Evaluation of Bond Strength between Premixed Calcium Silicate-based Cements and Dure Cure Resin

Kang, Seori

Department of Dentistry
Graduate School
Yonsei University

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Advisor SuJung, Shin

**A Master's Thesis Submitted
to the Department of Dentistry
and the Graduate School of Yonsei University
in partial fulfillment of the
requirements for the degree of
Master of Dental Science**

Kang, Seori

June 2025

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This Certifies that the Master's Thesis of Kang, Seori is Approved

Committee Chair	**Kim, Do hyun**
Committee Member	**Shin, Su Jung**
Committee Member	**Jeon, Mi Jeong**

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Graduate School
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June 2025

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ABSTRACT

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Calcium Silicate-based Cement (CSC) is gaining more attention as it is used in the vital pulp therapy (VPT) procedure. Conventional mineral trioxide aggregate (MTA) was used by mixing powder and liquid, but recently, several manufacturers have introduced premixed-type CSC. This new type of CSC offers improved handling property and a shorter setting time compared to the previous versions. The aim of this study was to compare and investigate the shear bond strength between two types of CSC, conventional powder/liquid-type CSC and premixed-type CSC, and dure cure resin.

The specimens were divided into four groups: PMTA group (N=15), ProRoot MTA; EMTA group (N=15), Endocem MTA Premixed Regular; WRPT group (N=14), Well-Root PT; Z250 group (N=10), Filtek Z250;. Each material was fabricated as a cylindrical specimen with dimensions of 6 mm in diameter and 2 mm in height. The specimens of CSC groups were immersed in distilled water for 24 hours to allow complete setting. After that, the dual cure resin bonding process was performed using Luxacore Z Dual and Clearfil SE Bond. The bonding system used was Clearfil SE Bond according to the manufacturer's instructions. Afterward, all specimens were stored in distilled water at 37°C for 7 days. Shear bond strength was measured using the prepared specimens, and the fractured surfaces were examined through scanning electron microscope (SEM) image.

Shear bond strength (SBS) of the Z250 group was the highest with a median of 21.54 MPa (range, 8.69-32.74 MPa). Following this, the WRPT group showed SBS as a median of 4.13 MPa (range, 0.81-6.00 MPa). Next, the PMTA group was as 3.26 MPa (range, 1.91-11.73 MPa). Finally, the EMTA group was as 2.02 MPa (range, 1.15-5.03 MPa). The Z250 group exhibited a significantly higher bond strength compared to the CSC groups, and there was no significant difference within the three CSC groups. According to the failure mode analysis, failures observed in the CSC groups were limited to adhesive, mixed, or cohesive failures within the CSC material, without involvement of the restorative material.

According to the outcomes of this study, there was no significant difference in SBS values between the premixed-type CSC group and the conventional powder/liquid-type CSC group, indicating that the shear bond strength was not affected by the formulation type. The SBS between CSC and the overlying dual cure resin appears to be significantly lower than that of the Z250 group. However, in clinical situations, it remains unclear whether the low SBS observed in the CSC groups would affect the treatment outcome. Further studies that better simulate clinical conditions are necessary in the future.

Key words: **premixed calcium silicate-based cements; vital pulp therapy; shear bond strength; dure cure resin**

1. Introduction

When the pulp is exposed, vital pulp therapy such as pulpotomy or direct pulp capping that aim to protect the vitality of the pulp can be performed based on considerations such as pulp status, symptoms, size of exposure, and the cause of exposure. As stated in the 2021 position paper by the American Association of Endodontists (AAE), "Vital pulp therapy (VPT) techniques are means of preserving the vitality and function of the dental pulp after injury resulting from trauma, dental caries, or restorative procedures." (1) The aims of VPT are to preserve the pulp tissue, eliminate infected tissue, and promote the development of mineralized tissue barrier. (2) In an animal model using healthy dentin, it has been demonstrated that when bacterial infection is eliminated and the tooth is properly restored, the pulp tissue has the ability to recover on its own. (3) The formation of dentin barrier takes place only when pulp inflammation and infection are controlled, enabling the restoration of tissue homeostasis and healthy pulp condition. (4) In the success of VPT, disinfection is important.

Various materials have been used in VPT, with calcium hydroxide being widely used in the past. (5) However, calcium hydroxide has several drawbacks, including the potential to induce inflammatory reactions and necrotic changes on the pulp surface, high solubility, microleakage, and the formation of tunnel defects in the dentin bridge. (2, 6) Calcium silicate-based cement (CSC) is gaining more attention as it is used in the VPT procedure. (7, 8) CSC is a group of materials that includes tricalcium silicate, dicalcium silicate, hydraulic calcium silicate cement, and bioceramics. CSCs are widely applied in endodontic treatments including pulpal regeneration and hard tissue repair. (9) Clinical results show that these materials have a consistent success rate. (1)

With the development of CSC, it has started to replace calcium hydroxide in clinical practice. CSC has shown favorable results in terms of its chemical and physical properties, antimicrobial activity, biocompatibility, and sealing ability. (10, 11)

The traditional CSC was used by mixing powder and liquid, however, CSC also has some drawbacks, including a long setting time, difficulties in handling, and the potential for dissolution and washout from oral fluids or blood. (12) But recently, several manufacturers have introduced premixed CSC. The premixed CSC has a reduced setting time and easier handling compared to the traditional one.

Preventing bacterial infection during vital pulp therapy is an important aspect of treatment. Law has stated that one of the common elements in successful regenerative endodontic procedures is the effective sealing of the pulp space and the final sealing after restoration. (12) High bond strength is associated with low microleakage, and conversely, low bond strength corresponds to increased microleakage. (13) Bacterial microleakage is strongly associated with pulp inflammation, highlighting the importance of proper restoration to prevent bacterial infiltration and protect the pulp. (14) If the bond strength is low, there is a higher possibility of microleakage, which can induce re-infection. In VPT, the cement placed on the pulp comes into direct contact with the restorative material. The success of vital pulp therapy and dental restorations is influenced by the bond strength between pulp capping material and restorative material. (15, 16) Adequate bonding of composite resins to pulp capping biomaterials produces the adhesive joint, which is capable of spreading stress relatively evenly over the entire region of the bond. (17, 18)

Various studies have explored the bond strength between CSCs and overlying restorative materials. Research often includes various CSC materials, such as Biodentine and TheraCal. (19, 20) Researches have also been investigated the bond strength of CSCs with surface treatments and bonding agents. One study showed that the total-etch technique enhanced the bond strength between resin and CSC. (21) However, another study found that the use of different adhesives did not produce a significant variation in SBS values. (22) It can be inferred that many studies have been conducted in this area due to the recognized need to evaluate the bond strength between CSC and restorative materials. Research on premixed-type CSC remains limited, and further investigations are needed to fully understand their properties and clinical performance.

The aim of this study was to compare and investigate the shear bond strength between powder/liquid-type CSC, premixed CSC and dure cure resin. The null hypothesis was that there is no significant difference in the shear bond strength of the dual-cure resin when bonded to the control group and the CSC groups, regardless of the material formulations.

2. Materials and methods

2.1. Materials used

The following materials were used in this study: The CSCs used were ProRoot MTA (Dentsply, Tulsa, OK, USA), Endocem MTA (Maruchi, Chuncheon, Korea), and Well-Root PT (Vericom, Wonju, Korea), while the control group used the resin Filtek Z250 (3M ESPE, St. Paul, MN, USA). The composition, setting time, and instructions for use of the CSC employed in this study are shown in Table 1. The resin used for bonding to the CSC was the dual cure resin Luxacore Z Dual (DMG, Hamburg, Germany), and the bonding agent used was Clearfil SE Bond (Kuraray, Osaka, Japan). Details of the composite resin and bonding agent utilized in this study are provided in Table 2.

Table 1. Composition, manufacturer, setting time, and instructions for use of calcium silicate-based cements.

	composition	**Manufacturer**	**setting time**	**instructions for use**
ProRoot MTA	tricalcium silicate dicalciumsilicate tricalcium aluminate tetracalciumaluminoferrite bismuth oxide gypsum	Dentsply Tulsa, OK, USA	180 min	mix the powder and liquid
Endocem MTA Premixed Regular	zirconium dioxide tricalcium silicate calcium aluminate calciumsulfate dimethyl sulfoxide thickening agent	Maruchi, Chuncheon, Korea	3-5min	inject with syringe
Well-Root PT	calcium aluminosilicate compound zirconium oxide thickening agent	Vericom, Wonju, Korea	25 min	inject by applicator gun

Table 2. Composition, and manufacturer of resin and bonding agent.

	composition	manufacturer
Filtek Z250	bis-EMA, UDMA, bis-GMA, TEGDMA, silica, zirconia, pigments, camphorquinone	3M ESPE, St. Paul, MN, USA
Luxacore Z Dure	bis-GMA, barium glass, pyrogenic silicic acid, nano fillers, zirconium oxide	DMG, Hamburg, Germany
Clearfil SE bond (Primer)	HEMA, hydrophilic, dimethacrylate, 10-MDP, toluidine, camphorquinone, water	Kuraray, Osaka, Japan
Clearfil SE bond (Adhesive)	10-MDP, bis-GMA, HEMA, hydrophilic dimethacrylate, microfiller	

2.2. Sample preparation

Using a cylindrical polypropylene mold, a rubber with dimensions of 6 mm in diameter and 2 mm in height was embedded into the acrylic resin. (Fig.1) After the acrylic resin had cured, the rubber was removed, and 58 specimens were prepared. The specimens were classified into four groups as follows: PMTA group (N=15), ProRoot MTA; EMTA group (N=15), Endocem MTA Premixed Regular; WRPT group (N=14), Well-Root PT; Z250 group (N=10), Filtek Z250. Although 15 specimens were initially prepared for the WRPT group, one was excluded due to an error during the preparation process, and the experiment was conducted with the remaining 14 specimens. The rubber was removed, and the resulting cylindrical space with dimensions of 6 mm in diameter and 2 mm in height was filled with each material.

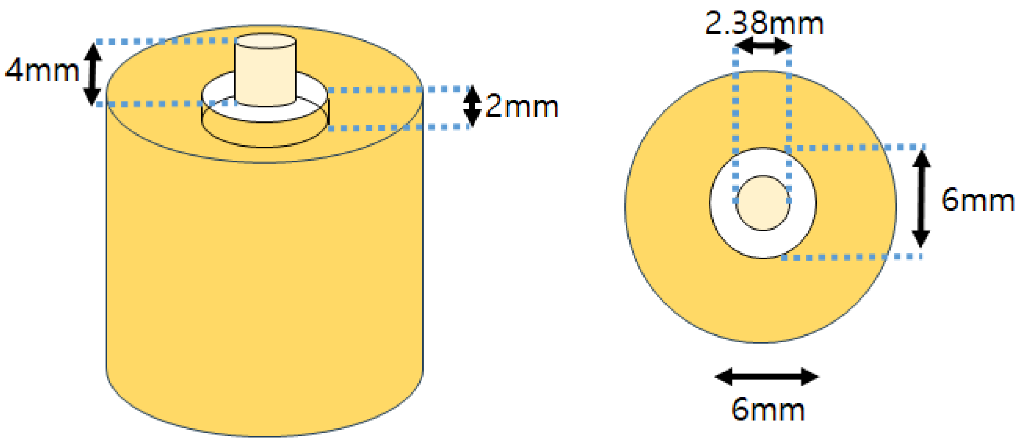

Fig1. Design of the specimen fabricated using a cylindrical polypropylene mold and specimen.

PMTA group had ProRoot MTA mixed following the manufacturer's guidelines and filled the empty space in the specimen, forming a smooth surface with a celluloid strip. EMTA and WRPT group injected premixed type CSC into the empty space of the specimen and formed a smooth surface with a celluloid strip. Subsequently, PMTA, EMTA and WRPT group were immersed in distilled water at 37°C for 24 hours to allow the materials to complete setting. The Z250 group was filled with Z250 using a resin applicator, the smooth surface was made using a celluloid strip, and light polymerization was performed for 20 seconds.

After 24 hours for PMTA, EMTA, and WRPT group, and after light polymerization for the Z250 group, grinding was performed using 600-grit silicone carbide paper at 300 RPM for 30 seconds. After grinding, Clearfil SE Primer was applied to the surface of the materials with a microbrush for 20 seconds, air-dried for 5 seconds to evaporate the solvent, and then Clearfil SE Bond was applied with a microbrush for 10 seconds. It was air-dried for 5 seconds and light-polymerized for 10 seconds. Using a bonding clamp mold (Ultradent, Salt Lake City, Utah, USA), Luxacore Z Dual was injected into the upper surface of each material for restoration, with a diameter of 2.38 mm and a height of 4 mm, and light-polymerized for 20 seconds (Fig. 1). Afterward, all specimens were immersed in distilled water at 37°C for 7 days.

Out of 58 specimens, 54 specimens were included in the main experiment, while 4 specimens were excluded and selected to test the bon strength of the premixed type CSC after initial setting. Two specimens were filled with Endocem MTA Premixed Regular, and the other two with Well-Root PT, and smooth surfaces were made using a celluloid strip. The manufacturer suggests that the initial setting time for Endocem MTA Premixed Regular is 3-5 minutes, while Well-Root PT has an initial setting time of 25 minutes. Therefore, after storing them in distilled water at 37°C for 25 minutes for initial setting, grinding was performed using 600-grit silicone carbide paper at 300 RPM for 30 seconds. Then, Luxacore Z Dual was bonded in the same way as in the previous resin bonding process. However, when trying to bond, the surface of the CSC, which appeared to be cured, detached, leading to a failure in bonding.

Figure 2. Bonding clamp used in this study. (Ultradent, Salt Lake City, Utah, USA)

2.3. Shear Bond Strength Test

The 34 specimens were placed on the Universal testing machine (Model 3366; Instron Co., Norwood, MA, USA), and the shear bond strength was measured at a crosshead speed of 1 mm/min until the restoration detached (Fig. 2).

The bonding area had a size of 2.38mm in diameter, and the bonding area was calculated to be 4.45 mm^2. The shear bond strength was calculated using the following equation:

Shear bond strength (MPa) = Force (N) / Bonding area (mm^2).

Figure 3. Universal testing machine (Model 3366; Instron Co., Norwood, MA, USA)

2.4. Surface analysis

After the bond strength test, the fractured surfaces were evaluated by a single operator using a dental operative microscope (Extaro 300, Zeiss, Oberkochen, Germany) at ×12.5 magnification, and the failure modes were classified as follows: 1 = adhesive failure (fracture at the interface between the specimen and the restoration material), 2 = cohesive failure (fracture within the specimen), 3 = cohesive failure (fracture within the restoration material), 4 = mixed failure (a combination of adhesive and cohesive fracture).

Image analysis was performed to the specimen from each material group via Field Emission Scanning Electron Microscopy (FE SEM, ZEISS Sigma 500, Carl Zeiss AG, Oberkochen, Germany). Each specimen was adjusted to the size of 1mm × 1mm × 0.4mm, gold plated before being photographed by SEM. The surface of the specimen was scanned and representative areas were photographed at ×30 magnification with acceleration voltage of 3.50 kV.

2.5. Statistical analysis

Data were analysed with SAS version 9.4 (SAS Institute, Cary, NC, USA). Initially, normality was assessed, and since the data was not normally distributed, the Kruskal–Wallis test was used for statistical analysis, and post-hoc analysis was subsequently conducted using the Bonferroni method to determine specific group differences. The significance level was established as $p<0.05$. The failure mode ratios of each group was analyzed.

3. Results

3.1. SBS Test

The mean bond strength was compared using multiple comparison of the Kruskal-Wallis test. The test revealed a significant difference among the groups. The Median (Min–Max) SBS values (MPa) of shear bond strength for each group are shown in Table 2, and

Figure 3 shows it as a graph. The Z250 group showed the highest SBS, with a median of 21.54 MPa (range, 8.69-32.74 MPa). Following this, the WRPT group showed SBS as a median of 4.13 MPa (range, 0.81-6.00 MPa). Next, the PMTA group was as 3.26 MPa (range, 1.91-11.73 MPa). Finally, the EMTA group was as 2.02 MPa (range, 1.15-5.03 MPa). Therefore, the highest values were observed in the following order: Z250, Well-Root PT, ProRoot MTA, and Endocem MTA.

Post-hoc analysis revealed that the Z250 group exhibited significantly higher bond strength compared to the CSC groups, while no significant differences were observed among the three CSC groups.

Table 3. Median (Min–Max) SBS values (MPa) of the tested groups analyzed using the Kruskal–Wallis Test

Group	N	Median (Min-Max)	Significance notation
ProRoot MTA (PMTA)	15	3.26 (1.91-11.73)	a
Endocem MTA Premixed Regular (EMTA)	15	2.02 (1.15-5.03)	a
Well-Root PT (WRPT)	14	4.13 (0.81-6.00)	a
Filtek Z250 (Z250)	10	21.54 (8.69-32.74)	b

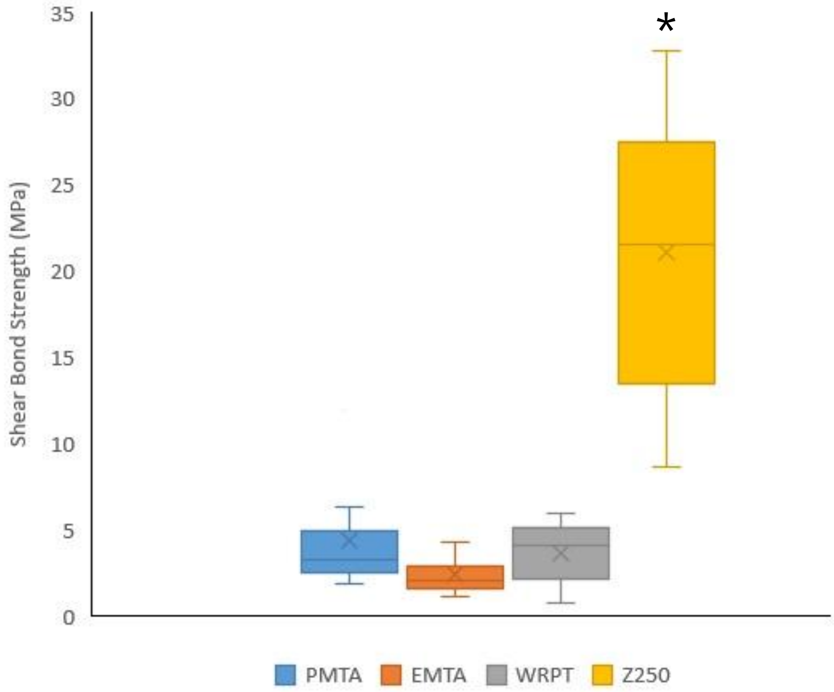

Figure 4. Shear bond strength values of CSCs and Z250 (MPa). An asterisk (*) indicates statistical significance. ($p<0.01$)

3.2. Failure analysis

The failure mode analysis results of the specimen's fractured surface through the SBS test are shown in Table3. In the CSC group, all fractures occurred not within the restorative material, but as adhesive failure, mixed failure, or cohesive failure within the CSC. In the PMTA group, 60% showed mixed failure, 27% adhesive failure, and 13% cohesive failure within the MTA. In the EMTA group, 33% showed mixed failure, 40% adhesive failure, and 27% cohesive failure within the CSC. In the WRPT group, 57% showed cohesive failure within the CSC, 43% showed mixed failure, and there were no adhesive failures. In the Z250 group, 60% showed mixed failure, 30% showed adhesive failure and 10% showed cohesive failure within restorative material.

Table 4. Failure mode of the tested groups following the SBS test

Group	N	1 = Adhesive	2 = Cohesive (failure within CSC)	3 = Cohesive (failure within restorative material)	4 = Mixed
PMTA	15	4	2	0	9
EMTA	15	6	4	0	5
WRPT	14	0	8	0	6
Z250	10	3	0	1	6

A representative specimen was selected from each group. A mixed failure specimen was selected from the PMTA group, an adhesive failure specimen from the EMTA group, a cohesive failure within the CSC specimen from the WRPT group, and an adhesive failure specimen from the Z250 group. Scanning electron microscopy (SEM) images were obtained, as shown in Fig. 4.

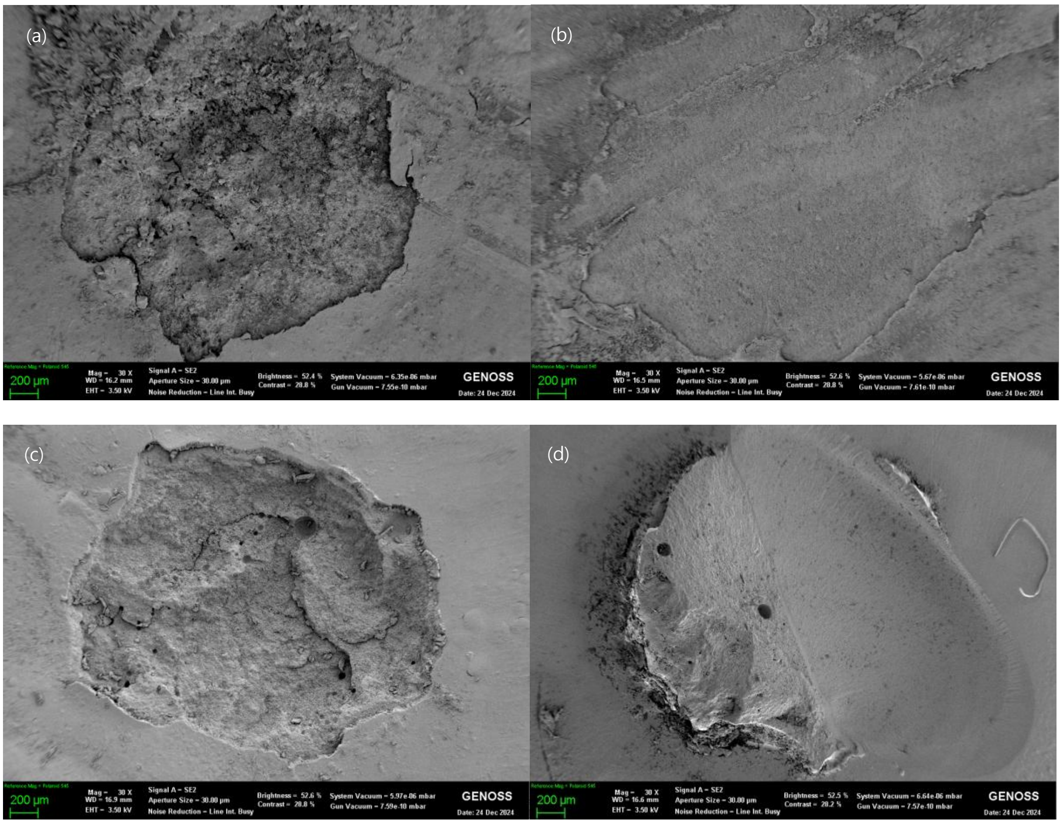

Figure 5. Scanning electron microscopy images of CSC and Filtek Z250 (control) surface (magnification 30×). (a) ProRoot MTA, mixed failure; (b) Endocem MTA, adhesive failure; (c) Well-Root PT, cohesive failure in CSC; (d) Filtek Z250, mixed failure

4. Discussion

Within VPT, proper caries management focuses on removing microbial contamination, preventing further bacterial infection, and applying sealing dental biomaterials to prevent exposed dentin and pulp from external stimuli. The ultimate goal of caries control and VPT is to prevent bacterial contamination, inhibit the progression of caries, promote tertiary dentin formation, induce pulp recovery, and provide a well-sealed restoration for long-term preservation.

Researches on the premixed type CSC have been conducted, and several studies have assessed the bond strength between CSC and restorative materials. One study reported the mean shear bond strength between dual-cure resin and CSC materials as 7.96 MPa for ProRoot MTA, 9.18 MPa for Biodentine, 4.47 MPa for Endosequence RRM, and 5.72 MPa for NeoMTA. In that study, cohesive fractures within the CSC material accounted for 43% of all failure modes. (19) In another study that evaluated the micro-shear bond strength between a bulk-fill resin and CSC materials, TheraCal LC showed a value of 3.07 MPa, NeoMTA 2 showed 2.03 MPa, and NeoPutty showed 2.36 MPa. Among the 30 specimens tested in that study, 25 were classified as exhibiting cohesive failure within the CSC material. (20) There was variability in experimental conditions such as materials and storage periods, but they generally showed relatively low shear bond strength, typically below 10 MPa, in previous studies, which is consistent with the present study. Also, similar to the present study, a considerable number of cohesive failures within the CSC material were also observed in those studies. However, the NeoPutty, NeoMTA, and Endosequence RRM used in those studies are not commonly used products in Korea, which may limit their clinical applicability in the local context. Additionally, the studies focused on the use of a wider range of materials, such as Biodentine and TheraCal LC, whereas the present study places more emphasis on comparing premixed-type CSC with conventional powder/liquid-type CSC.

In this study, the Z250 group had a significantly higher SBS value than the three CSC groups. There were no statistically significant differences in SBS values among the three CSC groups. Therefore, the null hypothesis of this study was partially rejected: although there was no significant difference in shear bond strength among the CSC groups regardless of their formulations, a significant difference was observed between the CSC groups and the control group.

Bond strength values ranging from 15 MPa to 25 MPa are considered clinically acceptable, as it falls within the bond strength range between dentin and resin. (23) Achieving a minimum bond strength of 17 MPa is important, with 7 MPa required to balance the polymerization shrinkage of light-cured composite resin, and 10 MPa needed to endure the masticatory forces. (16, 24-26) Considering this, the SBS value between CSC and the dure cure resin used for the upper restoration in this study is very low to be clinically acceptable. Therefore, in procedures using CSC, it is believed that the restoration of bond strength through surrounding tooth structure or other restorative materials, in addition to CSC, may be necessary. However, in clinical situations, it remains unclear whether the low SBS observed in the CSC groups would affect the treatment outcome. Further studies that better simulate clinical conditions are necessary in the future.

While phosphoric acid etching was not employed in the present study, a previous study reported that applying 35% phosphoric acid to the surface of calcium silicate cements removes the smear layer and creates a clean, honeycomb-like pattern that enhances micromechanical retention and subsequently increases bond strength. (27) CSC materials are hydrophilic and set in the presence of moisture. Since there is no resin structure in CSC, the bond between CSC and resin is considered to rely on micromechanical bonding. (28) This could be the reason for the lower bond strength observed between CSC and dual-cure resin compared to that between composite resin and dual-cure resin.

Also, in this study, the standard deviations of the bond strengths were found to be large. In other words, it indicates that the process is technically sensitive, and as a result, the outcomes may exhibit considerable variability in clinical situations. This variability could also be attributed to the lack of clinical experience or proficiency of the operator.

In the failure mode analysis, cohesive failures within the CSC material were more frequently observed in the CSC groups than in the Z250 group, with the Well-Root PT group showing the highest incidence. This result may be attributed to the relatively low material strength of certain CSC materials, particularly Well-Root PT, which appears to be weaker than its bond strength. No literature currently exists reporting the compressive strength of Well-Root PT, whereas the compressive strength of ProRoot MTA has been reported to range between 50 and 100 MPa on average, (29) while that of Endocem MTA Premixed Regular has been reported to range between 30 and 60 MPa in one study. (30) In one study, the compressive strength of Filtek Z250 was reported to be approximately 449 MPa, (31) which is significantly higher than that of ProRoot MTA and Endocem MTA Premixed Regular. This may explain the frequent cohesive failures observed within the

CSC material in the CSC group.

The setting time in this study was set to 24 hours, including the complete setting time suggested by the manufacturer, and bonding procedure was performed after the complete setting of CSC. However, this may differ from clinical situations. Clinically, immediate restoration may be often performed after the initial setting of CSC. In this study, the bonding procedure was performed after an initial setting time of 25 minutes. It should be noted that even 25 minutes may be difficult to maintain in clinical practice. Nevertheless, at this point, the strength of CSC material was still weak, and it was observed that part of the CSC easily detached along with the restorative material.

Additionally, although this study stored the specimens in distilled water at 37°C, CSC has the property of releasing ions when immersed in water, which may have resulted in different outcomes compared to actual clinical conditions. (32) If the samples had been stored at 100% relative humidity instead, different results might have been observed. Also, although the specimens were stored in distilled water for 7 days in this study, the extent of artificial aging may have been insufficient.

Mechanical polishing was performed to standardize the surfaces of the resin and CSC, however, this may have affected the strength of the CSC and eliminated the oxygen-inhibited layer of the resin, creating a situation different from clinical conditions.

Of course, since bonding procedure was performed after the initial setting and the bond strength of CSC after complete setting in that state was not measured, it is difficult to state anything definitely. In this study, complete setting was the only condition tested due to initial bonding failure after initial setting time, but if appropriate conditions were set and bonding procedure was performed well, the results could be different from our expectations.

Additionally, when performing an upper restoration over CSC, the adjacent bonded area may involve another restorative material, but in most cases, it is expected to be dentin. It would have been better if this study had set the control group based on the bond strength between dentin and dure cure resin.

CSC is continuously being developed and updated to overcome various drawbacks. Premixed-type CSC is more convenient to handle than the powder/liquid type, and its setting time has improved. However, it is likely that further development will be necessary in the future.

5. Conclusion

From the results of the study, the following conclusions are made.

1. There was no significant difference in SBS values between the premixed-type CSC (Endocem MTA and Well-Root PT) and the conventional powder/liquid-type CSC (ProRoot MTA), indicating that the shear bond strength was not affected by the formulation type.

2. Based on the results of this study, the SBS between CSC and the overlying dual-cure resin appears to be significantly lower than that of the Z250 group.

3. In the failure mode analysis, the CSC group demonstrated a greater tendency toward cohesive failures within the CSC material compared to the Z250 group, particularly in the Well-Root PT group.

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Abstract in Korean

미리 혼합된 칼슘 실리케이트 기반 시멘트와 상부 이중 중합 레진과의 접착 강도 평가

칼슘 실리케이트 기반 시멘트는 생활 치수 치료 절차에서 사용되면서 점점 더 주목받고 있다. 기존 MTA 는 분말과 액체 를 혼합하는 방법으로 사용하였는데, 최근 여러 제조사에서 미리 혼합된 형태의 칼슘 실리케이트 기반 시멘트를 출시하고 있으며, 이는 이전 MTA 보다 개선된 조작성과 짧아진 경화 시간을 보인다. 본 연구의 목적은 분말/액상형 칼슘 실리케이트 기반 시멘트 및 미리 혼합된 칼슘 실리케이트 기반 시멘트와 이중 중합 레진간의 전단 결합 강도를 알아보고 비교하는 것이다.

시편은 각 4 개의 그룹으로 나누어졌다. ; PMTA 그룹(N=15), ProRoot MTA ; EMTA 그룹(N=15), Endocem MTA Premixed Regular ; WRPT 그룹(N=14), Well-Root PT; Z250 그룹(N=10), FIltek Z250 ;. 각 재료는 지름 6mm, 높이 2mm 의 원형의 시편으로 준비되었으며, 재료를 24 시간 동안 증류수에 보관하여 완전 경화 시킨 뒤 상부 이중 중합 레진 접착 과정이 시행되었다. 접착제로는 Clearfil SE Bond 를 제조사의 지침에 따라 사용하였다. 이후 모든 시편은 37°C 증류수에 7 일간 보관되었다. 그리고 시편의 전단 결합 강도를 측정하였으며, 파절된 단면은 주사전자현미경 영상을 통해 분석되었다.

Z250 그룹의 전단 결합 강도 중앙값은 21.54 MPa (범위 : 8.69-32.74 MPa) 로 가장 높았다. 그 다음으로 WRPT 그룹은 4.13 MPa (범위 : 0.81-6.00 MPa)의 전단 결합 강도를

보였다. 이어서 PMTA 그룹은 3.26 MPa (범위 : 1.91-11.73 MPa)로 나타났다. 마지막으로 EMTA 그룹은 2.02 MPa (범위 : 1.15-5.03 MPa) 로 측정되었다. Z250 그룹의 결합 강도는 칼슘 실리케이트 기반 시멘트 그룹보다 유의하게 높았으며, 세 개의 칼슘 실리케이트 기반 시멘트 그룹 간에는 유의한 차이가 없었다. 또한 파절 유형 분석 결과, 칼슘 실리케이트 기반 시멘트 그룹에서는 접착 파절, 혼합 파절 또는 칼슘 실리케이트 기반 시멘트 재료 내의 응집 파절로 발생하였으며, 수복 재료 내의 응집파절은 관찰되지 않았다.

본 연구 결과에 따르면, 미리 혼합된 칼슘 실리케이트 기반 시멘트 그룹은 분말/액상형 칼슘 실리케이트 기반 시멘트 그룹과 전단 결합 강도 값에서 유의한 차이가 없었으며, 이는 제형 유형이 전단 접착 강도에 영향을 미치지 않았음을 나타낸다. 칼슘 실리케이트 기반 시멘트와 상부 수복되는 이중 중합 레진과의 전단 결합 강도 값은 Z250 그룹에 비해 유의하게 낮은 것으로 나타났다. 그러나 임상 상황에서는 칼슘 실리케이트 기반 시멘트 그룹에서 관찰된 낮은 전단 결합 강도가 치료 결과에 영향을 미치는지는 여전히 불확실하다. 따라서 향후 임상 조건을 보다 잘 반영한 추가 연구가 필요할 것이다.

핵심되는 말 : 미리 혼합된 칼슘 실리케이트 기반 시멘트, 생활 치수 치료, 전단 결합 강도, 이중 중합 레진