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นางสาวสุภัควิณี สักกายะกรมงคล

จุฬาลงกรณ์มหาวิทยาลัย
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FRACTURE RESISTANCE OF VARIOUS RESTORATIONS FOR ENDODONTICALLY TREATED TEETH CAUSED FROM ABFRACTION

Miss Supakwinee Sakkayakornmongkol

จุฬาลงกรณ์มหาวิทยาลัย
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A Thesis Submitted in Partial Fulfillment of the Requirements
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สุภัควิณี สักกายะกรมงคล : การบูรณะแบบต่างๆในฟันที่รักษาคลองรากเหตุจากคอฟันสึกต่อความต้านทานการแตก (FRACTURE RESISTANCE OF VARIOUS RESTORATIONS FOR ENDODONTICALLY TREATED TEETH CAUSED FROM ABFRACTION) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ทญ. ดร.ปรารมภ์ ซาลิมี, 40 หน้า.

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาผลของความต้านทานการแตกและรูปแบบความล้มเหลวของการบูรณะฟันกรามน้อยบนที่จำลองคอฟันสึกและผ่านการรักษาคลองรากฟันด้วยวิธีต่าง ๆ ทำการคัดเลือกฟันกรามน้อยบนซี่แรก 2 รากที่มีขนาดและรูปร่างใกล้เคียงกัน จำนวน 32 ซี่ มาแบ่งออกเป็น 4 กลุ่ม กลุ่มละ 8 ซี่ ตามความแตกต่างของการบูรณะฟัน โดยมีกลุ่มควบคุมเป็นกลุ่มที่ไม่ได้จำลองคอฟันสึกแต่ได้รับการรักษาคลองรากฟันและอุดปิดคลองรากด้วยเรซินคอมโพสิต กลุ่มที่ 1 ถึง 3 เป็นกลุ่มที่จำลองคอฟันสึกและอุดด้วยเรซินคอมโพสิต จากนั้นทำการรักษาคลองรากฟันและบูรณะด้วยวิธีต่างๆ โดยกลุ่มที่ 1 (RF) อุดปิดคลองรากด้วยเรซินคอมโพสิต กลุ่มที่ 2 (P/RF) ใส่เดือยเสริมเส้นใยแล้วอุดปิดด้วยเรซินคอมโพสิต กลุ่มที่ 3 (P/ZC) ใส่เดือยเสริมเส้นใยแล้วอุดปิดด้วยเรซินคอมโพสิตและทำครอบฟันชนิดเซอร์โคเนีย นำฟันมาติดตั้งลงบนฐานอะคริลิกและจำลองเอ็นยึดปริทันต์ จากนั้นนำชิ้นงานมาทดสอบด้วยแรงกดบริเวณแอ่งกลางของด้านบดเคี้ยวโดยทำมุม 30 องศากับแนวแกนฟันจนเกิดความล้มเหลว นำข้อมูลที่ได้มาวิเคราะห์โดยการหาสถิติความแปรปรวนทางเดียวและการทดสอบเชฟเฟ่ที่ระดับความเชื่อมั่นร้อยละ 95 ผลการทดลองพบว่าค่าความต้านทานการแตกในกลุ่มควบคุม กลุ่ม RF และกลุ่ม P/RF ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($p>0.05$) ในขณะที่กลุ่ม P/ZC มีค่าสูงกว่ากลุ่ม RF และ P/RF อย่างมีนัยสำคัญทางสถิติ ($p<0.05$) แต่ไม่แตกต่างจากกลุ่มควบคุม เมื่อสำรวจความล้มเหลวของชิ้นงานพบว่าร้อยละ 80 ของกลุ่มควบคุม กลุ่ม RF และกลุ่ม P/RF เกิดการแตกที่ปุ่มฟันด้านเพดาน ในขณะที่ชิ้นงานทั้งหมดของกลุ่ม P/ZC เกิดรอยร้าวและแตกตามขอบของครอบฟันโดยที่เดือยเสริมเส้นใยยังคงยึดครอบฟันกับรากฟันไว้ได้ สรุปได้ว่าการอุดฟันด้วยเรซินคอมโพสิตบริเวณคอฟันสึกจำลองสามารถช่วยเพิ่มความต้านทานการแตกให้กับฟันได้ใกล้เคียงกับฟันที่ไม่มีการจำลองคอฟันสึก การใส่เดือยเสริมเส้นใยไม่มีผลต่อความต้านทานการแตกในฟันที่มีการจำลองคอฟันสึก แต่สามารถช่วยยึดครอบฟันกับรากฟันซึ่งป้องกันการสูญเสียเนื้อฟันอย่างทันทีได้ ส่วนการบูรณะด้วยครอบฟันเซอร์โคเนียและเดือยเสริมเส้นใยสามารถเพิ่มความต้านทานการแตกของฟันที่จำลองคอฟันสึกได้ นอกจากนี้ผนังเนื้อฟันที่เหลืออยู่บริเวณคอฟันเป็นปัจจัยสำคัญในการพิจารณาสำหรับการบูรณะที่เหมาะสม

ภาควิชา ทันตกรรมประดิษฐ์ ลายมือชื่อนิสิต ....

สาขาวิชา ทันตกรรมประดิษฐ์ ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

ปีการศึกษา 2559

5775829432 : MAJOR PROSTHODONTICS
KEYWORDS: ABFRACTION / ENDODONTICALLY TREATED TEETH / FIBER POST / FRACTURE RESISTANCE / ZIRCONIUM CROWN

SUPAKWINEE SAKKAYAKORNMONGKOL: FRACTURE RESISTANCE OF VARIOUS RESTORATIONS FOR ENDODONTICALLY TREATED TEETH CAUSED FROM ABFRACTION. ADVISOR: ASST. PROF. PRAROM SALIMEE, Ph.D., 40 pp.

The aim of this study was to evaluate fracture resistance and failure pattern of endodontically treated premolars with simulated abfraction in various restorations. Thirty-two extracted two-rooted maxillary first premolars with same sizes and shapes were randomly divided into 4 groups (n=8) for different restorations types. The control group was endodontically treated without simulated abfraction and restored with resin composite at access opening. Groups 1 - 3 were simulated with abfraction, filled with resin composite, endodontically treated and then restored with different methods. Group 1 (RF) was restored with resin composite at access opening, group 2 (P/RF) was restored with fiber post and resin composite and group 3 (P/ZC) was restored with fiber post, resin composite and zirconium crown. The teeth then were placed into acrylic blocks with simulated PDL. The specimens were loaded at central fossae, 30° to long axis of the teeth until failure. The data were analyzed by one-way ANOVA and Scheffe test at a 95% level of confidence. The results showed that the fracture resistance of control group, groups RF and P/RF had not statistically significant difference ($p>0.05$), while the fracture resistance of group P/ZC was significantly higher than those of groups RF and P/RF ($p<0.05$) with no significant difference from control group. For failure patterns, 80% of specimens in control group, groups RF and P/RF failed with palatal cusp fractures, while all specimens in group P/ZC cracked and fractured along crown margins and posts retained crowns to roots. The study concluded that resin composite filling at simulated abfraction could present the fracture resistance close to the teeth without abfraction. The fiber posts did not affect fracture resistance of the teeth with simulated abfraction, however, they retained the crowns to the roots which prevented sudden coronal crown lost. The zirconium crowns and fiber posts could significantly increase fracture resistance of teeth with simulated abfraction. In addition, the coronal remaining walls at the cervical areas are the main factors for proper restorations.

Department: Prosthodontics Student's Signature ....
Field of Study: Prosthodontics Advisor's Signature ....
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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CEJ	cemento-enamel junction
°C	degree Celsius
FEA	finite element analysis
FRC	fiber reinforced composite
GPa	gigapascal
mm	millimeter
MPa	megapascal
N	Newton
n	number
nm	nanometer

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CHAPTER I

INTRODUCTION

Cervical parts of teeth are the areas that tended to receive high stresses from occlusal forces that can damage the tooth structure and resulted in irreversible tooth wears (1). Currently, these cervical tooth wears are generally found clinically which are called non-carious cervical lesions (NCCLs) (2). Abfraction lesion is one of NCCLs that can eliminate the tooth structure of cervical regions. It caused from lateral occlusal force that created tensile stress on cervical surface to destroy enamel and cementum (3). These cervical tooth structures were partially destroyed and occurred fulcrums including high stresses in the lesions (4, 5). In addition, these lesions were commonly presented in positions of premolars, canines and molars respectively (6). Some deep lesions may progressively exposed pulp resulting in requiring endodontic treatments and proper restorations thereafter. Nevertheless, considerations for these final restorations depended on several factors, such as amount of remaining structures, and functional requirement (7). Therefore, the definite restorations which have been widely used for reinforcing and resisting to the forces should be investigated such as conventional filling, cusp coverage with or without post.

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A conventional filling in endodontically treated tooth which has been commonly used is resin composite filling. It is used for restoration of lost structures and strengthening the tooth. Additionally, it is flexible and effectively distribute the occlusal forces into the tooth structure because its modulus of elasticity is close to dentin (8, 9). The long-term using in restored tooth could be satisfied because of little failure rates for 5 and 10 years (10). However, in the teeth with severe lost structures, the fillings might not have sufficient strengths to resist high occlusal forces, then the cusp coverages should be considered for these conditions. Full coverage crowns are used for protection the cusps and covering weakened areas of the teeth especially for posterior teeth (11, 12). Although tooth preparation for the crown may reduce the structures, high strength materials of the crown could help to strengthen the teeth with lost structures. The crowns might protect and tend to reduce the fracture in these weak cervical lesions. Materials which have high strengths such as metal, ceramic, and zirconia, are currently fabricated for these crowns. Especially, the zirconia has been continually developed for clinical using with diverse colors and its mechanical properties is better than those of other ceramics (13-16). Thus, it is clinically acceptable alternative for the esthetic condition which substitute for the metal materials.

Prefabricated fiber-reinforced composite (FRC) posts are increasingly used in endodontically restorations which their modulus of elasticities harmonized with the teeth, resulting in good occlusal force distribution into tooth structures (17). They are used mainly to gain retention of roots and crowns (4, 18). However, some studies explained that the posts could strengthen the teeth for severe structural loss conditions (19-21). Thereby, post-endodontic method in case of loss of cervical structures from abfraction, the role of FRC posts might help to reinforce the teeth or not is still questionable.

The aim of this study was to evaluate the fracture resistance and failure pattern of endodontically treated premolars with simulated abfraction using with FRC posts, crown and resin composite filling. The null hypotheses were that the FRC post and/or crown placements with resin composite filling would not affect the fracture resistance in these teeth.

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Research Questions

1. Does FRC post placement with resin composite filling affect fracture resistance of endodontically treated teeth with simulated abfraction?
2. Do FRC post and crown placements with resin composite filling affect fracture resistance of endodontically treated teeth with simulated abfraction?

Objective

1. To evaluate the effect of FRC posts and crowns to the fracture resistance of endodontically treated premolars with simulated abfraction lesions
2. To determine for selection of optimal restorations of endodontically treated premolars with simulated abfraction lesions

Hypotheses

Hypothesis 1

Null hypothesis: FRC post placement with resin composite filling does not affect fracture resistance of endodontically treated premolars with simulated abfraction.

Alternative hypothesis: FRC post placement with resin composite filling affects fracture resistance of endodontically treated premolars with simulated abfraction.

Hypothesis 2

Null hypothesis: FRC post and crown placements with resin composite filling do not affect fracture resistance of endodontically treated premolars with simulated abfraction.

Alternative hypothesis: FRC post and crown placements with resin composite filling affect fracture resistance of endodontically treated premolars with simulated abfraction.

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Keywords: Abfraction, Endodontically treated teeth, Fiber post, Fracture resistance, Zirconium crown

Type of research: Laboratory experimental research

CHAPTER II

LITERATURE REVIEW

1. Abfraction

Abfraction was originated from the Latin words, ab – “away”, and fractio – “breaking” (22). It is a microstructural loss of tooth structures from breaking enamel rods including cementum and dentin in stress concentrated areas, where commonly found in cervical parts. When lateral occlusal forces caused the teeth to bend, tensile stresses were created and disrupted the chemical bonds of enamel and dentinal structures. Small molecules in oral cavity then penetrated to the spaces from cracking and prevent the reconstructions of these chemical bonds (Figure 1) (3). The occlusal forces from both normal functions and parafunctional habits caused creating fulcrums in the cervical areas (23). These resulted in the lesions were more aggressive and became larger continually. Many studies explored that the abfraction often occurred including with other multifactorial causes, such as stress, friction and erosion (1-3, 23, 24).

In 1984, Smith and Knight created a tooth wear index (TWI) for measuring and recording the tooth wear levels (25). They classified severities of the tooth wears into 5 scores from 0 to 4 which depended on depths and amounts of lost structures. The more amounts of structures were lost, the higher scores were indicated. These explained that when there is no change or no loss of tooth structure, this lesion was indicated as score 0. Conversely, score 4 implied to the most severe loss of tooth structures, such as more than 2-mm deep wear with exposed pulp.

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In 1991, Grippo explained a classification of abfraction, that had diverse shapes and were located on both enamel and dentin (22). The shapes of lesions were found on the enamel such as hairline cracks, striations, saucer-shaped, semilunar-shaped, and cusp tip invatigation. Moreover, the dentinal lesions generally occurred various forms such as gingival, circumferential, multiple, sub-gingival, lingual, interproximal, alternate, angular, crown margin, and restoration margin. However, this study did not mention in size and depth of the lesions obviously.

Many studies concluded that the abfraction is one of non-carious cervical lesions (NCCLs) which include abrasion, biocorrosion (erosion) and abfraction (1, 2, 23, 24, 26). These lesions were typically wedge-shaped, some lesions might occur in saucer or mixed shapes (Figure 2) (26). They are also found on cementum of sub-gingival areas (1, 23, 24, 26). Furthermore, they commonly occur in premolars, canines, and first molars respectively (6, 24). Particularly, first premolars were the most frequently involved with the NCCLs (28.6% in the maxillary arch and 19.6% in the mandibular arch) (6).

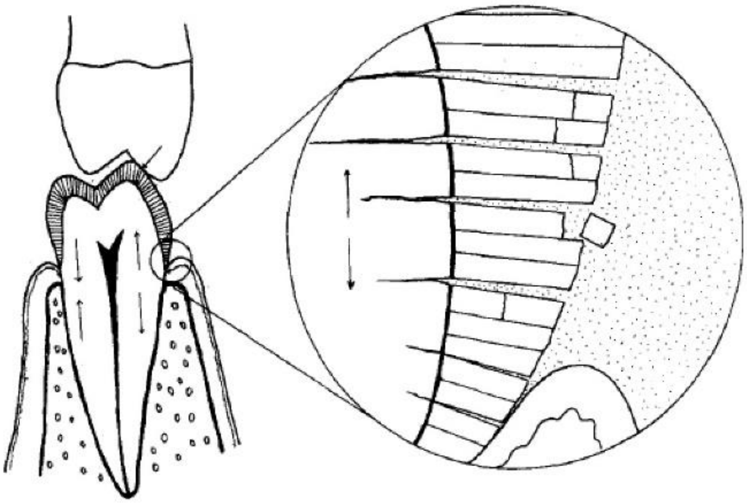

Figure 1 Abfraction etiology from lateral forces creating compressive and tensile forces (arrows)

(J Prosthet Dent 52(3):374-80) (3)

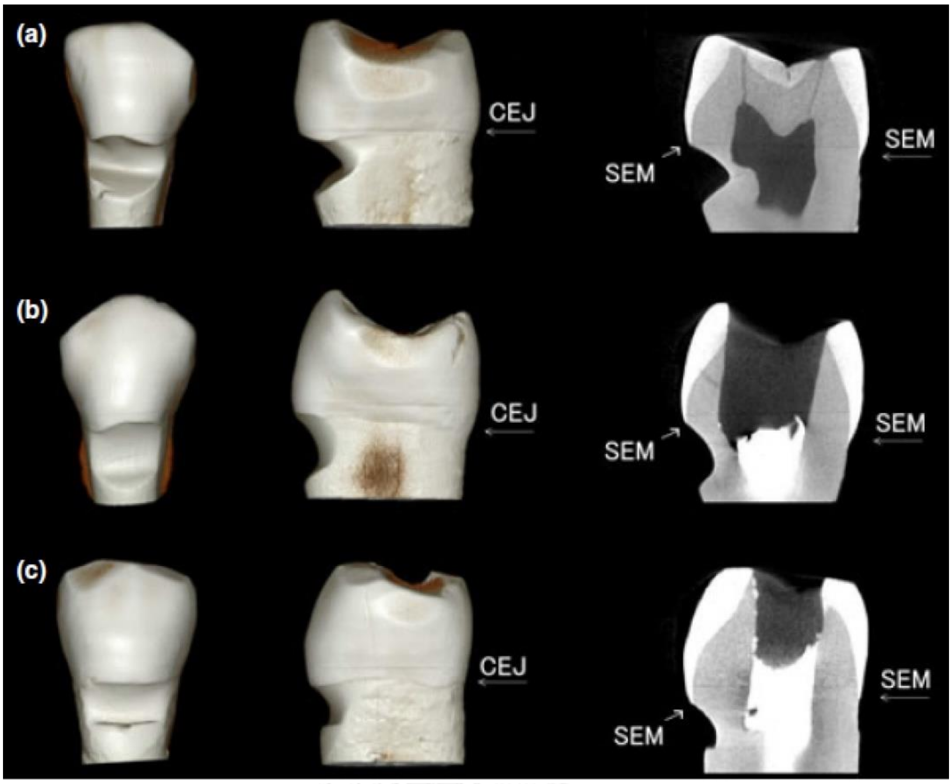

Figure 2 Three shapes of Abfraction lesions (a) wedge shape (b) saucer shape (c) mixed shape with scaning electron microscopic (SEM) on the right side (J Oral Rehabil 38(6):469-74) (26)

2. Restorations of endodontically treated teeth

Restorations of endodontically treated teeth have been occurred in various types for many years. They are commonly presented in terms of conservative restorations, such as amalgam and resin composite fillings, and progressive methods, such as full and partial coverages with or without posts. They depended on the amount of the residual structures of the teeth.

In case of partial lost tooth structures, the conservative restorations could help to preserve the structures and strengthen the teeth by using various restorative materials, such as amalgam, glass ionomer, and resin composite. Currently, the most restoration which clinically presented is resin composite filling because its strength is close to the dentin and it helps distribute the occlusal forces in the tooth structure (27). In addition, amalgam was rarely used to restored in these teeth because it had very high stress inside the structures when resisted the forces. It might then increase a risk to accidentally fractures. In case of glass ionomer, its strength was also weaker than the resin composite (28). Accordingly, the resin composite was an appropriate material to use as a conventional filling in some lost coronal structures.

On the contrary, severe lost structures were commonly found in endodontic cases because large pathologic conditions resulted in damage many surfaces of the teeth. The prostheses, such as post, core and crown, then took advantages to improve the tooth structures better than the conventional filling. Particularly in case of posts, the chief purpose is the retention to the crowns (4, 18). The considerations for the post placement were based on the position of the tooth, the amount of remaining coronal tooth structure, and the functional requirement of the tooth (29). Therefore, the remaining tooth structures was significant for decisions in any restorations. Moreover, full and partial coverages were used for covering and protection of the cusps where the structures were severely lost and not able to be restored with conservative methods. Regarding the coronal structures, the coverages that surrounded the cervical tooth structure was well-known as the ferrule effect that could helped to protect and reinforce the tooth structure (30). This meant that a crown could strengthen the tooth and was required in case of reduced coronal tooth structure.

In 2004, Schwartz and Robbins concluded clinically basic principles for the restorations of endodontically treated teeth , such as completed root canal treatment, cusp coverages for posterior teeth, tooth structure preservation, sufficient strength and length of retrievable posts, adequate ferrules for good resistance (12).

3. Ferrule and remaining coronal walls

A definition of ferrule was a crown that covered cervical tooth structure circumferentially. It took a positive effect for protecting the structures from fractures and improving the tooth strengths that was called “ferrule effect” (31). This effect was depended on remaining coronal structures around cervical areas of the tooth at least 1.5-2 mm high and 2 mm thick (21, 30). When the remaining coronal structures decreased, the tooth strength then was weaker. Although, there were partial losses of the coronal structures, these imperfect ferrules were more positive effects than the absence of the structure (30).

Concerning these existing structures, the ferrule effect was capable to help the restorations to resist the occlusal forces. These remaining structures were then indicated to the strength of the teeth and required for considerations of the proper restorations (32). A study of Mangold and Kern involving with the remaining coronal walls concluded that these coronal walls affected to the fracture resistance of the teeth. The walls were explained that when they were at least 2 walls, they could be sufficiently strong for the teeth without post placements. contrarily, if there was less than 2 walls existing, the tooth strength was reduced and the posts were then provided to increase the fracture resistance of the teeth (20). It was concurred by a study of Samran, Bahra and Kern that summarized about increasing of the remaining tooth structure could provide the higher fracture resistance (33). Thus, it was significant to preserve the residual coronal structures as much as possible to keep the strength of the teeth for the prolong using.

4. Resin composite filling

A resin composite has been commonly used for core build-up and filling. Their moduli of elasticities are mostly close to those of dentin (15 GPa) (8, 9). Therefore, they leaded to stress distribution of the occlusal forces to the tooth structures and increasing the fracture resistance to strengthen the teeth (34). Consistently, previous finite element analysis (FEA) studies supported this concept about comparison between resin composite filling groups and non-filling groups. They explained that the filling groups showed the stresses inside the tooth structures less than the non-filling groups and their stress distributions seem like those of sound teeth. Moreover, the strength of the filling groups was higher than those of unrestored group (27, 34, 35). It clinically implied that the resin composite restoration could strengthen the teeth. Therefore, it is an appropriate material using to be restored the defective structures of the teeth in a conservative method.

Compositions of resin composite have been developed for many years to improve the strength and ease for application. Nano-hybrid resin composite is widely used for many restorations, such as core build-up, splinting, direct and indirect restorations. It consists of approximately 60-80% by weight of several sized inorganic fillers (36). Its particles were developed from micro-hybrid composites and added nano-sized fillers (Figure 3). Additionally, the improved mechanical properties of this resin composite have been clinically acceptable and widely used for restorations, such as 252-298 MPa of compressive strength, 35-54 MPa of tensile strength, and 73-140 MPa of flexural strength, which are durable to the occlusal forces effectively (37).

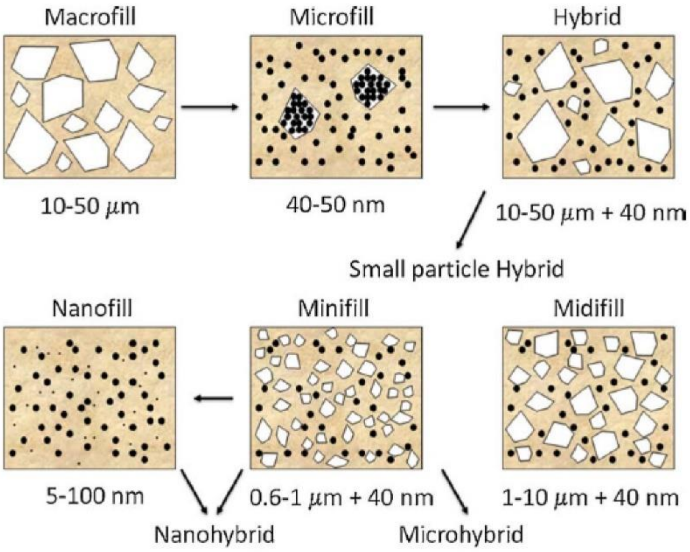

Figure 3 Filler particles of dental resin composites

(Dent Mater 27(1):29-38) (38)

5. Prefabricated fiber-reinforced composite posts

For several years, metal posts have been commonly used. Their designs included tapered and parallel, which the parallel post induced the greatest retention. Although, passive tapered posts provided the low retention, they allowed minimal removal of radicular dentin and created lower stress on the root compared with the parallel posts (12). The metal posts were very rigid. Therefore, they were not flexible in the root canals when they received high occlusal forces, these resulted in high risks to root fracture of the teeth. Furthermore, the posts were visible through all ceramic restorations or even seen as dark in the marginal gingiva (12). These disadvantages contributed to the development of the posts for esthetic and long-term usability.

Fiber-reinforced composite (FRC) posts have been available in a variety of shapes and sizes from different manufacturers. Carbon fiber posts, which were popular in the 1990s, manifested more flexibility than metal posts and a same modulus of elasticity (stiffness) as dentin (39). Adversely, carbon fiber posts were dark, which was a potential problem when considering post-restorative esthetic condition. Other types of fiber posts were also available, including quartz fiber, glass fiber, and silicon fiber posts. They were typically bonded with resin luting cement and retained with composite cores, resulting in a highly esthetic restoration (11). The posts were flexible, which could reduce the risk of root fracture, which were similar as carbon posts. Most fiber posts were relatively radiolucent compared with traditional posts (12). However, they were detected on radiographs easier than carbon posts. In addition, they were retrievable, which meant they could be removed easier for endodontic retreatment. These FRC post have physical properties close to the dentin (40). Therefore, it is appropriate alternative for using in post-endodontic treatment.

A review of Aurelio, Fraga, Rippe and Valandro concluded that there were insufficient studies for verifying explicitly clinical guidelines for the posts. However, they described both of laboratory and clinical evidences associated with using of the posts. For laboratory studies, more than 50**%** of the coronal structures in premolars and molars remaining and decisions of cusp coverages, the posts were not required. While there was no plan for coverages, the posts might be advantage. Furthermore, incisors were supported by additional posts to create retention. In clinical studies, there were controversial that some studies mentioned the posts did not influence to survival rate of the teeth, some studies conversely stated that the post could increase survival rates (41). Thus, the posts that were clinically used should be further investigated.

6. Zirconium crown

Currently, the crowns have commonly been used for protection of the tooth structures and functions. Many types of materials were used for the crowns because of high strengths, including full metal crown, porcelain fused to metal (PFM) crown, all ceramic crown (lithium disilicate, zirconia). They were depended on several factors for the proper restorations. The lithium disilicate ceramic has several colors for esthetics, it has then been used in anterior regions. The disadvantage was lower strength than other types of materials, it might crack easier and tend to fracture. In contrast, the full metal crowns were usually used in posterior teeth because of their high strengths and unsatisfied colors. Furthermore, the PFM crowns have been presented in both anterior and posterior areas whether they are used to keep the good strength from metal substructures and esthetic satisfaction of porcelain veneers.

For zirconia (ZrO_2), it is one of advance materials that has been accepted to use for clinical prostheses because of its biocompatibility and many satisfied shades. It has been developed for many years and mostly used for monolithic and zirconium framework with veneering porcelain. However, veneering porcelain might be chipped or fractured in high stress situations including bruxism. It had several high mechanical properties, such as 2000 MPa of compressive strength, 636-786 MPa of tensile strength, 800-1,100 MPa of flexural strength, 224 GPa of modulus of elasticity, and 6-8 MPa $m^{0.5}$ range of fracture toughness, that could help to effectively resist the masticatory functions in oral cavities (13, 14, 42, 43). Due to phase transformation of the original zirconia, they were then added metal oxides in microstructures, such as CeO_2, Y_2O_3, to stabilized the mainly molecules into cubic phases in room temperature with some small parts of monoclinic and tetragonal phases. These stable molecules then helped to restrain the phase transformation resulting in reducing of the stress inside the material from expansion. Accordingly, these stabilized phase process was known as a concept of “transformation toughening” that took a positive effect clinically because the phase shifting particularly occurred on cracked and stress areas resulting in volume expansion to block crack propagation (44). However, the surfaces of zirconia were very

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difficult to bond, pretreatment of surfaces and selection of the cement should be necessary.

Resin cements have regularly used with zirconium prostheses because of their high bond strengths (44). When they were used with zirconium crowns, it leaded to higher compressive strength than glass ionomer and zinc phosphate cement (45). Moreover, phosphate monomers, such as 10-Methacryloyloxydecyl dihydrogen phosphate (10-MDP), anhydride groups, such as 4-methacryloxyethyl trimellitate anhydride (4-META), silica coating and silane coupling agent that were added in primers and resin cements could help to increase bond strengths to the surfaces of zirconia (44, 46, 47). On the contrary, other surface treatments, including air abrasion and acid, for improving mechanical bond have been few evidence should be studied further.

For tooth preparation of zirconium crown placement, the tooth reduction should be at least 0.5-mm axial deep for the crown thickness that provide good strength and resistance of the crown (45). Furthermore, computer aided design and manufacturer (CAD/CAM) have been used to fabricate the zirconium prostheses for design the prostheses and compensating the volume change from sintering processes.

7. Fracture resistance of endodontically treated teeth

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Fracture resistance test was widely used for measuring the strengths of materials when fractured by universal testing machine. Regarding to the fracture resistance of endodontically treated teeth, it depended on definite restorations and amounts of tooth structures which could effectively strengthen the teeth. Therefore, the fracture resistance of these materials should be high, the materials restored the teeth should be sufficiently strong to resist occlusal forces for long term using. The ferrule effect and a large amount of residual structure has been proven to increase tooth resistance to fracture (30, 31). A minimum of 1.5-2 mm high ferrule was necessary to stabilize the restored tooth (30). Some studies showed that the post did not affect the fracture resistance of endodontically treated teeth (4, 18). If coverage crowns were unnecessary, the posts were not required (48). However, the other studies found that the post could improve the fracture resistance in the teeth without ferrule or one remaining cavity wall (20, 49).

However, the posts might be able to strengthen the teeth in some conditions. It was supported by a previous study of Abduljawad et al which concluded that the glass fiber posts could improve the strengths of maxillary central incisors which had cervical lesions and root canal treatments (50). These results explained that the posts significantly increased the fracture resistance of endodontically treated teeth with cervical lesions and these fracture resistance values were close to those of the control teeth without cervical lesion. Besides mostly receiving shear forces, the incisors had small coronal structures compared with other teeth. Thus, these weak incisors were possibly affected their strengths by the posts.

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CHAPTER III

MATERIALS AND METHODS

Tooth preparation

Thirty-two extracted two-rooted maxillary first premolars were collected from orthodontic reasons. The teeth were similar in shapes and sizes, without pathologic lesion or existing restoration. This study was approved by the ethics committee of the faculty of dentistry, Chulalongkorn university (HREC-DCU 2015-063). The teeth were cleaned and kept in 0.9% saline solution.

All teeth were randomly divided into 4 groups (n=8) for different types of the restorations after endodontically treated (Figure 4); control group: resin composite filling at the access opening without abfraction simulation, groups 1, 2 and 3: abfraction simulation with resin composite filling. For group 1, the teeth were filled with resin composite at the access openings (RF). For group 2, FRC posts were placed in buccal root canals and the resin composite were filled at the access openings (P/RF). For group 3, FRC posts and resin composite were applied as same as group 2 and then zirconium crowns were used (P/ZC).

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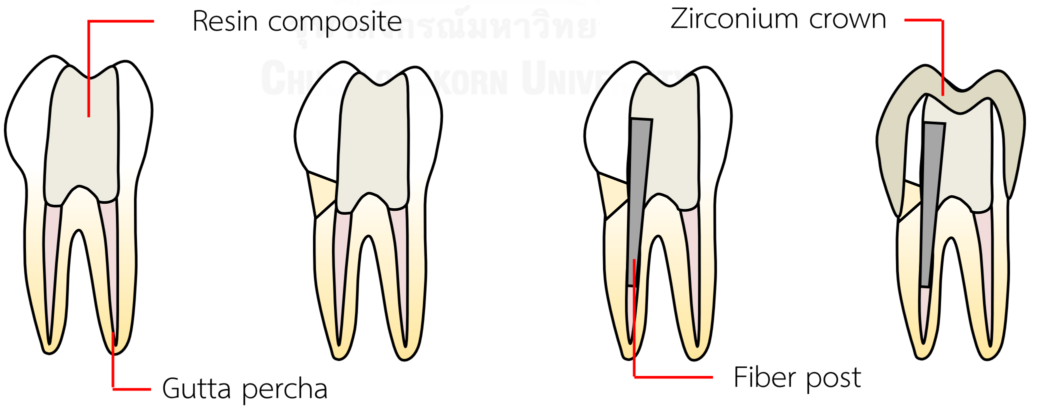

Control group: resin composite filling without abfraction (Control)

Group 1: resin composite filling (RF)

Group 2: FRC post with resin composite filling (P/RF)

Group 3: FRC post with resin composite filling and zirconium crown (P/ZC)

Figure 4 Schematic drawings of four restoration types

For simulation of abfraction in groups 1, 2 and 3, the teeth were prepared on the bucco-cervical areas with diamond instruments. These lesions were 3.5-mm high and 4.5-mm wide 3-mm deep to exposed the pulp (Figure 5). Upper and lower borders of the lesions were both 30° from the cemento-enamel junctions (CEJ). 37% phosphoric acid (Scotchbond etchant, 3M ESPE, St. Paul, MN, USA) was applied on surfaces for 15 seconds. The tooth structures then were rinsed by the water spray for 15 seconds and dried by compressed air. A bonding agent (Adper single bond 2 adhesive, 3M ESPE, St. Paul, MN, USA) was applied on the etched surfaces for 15 seconds and the compressed air was used gently for 5 seconds. A light curing unit (Elipar S10, 3M ESPE AG, Seefeld, Germany) was used for 10 seconds. After that, resin composite (Filtek Z250XT, 3M ESPE, St. Paul, MN, USA) was applied each 2-mm thick layer into the lesions for reducing the risk of polymerization shrinkage and a light curing unit was used for 20 seconds for complete polymerization. These materials were used following to instructions of the manufacturers and finally polished. The teeth were kept at 37°C in 100% humidity distilled water.

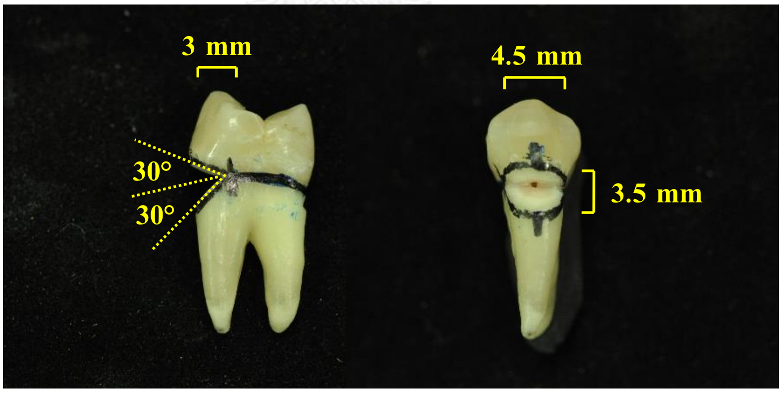

Figure 5 Abfraction simulation on first maxillary premolars

Root canal and access preparation

An access opening was prepared on the occlusal surface of each tooth for root canal treatment. Each root canal was prepared to a No.30 K-files (M access, Dentsply Maillefer, Ballaigues, Switzerland) with 1-mm working length above the apexes. The canals were obturated with gutta percha (Hygenic, Coltène/Whaledent Inc, Langenau, Germany) and root canal cement (AH Plus, Dentsply, Konstanz, Germany). The excess gutta percha was removed at orifices of the root canals. These openings were temporarily restored by cotton pellet and provisional restoration (Cavit, 3M ESPE, Neuss, Germany). All teeth were kept in distilled water at 37°C for 24 hours for complete setting of root canal cement (49).

Resin composite filling and post placement

For control group and group RF, after removal of the provisional restorations, resin composite fillings were restored at the access openings as the final restorations.

For groups P/RF and P/ZC, post spaces were prepared by peezo reamers into buccal root canals for sizes of No.1 FRC posts (D.T. light-post Illusion X-RO, RTD, St. Egrève, France). The remaining gutta percha was 4 mm for an apical seal. The fiber posts were cemented with self-adhesive resin cement (RelyX U200, 3M ESPE, Neuss, Germany). The excess parts of the posts were removed to 2-mm depth under the occlusal surfaces. Resin composite was finally restored into the access openings for core materials.

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Acrylic resin block preparation

Root surfaces were dipped into melted pink wax as wax spacers to simulate a 0.2-mm thickness of the periodontal ligaments (PDL). Self-cured acrylic resin (Unifast Trad, GC Corporation, Tokyo, Japan) was then applied into PVC tubes (22-mm diameter and 25-mm high) for providing acrylic resin blocks. The teeth were pressed into the blocks, perpendicular to the horizontal plane using a dental surveyor (The J.M. Ney company, Vernon hills, IL, USA). The resin acrylic was 2-mm below the CEJ levels and lower margins of resin composite fillings (Figure 6). The teeth were pulled out from the blocks and removed the waxes. Silicone materials (Express XT, 3M ESPE, Neuss, Germany) were applied around the root surfaces for replacing the waxes. The teeth were finally pressed into the blocks with the same positions by using silicone indexes.

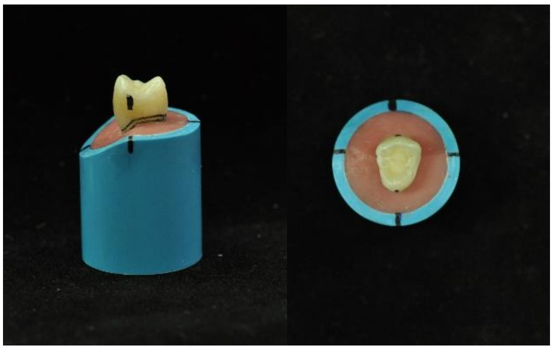

Figure 6 The specimens placed in the resin acrylic blocks

Crown placement

For group P/ZC, the final restorations were monolithic zirconium crowns (LAVA^{TM} Plus, 3M ESPE, St. Paul, MN, USA). The teeth were prepared by diamond burs with 0.5-0.8 mm axial reduction and chamfer finishing lines circumferentially. Average final dimensions of the prepared tooth were 6-mm high, 3-mm mesio-distally and 7.5-mm bucco-palatally. The crowns were fabricated by a CAD-CAM technique using stone dies created from silicone impression (Express XT). Crown margins covered the lower borders of resin composite fillings on buccal sides and were at the CEJ on the other sides. The resin cement (RelyX U200) was applied for crown cementation. The specimens were then kept in distilled water at 37°C for 24-hour complete cement setting before testing (51).

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Fracture resistance test

Fracture resistance test was performed using a universal testing machine (Instron 8872, Instron Corporation, Canton, MA, USA). 2-mm diameter loading tip was located at central fossae of occlusal surfaces and 30° to the long axis of the teeth directed to palatal cusps (Figure 7). The compressive forces were applied with a 1 mm/min crosshead speed until failure. The fracture resistance was presented in Newton (N). The data were analyzed by one-way ANOVA and Scheffe test at a 95% level of confidence. Each specimen was investigated failure patterns under a stereomicroscope (Olympus SZ61, Tokyo, Japan).

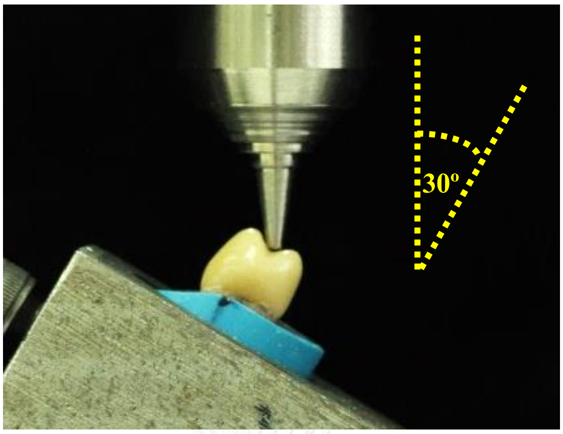

Figure 7 The specimen was located on universal testing machine at 30° to the long axis of the tooth

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CHAPTER IV

RESULTS

The mean fracture resistance ranged from 842 to 1004 N (Figure 8). One-way ANOVA and Scheffe test indicated that the fracture resistance of control group, group RF and group P/RF had not statistically significant difference (p>0.05). While the fracture resistance of group P/ZC was significantly higher than those of groups RF and P/RF (p<0.05), it was not significantly different from the fracture resistance of control group.

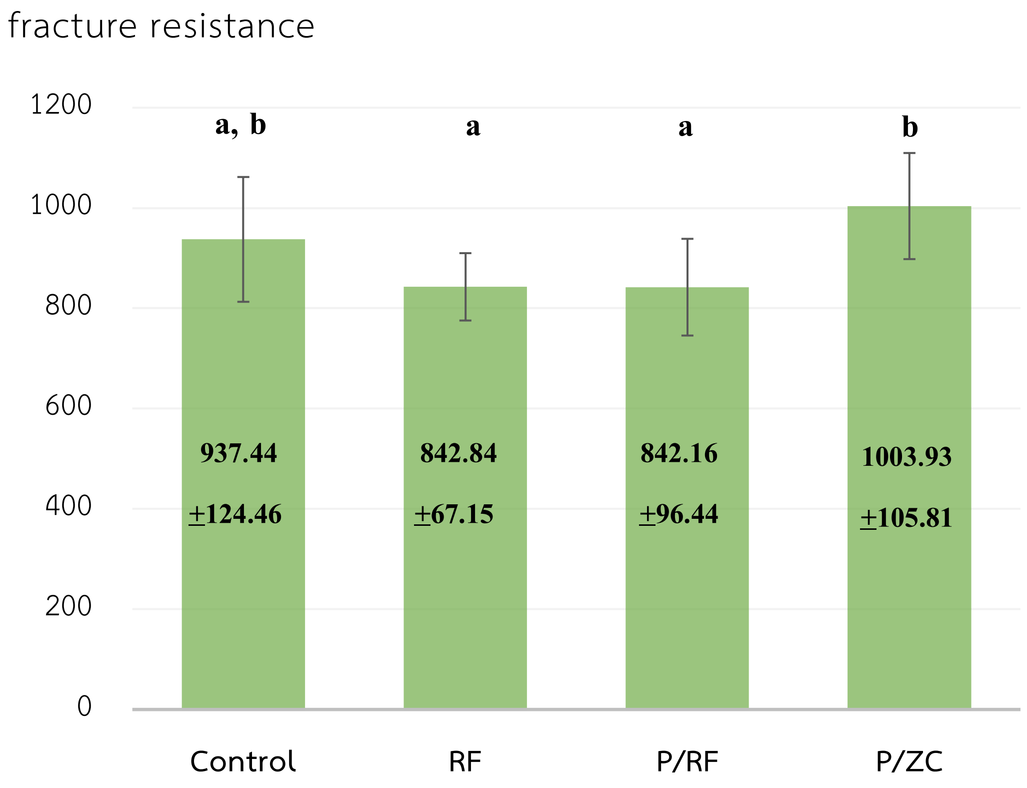

Figure 8 Mean and standard deviation of the fracture resistance in three groups, same letters indicated that there was no statistically significant difference between groups (p>0.05)

The failure patterns in this study were divided into 3 patterns: palatal cusp fracture, coronal fracture, and fracture along zirconium crown margin (Table 1 and figure 9). 80% of the specimens in non-crown groups (control, RF and P/RF) failed with palatal cusp fractures. All specimens in group P/ZC cracked and fractured along crown margins and the posts retained the crowns to the roots when fractures occurred.

Table 1 The failure patterns of the investigated specimens in each group

Groups (n=8)	Failure patterns		
	Palatal cusp fracture (n)	Coronal fracture (n)	Fracture along crown margin (n)
Control	8	-	-
RF	7	1	-
P/RF	6	2	-
P/ZC	-	-	8

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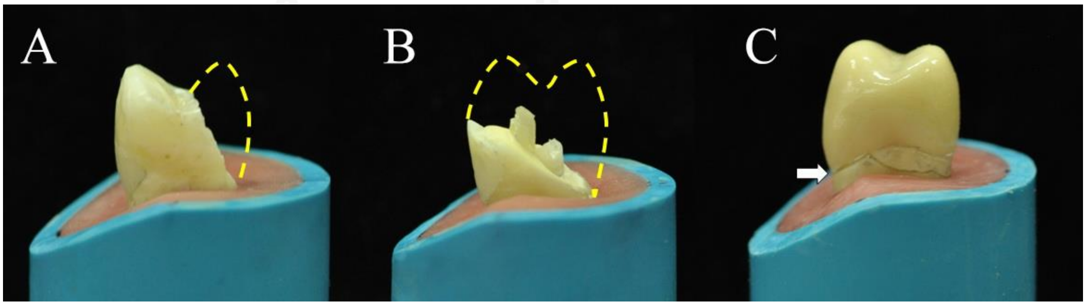

Figure 9 The failure patterns were divided into 3 types; (A) palatal cusp fracture, (B) coronal fracture, (C) fracture along crown margin (arrow)

CHAPTER V
DISCUSSION

A cervical part of the tooth is important to resist the masticatory force since it act as a fulcrum when function (3, 4, 27, 52). Loss of cervical structures from NCCLs lesions caused a critical condition to be considered for appropriate restorations especially after the teeth lost their vitality. Apart from increasing brittleness, the stresses would continue to concentrate at the cervical areas during function.

The null hypothesis in the effect of the FRC post with resin composite filling was accepted that there was no significant difference between groups RF and P/RF ($p>0.05$). Moreover, the fracture resistance of groups RF and P/RF were not significantly different from control group. It indicated that the fiber posts did not improve the strength of the teeth with simulated abfraction. Although, there were the loss of structures on bucco-cervical sides from abfraction, the other remaining walls were sufficient to resist the lateral forces without post. The simulated abfraction in this study resulting in the reduction of less than two coronal walls circumferentially, the remaining coronal walls then took a positive effect to the teeth that were more effective than the fiber posts. It was supported by a study of Mangold and Kern that when more than two remaining coronal walls were kept, the posts were not essential to increase the fracture resistance (20). While they could strengthen the teeth when there was absence or one remaining coronal wall left. Therefore, when the sufficient amounts of remaining walls were existed, there was no effect of post for reinforcing the teeth. The resin composite fillings could still take the advantage to improve the teeth in case of present and absence of the posts.

The null hypothesis in the effect of FRC post and crown placements with resin composite filling was rejected because the fracture resistance of group P/ZC was significantly higher than those of groups RF and P/RF ($p<0.05$). Although, the preparation of the crowns reduced the thickness of axial structures resulting in weakening of remaining tooth structures, the crowns were still capable to resist more occlusal forces than conventional fillings and FRC post in groups RF and P/RF. This

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meant that the strength of the crown could reinforce the teeth more than those of FRC post and resin composite. Regarding to 1100 MPa of high strength zirconium crowns, they could protect the cusp from fracture and were used for a long-term duration (43). It was agreed by a clinical study of Stavropoulou and Koidis which stated that the endodontically treated teeth with crowns had high long-term survival rates, while Aquilino and Caplan showed that they were up to six times higher survival rates than the teeth without crown (53, 54). However, there was no significant difference of the fracture resistance between control group and group P/ZC ($p>0.05$). It indicated that the restorations with FRC posts and crowns provided the sufficient strength similar as the teeth without abfraction. Concerning to the failures patterns, the posts could help to retain the crowns from sudden fracture, thus, they would be a good advantage.

The zirconium crowns in this study were full coverages of the tooth structures. Thus, they could protect these structures and distribute the forces apically. Moreover, partial cusp coverages (onlays) could also protect the cusps and reinforce the teeth. It was agreed by a previous study that onlays could help to strengthen the teeth because they increased the fracture resistance significantly compared with unrestored teeth (55). In addition, the fractured teeth with onlays might be less severe than the teeth with full coverages because of less tooth preparation (56). This was more conservative which alternatively reduced the loss of tooth structures and the risk of sudden coronal crown lost. The materials for crown of premolars can be used in several types, such as full metal, all ceramic and porcelain fused to metal. The first maxillary premolars are commonly restored with esthetic crown, including lithium disilicate or zirconia. The strength zirconia was comparable to metal, which could be used for cusp protection and had lower risk of fracture than other ceramics (43).

The insignificant difference of the fracture resistance between group RF and control group can be explained that the resin composite in the cervical lesions could help to reinforce the tooth structures and distribute the occlusal forces because its modulus of elasticity was similar as those of dentins (8, 9). It was supported by the study of Soares et al that summarized about the role of resin composite which could reduce the stress inside the teeth with cervical lesions (35). The previous studies agreed with this concept that resin composite could strengthen the teeth when compared with unrestored teeth (34, 57, 58).

In this study, we simulated the abfraction in two-rooted maxillary premolars which were often found clinically (59). The load in oblique direction was to imitate the situations causing the lesions from lateral forces. These loads could generate about two-fold higher strain than normal axial loads (5). Moreover, abfraction occured in two-rooted maxillary premolars are prone to be more aggressive since the strains at the lesions increased more than three-fold compared with the one-rooted premolars as shown by a finite element analysis (FEA) study (5). The average range of fracture resistance in this study was 840-1000 N that was higher than the 633 N maximum bite force of first premolars (60). Therefore, all restorations of this study could resist normal occlusal forces even in the resin composite fillings. They were supported by other studies which explained that any restorations were acceptable to keep the strength of endodontically treated teeth. While unrestored endodontically treated teeth tended to be gradually reduce the strength from dentin and enamel removal by endodontic process (27, 34). If weaker ceramic crowns such as lithium-disilicate were used, the fracture resistance and failure pattern might have been different (19). The high fracture resistance of the group P/ZC resulted from the crowns.

We used the loading direction at 30° from the tooth axis, toward the palatal cusp to induce the lateral forces that generated the abfraction. The forces tended to bend the teeth palatally where the palatal sides receiving compressive forces and buccal sides receiving tensile forces. In non-crown groups, the failures mostly occurred with palatal cusp fractures since the compressive forces overcame weaken structures at the access openings (61). The fractures at palatal sides involving the CEJ to the borders of acrylic resin, it meant that teeth with these fractures clinically required crown lengthening before final restorations. In crown groups, the tensile forces caused debonding interfaces between cements and fillings, the fractures initiated from the buccal crown margins which associated the fillings and extended to the palatal sides continually. Moreover, the crowns in group P/ZC were not completely separated from the roots after failures. They supported the concept that the posts could retain the crowns and might help prevent the teeth from coronal fractures (4, 12). It was a clinical advantage for reducing a severity of accidental condition. A previous study explored that the posts improved the survival rates of endodontically treated premolars with the crowns (62). Even though the posts might not help strengthen the teeth, they might prolong clinical durations.

The limitation of this study was a laboratory simulation of abfraction lesions without pathologic condition. The clinical abfraction lesions have sclerotic dentins with hypermineralized surfaces which can highly resist the acid etching and are difficult to create hybridization with adhesive materials (63). Although the sclerotic dentins are suggested to remove before adhesive procedures, there was difficulty to remove these dentins totally. Thereby, the materials rarely bonded to the sclerotic dentins that caused weaker restorations compared with the specimens in this study. Additionally, we studied the static loading that was different from the teeth in clinical situations which were usually subjected to fatigue forces. Further fatigue studies should be investigated.

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CHAPTER VI

CONCLUSIONS

Within the limitation of this study, we concluded as follows;

1. The resin composite filling restored in simulated abfraction areas showed the fracture resistance comparable to the teeth without abfraction.
2. The FRC posts did not affect fracture resistance of the endodontically treated premolars restored abfraction, but they retained the crowns to the roots which prevented sudden coronal crown lost.
3. The zirconium crowns and FRC posts significantly increased the fracture resistance of the teeth with simulated abfraction lesions.

To restore the endodontically treated teeth with abfraction, the remaining coronal walls at the cervical areas are the main factors to consider for proper restorations.

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APPENDIX

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APPENDIX

- **Compositions of materials in this study**
- **Statistical analysis**
  - Data of fracture resistance in Newton
  - Descriptive data
  - Tests of Normality
  - One-way ANOVA
  - Test of Homogeneity of Variances
  - Multiple Comparisons: Scheffe test

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Compositions of materials in this study

Material	Manufacturer	Type	Composition
Adper single bond 2 adhesive	3M ESPE, St Paul, MN, USA	Dental adhesive	- 10% by weight of 5-nm sized silica particles - BisGMA, HEMA, dimethacrylates, ethanol, water, a photoinitiator, a methacrylate functional copolymer of polyacrylic and polyitaconic acids
D.T. light-post Illusion X-RO	RTD, St. Egrève, France	Quartz fiber composite post	- Quartz fiber 60% - Epoxy resin 40%
Express XT	3M ESPE, Neuss, Germany	Light body and putty typed silicone	Carbon-carbon double bond (vinyl) terminated polydimethylsiloxane (vinyl polysiloxane, VPS) with cross linker and platinum catalyst
Filtek Z250XT	3M ESPE, St. Paul, MN, USA	Nano-hybrid resin composite	Fillers: 82% by weight (68% by volume) with 20-nm sized silica and 0.1-10 microns sized zirconia/silica particles Matrix: BIS-GMA, UDMA, BIS-EMA, PEGDMA, TEGDMA resins

Material	Manufacturer	Type	Composition
LAVA Plus	3M ESPE, St. Paul, MN, USA	Zirconia material	Tetragonal polycrystalline zirconia partially stabilized with 3 mol% of Yttrium stabilizers
RelyX U200	3M ESPE, Neuss, Germany	Self-adhesive resin cement	Base paste: Methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, initiator components, stabilizers, rheological additives Catalyst paste: methacrylate monomers, alkaline (basic) fillers, silanated fillers, stabilizers initiator components, pigments, rheological additives
Scotchbond etchant	3M ESPE, St. Paul, MN, USA	Etching acid	35% by weight of phosphoric acid
Unifast Trad	GC Corporation, Tokyo, Japan	Self-cured acrylic resin	Liquid: 99-100% Methyl methacrylate (MMA), 1-5% accelerant, less than 1% UV-light absorber and less than 0.5% dimethacrylate Powder: 5-10% dibenzoyl peroxide and less than 0.5% iron oxide

Statistical analysis

Data of fracture resistance in Newton

Specimen	Group 1	Group 2	Group 3	Group 4
1	798.59	755.98	677.81	875.52
2	799.14	768.73	770.72	887.87
3	820.36	804.48	800.29	897.90
4	921.73	822.35	822.74	1037.55
5	961.24	872.77	862.51	1039.16
6	1020.82	879.36	904.69	1057.97
7	1051.99	883.14	906.82	1063.07
8	1125.68	955.90	991.68	1172.40

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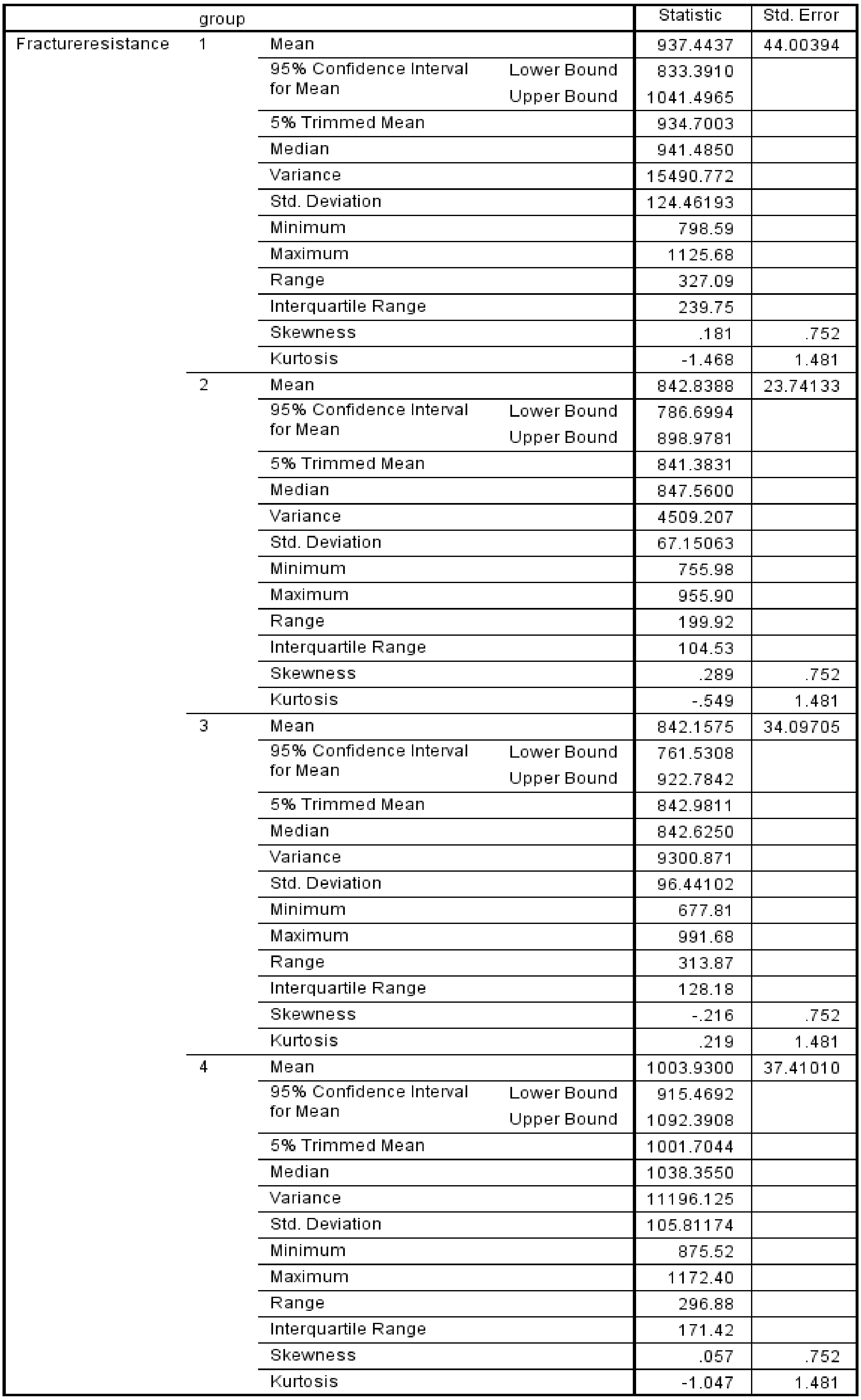
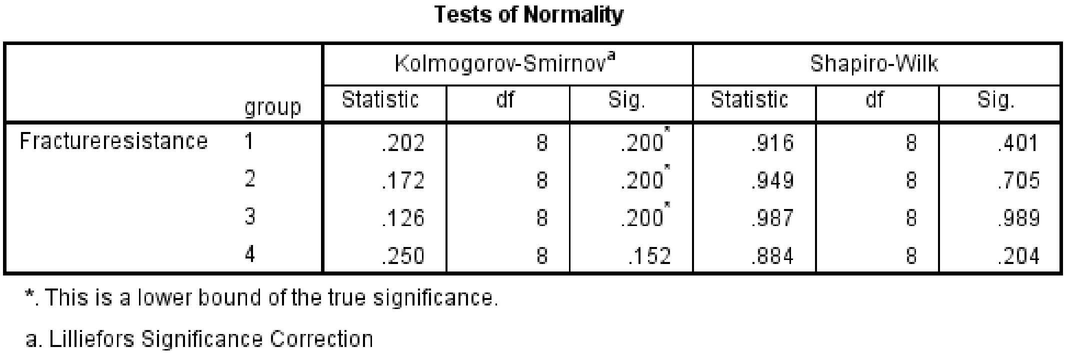
Descriptives



	group			Statistic	Std. Error
Fractureresistance	1	Mean		937.4437	44.00394
		95% Confidence Interval for Mean	Lower Bound	833.3910	
			Upper Bound	1041.4965	
		5% Trimmed Mean		934.7003	
		Median		941.4850	
		Variance		15490.772	
		Std. Deviation		124.46193	
		Minimum		798.59	
		Maximum		1125.68	
		Range		327.09	
		Interquartile Range		239.75	
		Skewness		.181	.752
		Kurtosis		-1.468	1.481
	2	Mean		842.8388	23.74133
		95% Confidence Interval for Mean	Lower Bound	786.6994	
			Upper Bound	898.9781	
		5% Trimmed Mean		841.3831	
		Median		847.5600	
		Variance		4509.207	
		Std. Deviation		67.15063	
		Minimum		755.98	
		Maximum		955.90	
		Range		199.92	
		Interquartile Range		104.53	
		Skewness		.289	.752
		Kurtosis		-.549	1.481
	3	Mean		842.1575	34.09705
		95% Confidence Interval for Mean	Lower Bound	761.5308	
			Upper Bound	922.7842	
		5% Trimmed Mean		842.9811	
		Median		842.6250	
		Variance		9300.871	
		Std. Deviation		96.44102	
		Minimum		677.81	
		Maximum		991.68	
		Range		313.87	
		Interquartile Range		128.18	
		Skewness		-.216	.752
		Kurtosis		.219	1.481
	4	Mean		1003.9300	37.41010
		95% Confidence Interval for Mean	Lower Bound	915.4692	
			Upper Bound	1092.3908	
		5% Trimmed Mean		1001.7044	
		Median		1038.3550	
		Variance		11196.125	
		Std. Deviation		105.81174	
		Minimum		875.52	
		Maximum		1172.40	
		Range		296.88	
		Interquartile Range		171.42	
		Skewness		.057	.752
		Kurtosis		-1.047	1.481

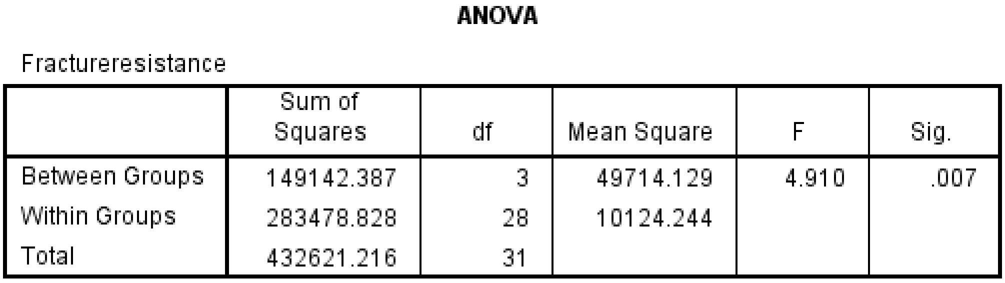


Tests of Normality

	group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Fractureresistance	1	.202	8	.200*	.916	8	.401
	2	.172	8	.200*	.949	8	.705
	3	.126	8	.200*	.987	8	.989
	4	.250	8	.152	.884	8	.204

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction



ANOVA

Fractureresistance

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	149142.387	3	49714.129	4.910	.007
Within Groups	283478.828	28	10124.244		
Total	432621.216	31			

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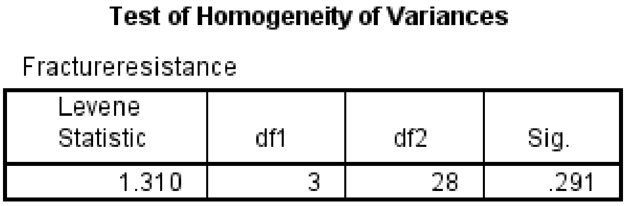
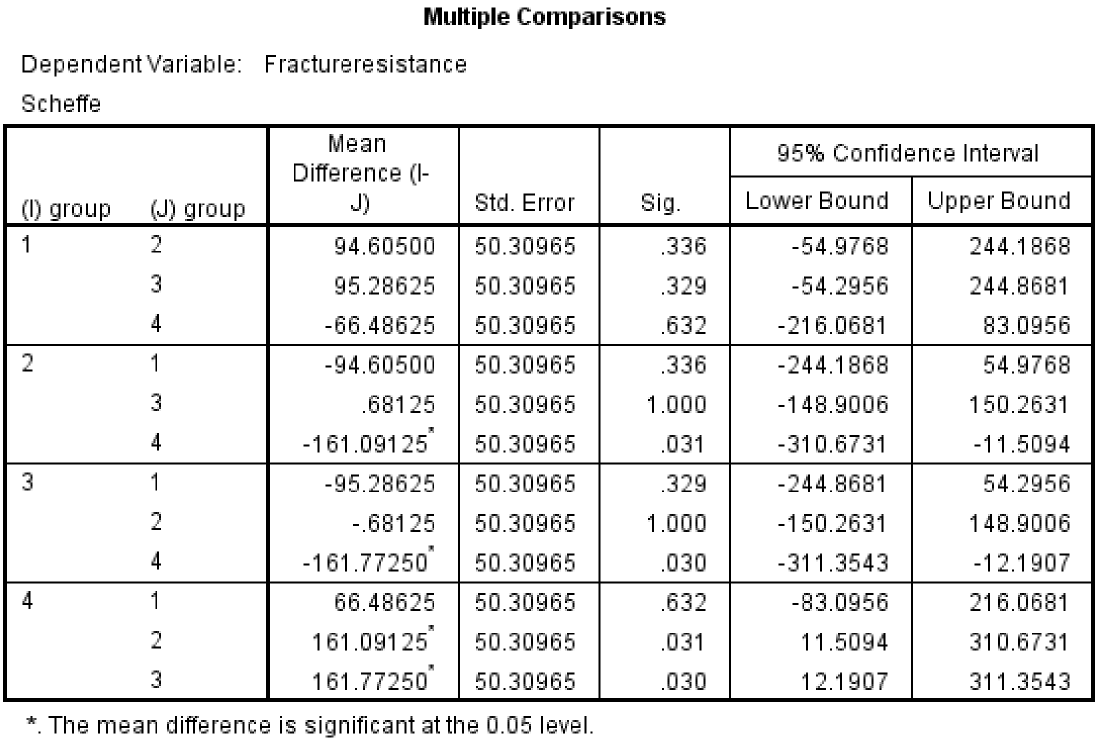


Test of Homogeneity of Variances

Fractureresistance

Levene Statistic	df1	df2	Sig.
1.310	3	28	.291



Multiple Comparisons

Dependent Variable: Fractureresistance

Scheffe

(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	94.60500	50.30965	.336	-54.9768	244.1868
	3	95.28625	50.30965	.329	-54.2956	244.8681
	4	-66.48625	50.30965	.632	-216.0681	83.0956
2	1	-94.60500	50.30965	.336	-244.1868	54.9768
	3	.68125	50.30965	1.000	-148.9006	150.2631
	4	-161.09125*	50.30965	.031	-310.6731	-11.5094
3	1	-95.28625	50.30965	.329	-244.8681	54.2956
	2	-.68125	50.30965	1.000	-150.2631	148.9006
	4	-161.77250*	50.30965	.030	-311.3543	-12.1907
4	1	66.48625	50.30965	.632	-83.0956	216.0681
	2	161.09125*	50.30965	.031	11.5094	310.6731
	3	161.77250*	50.30965	.030	12.1907	311.3543

*. The mean difference is significant at the 0.05 level.

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VITA

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