And the 40 teeth were randomly divided into two groups with 20 teeth each, corresponding to the different restorative systems (Table 1).

Group 1 : Adper™ Single Bond(20 teeth)

The teeth were etched with 37% phosphoric acid for 15 seconds, followed by an air-water rinse of 5 seconds. Adper™ Single Bond was brushed on the etched enamel surface and vigorously air for 5 seconds and then light-cured for 20 seconds with visible light curing unit(Curing Light 2000, 3M dental product, USA).

Group 2 : Adper™ Prompt™ L-Pop(20 teeth)

According to the manufacture's instruction, Adper™ Prompt™ L-Pop was applied onto teeth surface with a saturated microbrush and rubbed in for 15 seconds. Thin air stream was then applied to create even, shiny film and was followed by a 10 sec-

onds polymerization.

Cavities of all groups were filled with Filtek™ Supreme(3M-ESPE, USA) by an incremental oblique technique²⁰⁾ and light cured for 20 seconds. All restorations were polished with disks(Sof-Lex™, 3M ESPE, USA) within 5 minutes after light polymerization. The restored teeth were stored in distilled water at 37 °C for 24 hours.

2. Thermocycling

All teeth were thermocycled in distilled water at between 5 °C~55 °C for 1000 cycles with dwell time of 30 seconds and a draining time of 10 seconds between cycles. After thermocycling, two layers of nail varnish were placed on the teeth surfaces except for 1mm around the restoration margin.

For the measurement of microleakage, 10 teeth from each groups were evaluated using micro-CT. Other 10 teeth from each groups were using dye penetration method.

3. Microleakage evaluation using micro-CT

The teeth were immersed in a 50 wt% ammonical silver nitrate solution(pH=9.5) for 24hrs. Ammonical silver nitrate was prepared by the dissolution of 25g of silver nitrate crystals(Sigma Chemical Co., St Louis, MO, USA) in 25ml of distilled water. Concentrated(28%) ammonium hydroxide(Sigma) was used to titrate the black solution until it became clear as ammonium ions complexed the silver into diamine silver ions([Ag(NH₃)₂]⁺). This solution was diluted to 50ml with distilled water, yielding a 50 wt% solution(pH = 9.5). Varnish-coated teeth were immersed in the tracer solution for 24 hrs as previously described²¹⁾.

Table 1. Dentin bonding agents used in this study

System	Compositions	Manufacture
Adper™ Single Bond	HEMA, polyacrylic acid, Bis-GMA, alcohol	3M-ESPE, USA
Adper™ Prompt™L-Pop	Liquid 1(red blister) : Methacrylated phsphoric esters. Bis-GMA, Initiators based on camphoroquinone, Stabilizers Liquid 2(yellow blister) : Water, HEMA, Polyalkenoic acid, Stabilizers	3M-ESPE, USA

The silver-impregnated teeth were then rinsed thoroughly in distilled water and placed in photodeveloping solution for 10 hrs under a fluorescent light to reduce the silver or diamine silver ions into metallic silver grains.

After removal from the photodeveloping solution, the teeth were rinsed with distilled water and the nail varnish on the teeth surfaces is removed with acetone for reducing the error caused by Ag on nail varnish.

A desktop micro-CT system Skyscan 1072(Aartseelaar, Belgium) was used for detecting the penetrated silver grains. It consists of microfocus sealed X-ray tube 20~80kV/100uA with 8 μ m spot size, a precision object manipulator for object rotation and movement inside the conical x-ray CCD-camera with field of view 20 \times 20mm. The CCD-camera pixel size is 1024 \times 1024 and the magnification ranges between 4.5~120. In this method, the authors determined the scanning conditions as following :

Magnification : 65

Exposure time : 10 seconds

Voxel size : 4.206 \times 4.206 μ m

Source : 80kV/100uA

Filter : Al 1mm

Spatial resolution : 8 μ m

Considering of the composite restoration size and the scanning view field, the optimal magnification size was 65. The voxel size is determined as the magnification.

And to detect silver particles exactly, we needed to increase the x-ray beam energy. At the low energy, the image of the tooth(enamel and dentin) is very obvious but silver grains is not clearly distinguished with resin or the teeth. The silver particles have very higher density rather than resin or tooth components, but in low x-ray beam energy, they had similar contrast with resin which in turn indistinguishable with resin. In this method, the author raised x-ray source energy for obtaining high radiographic density, contrast, and sharpness of silver particles image. The ways of raising X-ray energy are to increase tube voltage, current, or exposure time²²⁾. The exposure time was only possible to be increased on account of the character of that machine. The images at 5.9 second and 10.0 second(exposure time) are shown in Fig. 1. and Fig. 2. To obtain high sharpness of the image and reduced scattering, the aluminum 1 filter was used in this method.

After scanning, the attenuated data on CCD is changed 2D cross section images as a result of reconstruction. On this way, we could obtain the image of only silver grains for controlling the value of maximum and minimum reconstruction numbers. Controlling the reconstruction values, dentin, enamel and resin image are disappeared in sequence and finally the silver grains image is only remained (Fig. 3).

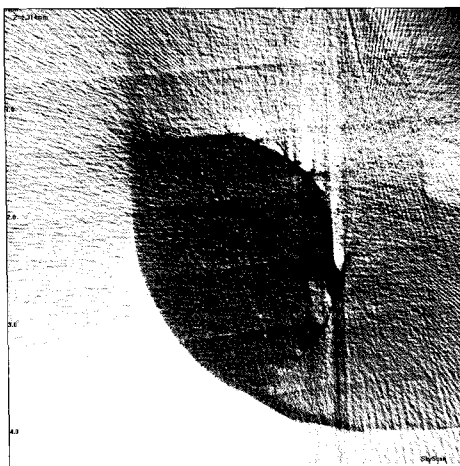


Fig. 1. 2D micro-CT image of group 2 in 5.9 seconds of exposure time.

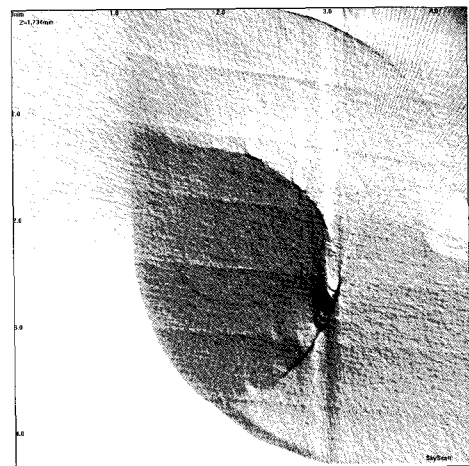


Fig. 2. 2D micro-CT image of group 2 in 10.0 seconds of exposure time.

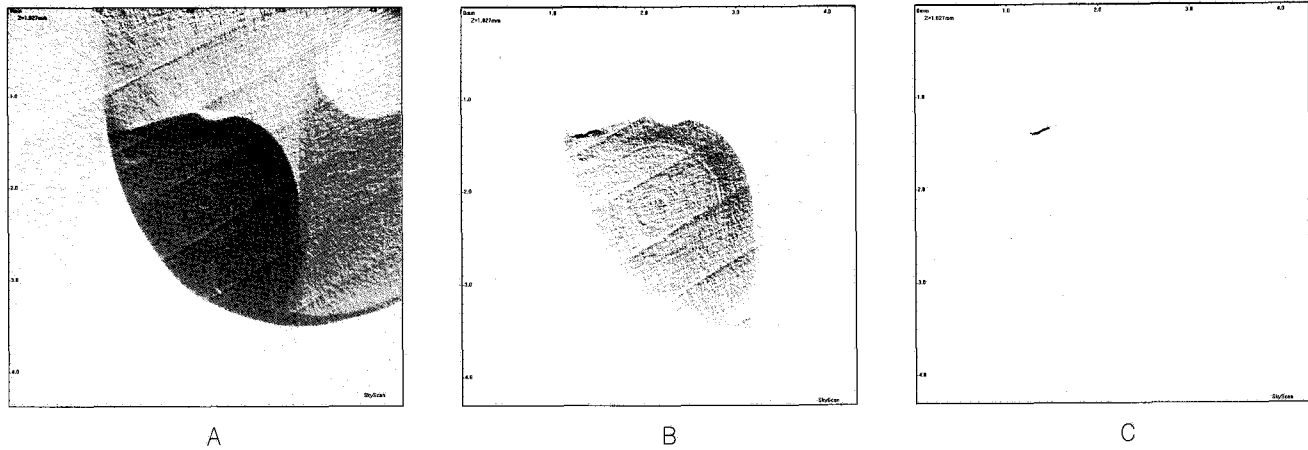


Fig. 3. Reconstruction process for obtaining Ag image of group 1 : A. Before reconstruction process, B. reconstruction for disappearing of tooth components, C. Final image after finishing reconstruction process for disappearing of resin.

The gaining images of the silver grains were made to realistic 3D images through the 3D image processing programs in the Skyscan 1072 system. And using this programs, we could calculate the volume of the penetrated silver particles, and evaluate the patterns of microleakage by observing the reconstructed 3D images. Calculated volume was defined as microleakage.

4. Microleakage evaluation using conventional dye penetration method

The teeth for dye penetration method were mounted in clear acrylic resin block. Then, the teeth were immersed in 1% methylene blue solution for 24 hours at 37 °C. Upon removal from the dye, the teeth were rinsed with distilled water and sectioned longitudinally in a buccolingual direction with a low-speed saw(Isomet™, Bueher, USA).

The depth of dye penetration was evaluated with an binocular stereomicroscopy(Olympus SZ-PT, Olympus Co, Japan) at ×25 magnification and scored as the following criteria :

- 0 = No dye penetration
- 1 = Dye penetration extending up to one-third the depth of the resin
- 2 = Dye penetration extending between one-third and two-thirds the depth of the resin
- 3 = Dye penetration extending over two-thirds of the resin

4 = Dye penetration extending underlying cavities

The data from this study was analyzed using the Statistical Package for Social Science(SPSS), Version 12.0. For the method using micro-CT, Mann-Whitney U-test was used and for the dye penetration method, Fisher's exact test was used to evaluate the statistical significance between the two groups.

III . RESULTS

1. Microleakage evaluation using micro- CT

Fig. 4 and 5 showed the 3D images of microleakage in the Group 1 and 2. Comparing the microleakage volume of the two groups, Group 1 showed significantly lower mean value than Group 2 and there was statistically significant difference($p < 0.01$) between Group 1 and Group 2(Table 2 and Fig. 6). Showing Fig. 4 and 5, we could notice that microleakage of enamel margin is less than that of dentin margin in all groups optically. That figures showed the general pattern of the microleakage such as surface shape, penetration portion, and etc.

2. Microleakage evaluation using dye(methylene blue) penetration

The microleakage scores and mean values of the two groups are listed in Table 3 and 4. Group 1 leaked less than Group 2 and there was statistically

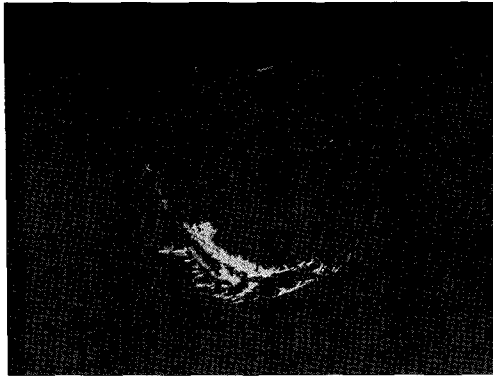


Fig. 4. 3D image of microleakage in Group 1(Adper™ Single Bond).

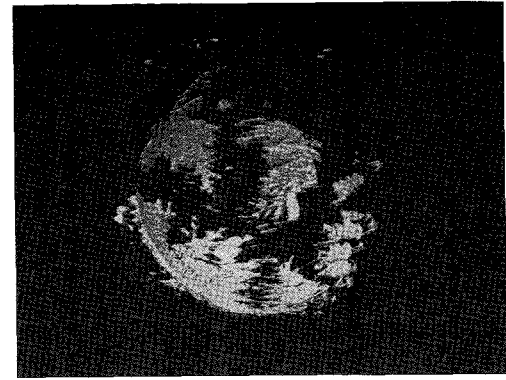


Fig. 5. 3D image of microleakage in Group 2(Adper™ Prompt™ L-Pop).

Table 2. Mean volume in microleakage evaluation using micro-CT

Adhesive System	Mean(cubic mm)	SD
Group 1	0.00351806	0.00540947
Group 2	0.09364218	0.12517898

Table 3. Frequency of microleakage score in each group

Score	Frequency in Group 1	Frequency in Group 2
0	4	1
1	9	5
2	3	0
3	2	2
4	2	12
Total	20	20

Table 4. Mean scores in in microleakage evaluation using dye penetration

Adhesive System	Mean	SD
Group 1	1.45	1.234
Group 2	2.95	1.468

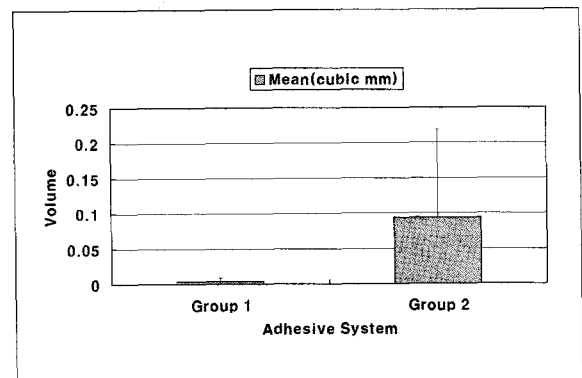


Fig. 6. Mean volume in microleakage evaluation using micro-CT.

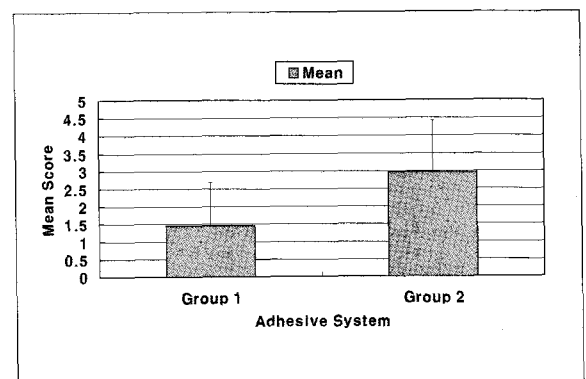


Fig. 7. Mean scores in in microleakage evaluation using dye penetration.

significant difference($p < 0.01$) between two groups. But, in the evaluation method using micro-CT, the

differences between two groups was more serious (Fig. 6 and 7) than using dye penetration method.

IV. DISCUSSION

The goal of this study was to demonstrate a new method for evaluating microleakage quantitatively with micro-CT. There are so many methods for evaluating microleakage of composite resin restorations, but with none of them, microleakage can be evaluated exactly. At present, there is no method of assessing the total volume or quantity, exact portion and shape of the microleakage completely.

Micro-CT allows reconstructing the internal three-dimensional microstructures of the objects without any preparation, non-destructively¹³⁻¹⁵. And using the 3-D reconstruction programs in the micro-CT software package, 2-D sliced x-ray images is changed into the realistic 3-D images and the various values such as volume, surface, mineral density, volume fraction, degree of anisotropy, and etc., are able to be calculated¹³. So the authors devised the idea of detecting and imaging Ag grains which were penetrated into the tooth-composite interface with micro-CT.

Silver nitrate staining is one of the most commonly used methods for microleakage evaluation. Because Ag⁺ ions has much high atomic number(47), high density and very small grain size(3~5 nm), it has been used in nanoleakage evaluation using SEM. In this study, Ag⁺ ions had much higher density than composite resin or tooth components as to be applied in micro-CT scanning and it provided sharp X-ray pictures(Fig. 2) of penetration at tooth-restoration margin.

Leakage patterns in the systems using conventional 50 wt% silver nitrate solution(pH=4.2) are artifacts caused by mineral dissolution in mildly acidic silver nitrate²¹. So basic 50 wt% ammonical silver nitrate solution(pH=9.5) was used in this study²¹.

According to the study of R. Santis et al.¹⁸, Ag penetrates the dentin-adhesive interface, while, in the adhesive-composite interface, there are no appreciable penetrations in most of the samples. Ag may reach an internal point of the dentin-dentin bonding system(DBS) interface following two different paths : leakage through not conditioned dentin and leakage through the hybrid layer, i.e. the dentin adhesive interface itself. The extent of Ag penetration is higher in the hybrid layer in which the depth is about 300

μm. And localized Ag penetration was showed at the DBS-dentin interface rather than the DBS-composite interface. It suggested that the adhesive is not so effective in sealing the demineralized dentin. Therefore, from a clinical point of view, the observed leakage may represent potentially critical pathways for bacteria or bacterial metabolic materials penetration leading to premature failure of the dental restoration¹⁸.

If the image scanning of the object is performed under low exposure time, it is too difficult to detect only silver grains. The first reason is that not as silver particles but also resin are fined to have similar density so Ag particles are overly detected. Second reason is that, in 2D reconstruction image it is difficult to detect only Ag by controlling reconstruction values. That is, during reconstruction process, Ag portion is disappeared with resin image or Ag image is mixed with resin image, and Ag may be more over or under evaluated than real value. In this study, increasing exposure time led to increase in X-ray source energy and the high contrast between Ag and resin could be acquired as result.

After that, through controlling the reconstruction value(maximum and minimum), dentin, enamel, and composite resin image was made to be disappeared in sequence, and finally remained image would be Ag portion. The control of minimum value had a role to disappear lower density materials than Ag, and maximum value was used for increasing radiographic density, contrast, and sharpness of silver portion image(Fig. 3, 4, and 5). The final minimum value were determined as the value just after disappearing resin image by raising minimum value in order, and the final maximum value was determined as 0.01 higher than minimum value. Reconstruction values of micro-CT are variable according to the several conditions such as object density, magnification, X-ray energy(in this system, especially exposure time), and filter type, and etc. Accordingly, if these conditions are changed, optimal reconstruction values are also changed. In this study, final reconstruction values were not changed and the same values were applied to all teeth because these conditions were maintained.

Usually, it is better using no filter for raising X-ray source energy, but in this study, the authors used

aluminum 1 filter. The reason lies in that using no-filter provided lower image sharpness than using Al 1 filter.

Nevertheless, the image of the tooth component was not clear as seeing Fig. 3. The reason is not also increased x-ray energy but the mechanical problem of skyscan 1072 system. In this study, the maximum magnification was needed for calculating exact microleakage volume, but skyscan 1072 could not accept the clear image of specific part (around the cavity) of the big object (tooth). But Ag image is not distorted because of central position and high density of itself. For solving this problem, multilayer tomosynthesis concept²³⁾ was required. Multilayer tomography based on the local irradiation of the specific part of the big planar object by inclined x-ray beam with data acquisition by synchronous rotation of the object and the detector. With such x-ray geometry one can investigate any big planar object locally part by part. And modern digital technique allows improving several important details in classical laminographic methods. All projection images during one complete object turn can be collected now directly into the computer memory without camera rotation. Instead of physical camera rotation, the images can be rotated in the computer memory. By this way the multilayer separation can be done in once just by re-rotation of initial images around corresponding points. Image rotation in the computer memory can be done more accurate than coplanar mechanical camera rotation and don't need complicated and precious mechanics. But, multilayer tomography and digital microlaminography system is needed very high-cost equipments. In this study the distortion may be reduced by decreasing magnification, but also it could have effect such as the increase in pixel size (19.53 μm in 14 magnification) and decrease in resolution.

Accepting high-energy x-ray, raising tube voltage and current had to be attained but it is not easy in skyscan 1072 system. However, according to the information of the company, in order to study high-density materials the system can be supplied with a 130kV/300uA sealed tube.

In this micro-CT system, spatial resolution is limited by the X-ray spot size. So the attainable resolution is in the order of 8-10 μm . On the other hand,

the size of micro-organs such as *Mutans streptococci* is 0.5~0.75 μm and the size of silver grains is about 3~5 nm. For more exact evaluation, it will be needed to develop the new machine system that x-ray spot size so small as to obtain similar resolution to the size of micro-organs. But these limitations of micro-CT were no matter in comparing study like this study because of using the same scanning and reconstruction condition. With the steady technological improvement one can expect submicron X-ray sources in the coming years.

Thermal change is the critical fact that causes microleakage²⁴⁾. On the other hand, mechanical load cycling is very less influence on microleakage than thermo-cycling^{25,26)}. Hence, thermo-cycling was only performed for basic load in this study.

There were so many studies to compare microleakage between one-bottle or total etching system and self-etching system. The studies about microleakage in enamel margin, most results showed that there was no significant difference between two systems, and even Prompt L-pop showed the lowest microleakage scores in some studies. Hannig M et al²⁷⁾, found the high rates of perfect marginal adaptation when self-etching agents were used on enamel, and Pontes et al.²⁸⁾ reported that all-in-one adhesive was lower scores of microleakage than one-bottle system in enamel margin and Prompt L-pop had the minimum microleakage scores. That reason was that the acidic monomer in Prompt L-pop consisted of diesters of methacrylate phosphoric acid monoester and it had enough low pH to demineralize enamel²⁹⁾. Prompt L-pop had the lowest pH in the several all-in-one systems (pH 1.17)³⁰⁾.

On the other hands, the studies about dentinal leakage showed various results. Santini and Mitchell³¹⁾ evaluated three recent dentin-bonding agents and documented that there was no significant difference between self-etching adhesives and one-bottle adhesives. Cardoso et al.³²⁾ reported that the self-etching adhesives revealed similar leakage scores in dentin when compared to one-bottle systems and were similar to a previous in vitro microleakage experiment. Gagliardi and Avelar³³⁾ documented that there was no significant difference between one-bottle adhesives and self-etching adhesives in dentin/cementum margin, and Prompt L-pop produced the lower scores

than Single Bond. Gagliardi and Avelar³³⁾ explained the reason of the results as two facts. One is that self-etching adhesives are less sensitive to water because water is an essential components of Prompt L-pop so the water may improve the Prompt L-pop adhesive behavior. Another reason is that the lower pKa of Prompt L-pop is sufficient to etch beyond the smear layer and demineralize the underlying intact dentin with the formation of an authentic hybrid layer³⁴⁾. Atash and Abbeele³⁵⁾ documented that Prompt L-pop showed the lowest microleakage in both enamel and dentinal margin among the 7 kinds of self-etching adhesives, and the reason was in the low pH and water solvent.

But, Swift and Bayne³⁶⁾ reported that the self-etching adhesive which had water solvent, showed higher microleakage in dentinal margin because the water was evaporated so slow compared with the acetone or alcohol solvent as to drop the concentration of HEMA filled in collagen reticular fibers. Telles et al.³⁷⁾ fined the gap in the Prompt L-pop-dentin interface with SEM, and explained the reason as that the low pH of Prompt L-pop interfered with polymerization of the resin monomer and so the hybrid layer could be formed. And Pradelle Plasse et al.³⁸⁾ reported that Prompt L-pop showed the highest score of microleakage in dentinal margin because it had no fillers.

Summarizing the above studies, the results compared one-bottle adhesives(Single Bond) with self-etching adhesives(Prompt L-pop) were very various. There are many reasons to that variety, but one of the main reason lied in that the dye penetration and scoring method was selected for evaluation of microleakage. That is, the results were led from a few 2D-sectional images.

In this study, significant difference was showed between two groups in all two evaluation methods, but the difference is clearer in the method using micro-CT. The reason lies in that the result of the micro-CT evaluation is from the 3D images evaluation, or the sum of the results from 2D images. In addition, Fig. 6 and 7 showed that significant more quantity of microleakage of Prompt L-pop adhesive system was occurred not only in dentinal margin but also enamel margin contrary to the existing studies. Other 3D images showed similar patterns.

3D image from micro-CT also showed the facts as following :

- (1) Much quantity of microleakage was came out in the Group 2 compared with Group 1.
- (2) The main portion of microleakage from both Group 1 and Group 2 is dentinal- carvosurface margin of the cavities, but other 3D images showed various pattern of it.

The limit of the new method in this study is much due to mechanical problems of Skyscan 1072 system, but it will be solved with new-developed micro-CT systems.

Recently developed Skyscan 1172(Aartselaar, Belgium) system has higher spatial resolution (a nominal resolution (pixel size) of lower than 1 μ m with 10Megapixel camera), tube voltage(100kV), and tube current(250uA) compared with 1072 system. And in 1172 system, multilayer tomosynthesis concept was applied. The most recently developed Skyscan 2011(Aartselaar, Belgium) has very high resolution until nano unit so using it, microleakage volume can be evaluated more exactly. Actually, it should be named as the method for evaluation of nanoleakage.

The new method using Micro-CT for evaluation of microleakage compared with the conventional dye penetration method has several advantages as follows:

First, it is perfectly quantitative and completely none-destructive method, and is capable of repetitive evaluation with same teeth. In this study, there were no teeth to be sectioned with saw. Second, it is possible the direct visual recognition of the general informations of microleakage such as 3D image shape, portion, volume and surface of microleakage. Finally, because quantity of microleakage is evaluated by computer program, it is more objective and accurate than conventional method.

In summary, existing evaluation method with dye penetration is inaccurate and imperfect for assessing of microleakage exactly, and a new method with micro-CT in this study proposes the capability of exact and quantitative evaluation of microleakage patterns in many kinds of restorations including several dentin bonding systems(sealant, class I~VI resin restorations, glass ionomer restorations, etc.)

V. CONCLUSION

The purpose of this study was to evaluate microleakage of composite resin restoration quantitatively with a new method using micro-CT, and to compare the method with the conventional dye penetration method. The conclusions were as follows:

1. Using micro-CT, Group 1 showed significantly less microleakage than Group 2 and there was statistically significant difference($p < 0.01$) between two groups.
2. Using conventional dye penetration method, Group 1 leaked less than Group 2 and there was statistically significant difference($p < 0.01$) between two groups.
3. The difference between two groups is more evident in the method using micro-CT.
4. In all two methods, microleakage appeared more into the cavities to dentinal margins than enamel margins.

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국문초록

Micro-CT를 이용한 복합 레진 수복물 미세 누출도의 정량 분석

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치과 수복 재료 검사 시 가장 중요하고 기본적인 것은 치아와 수복물 사이의 미세누출에 대한 평가이다. 미세 누출을 평가하는 방법은 여러 가지가 있지만 이들 대부분은 많은 단점들을 가지고 있다.

최근에 개발된 미세 단층촬영법(micro-CT)을 이용하면 시편을 비파괴적으로 처리하여 특정 밀도에 해당하는 부분의 3차원적 영상을 얻을 수 있으므로, 이를 이용하면 정확하고 정량적인 미세누출 평가도 가능할 것이다.

이 연구의 목적은 micro-CT를 사용하여, 레진 수복물의 미세 누출도를 정량적이고 비파괴적으로 측정할 수 있는 새로운 방법을 찾아내고, 이 새로운 방법을 기존의 색소 침투법과 비교해보는 것이다. 이를 위해, 위의 두 가지 방법을 사용하여 두 종류의 상아질 접착 시스템의 미세누출도가 평가되었다.

사람의 건전 소구치 40개를 임의로 20개씩 두 군으로 나누고 다음과 같이 처리하였다.

Group 1 : Adper™ Singe Bond 사용 후 제 V급 와동 레진 수복

Group 2 : Adper™ Promp™ L-pop 사용 후 제 V급 와동 레진 수복

모든 치아의 5급 와동은 Filtek™ Supreme으로 수복하였다. 그 후 각 군 중 10개의 치아는 micro-CT를 사용하여 미세 누출도를 평가하고, 나머지 10개는 기존의 색소 침투법으로 평가하였다.

이 연구의 결과는 다음과 같았다.

1. Micro-CT를 사용한 경우, 1군은 2군보다 통계적으로 유의성 있게 적은 양의 미세 누출을 보였다($p < 0.01$).
2. 기존의 색소 침투법을 사용한 경우에서, 1군은 2군보다 적은 미세누출을 보였으며 이는 통계적으로 유의성이 있었다($p < 0.01$).
3. 두 군간의 미세 누출도는 micro-CT를 사용한 방법에서 더 현저한 차이를 보였다.
4. 두 가지 방법 모두에서 법랑질 변연 부분보다 상아질 변연 부분에서 더 많은 미세 누출을 보였다.

주요어 : 미세누출, 미세전산화단층촬영(micro-CT), 색소 침투법, 3차원 영상