

**Influence of Post Types and Sizes
on Fracture Resistance
in the Immature Tooth Model**

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**Influence of Post Types and Sizes
on Fracture Resistance
in the Immature Tooth Model**

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감사의 글

아직도 많이 부족한 제가 한 편의 논문을 완성할 수 있도록 도움을 주시고 격려해 주신 모든 분들께 이 자리를 빌어 감사의 마음을 전합니다.

저의 미숙한 의견까지도 경청해주시며 자유롭게 실험할 수 있도록 저를 이끌어주시고 지켜봐 주셨던 지도교수 정일영 교수님께 특별한 감사를 드립니다. 짧은 문답 속에서 날카롭고 탁월한 조언을 해주셨던 박성호 교수님, 저의 실험 과정과 논문을 꼼꼼하게 살펴보시고 교정해주신 자상하신 박정원 교수님과의 심사 과정이 저에게는 즐거운 시간이었고, 깊은 감사를 전하고 싶습니다.

지칠 줄 모르는 열정과 깊은 통찰력으로 이제 출발선에 서게 된 저에게 귀감이 되어주신 이찬영 교수님과 이승종 교수님, 논문을 읽는 법부터 시작해서 논문을 쓰기까지 세심하게 기초를 가르쳐주신 노병덕 교수님, 김의성 교수님, 공형규 교수님께 감사를 드립니다. 귀찮을 정도로 질문이 많았지만, 항상 웃으시며 대답해주신 동경하는 신수정 교수님께도 깊은 감사를 전합니다. 훌륭하신 교수님들의 높은 어깨를 빌어 더 멀리 볼 수 있었던 지난 2 년간의 시간은 저에게는 무엇보다 바꾸지 못할 소중한 자산이 되었습니다.

언제나 든든한 내 편이 되어주었던 부모님과 사랑하는 형제 중범오빠와 종원이, 평범한 저를 특별하게 만들어주신 시부모님과 수정 언니, 그리고 함께 있어 행복했던 동기 진희에게 고마움을 전합니다. 마지막으로 제 인생의 등불이 되어준 사랑하는 남편 이중석씨에게 이 논문을 바칩니다.

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저자 씀

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ABSTRACT

Influence of Post Types and Sizes on Fracture Resistance in the Immature Tooth Model

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When pulp necrosis of immature tooth is developed, thickness of root dentin wall remains thin for the discontinuation of tooth development, and long-term exposure to calcium hydroxide for conventional apexification procedure weakens root structures. Therefore, there is a need to reinforce root structures after apexification procedure of immature tooth. To date, various restorative techniques for root strengthening of immature tooth have been introduced, however, no treatment procedures are established as a gold standard for restoration of immature root canals. The purpose of this study was to determine the effect of post types and sizes on fracture resistance in immature tooth model with various restorative techniques.

Bovine incisors were prepared to simulate immature tooth model and conventional endodontic treatments were performed. In control group, canals were restored with thermoplastic gutta-percha and resin core over 4-mm-thick portland cement apical barrier. Specimens of experimental groups 1, 2, 3 were reinforced of dentin wall with dual-cured resin core material, followed by placement of D.T. LIGHT-POST[®] (Bisco Inc.) #3, ParaPost[®] XTTM (Coletène/Whaledent Inc.) #6, and EverStick[®] Post (StickTech) 0.9 individually. In group 4, several EverStick[®] Post 1.5 were bonded and shaped to each other according to the root canal

in customized size. All of specimens were stored in the distilled water for 72 hours and underwent 6,000 thermal cycles. After stimulation of periodontal ligament structure with polyether impression material, compressive load was applied at 45 degrees to the long axis of the specimen until fracture was occurred.

Experimental groups reinforced with post and composite resin were shown significantly higher fracture strength than control group without intra-radicular reinforcement technique ($p < 0.05$). Post types did not influence on fracture resistance significantly when cement space was filled with dual-cured resin composite. In addition, no statistically significant differences were seen between customized and standardized glass fiber posts, which cement spaces were filled with resin cement or composite resin individually. Therefore, it is recommended post placement for root strengthening in immature teeth regardless of post types and sizes.

Keyword : Immature tooth, Fracture resistance, Fiber post, Titanium post, EverStick® Post,

Post size

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I. Introduction

When pulp necrosis of immature tooth is developed, tooth development would not continue any longer, and thickness of root dentin wall remains thin for the discontinuation of tooth development. In developing immature dentin, fine particles are found which may be single crystals, as mature dentin is composed of larger particles due to aggregation of the smaller crystals in the electron microscopic examination. Peritubular dentin appears higher mineral deposition in mature dentin than developing dentin (Takuma 1960). In addition, it is reported that 180-day of calcium hydroxide dressing decrease 10 to 20% reduction of fracture strength and increase the likelihood fracture of teeth (Doyon, Dumsha and von Fraunhofer 2005). A study by Cvek (Cvek 1992) pointed out that endodontically treated immature tooth is prone to fracture, especially at the cervical third. Therefore, there is a need to reinforce root structures after apexification procedure of immature tooth.

To date, various techniques for root strengthening of immature tooth have been introduced, for example, the reinforcement of wall thickness with composite resin or mineral trioxide

aggregates (MTA) and post placement. It has been demonstrated that the increase in wall thickness of weakened tooth model using composite resins increased resistance to fracture (Goncalves, Vansan, *et al.* 2006). Also, it is documented that zirconium fiber post or composite resin can increase significantly the structural resistance in weakened teeth (Carvalho, Valera, *et al.* 2005). In addition, twice fracture resistance was obtained compared with that of an apical MTA and filling with gutta-percha and sealer (Bortoluzzi, Souza, *et al.* 2007). Recently, a clinical approach has been introduced to use titanium post and MTA for root reinforcement (Bramante, Menezes, *et al.* 2006).

Ideal materials for root reinforcement should bond to root dentin and have a similar elastic modulus with root dentin (Tay and Pashley 2007). MTA lacks of bonding to dentin and has low strength in tension. Also, MTA is not clinically appropriate for root reinforcement because of difficulty in manipulation, longer setting time, and possibility of tooth discoloration. In comparison, dual-cured resin composite can bond to dentin with adhesive systems, polymerize chemically without a light source, and has a superior strength and elastically compatible with dentin. Therefore, Dual-cured resin composite can reinforce weakened root structure in immature teeth. Dual-cured resin composite, however, undergoes polymerization shrinkage more at the site of high C-factor like root canal. Also, although dual-cured composite can be polymerized chemically, its degree of conversion is mostly dependent on light curing.

Metal posts have higher elastic modulus than dentin by five times or more, and its stiffness can prevent post-and-core structures from deformation. However, the appreciable difference in elastic modulus with surrounding structure can lead to root fracture. Among them, as titanium posts have elastic modulus closer to dentin, its application is promising. A few cases were reported to use titanium posts clinically in immature teeth (Bramante, Menezes, *et al.* 2006).

Fiber posts have similar elastic modulus with dentin and can bond with resin cement through surface treatment and bonding procedure. In addition, fiber posts can transmit light to deeper part of the canal so they can improve degree of polymerization of resin cements (Radovic, Corciolani, *et al.* 2009). Previous studies of fiber posts reported that fiber posts tend to result favorable fracture pattern compared with metal posts, because metal posts concentrate stress on surrounding dentin at the level of apical end of metal posts, rather than redistributed along the post surface as in fiber posts. It can be said that fiber posts with resin cement, therefore, are the most appropriate for root strengthening procedure clinically.

It is difficult to place post closely fitted in the flared canal of immature tooth because most post systems are standardized in size, so an increase in cement thickness is inevitable. Generally, mechanical and bonding properties are compromised when the film thickness is too great (D'Arcangelo, Cinelli, *et al.* 2007). To attain uniform cement thickness, two types of post can be considered as a candidate; cast post and recently released EverStick® Post. Experimental studies of cast post revealed that cast post demonstrated high incidence of catastrophic root fracture on fracture strength testing. Because of a marked difference in modulus of elasticity between cast post and dentin, however, it cannot reinforce root structure particularly in the case of thin-walled immature tooth (Yoldas, Akova and Uysal 2005). EverStick® Post has comparable elastic modulus with dentin and can be customized in size by bonding to each other to adapt a large flared canal. Accordingly, EverStick® Post can be used to reinforce immature root with resin cements.

Previous studies demonstrated that root reinforcement with composite resin in immature tooth improves fracture resistance (Carvalho, Valera, *et al.* 2005; Yoldas, Akova and Uysal

2005). Nevertheless, comparative studies of fiber post and titanium post in flared large canal reinforced with composite resin has not been published. Furthermore, the use of resin composite for root strengthening has not been proved to be effective over post in customized size. Therefore, the purpose of this study was to determine the effect of post types and sizes on fracture resistance with or without resin reinforcement. Fracture strength of immature bovine incisors were compared which canals were restored with gutta percha, fiber post, titanium post and customized fiber post (EverStick[®] Post), which cement spaces were filled with dual-cured composite resin and resin cement after in vitro aging procedure.

II. Materials & Methods

Specimen Preparation

One hundred forty-three immature bovine incisors were extracted and sectioned 8mm above and 12mm below the cemento-enamel junction, total length of 20mm using the water-cooled diamond points (Bortoluzzi, Souza, *et al.* 2007) (Fig. 1). Tooth specimens were excluded which had cracks or defects on surfaces. Apical root shape, buccolingual or mesiodistal diameter, and remaining dentin thickness were measured using a digital caliper (Fig. 2). Specimens of the size confined to limited range were selected, total 57 specimens were used in this experiment.

Access cavities were prepared and pulps were extirpated, any debris in the canals were removed with minimal instrumentation. Canals were irrigated copiously with 5.25% sodium hypochlorite and 18% EDTA and finally dried. Portland cements were filled 4-mm-thick in apical area using sterile paperpoints and endodontic condensers. Filling qualities were evaluated with periapical radiographs and any specimens which were recognized gaps or voids were corrected with ultrasonic filling technique. Portland cements were mixed with a ratio of 3 to 1, powder to liquid, allowed to set and stored more than four hours in 100% humidity.



Fig. 1. Model of immature permanent incisor.

Sectioned parts of bovine tooth ; the crown length is 8 mm from the cementoenamel junction, the root length is 12 mm from the cementoenamel junction

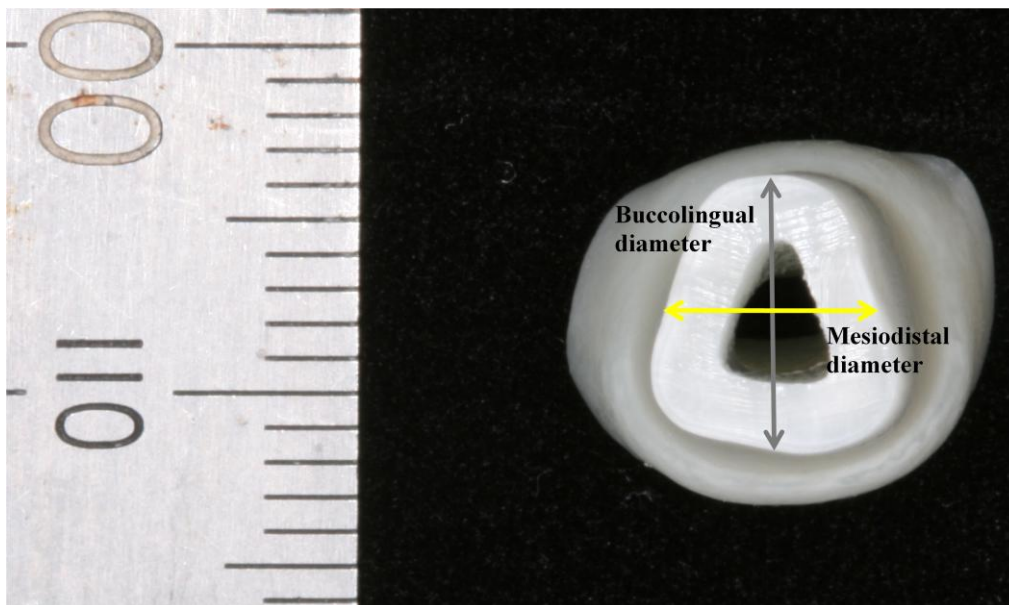


Fig. 2. The width of remaining root dentin and the size of the specimen is measured with the electronic digital caliper.

Control group : After drying root canals with paperpoints, canals were filled with gutta percha and AH 26[®] (Dentsply DeTrey[®]) sealer using thermoplastic injection technique (Duo-beta, B&L Biotech.) 2mm below the buccal cemento-enamel junction. Access cavities were filled with Cavit[™] G (3M ESPE) for temporary sealing, and specimens were stored in distilled water for 24 hours. After temporary sealing material was removed, semi-gel type of 37% phosphoric acid was used to etch endodontic cavity for 15 seconds. The canal was washed and left in slightly moistened state, two coats of ONE-STEP[®] (Bisco Inc.) were applied with microbrushes and gently dried. The adhesive was polymerized with light curing for 20 seconds, and dual-cured resin core material, LuxaCore[®] Smartmix Dual (DMG) was injected, light-cured for 40 seconds.

Group 1 : D.T. LIGHT-POST[®] (Bisco Inc.) #3 was cut with a diamond bur to 14mm in length, ONE-STEP[®] was applied on the post surface and light cured for 10 seconds, gently dried as manufacturer's instruction. A canal was treated as access cavities of control group, and the space between the post and the canal was filled with LuxaCore[®] Smartmix Dual. LuxaCore[®] Smartmix Dual was injected in twice, the first layer was light-cured for 10 seconds, and finally for 40 seconds.

Group 2 : A serrated parallel titanium post, ParaPost[®] XT[™] (Coletène/Whaledent Inc.) #6 was prepared for 14mm in length and tribochemical silica coating and silanization with Monobond-S (Ivoclar Vivadent) on the post surface were followed (Schmage, Sohn, *et al.* 2006). The post surface was dried with oil-free air syringe after 60 seconds, two coats of ONE-STEP[®] were applied and gently dried, polymerized with light curing for 10 seconds. The same procedures were followed as group 1.

Group 3 : EverStick[®] Post (StickTech) 0.9 was prepared for 14mm in length and light-cured for 40 seconds. After removal of the post, Adper[™] Scotchbond[™] Multi-Purpose Adhesive(3M ESPE), an enamel bonding agent, was applied for activation of post surface and left for 3 to 5 minutes under a light shield to prevent from premature curing, as manufacturer's recommendations. The post surface was air dried with oil-free air syringe and light-cured for 10 seconds. The same procedures were followed as group 1.

Group 4 : EverStick[®] Post 1.5 was prepared for 14mm in length, and light-cured for 20 seconds inside the canal. Additional posts were bonded and shaped to the main post according to the root canal with a thin layer of Adper[™] Scotchbond[™] Multi-Purpose Adhesive, and then light-cured for 10 seconds inside the canal. The post surface was treated as group 3. The canal was etched for 15 seconds with 37% phosphoric acid, ONE-STEP[®] was applied twice and light-cured for 10 seconds. A dual-cured resin cement, Variolink[®] II (Ivoclar Vivadent) was applied in the canal with lentulo spiral, and the post was placed, polymerized with light curing for 40 seconds.

Periapical radiographs were taken to assess the quality of root canal restoration and specimens with voids were excluded in this study. All of specimens were stored in the distilled water for 72 hours.

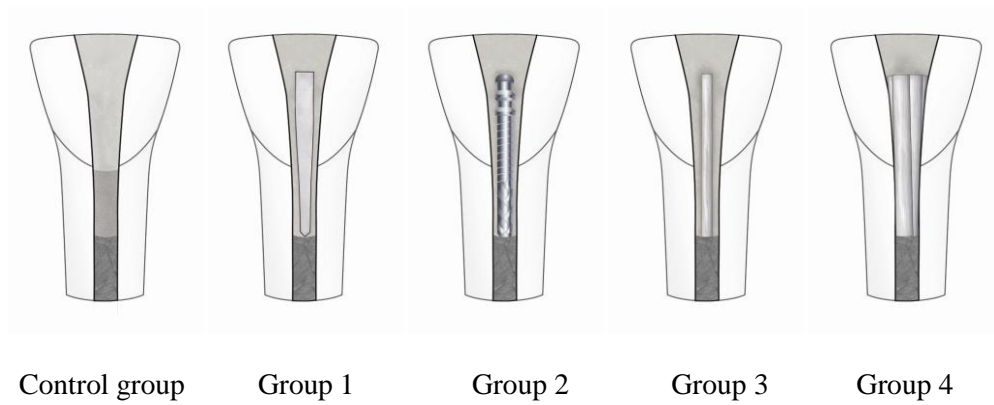


Fig. 3. Schematic diagrams of intracanal and coronal restorations.

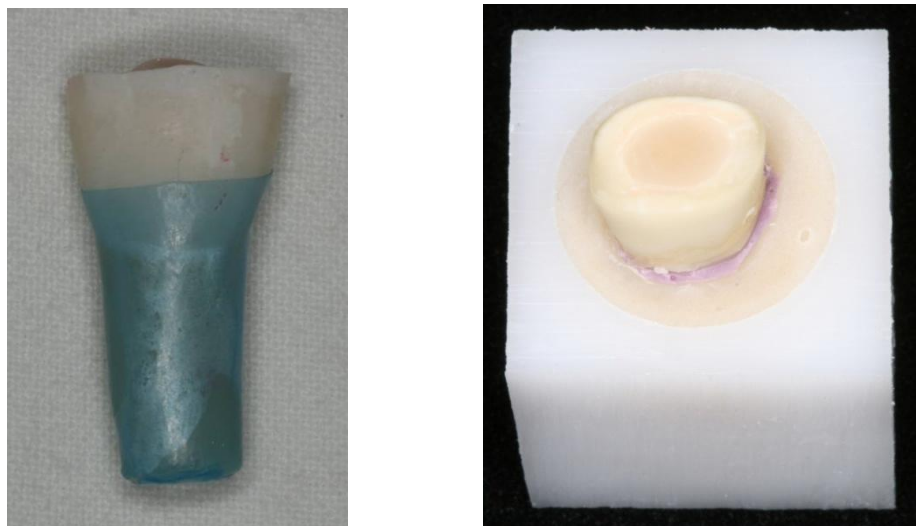


Fig. 4. 0.2 mm-thick sheet wax is pressure welded on the root surface. The specimen is placed in the acetal mold, and autopolymerizing acrylic resin is injected into the mold.

Fracture Strength Testing

All specimens underwent 6,000 thermal cycles between 5 °C and 55 °C, with a dwell time of 30 seconds and a transfer time of 5 seconds (Krejci and Lutz 1990). Afterwards, specimens were preserved in 100% humidity for a week. 0.2mm-thick blue sheet waxes were pressure-welded on root portion of specimens uniformly. They were mounted in the prefabricated acetal blocks, and embedded in acrylic resin up to 2mm from the buccal cemento-enamel junction. After setting of injected acrylic resin, specimens were pulled out of the block and waxes were removed from the surfaces. The 0.2mm-gaps were filled with polyether impression material, Impregum™ F(3M ESPE) for periodontal ligament simulation (Fig. 4). Any excesses were carefully removed with blades after setting of polyether (Soares, Pizi, *et al.* 2005).

Specimens individually were tested fracture strength using Universal Testing Machine Instron (INSTRON Corporate Headquarters) at a constant speed of 0.5mm/min. Compressive load was applied at 45 degrees to the long axis of the specimen, at the point of lingual incisal edge (Fig. 5). The loads at fracture were recorded, at the point that stress was abruptly reduced. Fractured specimens were analyzed a direction and location of line of fracture, and they were classified into restorable and non-restorable fracture. Cervical fracture restricted within coronal third of the root was recorded as restorable fracture, and vertical or horizontal fracture extended into middle and apical third of the root as non-restorable fracture.

Statistical Analysis

Kruskal-Wallis ANOVA on Ranks was performed to determine significant differences between groups. Post hoc multiple comparison was applied using Bonferroni/Dunn test when data analysis showed significant difference, with a significance level of $p < 0.05$.

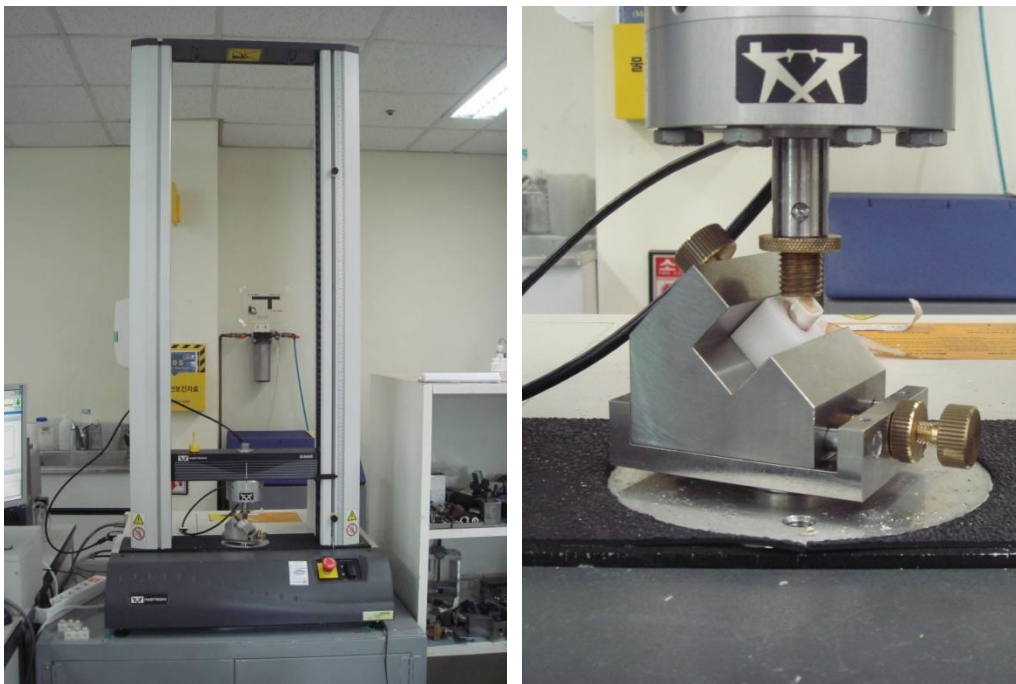


Fig. 5. Device is positioned for the compressive load application at 45° to the long axis of tooth specimen. Compressive load is applied to the lingual incisal edge of the specimen.

III. Results

Specimens were selected for similar size, and mean root diameters in buccolingual and mesiodistal direction were 7.41mm (S.D. 0.47mm) and 5.98mm (S.D. 0.49mm) respectively. Remaining dentin thickness of all specimens ranged between 2.0±0.2mm. Twelve specimens with gaps in the periapical radiographs were excluded, and total forty-five specimens were submitted to fracture strength test.

Mean fracture strengths of the groups are shown in Table 2. Specimens of all experimental groups demonstrated significantly higher load at fracture than control group ($p < 0.05$), and group 4 showed slightly higher fracture strength compared with group 1, 2 and 3, but the difference was not statistically significant (Fig. 6). ($p > 0.05$). The result of fracture analysis is also shown in Table 2. No significant differences in the incidence of restorable and non-restorable fracture were found between groups (Fig. 7,8). Location of fractures in control group was detected at the margin of core. All specimens fractured extended to cemento-enamel junction, not limited to crown portion.

Table 1. Median fracture strength (25th and 75th percentiles) and location of failure of control and experimental groups

	No.	Median (N)	25 th /75 th percentiles	Location of failure	
				Restorable	Non-restorable
Control	5	470.6	19.8 / 6.3	5	0
Group 1	10	2149.4 [†]	253.05 / 66.775	7	3
Group 2	10	1963 [†]	113.95 / 707.5	7	3
Group 3	10	2304.7 [†]	404.225 / 103	8	2
Group 4	10	2500 [†]	394.35 / 194.35	6	4

[†] : Statistically significant difference was found ($p < 0.05$).

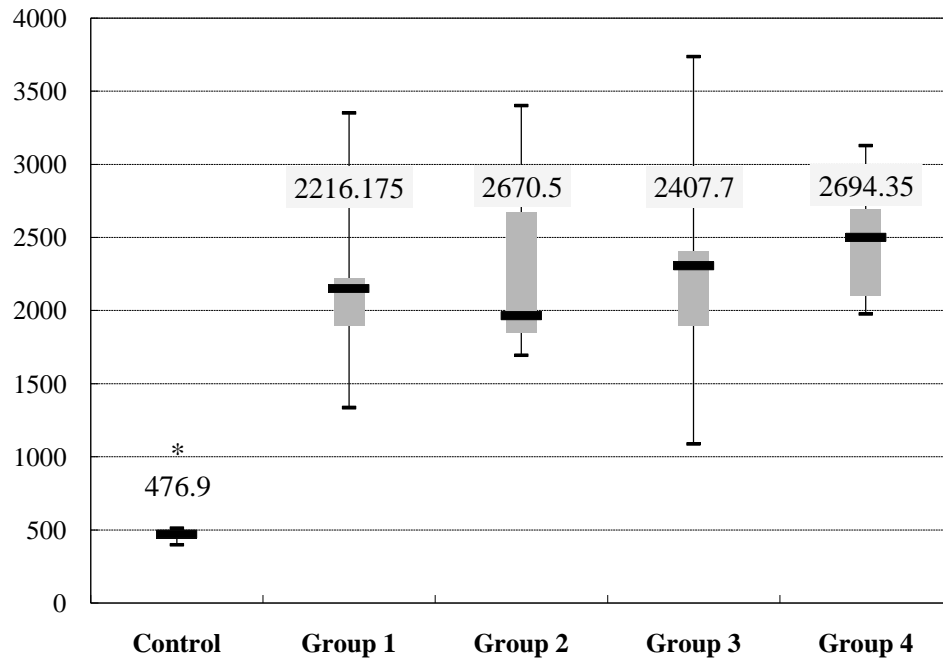


Fig. 6. Box plots of fracture load (median, 25th and 75th percentiles) of the control and experimental groups (N). * : statistically significant difference was found.

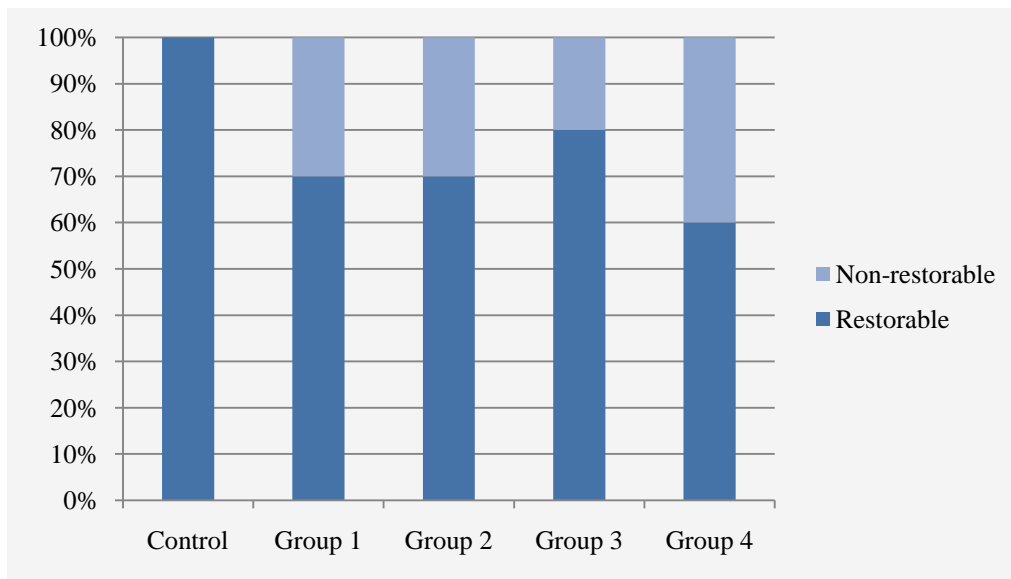


Fig. 7. The ratio of restorable and non-restorable fractures in the control and experimental groups.

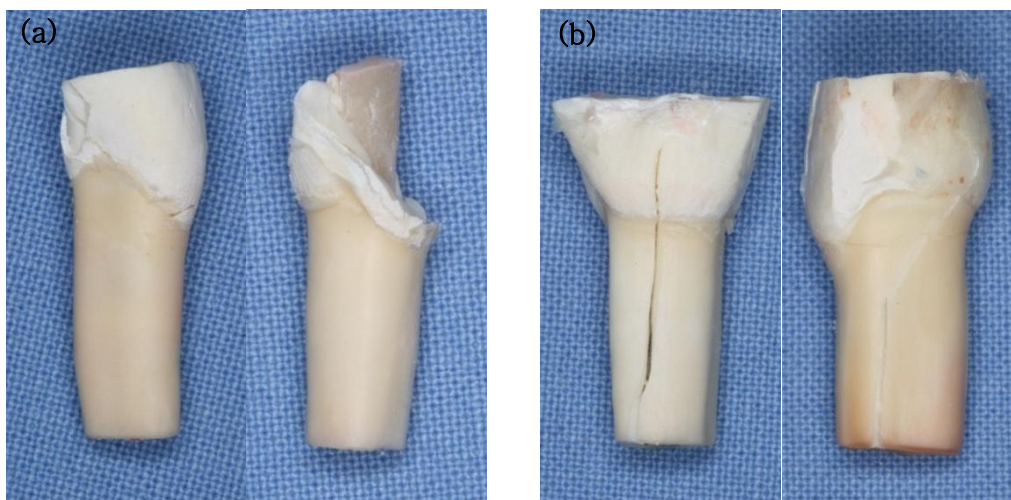


Fig. 8. Location of fracture line (a) Restorable fractures (b) Non-restorable fractures

IV. Discussion

Necrotic immature teeth require restorative procedure for root reinforcement due to discontinuation of root development. Thin root dentin and calcium hydroxide treatment reduce fracture resistance of immature teeth, although loss of coronal structure is minimal. Generally posts are used for the purpose of increasing retention of core and crown structures, not of root strengthening. In the case of endodontically treated immature teeth, however, posts can be used for root reinforcement (Carvalho, Valera, *et al.* 2005; Moosavi, Maleknejad and Kimyai 2008; Naumann, Preuss and Frankenberger 2007; Yoldas, Akova and Uysal 2005). This study is designated for the determination of root reinforcement effect of posts, and for comparison of fracture resistance with combination of various post and cement systems.

Bovine teeth differ from human teeth morphologically. In addition, it is reported that bovine teeth are more susceptible to thermal fatigue and crack propagation after thermocycling than human teeth (Brown, Jacobs and Thompson 1972). However, ultimate tensile strength and elastic modulus of bovine teeth are not significantly different from those of human teeth (Sano, Ciucchi, *et al.* 1994), and bovine teeth facilitate to ensure large number of immature incisors of similar sizes. Therefore, bovine teeth were selected in this study as simulation of immature permanent teeth.

Mean fracture strength of bovine teeth restored with gutta percha over MTA apical plug in bovine teeth was 461.4 N in this study, and this value is relatively low compared with previously published studies of Carvalho and Bortoluzzi, 767 N and 872 N respectively (Bortoluzzi, Souza, *et al.* 2007; Carvalho, Valera, *et al.* 2005). That is because thermocycling

was not performed in the above studies and thermocycling may reduce fracture resistance of bovine teeth due to thermal fatigue.

MTA has superior biocompatibility, sealing ability and high strength although it has lack of bonding ability to dentin. Therefore, it has been widely used in apexification procedure of immature permanent teeth. 4-mm-thick MTA is recommended for prevention of apical leakage (Hachmeister, Schindler, *et al.* 2002; Valois and Costa 2004). Portland cement and MTA are similar in chemical compositions, sealing ability and solubility (Coneglian, Orosco, *et al.* 2007). Also, the compressive elastic modulus of Portland cement is up to that of dentin (Tay and Pashley 2007). Therefore, MTA can be replaced with Portland cement in experimental study. In this study, accordingly, 4-mm-thick portland cement was used as a substitute for MTA apical plug.

A simulation of periodontal ligaments influences on fracture modes. The teeth with periodontal ligament simulation tended to fracture at root, while the teeth without periodontal simulation tended to fracture on top of resin blocks (Soares, Pizi, *et al.* 2005). That is because periodontal ligament transfers the load to the alveolar bone and the stress is redistributed in all root surfaces. Polyether, elastomeric impression material, can reproduce periodontal ligaments suitably based on its deformation limit, value and high ultimate tensile strength. On the analysis of fracture pattern in this study, fracture levels of all specimens are beyond the cemento-enamel junction.

Bonding ability and elastic modulus similar to dentin are basic requirements of restorative materials for root strengthening (Tay and Pashley 2007), and composite resin is a corresponding material. Large flared root canals in immature teeth have the advantages of accessibility and C-factor for composite resin filling. In addition, dual-cured resin composites

can be polymerized deep in the canal where light transmission is limited. However, canal obturation with dual-cured resin composite results in reduced mechanical properties because a large portion of dual-cured resin composite is dependent on light curing. For these reasons, resin reinforcement of root canal without post has not been attempted. In this experiment, light-curing time was increased and dual-cured resin composite was injected through two times, each layer was light-cured individually for improved polymerization.

Elastic modulus of materials within the canal for root reinforcement is an important factor for fracture resistance of weakened roots. The more rigid component in the canal can resist greater forces without distortion but it induces stresses within the canal. In contrast, a material

Table 2. The modulus of elasticity of materials employed within the root canal space

Materials	Modulus of elasticity (GPa)
Human dentin ¹	14.0 – 18.6
Bovine dentin ²	13.7 – 14.7
Gutta-percha ¹	0.074 - 0.079
Portland cement ¹	15 - 30
LuxaCore® ³	8.8
D.T. LIGHT-POST® ⁴	30 - 34
ParaPost® XT™ ⁴	54 - 68
EverStick® Post ⁵	13-16
Variolink II ⁶	7.4

These data are from following references ; 1. Tay and Pashley 2007 2. Sano, Ciucch, *et al.* 1994 3. Information given by the manufacturers 4. Beck, Ghuman, *et al.* 2009 (unpublished data) 5. Lassila, Tanner, *et al.* 2004 6. Ceballos, Garrido, *et al.* 2007

with low elastic modulus of the material cannot prevent from distortion but it acts as a shock absorber increasing tooth strength. It means that resistance for distortion and stress distribution are dependent on elastic modulus of materials within the canal (Tay and Pashley 2007) .

The effect of elastic modulus of posts on fracture strength was evaluated from glass fiber posts and titanium posts. D.T. LIGHT-POST[®] is composed of unidirectional quartz-fiber post system with double tapers. It can transmit light along the post to improve degree of conversion of resin cements deep in the canal (Radovic, Corciolani, *et al.* 2009), and elastic modulus of the post is similar to dentin. ParaPost[®] XT[™] is titanium post system and elastic modulus is about 60 GPa (P. Beck 2009), which the value is closer to that of dentin than stainless steel (Tay and Pashley 2007). It has threaded surface for mechanical retention, and the gap between post and canal was filled with composite resin in the experiment. This study revealed that fracture strengths of specimens restored with D.T. LIGHT-POST[®] and ParaPost[®] XT[™] were not significantly different. In addition, the incidence of restorable and non-restorable fracture was not significantly different between post types. Many previous studies have reported that titanium post presents higher fracture resistance than fiber post and higher incidence of catastrophic fracture (Abdul Salam, Banerjee, *et al.* 2006; Akkayan and Gulmez 2002; Al-Omiri and Al-Wahadni 2006; Mitsui, Marchi, *et al.* 2004). It is known that maximum load capability is affected less by post strength, but more by the amount of surrounding hard tissue (Naumann, Preuss and Frankenberger 2007). These specimens are of sufficient tooth structures and height of coronal dentin as well as resin-reinforced dentin wall. For this reason, higher modulus of elasticity of titanium post does not increase fracture strength and the incidence of oblique root fracture. Therefore, both fiber posts and titanium posts improve fracture resistance and tend to induce favorable fractures in immature tooth model.

EverStick[®] Post consists of unidirectional E-glass and unpolymerized Bis-GMA matrix, and it has elastic modulus similar to dentin (Lassila, Tanner, *et al.* 2004). An enamel bonding agent without solvent like acetone can penetrate into and partly solve unpolymerized resin matrix monomers, allowing to bond with resin cements (Abo El-Ela, Atta and El-Mowafy 2008; Mannocci, Sherriff, *et al.* 2005). In addition, EverStick[®] Post can be bonded each other and trimmed for adaptation to root canal. It is intended to compare fracture strength according to width of cement space with customized and standardized EverStick[®] Posts. Customized EverStick[®] Posts tended to show slightly higher fracture strength than standardized EverStick[®] Posts, but the values were not statistically different. Several studies (D'Arcangelo, Cinelli, *et al.* 2007; Hagge, Wong and Lindemuth 2002) reported that retentive strength of posts are reduced as cement thickness increases, by reason that increased cement space may result in procedural errors, decreased integrity of cements, and these structural flaws can compromise mechanical properties of restorations. Root canals of immature teeth, however, are reinforced with high-strength dual-cured composite resin instead of resin cement in this study. Accordingly, a customized fiber post did not demonstrate additional advantages in spite of its labored procedure.

Immature teeth with sufficient crown structures were used in this study and this may contribute to high fracture strength independent of post types. The amount of remaining tooth structures are known to much influence on fracture strength of teeth restored with post and core (Isidor, Brondum and Ravnholt 1999; Pereira, de Ornelas, *et al.* 2006). However, post groups showed significantly increased fracture strength compared with control group restored with gutta-percha and resin core. Therefore, it is recommended post placement for root strengthening in immature teeth. Further studies are needed to evaluate the effect of post types on fracture resistance of immature teeth in a model of severe loss of crown structures.

V. Conclusions

This study evaluated the effect of post on root strengthening and fracture resistance according to post types and post fitness in a model of immature bovine incisors. Experimental groups were designed to use fiber posts and titanium posts. Also, the effect of post fitness was compared using standardized and customized fiber posts. Within the limitation of this in vitro study, the following conclusions can be drawn :

1. In a model of immature bovine incisors, experimental groups reinforced with post and composite resin were shown significantly higher fracture strength than control group without intra-radicular reinforcement technique ($p < 0.05$).
2. Post types did not influence on fracture resistance significantly when cement space was filled with dual-cured resin composite.
3. No statistically significant differences were seen between customized and standardized glass fiber posts, which cement spaces were filled with resin cement or composite resin individually.

VI. References

- S. N. Abdul Salam, A. Banerjee, *et al.* (2006). "Cyclic loading of endodontically treated teeth restored with glass fibre and titanium alloy posts: fracture resistance and failure modes" *Eur J Prosthodont Restor Dent* 14(3): 98-104
- O. A. Abo El-Ela, O. A. Atta and O. El-Mowafy (2008). "Microtensile Bond Strength of Nonmetallic Dowels Bonded to Radicular Dentin with Self-Etch Adhesives" *J Prosthodont*
- B. Akkayan and T. Gulmez (2002). "Resistance to fracture of endodontically treated teeth restored with different post systems" *J Prosthet Dent* 87(4): 431-7
- M. K. Al-Omiri and A. M. Al-Wahadni (2006). "An ex vivo study of the effects of retained coronal dentine on the strength of teeth restored with composite core and different post and core systems" *Int Endod J* 39(11): 890-9
- E. A. Bortoluzzi, E. M. Souza, *et al.* (2007). "Fracture strength of bovine incisors after intra-radicular treatment with MTA in an experimental immature tooth model" *Int Endod J* 40(9): 684-91
- C. M. Bramante, R. Menezes, *et al.* (2006). "Use of MTA and intracanal post reinforcement in a horizontally fractured tooth: a case report" *Dent Traumatol* 22(5): 275-8
- W. S. Brown, H. R. Jacobs and R. E. Thompson (1972). "Thermal fatigue in teeth" *J Dent Res* 51(2): 461-7
- C. A. Carvalho, M. C. Valera, *et al.* (2005). "Structural resistance in immature teeth using root reinforcements in vitro" *Dent Traumatol* 21(3): 155-9
- P. Z. Coneglian, F. A. Orosco, *et al.* (2007). "In vitro sealing ability of white and gray mineral trioxide aggregate (MTA) and white Portland cement used as apical plugs" *J Appl Oral Sci* 15(3): 181-5
- M. Cvek (1992). "Prognosis of luxated non-vital maxillary incisors treated with calcium

hydroxide and filled with gutta-percha. A retrospective clinical study" *Endod Dent Traumatol* 8(2): 45-55

C. D'Arcangelo, M. Cinelli, *et al.* (2007). "The effect of resin cement film thickness on the pullout strength of a fiber-reinforced post system" *J Prosthet Dent* 98(3): 193-8

G. E. Doyon, T. Dumsha and J. A. von Fraunhofer (2005). "Fracture resistance of human root dentin exposed to intracanal calcium hydroxide" *J Endod* 31(12): 895-7

L. A. Goncalves, L. P. Vansan, *et al.* (2006). "Fracture resistance of weakened roots restored with a transilluminating post and adhesive restorative materials" *J Prosthet Dent* 96(5): 339-44

D. R. Hachmeister, W. G. Schindler, *et al.* (2002). "The sealing ability and retention characteristics of mineral trioxide aggregate in a model of apexification" *J Endod* 28(5): 386-90

M. S. Hagge, R. D. Wong and J. S. Lindemuth (2002). "Effect of dowel space preparation and composite cement thickness on retention of a prefabricated dowel" *J Prosthodont* 11(1): 19-24

F. Isidor, K. Brondum and G. Ravnholt (1999). "The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts" *Int J Prosthodont* 12(1): 78-82

I. Krejci and F. Lutz (1990). "[In-vitro test results of the evaluation of dental restoration systems. Correlation with in-vivo results]" *Schweiz Monatsschr Zahnmed* 100(12): 1445-9

L. V. Lassila, J. Tanner, *et al.* (2004). "Flexural properties of fiber reinforced root canal posts" *Dent Mater* 20(1): 29-36

F. Mannocci, M. Sherriff, *et al.* (2005). "Penetration of bonding resins into fibre-reinforced composite posts: a confocal microscopic study" *Int Endod J* 38(1): 46-51

F. H. Mitsui, G. M. Marchi, *et al.* (2004). "In vitro study of fracture resistance of bovine roots using different intraradicular post systems" *Quintessence Int* 35(8): 612-6

H. Moosavi, F. Maleknejad and S. Kimyai (2008). "Fracture resistance of endodontically-treated teeth restored using three root-reinforcement methods" *J Contemp Dent Pract* 9(1): 30-7

- M. Naumann, A. Preuss and R. Frankenberger (2007). "Reinforcement effect of adhesively luted fiber reinforced composite versus titanium posts" *Dent Mater* 23(2): 138-44
- T. G. P. Beck, D. Cakir, L. Ramp, J. Burgess (2009). "Evaluation of Flexural Strength and Elastic Modulus of Endodontic Posts"
- J. R. Pereira, F. de Ornelas, *et al.* (2006). "Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts" *J Prosthet Dent* 95(1): 50-4
- I. Radovic, G. Corciolani, *et al.* (2009). "Light transmission through fiber post: The effect on adhesion, elastic modulus and hardness of dual-cure resin cement" *Dent Mater*
- H. Sano, B. Ciucchi, *et al.* (1994). "Tensile properties of mineralized and demineralized human and bovine dentin" *J Dent Res* 73(6): 1205-11
- P. Schmager, J. Sohn, *et al.* (2006). "Effect of surface treatment of titanium posts on the tensile bond strength" *Dent Mater* 22(2): 189-94
- C. J. Soares, E. C. Pizi, *et al.* (2005). "Influence of root embedment material and periodontal ligament simulation on fracture resistance tests" *Braz Oral Res* 19(1): 11-6
- S. Takuma (1960). "Preliminary report on the mineralization of human dentin" *J Dent Res* 39(964-72
- F. R. Tay and D. H. Pashley (2007). "Monoblocks in root canals: a hypothetical or a tangible goal" *J Endod* 33(4): 391-8
- C. R. Valois and E. D. Costa, Jr. (2004). "Influence of the thickness of mineral trioxide aggregate on sealing ability of root-end fillings in vitro" *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 97(1): 108-11
- O. Yoldas, T. Akova and H. Uysal (2005). "An experimental analysis of stresses in simulated flared root canals subjected to various post-core applications" *J Oral Rehabil* 32(6): 427-32

국문요약

미성숙 치아 모델에서 포스트의 종류와 크기가 치아의 파절 저항성에 미치는 영향에 관한 연구

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미성숙 치아의 치수가 과소되면 치근의 발육이 완성되지 않은 상태에서 발육이 정지되며, 근침형성술 과정에서 장기간 수산화칼슘을 근관 내에 적용하게 되면 치근의 두께가 얇고 잔존상아질이 약화되므로, 적절한 치근 강화 술식이 필요하다고 보고되었다. 따라서 현재까지 보고된 다양한 치근 강화 술식을 토대로 본 실험에서는 미성숙 우치 모델을 이용하여 가타퍼차 및 다양한 포스트와 코아 시스템을 이용하여 근관을 수복한 후 치아의 파절 강도를 비교해보고, 포스트-시멘트의 종류와 시멘트의 두께와 포스트의 적합도가 치아의 파절 저항성에 어떠한 영향을 미치는지 in vitro aging procedure 후에 평가하였다.

미성숙 우치의 근관 치료 후 대조군은 가타퍼차와 이원중합형 복합레진인 LuxaCore® Smartmix Dual (DMG)로 코어 수복을 시행하였다. 제 1 실험군은 fiber 포스트인 D.T. LIGHT-POST® (Bisco Inc.) #3를 식립하고 남은 공간을 LuxaCore® Smartmix Dual로 채워넣었으며, 제 2 실험군은 타이타늄 포스트인 ParaPost® XT™

(Coletène/Whaledent Inc.) #6와 LuxaCore® Smartmix Dual로 수복하였다. 제 3 실험군은 EverStick® Post (StickTech) 0.9와 LuxaCore® Smartmix Dual로 수복하였고, 제 4 실험군은 EverStick® Post 1.5를 여러 개 접착하여 근관의 크기에 맞춘 후 Variolink® II (Ivoclar Vivadent) 레진시멘트를 적용하였고, LuxaCore® Smartmix Dual로 코아 수복하였다. 이후 모든 시편을 72 시간 동안 증류수에 저장한 후 6,000회의 thermocycling을 진행하였다. 시편을 자가중합형 아크릴릭 레진에 위치시키고, 폴리이써 인상재를 이용하여 실험적으로 치주인대의 물성을 재현한 후, Instron (INSTRON Corporate Headquarters)에 시편을 45도로 위치시켜 압축부하를 가해 시편이 파절되는 강도를 측정하고, 파절 부위를 분석하였다.

실험 결과, 포스트를 이용하여 수복한 실험군이 대조군에 비해 파절 저항성이 통계적으로 유의하게 증가하였으며 ($p < 0.05$), 포스트의 종류 및 포스트의 적합도는 결과에 통계적으로 유의한 차이를 나타내지 않았다. 파절 부위는 대조군의 모든 시편이 수복 가능한 범위에서 파절되었고, 각 실험군의 대부분의 시편에서 수복 가능한 파절이 나타났으며, 실험군에 따른 파절 부위의 유의한 차이는 나타나지 않았다.

그러므로 미성숙 우치 모델을 이용한 본 연구에서는 미성숙 치아의 근관치료 후 치근 강화 술식이 필요함을 확인하였고, 치근 강화 효과에 있어서 fiber 포스트와 타이타늄 포스트 및 포스트의 적합도는 거의 영향을 미치지 않는다고 결론지을 수 있다.

핵심되는 말: 미성숙 치아, 파절 저항성, Fiber 포스트, 타이타늄 포스트, EverStick® Post, 포스트 적합도