# Evaluation of fracture resistance of roots obturated with different root canal sealers and corresponding root canal filling techniques

Yun Song

The Graduate School

Yonsei University

Department of Dentistry

# Evaluation of fracture resistance of roots obturated with different root canal sealers and corresponding root canal filling techniques

Directed by Professor Kee-Deog Kim, D.D.S., M.S.D., Ph.D.

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Thesis Supervisor: Kee-Deog Kim

Thesis Committee Member: Wonse Park

Thesis Committee Member: Nan-Sim Pang

The Graduate School

Yonsei University

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# ABSTRACT

## Evaluation of fracture resistance of roots obturated with different root canal sealers and corresponding root canal filling techniques

**Yun Song**

**Department of Dentistry**

**The Graduate School, Yonsei University**

**(Directed by Professor Kee-Deog Kim, D.D.S., M.S.D, Ph.D.)**

**Aim:** The purpose of this study is to comparatively evaluate the fracture resistance and fracture patterns of roots obturated with various root canal sealers and corresponding root canal filling techniques using in vitro methods.

**Materials and Methods:** Fifty non-carious, recently extracted, mandibular premolar teeth with similar buccal-lingual and mesial-distal dimensions were divided into five groups (n = 10 each). Group 1 served as negative control and received no canal shaping and obturation of root canals. Group 2 served as positive control and received canal shaping but no obturation of root canals. Group 3 received canal shaping and obturation of root canals with resin based sealers (AH Plus®) using continuous wave compaction technique. Group 4 received canal shaping and obturation of root canals with bioceramic based sealers (Ceraseal®) using single-cone technique. Group 5 received canal shaping and orthograde obturation of root canals with MTA (ProRoot MTA®) using monoblock obturation technique. All samples were radiographed buccolingually and mesiodistally to assess quality of the root canal obturation. All samples were mounted on universal testing machine (Instron, South Korea) for fracture resistance test. Fracture was determined when the load showed instantaneous drop. One general dentist performed all root canal treatment and fracture resistance test. The same general dentist examined fracture feature of all samples under dental microscope (Zeiss, Dentsply, South Korea) with 12.5x widefield eyepieces after fracture resistance test.

**Results:** Resin based sealer (AH plus) (53.4 MPa), bioceramic based sealer (68.6 MPa) and MTA (ProRoot MTA®) (52.7 MPa) showed mean force higher than negative control (50.8 MPa) and positive control groups (44.4 MPa). Bioceramic sealer with single-cone technique showed highest fracture strength (68.6 MPa) with statistically significant difference ($P < 0.05$).

**Conclusion:** Under the limitation of this study, the combination of bioceramic based sealer and single-cone filling technique showed highest fracture resistance compared to resin based sealer with continuous wave compaction technique and MTA with monoblock obturation technique.

**Key words:** Vertical Root Fracture, Fracture Resistance, Mineral Trioxide Aggregate, Bioceramic based sealer, and Epoxy Resin based sealer

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**Yun Song**

*Department of Dentistry*

*The Graduate School, Yonsei University*

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## I. Introduction

Root canal treatment is a procedure that treats infectious disease and injuries at the pulp in root canals and periapical tissue; the procedure of removing pulp tissue, microorganisms and debris, then filling with obturation material and sealer in canals to maintain aseptic environment(Endodontology, 2006). However, removal of intracanal hard tissues may weaken the structure of the tooth, increasing the likelihood of root fracture(Johnson et al., 2000). Gutta percha is a commonly used material to obturate root canals, but the low modulus of elasticity of such material compared to that of the dentin requires the use of additional sealers. Therefore, various sealers and root canal obturation methods were developed to reinforce lost tooth structure during root canal treatment(Ribeiro et al., 2008).

The physical properties of root canal sealers influence the quality of root canal treatment. Various properties such as setting time, working time, radiopacity, flowability, solubility, and volume change are often evaluated when developing new sealers. Grossman suggested that an ideal root canal sealer must provide adequate adhesion with dentin walls, slow setting time, sufficient working time, insolubility to fluids, dimentional stability to minimize volume change over time, biocompatibility and excellent seal(Zhou et al., 2013).

Long-term success of root canal treatment is affected by microleakage from obturation materials due to various causes(Jafari & Jafari, 2017; Muliyar et al., 2014; Wu et al., 2000). Studies have shown that filling root canals with only gutta percha material showed more microleakage than roots filled with gutta percha and sealers(Hata et al., 1992; Wu et al., 2000). However, sealers also show volume shrinkage due to dissolution over time. Some root canal filling techniques try to minimize these volume changes by softening gutta percha and applying thin layer of root canal sealers(Wu et al., 2000).

Existing studies show that epoxy-resin based sealers (AH Plus®, Dentsply, Germany) have a higher bond strength than that of its alternatives, including glass ionomer, zinc-oxide eugenol, and calcium hydroxide based sealers(Fisher et al., 2007). Moreover, AH Plus® is commonly used due to its easy handling, good sealing property and better wettability to gutta-percha and dentin surfaces(Phukan et al., 2017). Donnermeyer et al. suggested that AH plus® sealer does not show relevant chemical or physical changes after thermal treatment and therefore is a suitable sealer for warm vertical filling techniques(Donnermeyer et al., 2020).

MTA (Mineral trioxide aggregate) is a biocompatible material that can be used in hydrophilic settings and induces formation of mineralized hard tissue. MTA was originally used for perforation repair and retrograde root filling(Bodrumlu, 2008). *In vitro* studies(Pelliccioni et al., 2004; Torabinejad et al., 1995; Zhu et al., 2000) showed that MTA had less cytotoxicity than that of IRM, super-EBA and amalgam material. Human osteoblastic cell line proliferated only on MTA material(Pelliccioni et al., 2004). Osteoblast showed more favorable response to MTA surfaces than that of amalgam or super-EBA material(Zhu et al., 2000). The advantageous physical properties of MTA led to some dental practitioner using MTA for orthograde filling in recent years. However, the difficulty in clinical manipulation of MTA may cause voids when obturating root canals and does not ensure complete sealing of root canals(An et al., 2021).

Drawbacks of using MTA, such as difficult handling and long setting time, led to the development of calcium-silicate cements(Gandolfi et al., 2009; Gomes-Filho et al., 2009; Marciano et al., 2016). Bioceramic sealer is a calcium-silicate based sealer that has gained popularity due to convenience of single-cone technique(Elizabeth A. Chybowski et al., 2018), chemical stability, biocompatibility, radiopacity, hydrophilicity, flowability and slight expansive properties(E. A. Chybowski et al., 2018). However, higher sealer to gutta-percha ratio of single-cone technique compared to other root canal filling techniques may affect the fracture resistance of obturated roots due to sudden shrinkage and expansion of such material leading to microleakage and cracks(Camilleri et al., 2013).

Vertical root fracture has been found more frequently in previously treated tooth than in vital tooth(Cohen et al., 2006; Patel et al., 2022; Yoshino et al., 2015). Yoshino *et al.* examined 736 extracted teeth from 24 dental clinics and found that a total of 31.7% teeth were extracted due to vertical root fracture. 93.6% of these teeth with vertical root fracture were previously treated(Yoshino et al., 2015). The survival and fracture resistance of previously treated tooth is affected by quality and quantity of remaining tooth structure after root canal treatment(Ferrari et al., 2012). Previous studies suggested that root canal preparation may increase dentin defects such as microcracks(Bier et al., 2009; Shemesh et al., 2009). However, recent studies used micro-CT to prove that root canal preparation does not produce new dentin defects, and that microcracks were already present in all teeth before procedure(De-Deus et al., 2014; Martins et al., 2021). On the other hand, excessive forces applied during root canal obturation may increase risk of vertical root fracture(Patel et al., 2022). Application of spreader in lateral condensation filling technique produce wedging effect on teeth. Vertical condensation filling technique apply considerable vertical load on teeth. Saw & Messer found that teeth obturated with thermoplasticized gutta-percha using Obtura delivery system generated higher strain than teeth obturated with Thermafil Obturators or lateral condensation technique(Saw & Messer, 1995).

Previous studies examined the effect of different sealing materials on fracture resistance using same obturation techniques(Celikten et al., 2015; Mandava et al., 2014; Uzunoglu Ozyurek & Aktemur Turker, 2019) or different obturation techniques with same sealing materials(Patel et al., 2022; Saw & Messer, 1995). However, not many studies examined how different combinations of sealing materials and obturation techniques that are used in dental clinic (such as lateral condensation technique for epoxy-resin based sealers and single-cone technique using bioceramic sealers) affect the fracture resistance of teeth(Girish et al., 2017). The low modulus of elasticity of gutta percha compared to that of dentin led to some dental practitioner obturating root canals with MTA using monoblock obturation techniques(Ribeiro et al., 2008), but there needs to be more studies to determine whether this filling technique is appropriate. Not many studies examined whether the reinforcing effect of bioceramic sealers strengthen remaining tooth structures(Johnson et al., 2000).

The purpose of this study is to comparatively evaluate the fracture resistance and fracture patterns of roots obturated with various root canal sealers and corresponding root canal filling techniques using in vitro methods.

# II. Materials and Methods

## 1. Teeth selection and disinfection

Fifty non-carious, mandibular premolar teeth with similar buccal-lingual and mesial-distal dimensions were selected for this study. All teeth were immersed in 5% sodium hypochlorite (NaOCl) solution for 30 minutes after extraction and then stored in 0.1% thymol for disinfection. Preoperative radiographs and dental microscope (Zeiss, Dentsply, South Korea) were used to ensure that all teeth did not have root caries, crack lines, calcified canals, open apices or fracture.

## 2. Grouping method

Fifty teeth samples were randomly assigned into five experimental groups (n=10 each) shown below.

Group 1: Received no canal shaping and obturation of root canals (Negative control)

Group 2: Received canal shaping but no obturation of root canals (Positive control)

Group 3: Received canal shaping and obturation of root canals with epoxy-resin based sealer (AH Plus®) using continuous wave compaction technique

Group 4: Received canal shaping and obturation of root canals with calcium-silicate based sealer (Ceraseal®, MetaBioMed, South Korea) using single-cone technique

Group 5: Received canal shaping and obturation of root canals with MTA (ProRoot MTA®, Dentsply, USA) using monoblock obturation technique

### 3. Teeth preparation and obturation

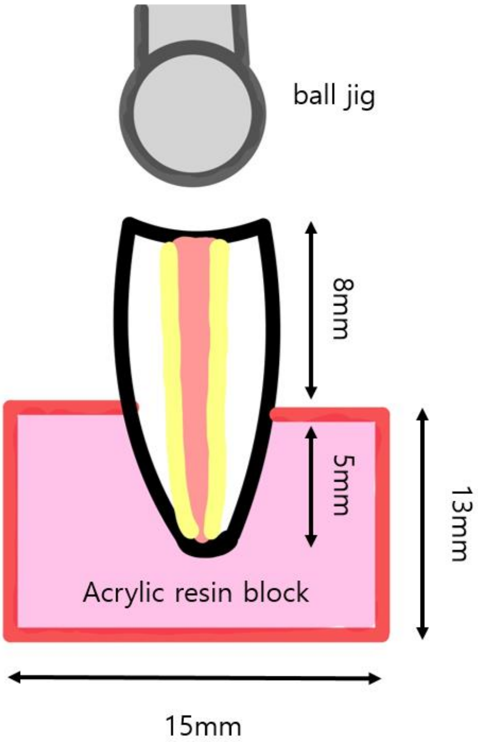
All teeth were decoronated to standard lengths of 13mm from apex using a wheel diamond bur. Then, coronal access was performed using #245 bur (excluding group 2). Working length was standardized by subtracting 1mm from root canal length. #10 K-file was inserted into the canal until the tip of the instrument was visible at apical foramen to measure the root canal length.

ProTaper Gold® rotary Ni-Ti files (Dentsply, South Korea) were used for shaping of root canals. The files were used in sequential order up to F3 at a speed of 250 rpm. The canals were irrigated with 5ml of 5% sodium hypochlorite (NaOCl) after each instrumentation. Final canal irrigation was performed with 17% EDTA, 5% sodium hypochlorite and normal saline.

Roots in group 2 were dried with paper points, but were not obturated (positive control). Group 1 received no instrumentation or obturation. Roots in group 3 were obturated with F3 ProTaper gutta-percha points and AH Plus® sealers using continuous wave compaction technique. Gutta percha was cut at 5mm short of working length using system B heat source and packed. Roots in group 4 were obturated with F3 ProTaper gutta-percha points and Ceraseal® using single-cone technique. Roots in group 5 were obturated with ProRoot MTA® using MTA messing gun. Post-obturation radiographs were taken to ensure adequate canal filling without voids. One general dentist performed all root canal treatment.

## 4. Storage and preparations for fracture test

All samples were stored at 37℃ and 100% humidity for 2 weeks for materials to set completely. Then, 5mm of each root was embedded vertically into an acrylic tube (autopolymerisable acrylic resin, Lang Dental, USA) of 15mm diameter, 13mm height to simulate alveolar bone and provide stable base for fracture resistance test [Figure 1].




**[Figure 1] Diagram showing root set up for fracture resistance test. The root was embedded vertically into an Ø15mm x 13mm acrylic resin block, leaving 8mm exposed.**

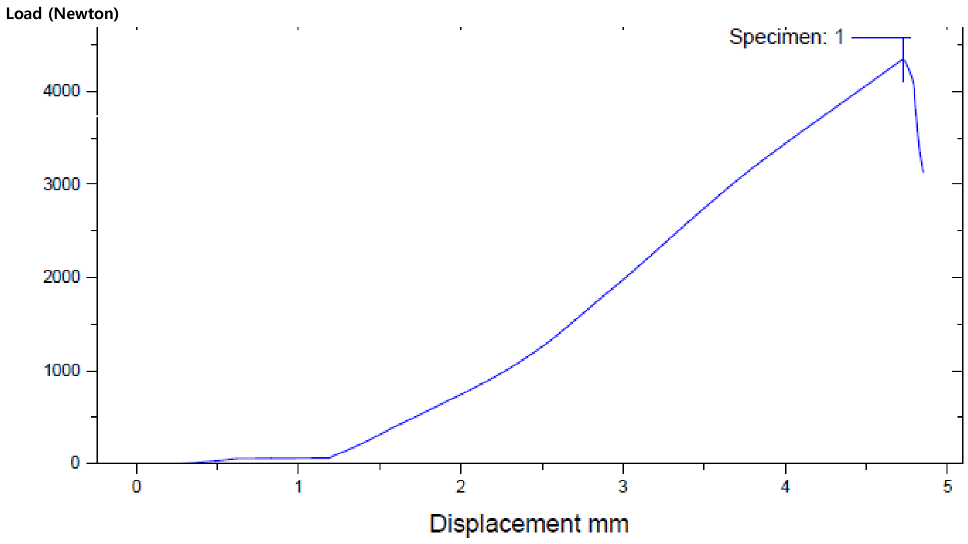
## 5. Fracture resistance test

All samples were mounted on universal testing machine (Instron, South Korea) for fracture resistance test. A ball tip indenter (5mm in diameter) was used to apply vertical load at a speed of 1mm/min until the root fractured. Fracture was determined when the load showed instantaneous drop [Figure 2].

Load of fracture resistance in Newtons converted to mega-pascal's using formula below.

MPA ($N/mm^2$) = Maximum load in Newtons (N) / ( ($\pi$/4) x (Ø 5mm)$^2$

- All samples used Ø 5mm ball jig for fracture resistance test.
- $\pi$ = 3.14 (constant value)




**[Figure 2] Data obtained from acrylic resin block showing gradual increase in load until instantaneous drop (fracture point).**

## 6. Statistical analysis

Normality of data distribution was first evaluated using Shapiro-Wilk test, and then homogeneity of variances using Levene's test. Statistical analysis was then performed using Analysis of variance (ANOVA), Least Significant Difference (LSD) test post hoc multiple comparisons and Duncan test. The level of significance was set at $P \leq 0.05$. Fisher's exact test was used to analyze failure modes ($P<0.05$). The statistical outliers of each experimental group (highest and lowest value of each experimental group) was removed for data analysis.

## 7. Evaluation of fracture modes of experimental groups

All experimental groups were examined under dental microscope (Zeiss, Dentsply, South Korea) with 12.5x widefield eyepieces after fracture resistance test. The failure type (adhesive failure or cohesive failure of sealing material) was evaluated. Fracture line passing through the border between the dentin and root canal filling was considered adhesive failure. Fracture line not passing through the border between the dentin and root canal filling was considered cohesive failure. Multiple fracture lines including both failure types were considered mixed type fracture. Complete fracture of coronal tooth structure was also considered mixed type fracture.

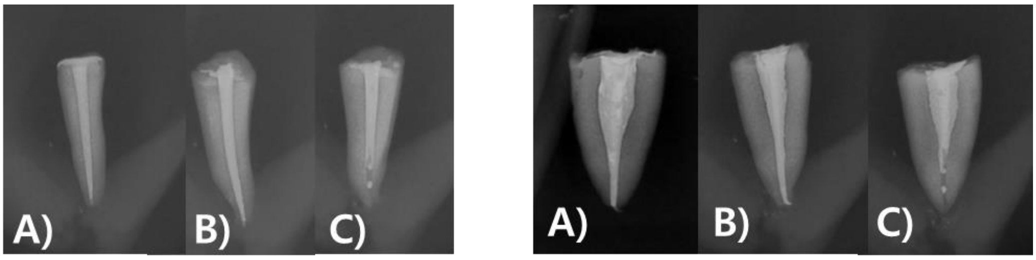
# III. Results

Examination of post-obturation radiographs showed that adequate filling without voids were more challenging to achieve with MTA and monoblock obturation technique. [Figure 3] Roots filled with resin based sealers and bioceramic sealers showed more uniform density of root filling without voids compared to roots filled with MTA.

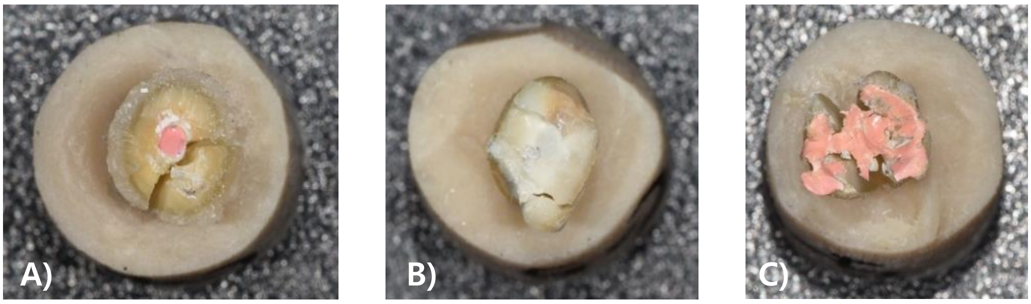
The mean and standard deviation values of fracture resistance strength (in MPa) for group 1 (negative control) was 50.8 ± 9.4 MPa, group 2 (positive control) was 44.4 ± 15.8 MPa, group 3 (AH plus) was 53.4 ± 17.0 MPa, group 4 (Ceraseal) was 68.6 ± 18.5 MPa and group 5 (MTA) was 52.7 ± 8.8 MPa [Table 1]. Comparison of fracture resistances between 5 groups using one-way ANOVA test at 5% level of significance showed that significant differences were observed between 5 groups ($F = 3.0155$, $P < 0.05$). [Table 2]

Negative control group showed higher fracture strength (50.8 MPa) compared to the positive control group (44.4 MPa) but was not statistically significant ($P > 0.05$). Bioceramic sealer with single-cone technique showed highest fracture strength (68.6 MPa) with statistically significant difference ($P < 0.05$). Resin based sealer (AH plus) (53.4 MPa) and ProRoot MTA (52.7 MPa) showed mean force higher than negative control group with no statically significant difference between them ($P > 0.05$).

Close examination of these samples under dental microscope revealed that resin based sealer (AH plus) had more adhesive failures than cohesive failures, while bioceramic sealers showed more cohesive failures than adhesive failures [Table 3] but was not statistically significant ($P > 0.05$). ProRoot MTA showed similar adhesive and cohesive failure modes.




**[Figure 3] Post-obturation radiographs of all groups that received obturation of root canals: (A) AH Plus® with continuous wave compaction technique group 3; (B) Ceraseal® with single-cone technique group 4; (C) ProRoot MTA® with monoblock obturation technique group 5**




**[Figure 4] Evaluation of failed samples: (A) adhesive failure between root canal sealer and dentin; (B) cohesive failure between root canal sealer and dentin; (C) mixed type fracture.**

**[Table 1] Mean and standard deviation of fracture strength for each group**

| Groups | Fracture strength (N) | | Fracture Strength (MPa) | | Significance |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| **Group 1 (Negative control)** | 997.6 | 184.4 | 50.8 | 9.4 | A |
| **Group 2 (Positive control)** | 872.1 | 310.7 | 44.4 | 15.8 | A |
| **Group 3 (AH Plus®)** | 1048.6 | 333.8 | 53.4 | 17.0 | A |
| **Group 4 (Ceraseal®)** | 1345.6 | 362.5 | 68.6 | 18.5 | B |
| **Group 5 (ProRoot MTA®)** | 1034.7 | 171.8 | 52.7 | 8.8 | A |

**[Table 2] Comparison of fracture resistances between 5 groups using one way ANOVA test**

| Source | Sum of Squares | df | Mean Square | F | p-value |
|---|---|---|---|---|---|
| **Between groups** | 2523.815 | 4 | 630.954 | 3.015 | 0.031 |
| **Within groups** | 7323.336 | 35 | 209.238 | | |
| **Total** | 9847.151 | 39 | | | |

$P \leq 0.05$. N: Newtons, ANOVA: Analysis of Variance, df: Degrees of freedom

**[Table 3] Failure modes of each obturated root canals after fracture resistance test**

| Groups | Adhesive failure | Cohesive failure | Mixed type fracture |
|---|---|---|---|
| **Group 3 (AH Plus®)** | 5 | 1 | 2 |
| **Group 4 (Ceraseal®)** | 2 | 4 | 2 |
| **Group 5 (ProRoot MTA®)** | 3 | 4 | 1 |

* Group 1 and Group 2 were not included in failure mode analysis because they did not receive obturation of root canals.

# IV. Discussion

There have been many in-vitro studies evaluating fracture resistance of endodontically treated teeth with different sealers(Phukan et al., 2017; Ribeiro et al., 2008; Zhou et al., 2013). However, there are comparably fewer studies evaluating fracture resistance of teeth with different filling techniques(Saw & Messer, 1995). Furthermore, dental practitioners use different combination of sealing materials and obturation techniques in dental clinic. This study examines whether root canal preparation and obturation weaken remaining tooth structure and compares the fracture resistance of roots obturated with different combinations of sealers and root canal filling techniques used in the dental clinic.

Mandibular premolars have been chosen for this study because of similar morphology. *Cleghorn BM et al.* show that most mandibular premolars were single rooted (99.6%) and anatomical variations were very rare(Cleghorn et al., 2007). This allows for uniform distribution of load and easier control of other variables between experimental groups. Premolars are also more sensitive to wedging stress of different root canal filling techniques due to smaller mesial-distal diameter(Pilo et al., 2017). However, this study used fifty mandibular premolars of various age group due to limited number of extracted teeth available. This was further complicated as this study required recently extracted mandibular premolars without caries, crack lines, calcified canals, open apices or fracture. Potential increase in fatigue and dentin microstructure change of premolars from old age group may have affected fracture resistance of teeth regardless of filling materials or filling techniques(Arola et al., 2017). All samples were non-carious with sound dentin, which may produce different fracture resistance values compared to infected dentin that dental practitioner usually face when providing root canal treatment to patients.

Positive control group showed lower fracture resistance strength compared to negative control group. This result indicate that instrumentation weaken the structure of the tooth. This result supports the study done by *Tavanafar S et al.* who states that instrumentation with NiTi hand K-file (HF, Dentsply-Maillefer; Ballaigues, Switzerland), BioRaCe rotary file (BR, FKG Dentaire; La-Chaux-de-

Fonds, Switzerland), and large WaveOne reciprocating single-file (WO, Dentsply-Maillefer) all showed significant reduction in fracture resistance compared to roots without instrumentation(Tavanafar et al., 2015). However, recent studies used micro-CT to prove that root canal preparation does not produce new dentin defects(De-Deus et al., 2014; Martins et al., 2021). Thus, the decrease in thickness of remaining tooth structure after instrumentation may have been more significant compared to instrument type, size or preparation techniques.

MTA monoblock, resin based sealer and bioceramic based sealers all showed higher fracture resistance than that of negative and positive control groups. However, there was no significant differences between groups excluding bioceramic based sealers. Bioceramic based sealer with single-cone technique showed highest fracture resistance strength between experimental groups with statistically significant difference ($P < 0.05$). ProRoot MTA monoblock obturation technique, on the other hand, showed lowest fracture resistance between experimental groups with no significant differences between them ($P > 0.05$). The advantageous physical properties of MTA led to some dental practitioner using MTA for orthograde filling in recent years. However, the difficulty in clinical manipulation of MTA may cause voids when obturating root canals(An et al., 2021). Figure 3 demonstrates that handling difficulty of MTA led to voids or incomplete filling on post-obturation radiographs. The low fracture resistance represented by MTA monoblock obturation technique in this study may have been due to the difficulty of MTA manipulation.

M. Prado *et al.* showed that instrumentation weaken tooth and lower fracture resistance. Filling using continuous wave compaction technique enhanced the tooth and increased resistance significantly compared to groups without filling, but still showed weaker resistance compared to negative control group(Prado et al., 2016). Previous studies demonstrated that retreatment of continuous wave compaction technique showed higher vertical root fracture than other filling techniques, possibly due to the wedging effect of warm vertical compaction procedure and difficulty in retreating heated instruments and excess gutta percha from apical third of root canals(Blum et al., 1998; Capar et al., 2015; Ersev et al., 2012; Taşdemir et al., 2008). On the other hand, C. Telli *et al.* suggested that warm vertical compaction procedure does not cause premature root fracture when performed skillfully(Telli et al., 1999). This study showed that fracture resistance of AH Plus sealer was higher than positive and negative control group but not significantly.

This study compares different canal filling techniques with different types of sealers and suggests that all methods enhance the fracture resistance of teeth undergoing root canal therapy with statistically significant difference ($P < 0.05$). Resin based sealer (AH plus) had more adhesive failures than cohesive failures, while bioceramic sealers showed more cohesive failures than adhesive failures. ProRoot MTA showed similar adhesive and cohesive failure modes but was not statistically significant ($P > 0.05$). Cimpean *et* al showed similar result where cohesive failure modes were predominant in root canals filled with bioceramic sealers, while adhesive failure modes were predominant with resin based sealers(Cimpean et al., 2022). Highest fracture resistance was recorded in root canals filled with bioceramic based sealers.

Further studies using thermocycling process and chewing simulation on roots may show different results compared to fracture under continuous vertical load. Volume shrinkage and dissolution of sealers over time, aging of dentin and other obturation materials may need to be further examined. Larger sample sizes and clinical long-term studies are required to evaluate the fracture resistance with different root canal sealers and corresponding root canal filling techniques.

# V. Conclusion

Under the limitation of this study, the following conclusions were drawn:

1. The combination of bioceramic based sealer and single-cone filling technique showed the highest fracture resistance compared to resin based sealer with continuous wave compaction technique and MTA with monoblock obturation technique with statistically significant differences.

2. MTA with monoblock obturation technique showed root fillings with voids under post-obturation radiographs. Fracture resistance was lowest among filled groups but was not statistically significant.

3. Adhesive failure was found most frequently in roots filled with resin based sealer (AH plus) using continuous wave compaction technique, but was not statistically significant.

4. Further studies are required to evaluate the efficacy of different sealers and canal filling techniques.

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국문 요약

## 근관충전재료로 사용되는 다양한 근관 실러 및 근관 충전법이 치근 파절에 미치는 영향

연세대학교 대학원 치의학과

송 윤

지도 교수: 김기덕

**연구 목적:** 본 연구는 다양한 근관실러와 근관충전을 할 때 나타나는 치근의 파절강도와 파절 양상을 in vitro 시험을 통하여 비교해보고자 한다.

**실험 재료 및 방법:** 치아 우식이 없으며 유사한 협설 폭 및 근원심 길이를 가진, 최근에 발거된 하악 소구치 50개를 각 10개씩 5개의 군으로 분류하였다. 1군은 음성 대조군으로 근관 성형 및 근관 충전을 시행하지 않았다. 2군은 양성 대조군으로 근관 성형은 시행하였으나 근관 충전을 시행하지 않았다. 3군은 근관 성형 및 continuous wave technique로 resin based sealers (AH Plus®)를 사용하여 근관 충전을 시행하였다. 4군은 근관 성형 및 single-cone technique로 bioceramic based sealers (Ceraseal®)를 사용하여 근관 충전을 시행하였다. 5군은 근관 성형 및 monoblock obturation technique로 MTA (ProRoot MTA®)를 사용하여 근관 충전을 시행하였다. 모든 실험군은 근관 충전 후 협설측 및 근원심 방향으로 방사선 사진을 촬영하여 충전의 질을 평가하였으며, 만능시험기(Instron, South Korea)로 치근 파절이 될 때까지 하중을 가하여 파절 저항을 측정하였다. 한 명의 치과의사가 모든 실험군의 근관 성형, 근관 충전 및 파절 강도 실험을 진행하였으며, 파절 강도

실험 후 미세 현미경(Zeiss, Dentsply, South Korea) 및 12.5x widefield eyepieces 으로 파절 양상을 비교하였다.

**실험 결과:** Resin based sealer (AH plus) (53.4 MPa), bioceramic based sealer (68.6 MPa), 그리고 MTA (ProRoot MTA®) (52.7 MPa)로 근관충전 한 실험군이 음성 대조군 (50.8 MPa) 및 양성 대조군(44.4 MPa) 에 비해 높은 평균 파절 저항을 보였다. Bioceramic sealer 및 single-cone technique 으로 충전한 실험군이 제일 높은 파절 저항 (68.6 MPa)을 보였으며, 통계적으로 유의미한 차이를 보였다 ($P < 0.05$).

**결론:** 본 연구자료에 의하면 bioceramic based sealer 와 single-cone technique 으로 근관치료를 진행하는 방법이 다른 근관실러와 충전법보다 더 높은 파절 저항을 보인다.

**핵심이 되는 말:** 수직 치근 파절, 파절 저항, Mineral Trioxide Aggregate, Bioceramic based sealer, Epoxy Resin based sealer