

**The Effect of Hydroxyapatite on
Bonding Strength in Light Curing
Glass Ionomer Dental Cement**

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The Effect of Hydroxyapatite on Bonding Strength in Light Curing Glass Ionomer Dental Cement

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Abstract

The Effect of Hydroxyapatite on Bonding Strength in Light Curing Glass Ionomer Cement

The mineral phase of bone and teeth is mainly hydroxyapatite. Currently, numerous researches are being conducted on the effect of the addition of hydroxyapatite to dental materials. Among them, several reported that the addition of hydroxyapatite to composite resin or glass ionomer cement resulted in an improvement in bonding strength and physical properties, but none examined the effects of the addition of hydroxyapatite to light curing glass ionomer cement. Therefore, this study will investigate the effect of adding hydroxyapatite to light curing glass ionomer cement on bonding strength. Two different light curing glass ionomer cement products were selected (Fuji II LC, GC Co., Japan and Vitremer™, 3M/ESPE, USA) and hydroxyapatite was mixed into the light curing glass ionomer cement at various ratio to create a hydroxyapatite-light curing glass ionomer cement mixture. In order to confirm that hydroxyapatite-light curing glass ionomer cement met the basic requirements of dental materials, sensitivity to ambient light,

depth of cure, and flexural strength were tested. From the results of the above mentioned tests, the hydroxyapatite-light curing glass ionomer cement with the most superior physical properties for each product (15% hydroxyapatite-Fuji II LC, 20% hydroxyapatite-Vitremer™) was bonded to natural teeth and then immersed in artificial saliva at 36.5°C for four weeks. Finally, the sectioned surface was observed under SEM after measuring the bonding strength of each specimen. As the hydroxyapatite content increased, the depth of cure decreased. However flexural strength increased and there was not much change in the sensitivity to ambient light. Bonding strength, which was the main focus of this study, increased with the addition of hydroxyapatite, and scanning electron microscope findings show a more cohesive type of fracture in the material with bone like apatite material formation along the tooth-material interface.

Keywords: Hydroxyapatite, Light curing glass ionomer cement, Bonding strength

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I. Introduction

The use of amalgam as a restorative material has been on a decline in recent years, and this can be attributed partly to the public's concern regarding the controversy on its safety (Widstrom E et al., 1992). There is now a trend towards the use of tooth-colored restorative materials, particularly composite resin (Fross H and Widstrom E, 2001). However, concerns about the estrogenicity of bisphenol-A (BPA) and other aromatic components leached from bis-GMA-based composites have been expressed (Imai Y et al., 2001). Another alternative restorative material is glass ionomer cement (GIC), which is known for its relative

ease of use, chemical bonding to the tooth substrate, fluoride ion release and recharge, low coefficient of thermal expansion, and acceptable esthetic quality (Naasan MA and Watson TF, 1998). GIC is also biocompatible with pulp tissue (Six N et al., 2000) and primary cultures of bone cells (Oliva A et al., 1996). In the clinic, however, the use of GIC is limited due to its relatively inferior mechanical properties and sensitivity to initial desiccation and moisture (Mount GJ, 1999). To overcome these problems, attempts have been made to combine glass-ionomer chemistry with the well-known chemistry of composite resin. Light curing glass ionomer cement (LC GIC) was developed in the 1980s to improve the toughness, speed of setting, and resistance to dehydration of conventional GIC while maintaining its properties - fluoride release over a prolonged period, specific adhesion to enamel and dentin, esthetics. Currently, LC GIC has a variety of clinical applications as it has superior physical properties to conventional GIC, and is more biocompatible than resin. However, it has certain limitations in that secondary dental caries may occur due to microleakage and that restorations lack adequate retention. Therefore, the need to increase the bonding strength and physical properties of LC GIC while maintaining its biocompatibility arose. Recently there are

studies being conducted on the effect of the addition of hydroxyapatite(HA) to various dental materials in an attempt to improve the physical properties. The use of HA in restorative dentistry offers several promising advantages, including intrinsic radiopaque response, enhanced polishability, and improved wear performance, because synthetic HA has a hardness similar to that of natural teeth. The main disadvantage of HA is its high refractive index when compared to those of light-activated polymers normally used in dental restoration(Labella R et al., 1994). Therefore, synthetic HA seems to be a suitable choice as inorganic fillers for dental restorations or bone implants. In addition, this material is less expensive than most inorganic fillers used today (Domingo C et al., 2001). A recent study showed that the addition of HA to conventional GIC and composite resin improved bonding strength and physical properties(Arcris RW et al., 2002), but so far there has been no study regarding the effect of the addition of HA to LC GIC. Therefore, this study introduced HA into LC GIC as the reinforcing filler. The aim of this study was to investigate the effect of adding bioactive HA to LC GIC on bonding strength.

II. Materials and Methods

1. Materials

Commercially available LC GIC and HA were purchased to prepare mixtures of light curing cement and HA. Fuji II LC(GC Co., Japan) and Vitremer™ (3M/ESPE, USA) were selected in this study(Fig. 1) with a light curing source (Elipar™ FreeLight, 3M/ESPE, USA) (Fig. 2).

Calcium phosphate tribasic(Sigma-Aldrich Inc., USA) was the HA powder of choice. Its molecular formula is $\text{Ca}_5(\text{OH})(\text{PO}_4)_3$ and has a molecular weight of 502.3. The HA powder used in this study was primarily in the form of aggregates of hexagonal column crystals(0.3-0.5 x 2-3 μm) with an average particle diameter of 5-10 μm .



(a)Fuji II LC(GC Co., Japan) (b)Vitremer™ (3M/ESPE, USA)

Fig. 1. Light curing glass ionomer cements used in this study.



Fig. 2. Light curing device (Elipar™ FreeLight) used in this study.

2. Methods

A. Preparing of HA-LC GIC

Two different LC GIC products(Fuji II LC(FC), VitremerTM(VM)) were used in this study and various ratios of glass powder ranging from 5% to 35% of weight were replaced by HA. The glass powder and HA powder were hand-mixed before the liquid was added as per the manufacturers' recommendations. The recommended powder-liquid ratio is 2 for FC and 1 for VM. Original FC and VM were used in the control group, and the test groups were HA-FC, HA-VM, respectively, according to the HA content and material used.

Table 1. Sample identification of light curing glass ionomer cement.

Fuji II LC	VitremerTM	wt% of HA
Control	Control	0
HA-FC 5	HA-VM 5	5
HA-FC 10	HA-VM 10	10
HA-FC 15	HA-VM 15	15
HA-FC 20	HA-VM 20	20
HA-FC 25	HA-VM 25	25
HA-FC 30	HA-VM 30	30
HA-FC 35	HA-VM 35	35

B. ISO Basic test

The depth of cure, sensitivity to ambient light, and flexural strength, which are the necessary requirements for dental water-based light activated cements, were determined under regulations of ISO 9917-2:1998(E). They were tested using pure LC GIC, 5~35% HA mixed LC GIC, keeping the constant liquid powder ratio.

(1) Depth of cure

HA-LC GIC was condensed into a mold (6mm long and 4mm in diameter) and was then pressed between two matrix strips and two glass plates. The glass plate covering top of the mold was removed and the exit window of light curing unit was gently placed on the matrix strip covering the mold. And then, the HA-LC GIC was cured for 20s recommended by the manufacturer. After curing, the specimen was gently removed from the mold and uncured portion was removed with knife. The height of cured portion was measured with micrometers, and was divided by two.

(2) Sensitivity to ambient light

Thirty milligrams of HA-LC GIC was placed as a spheroid mass on a glass slide and exposed for 30 seconds to a Xenon lamp, which provided an illuminance of 8,000 lux. The glass slide with the sample was then removed from the illuminated area and a second microscope slide was immediately pressed against the material with slight shear action to produce a thin layer. The HA-LC GIC was visually inspected to see whether it was homogeneous with no discernible voids or defects. The whole procedure was repeated twice using new samples of HA-LC GIC for each test.

(3) Flexural strength

Specimens with dimensions of (25x2x2)mm were prepared using stainless-steel split molds(Fig. 3). Material was packed into the mold which was placed on a polyester film. A second polyester film was placed on the material and was covered with a glass plate. Pressure was applied to express excess material. And then, the light curing unit was placed at the center of the specimen, which was irradiated for 20s. After curing, the assembly was placed in the water bath maintained at 37°C for 15 min. The specimen was then removed from the mold and stored in distilled water at 37°C for 24 hours before testing. And then, a load was applied to the specimen at a crosshead speed of 0.75mm/min with the testing machine(Instron, UK) until the specimen fractured. The applied load was recorded when the specimen fractured and the flexural strength(σ) was calculated in MPa using the following equation(ISO 917-1998(E)).

$$\sigma = 3FI/2bh^2$$

F = the maximum load applied (N)

I = the distance between the supports(mm)

b = width of the specimen(mm)

h = height of the specimen(mm)

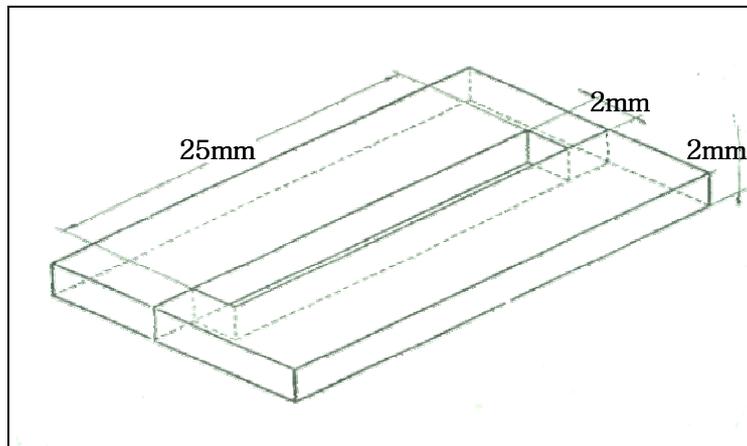


Fig. 3. Specimen mold for flexural strength (mm)

C. Bonding strength

From the results of three basic tests, the HA-LC GIC with the best physical properties (HA-FC 15%, HA-VM 20%) was chosen as the experimental group and its bonding strength was compared to that of conventional LC GIC. In order to measure the bonding strength, twenty permanent third molar were collected from the Department of Oral Maxillofacial Surgery at Yonsei Dental Hospital in Seoul, Korea. All the teeth were stored at room temperature in a 0.9% sodium chloride solution for up to one week before preparation for the bonding tests, and were embedded in cylindrical epoxy-resin molds (25x25x25mm), with the intended site for bonding facing the bottom of the mold. The embedded specimens were ground flat perpendicular to the long axis of each tooth until the exposed enamel or dentin surface was large enough to bond a cylinder of restorative material(Fig 4, a). The exposed surface was then etched with 35% phosphoric acid, removing the smear layer. A total of four groups were set up; two control groups consisting of original FC and original VM, and two experimental groups including HA-FC 15% and HA-VM 20%. Five specimens were produced for each group. Each cylindrical mold (6mm in diameter, 6mm in height)

was placed on the etched tooth surface and the material was poured into the mold. The cylindrical specimens were attached to the tooth surface by light curing for 20 seconds (Fig 4,b). Afterwards, the assembly was immersed in artificial saliva at 36.5°C. After four weeks, the cylindrical specimens were loaded by a metal rod on a testing machine (Instron, UK) in a direction perpendicular to the long axis at 1mm/min until fracture occurred. The shear bonding strength was calculated as the ratio of fracture load and bonding area, and was expressed in MPa.



(a)



(b)

Fig. 4. Samples for the investigation of bonding strength.

D. Surface observation by SEM

After measuring the shear bonding strength using the Instron, the fractured surface of the specimens were observed under various magnifications using an SEM (Hitachi S-800, Japan).

E. Statistic analysis

Statistically significant differences were analyzed using the one-way ANOVA, Duncan's Multiple Range Test at $p=0.05$, and student t-test. One-way ANOVA determines if a statistically significant difference exists between each group, and if the P value was less than or equal to 0.05 it was considered as statistically different. Duncan's Multiple Range Test means that the same letters are not statistically different. Student t-test is a method of comparing significant differences between two groups and in this study it was used for shear bonding strength. Also one way ANOVA and Duncan's Multiple Range Test were used for curing depth and flexural strength. The data were summarized as mean and range.

II. Result

1. ISO Basic test

A. Depth of cure

As the HA concentration increased, the curing depth of the HA-added specimens decreased (Table 2, 3, Fig.5). The statistical analysis methods used were one-way ANOVA and Duncan's multiple range test. There was statistical significance between the groups (FC: $P < .0001$, VM: $P < .0001$). Nevertheless, all samples containing HA, regardless of the amount, satisfied the requirements of ISO 9917-2:1998(E) curing depth.

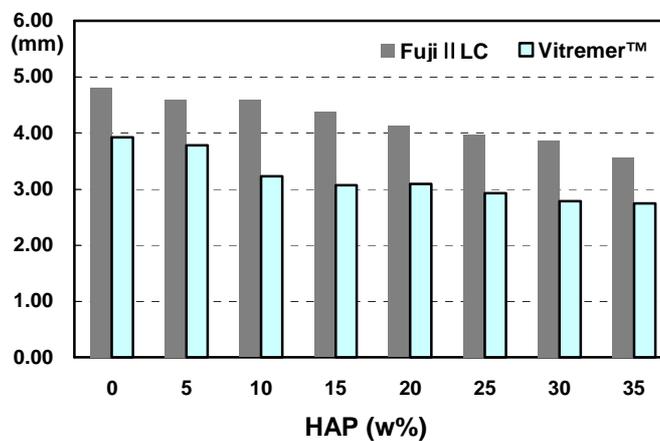


Fig.5. Curing depth

Table 2. Curing depth of Fuji II LC according to ratio of HA

HA (wt %)	Control (n=5)	HA- FC 5 (n=5)	HA- FC10 (n=5)	HA- FC15 (n=5)	HA- FC20 (n=5)	HA- FC25 (n=5)	HA- FC30 (n=5)	HA- FC35 (n=5)
Mean	4.81	4.59	4.59	4.37	4.12	3.98	3.86	3.56
±SD(mm)	±0.39 ^a	±0.11 ^{ab}	±0.14 ^{ab}	±0.16 ^{bc}	±0.17 ^{cd}	±0.19 ^{de}	±0.13 ^e	±0.10 ^f
One-way ANOVA	P< .0001							

a · b · c · d · e · f : Statistical grouping by Duncan's multiple range test(p=0.05)

Table 3. Curing depth of Vitremer™ according to ratio of HA

HA (wt%)	Control (n=5)	HA VM5 (n=5)	HA- VM10 (n=5)	HA- VM15 (n=5)	HA- VM20 (n=5)	HA- VM25 (n=5)	HA- VM30 (n=5)	HA- VM35 (n=5)
Mean	3.92	3.78	3.23	3.07	3.09	2.93	2.79	2.75
±SD(mm)	±0.31 ^a	±0.13 ^a	±0.36 ^b	±0.16 ^{bc}	±0.12 ^{bc}	±0.06 ^{cd}	±0.12 ^d	±0.06 ^d
One-way ANOVA	P< .0001							

a · b · c · d : Statistical grouping by Duncan's multiple range test(p=0.05)

B. Sensitivity to ambient light

At all concentrations of HA-LC GIC, homogeneity was maintained after the completion of the test with no clefts or voids. There was not much change in sensitivity to ambient light.

C. Flexural strength

Flexural strength gradually increased up to 15% in HA-FC and 20% in HA-VM and decreased afterwards (Table 4,5, Fig.6). Fuji II LC achieved 32.25MPa at 15% HA, and Vitremer™ achieved 53.65MPa at 20%, showing an increase in strength compared to the control groups. This signifies that the experimental and the control groups each belong to different groups in Duncan's grouping and that the increase in strength was statistically significant. Also statistical significance was observed between each of the groups using one way ANOVA (FC: $P=0.0083$, VM: $P=0.0023$).

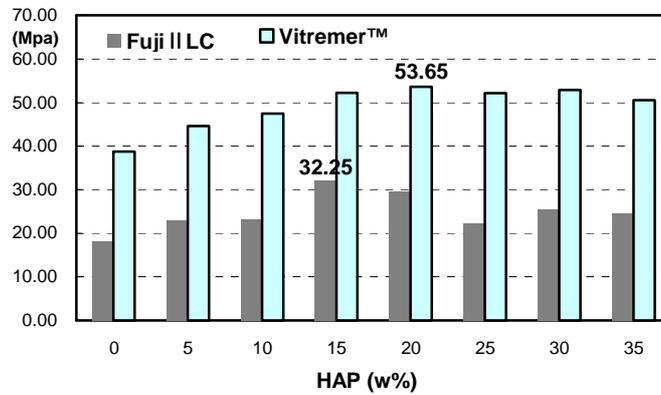


Fig. 6. Flexural strength

Table 4. Flexural strength of Fuji II LC according to ratio of HA

HA(wt%)	Control	HA- FC 5	HA- FC10	HA- FC15	HA- FC20	HA- FC25	HA- FC30	HA- FC35
	(n=5)	(n=5)	(n=5)	(n=5)	(n=5)	(n=4)	(n=4)	(n=4)
Mean	18.15	23.12	23.13	32.25	29.60	27.86	31.01	29.48
±SD(MPa)	± 4.67 ^c	±4.98 ^{bc}	±4.04 ^{bc}	±7.42 ^{ab}	±8.52 ^{ab}	±4.63 ^{ab}	±1.85 ^{ab}	±6.43 ^a
One-way ANOVA	0.0083							

a · b · c : Statistical grouping by Duncan's multiple range test(p=0.05)

Table 5. Flexural strength of Vitremer™ according to ratio of HA

HA(wt%)	Control	HA VM5	HA- VM10	HA- VM15	HA- VM20	HA- VM25	HA- VM30	HA- VM35
	(n=5)	(n=5)						
Mean	38.73	44.59	47.47	50.57	53.65	51.16	51.92	50.64
±SD(MPa)	± 2.97 ^c	±7.24 ^{bc}	±7.11 ^{ab}	±4.34 ^{ab}	±4.33 ^{ab}	±5.75 ^{ab}	±6.37 ^{ab}	±1.85 ^a
One-way ANOVA	0.0023							

a · b · c : Statistical grouping by Duncan's multiple range test(p=0.05)

2. Bonding strength

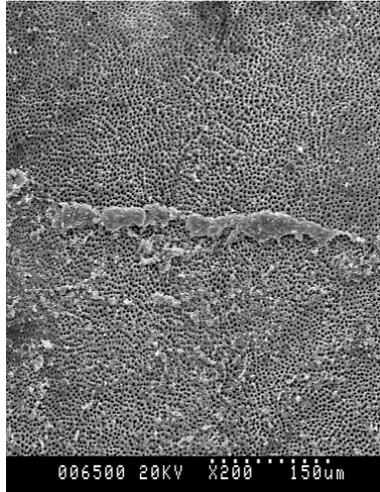
Compared to the control group, both 15% HA-FC and 20% HA-VM showed an increase in bonding strength (Table 6). Analysis using the student t-test showed a statistical significance between the experimental and control group. (FC : P=0.0064, VM : P =0.0018)

Table 6. The bonding strength between HA-LC GIC and the teeth

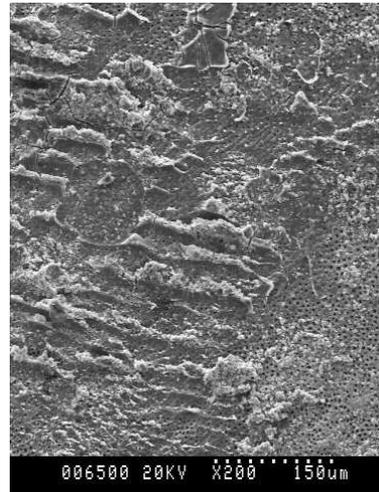
	HA-FC 0 (n=5)	HA-FC 15 (n=5)	HA-VM 0 (n=5)	HA-VM 20 (n=5)
Mean±SD	29.03	34.56	22.62	32.25
(MPa)	±2.13	±2.62	±4.22	±2.05
P value	0.0064		0.0018	

3. Surface microstructure observation by SEM

All of the specimens, both the control and the HA-LC GIC group, presented a cohesive mode of failure upon examination under SEM (Fig.7). Even in specimens that appeared to have adhesive failure at low magnification(Fig.7), a thin layer of the cement material was identified at higher magnifications on the dentin surface(Fig.8). The HA- LC GIC had a higher rate of cohesive failure than the group without HA(Fig.7), and bone-like apatite material(white arrow) in the interface between the tooth and the dental material was only observed in HA-added LC GIC(Fig.8).



(a) Control group (x2000)



(b) Experimental group (x2000)

Fig.7. Interface between tooth and HA-LC GIC under SEM

There is an increase in the appearance of cohesive failure in HA-LC GIC(b) compared to pure LC GIC(a)

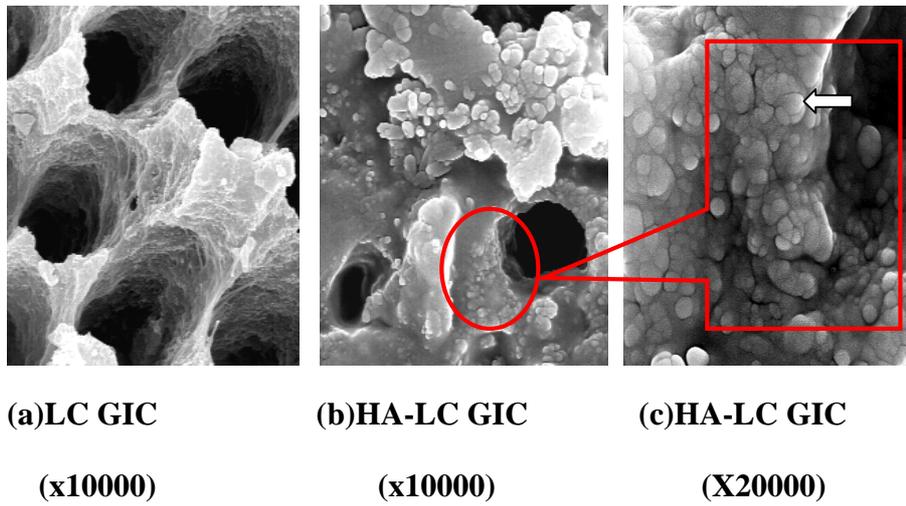


Fig.8. Interface between tooth and HA-LC GIC under SEM

(a)Pure LC GIC, No bone like apatite material is observed on the tooth surface.

(b) HA-LC GIC, Bone like apatite material (white arrow) can be seen in the red circled area.

(c) Higher magnification of (b).

IV. Discussion

HA is the major component of teeth and other hard tissues, and is used in a variety of fields. In dentistry, the efficacy of composite materials created by mixtures of dental materials and HA is being studied extensively. At present, such studies have been confined to HA added to light curing resin or conventional GIC, but none examined the effects of the addition of HA to LC GIC. The present study examined the effects of adding HA to LC GIC on bonding strength and other physical properties.

LC GIC is a water-based light-activated cement. To evaluate the suitability of HA-LC GIC for use as a dental cement, its curing depth, sensitivity to ambient light, and flexural strength was assessed according to ISO 9917-2:1998(E).

Curing depth was indirectly proportional to the HA content. This may be due to the light-scattering effect of HA particles (Acris RW et al., 2002). Although an increase in HA concentration resulted in a decrease in curing depth, its clinical significance was negligible.

Sensitivity to ambient light is a necessary parameter for light-activated materials as ambient light may cause premature curing and

result in crack and void formation during use. Sensitivity to ambient light was not observed in any of the materials containing HA in the present study.

Flexural properties give an indication of the durability of restorative materials (Gladys S et al., 1997). This study measured the flexural strength of materials using the three-point flexural strength method. In both FC and VM, flexural strength increased with the concentration of HA up to a certain point, after which a decrease in flexural strength was observed. Several views may explain this observation. First, since the average particle size of glass core is 13~19 μm (<45 μm), the particles of the comparatively smaller hydroxyapatite used in this study (5~10 μm) may have come between the glass core particles, creating a “packing effect”(Lucas ME et al., 2003). Second, since the glasses used in commercial GIC are all of the alluminosilicate type containing calcium and fluoride ions and react with polyacrylic acid to form ionic bonds, the addition of HA may have provided extra calcium ions, facilitating the initial reaction. A previous study indicated that the addition of HA also facilitates the increase in the initial flexural strength of GIC in an aqueous storage condition (Lucas ME, 2002). In LC GIC, when the polyacid reacts with the glass powder it selectively

binds to Calcium ions first and then reacts with other ions. Therefore, when HA is added the number of Calcium ions in the initial reaction increases and the initial ionic bonds are increased. Since the bond between polyacrylic acid and glass ions is the main reaction in LC GIC, an increase in flexural strength can be explained. The drop in flexural strength after a certain concentration of HA may be due to the light-scattering effect of HA. An increase in HA content delays the polymerization of LC GIC, which in turn decreases the role of light polymerization while increasing that of autopolymerization. LC GIC was originally developed in 1986 by Antonucci to replace part of the water content of the glass ionomer system with a water-soluble monomer system that is polymerized by ambient free radical polymerization (Mckinney IE, 1986). Thus, LC GIC has a dual-setting mechanism involving the acid-base reaction of the polyacid with the glass along with the polymerization reaction. Therefore, any portion of the material not cured by light can eventually be polymerized by autopolymerization. A study reported a decrease in strength when the material is cured by autopolymerization compared to light polymerization (Glasspoole EA et al., 2002). As such, if light polymerization is hindered by the light-scattering effect of HA, shifting

the dual-setting reaction towards autopolymerization, a decrease in strength may eventually result.

LC GIC is known for its ability to chemically bond to the tooth substrate, so an evaluation of the shear bond strength of HA-LC GIC to dentin was considered. The exact mechanism of the chemical bonding of LC GIC to dental structures is not completely known. Additional insights into this field were contributed by recent X-ray photoelectron spectroscopy studies (Sennou HE et al., 1999). Sennou have shown the formation of an intermediate dentin-glass ionomer layer on the surface of the materials that enables the exchange of mineral and organic elements, and consequently the adhesion of the material to dentin. A study analyzed the chemical interaction of a synthesized polyalkenoic acid with enamel and synthetic HA and pointed out that the carboxylic groups of polyalkenoic acid replaced the phosphate ions of the substrate and formed ionic bonds with the calcium ions of HA(Yoshida Y et al., 2000). For HA-LC GIC, it seems likely that the calcium from HA may participate in this ionic change. While the extent by which the added HA influences the chemical exchange requires further elucidation, it is evident from this study that HA does not interfere with the chemical bonding ability of LC-GIC and may even improve

bonding strength. SEM images revealed a higher rate of cohesive failure in the HA-added group compared to the control group in this study. Since the addition of HA increased the flexural strength of LC GIC, a high rate of cohesive failure may indicate an increase in bonding strength to the tooth surface.

V. Conclusion

The present study examined the effect of HA on the bonding strength of LC GIC by mixing the optimal concentration HA, which was determined after extensive tests involving curing depth, sensitivity to ambient light, and flexural strength, to LC GIC. The following conclusions were drawn:

1. Curing depth decreased as the concentration of HA increased. Although this was statistically significant (FC-HA: $P < .0001$, VM-HA: $P < .0001$) the curing depth in all cases satisfied ISO standards, thus having negligible effect clinically.
2. Regarding sensitivity to ambient light, homogeneity was maintained after the completion of the test with no clefts or voids in all concentrations of HA-LC GIC. There was not much change in the sensitivity to ambient light.
3. Flexural strength gradually increased up to 15% in HA-FC and 20% in HA-VM and decreased afterwards. This is an increase in strength compared to the group which had no HA added, and the result of Duncan's grouping showed a statistically significant difference.

Therefore we may conclude that the addition of HA can increase the strength of a material. The statistical significance between each group was also observed(FC : P=0.0083, VM : P=0.0023).

4. Compared to the control group, both 15% HA-FC and 20% HA-VM showed an increase in bonding strength, and this result showed statistical significance.(FC : P=0.0064, VM : P=0.0018).

5 After measurement of bonding strength, observation of the fracture surface under a scanning electron microscope revealed a higher ratio of cohesive failure in the HA-added group compared to the control group. Considering the fact that the addition of HA results in an improvement in the physical properties of a material, and that the ratio of cohesive failure increased in spite of it, we may infer that the increase in bonding strength is due to the addition of HA.

Various results were obtained as a result of adding different ratios of HA to LC GIC in the present study. Therefore, the optimal ratio of HA that yields the greatest improvement in the physical properties of materials, along with further studies on the mechanisms by which HA improves bonding strength are necessary for a more thorough understanding of the utility of HA in restorative dentistry.

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국문 요약

광중합형 글래스 아이오노머 시멘트의 결합강도에 대한 하이드록시아파타이트의 효과

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지도교수 : 최 형 준

이 연구의 목적은 다양한 비율의 하이드록시아파타이트를 함유한 광중합형 글래스아이오노머를 치면에 부착한 후 결합강도에 있어서의 효과를 알아보는 것이다. 본 연구에서는 두 종류의 광중합형 글래스아이오노머 제품인 Fuji II LC(GC Co., Japan)와 Vitremer™(3M/ESPE, USA)에 다양한 비율의 하이드록시아파타이트를 첨가하여 새로운 수복용 광중합형 글래스아이오노머를 제조하였다. 이에 대한 물리적 성질로서 ISO 9917-2:1998(E)의 기준에 따라 치과용 수성 광중합형 시멘트의 기본조건을 만족하는지 확인하기 위해 중합깊이, 주변광에 대한 민감도, 굽힘강도를 측정하고 그 결과를 바탕으로 물리적인 성질이 가장 향상된 복합재(15% HA-Fuji II LC, 20% HA-Vitremer™)를 선택하여 결합강도를 측정하였다. 또한 결합강도를 측정하고 난 후 재료가

떨어져 나간 치아의 표면 상태를 알아보기 위해 치아의 계면을 전자현미경을 이용하여 관찰하고 다음과 같은 결과를 얻었다

1. 광중합형 글래스아이오노머의 중합깊이는 하이드록시아파타이트 양이 증가함에 따라 감소하였으며 이 결과는 통계학적인 유의차가 존재하였다($P < 0.0001$).
2. 광중합형 글래스아이오노머는 하이드록시아파타이트의 양이 증가하여도 주변광에 대한 민감도는 거의 차이가 없었다.
3. Fuji II LC의 경우 15%, Vitremer™의 경우 20%까지는 하이드록시아파타이트의 농도가 증가함에 따라 굽힘강도가 증가하다가 이 이후부터는 감소하는 경향을 보였으며 이 결과는 통계학적인 유의차가 존재하였다($P < 0.05$).
4. 결합강도의 경우 하이드록시아파타이트가 첨가되지 않은 대조군과 비교시 Fuji II LC의 경우 15%, Vitremer™의 경우 20%의 하이드록시아파타이트를 첨가한 그룹에서 결합강도가 증가하였으며 이는 통계학적인 유의차를 보였다(FC : $P = 0.0063$, VM : $P = 0.0018$).
5. 결합강도의 측정 후 치아단면을 전자현미경으로 관찰한 결과 대조군에 비하여 하이드록시아파타이트를 첨가한 실험군에서 응집 파괴 (cohesive failure)의 비율이 높은 것이 관찰되었다.
광중합형 글래스아이오노머시멘트는 글래스아이오노머시멘트의 장점

인 불소의 유리효과는 유지하면서 보다 향상된 심미성과 조작성을 갖고 있기 때문에 소아치과 영역에서 사용이 증가되고 있는 재료이다. 그러나 컴포짓 레진에 비해 재료의 강도와 유지력은 부족하여 제한된 영역에서만 사용되었다. 따라서 이번 실험은 광중합형 글래스아이오노머의 물성을 향상시키기 위한 시도로 하이드록시아파타이트를 첨가하고 그 효과를 관찰하였다. 실험결과 하이드록시아파타이트는 기존의 광중합형 글래스아이오노머의 물리적 성질은 약화시키지 않으면서 굽힘강도와 결합강도를 향상시키는 긍정적인 효과를 나타내었다. 그러나 하이드록시아파타이트의 첨가비율이 높아질수록 중합깊이는 감소되었고 굽힘강도의 경우 강도가 증가하다가 감소한다는 한계점을 보였다. 이번 연구는 하이드록시아파타이트를 광중합형 글래스아이오노머에 첨가했을 때의 결과만 보고한 것으로 하이드록시아파타이트가 재료에 어떤 영향을 미치는가에 관한 정확한 기전을 규명하기 위하여 보다 다양한 영역에서의 연구가 필요할 것으로 사료된다.

핵심되는 말:하이드록시아파타이트, 광중합형글래스아이오노머,결합강도