In Vitro Comparison of PFM Crown Retention Following Endodontic Access and Subsequent Restoration: Amalgam, Composite, Amalgam with Composite Veneer, and Fiber Post with Composite

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DEDICATION

To my Parents, for their love and unyielding support

To Amber for her giving me the strength and support to follow my dreams

To my Daughters, for whom I work hard now to spend more time with later

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For your assistance and guidance in helping me complete this study, and for serving on my examining committee

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ABSTRACT

Introduction: An *in vitro* investigation of crown retention following endodontic access on molar porcelain fused to metal (PFM) crowns and subsequent restoration using amalgam, composite, amalgam + composite, or fiber post + composite.

Methods: 40 human extracted molars were mounted in acrylic resin and prepared for PFM crowns. PFM crowns were fabricated, cemented with zinc phosphate, and the force to displace each crown was measured with a tensile-testing machine before and after endodontic access preparations. The endodontic access area, crown preparation axial wall, and preparation surface area was measured for each sample for comparison. The crowns were then recemented and access openings restored with either amalgam or composite before displacement force was remeasured. The restorative material was removed from each access opening, access area measured, and restored again (amalgam with composite or fiber post with composite) for displacement force to be re-measured. To compare for retention without a restored access opening, 13 randomly selected samples were removed of the restorative material, recemented and crowns again removed. Paired T test was used to compare the means of displacement between groups. One-way analysis of variance (ANOVA) was used to compare the mean outcome measure within the groups.

Results: Statistical analyses showed retention following unfilled access was significantly lower than intact crowns. Amalgam, composite, amalgam + composite, and fiber post + composite increased retention beyond the original value. There was no statistical difference between amalgam and composite materials nor amalgam + composite from fiber post + composite. Qualitative results indicate that the restorative material remains in the crown following displacement regardless of the material used to restore the access.

Conclusions: The results from this study suggest that an endodontic access cavity decreases retention of a PFM. However, subsequent restoration with amalgam, composite, amalgam + composite, or post + composite may increase the original retention of the crown.

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INTRODUCTION

Teeth restored with full coverage crowns will be successfully retained for at least 5 years in 95% of patients (1). Vital teeth with crowns or abutments for a fixed partial denture, however, may develop pulpal disease (3-23%) requiring endodontic therapy (2). Pulpal demise is a result of a series of traumatic injuries leading to inflammation, degradation, and necrosis (3). The primary goal of endodontic therapy is the prevention and treatment of apical periodontitis. Tooth preparation, obturation, and restoration are all important factors when considering endodontic success (4, 5). Teeth with full coronal coverage restorations following root canal treatment show a 97% survival rate after 8 years and of the teeth that were lost, 85% had no full coronal coverage restoration (6). This suggests that coronal coverage is an important part of endodontic success which is in agreement with a prospective study by Ng et al. 2011, where 95% of endodontically treated teeth with cast restoration survived better than those without (7). Dentists often see patients presenting with a tooth which has an existing coronal restoration that also requires root canal treatment. An option for a tooth that requires root canal therapy is to access the infected pulp tissue through the crown. Crowns accessed for root canal therapy that are functional, esthetic, non carious, and with intact margins, may not require replacement and can often be restored. General practitioners and endodontists prepare an access opening through the crown and these crowns can be maintained as a final restoration (8).

Ideally, a restored access provides a permanent, leak proof seal, and substantiates the importance of a coronal restoration in successful endodontic outcome as supported by many authors (4, 5, 9, 10). However, there is research which indicates that all materials leak to an extent (11-13).

There are many materials used to restore access openings in crowns accessed for endodontic therapy. The choice of material may be based on biocompatibility, interface, chemical/ mechanical characteristics, esthetics, and practicality. Commonly used core materials are silver alloy amalgam, glass ionomers, composite resin, and posts.

The purpose of this study was to evaluate the effect of different access opening restorative materials on crown retention.

LITERATURE REVIEW

Amalgam

Silver amalgam alloy is a common choice for restoring access cavities in metal crowns likely due to simplicity and durability (14). Amalgam can be used as a coronal-radicular core alone, as a pin amalgam retained core, or as a core with a post with success, (15) especially when bonded (16, 17). Specific situations where a tooth's remaining structural integrity is compromised may also influence the use of certain materials. To overcome a compromised situation, Kane et al. showed that extension of amalgam 2mm into canal orifices was beneficial when the pulp chamber height was 2mm or less (18). Chamber retained amalgams can also be used for core retention. These restorations exhibit both adequate retention and resistance form by placing 2 - 4mm of amalgam into the canal (18). A study by Ferrier et al. found that amalgam used as a full cuspal coverage following root canal treatment failed less catastrophically and at forces exceeding normal mastication (19). Amalgam has good dimensional stability, high compressive strength, high elastic modulus comparative to dentin, and is cost effective (20). Amalgam does require set time prior to preparation, and may be culturally unesthetic.

Glass Ionomer

Glass ionomer and Resin Modified Glass Ionomer (RMGI) are other materials that are often used as core materials. Glass ionomer has many favorable characteristics, including adhesion to tooth structure, fluoride release, and a favorable coefficient of thermal expansion (21). Another advantage of glass ionomer materials is that they may be bulk filled into access cavities.   However, RMGI materials exhibit some polymerization shrinkage due to the addition of resin. As a group of materials, glass ionomers have disadvantages that limit their use including brittleness and poor fracture toughness (22). *In vitro* studies have evaluated the use of glass ionomer as a core material with results that suggest glass ionomer is unsuitable in areas subjected to stress (23, 24).

Composite Resin

Composite resin may be used as a core build-up material. It offers advantages such as rapid polymerization with light and potential for preparation at the same appointment. Composite resin is a common choice to restore the access in ceramic restorations because of esthetics (14). Resin-based composite has high compressive strength, with good tensile and flexural strength (20). Disadvantages of composite include high cost, technique sensitive placement, and polymerization shrinkage that may cause marginal discrepancy (25-27). Polymerization shrinkage of resin becomes amplified in access cavities due to the configuration factor (C-factor), which is the ratio of bonded to unbonded areas (28, 29). Composite placed in radicular orifices may have a C-factor greater than 100:1, which may increase the potential for microleakage (28). Incremental filling of light cured composite resins may overcome this problem. The "oxygen inhibited layer," which is an unpolymerized surface layer after cure, allows additional increments to be added (30). Varying the composite increments favors the amount of unbonded to bonded wall ratio lessening the C-factor shrinkage. Varying light curing techniques with a pulse delay may also help to overcome the potential C-factor problems (31). One concern is the ability to effectively light cure the material (32). Since curing light intensity is inversely proportional to distance, maximal increment thickness has been generally defined as 2 mm between cures (33). Since the average distance from to the pulpal floor to the cusp tips is approximately 10mm in a maxillary or mandibular molar (34), a conventional curing unit may not completely polymerize material on the pulpal floor, thus affecting bond strength. Another concern is that resin-based composite materials may be incompatible with zinc oxide eugenol (ZOE). ZOE found in many root canal sealers and obturation filling material may inhibit composite cure (35-40). Improper placement of composite may therefore lead to microleakage and decreased bond strength. Composite has also been shown to bond predictably to leucite impregnated porcelain surfaces after application of hydrofluoric acid and silane agent (41-43). Hydrofluoric acid dissolves the leucite within the porcelain and increases surface roughness for bonding (44). Composite resin is a material that when appropriately selected and placed may have a successful outcome.

Posts

A post is needed in the tooth when the amount of remaining tooth structure is insufficient to maintain the core (45). Posts may aid in retention of the core and restoration but potentially weaken the root structure if dentin is removed for post fit (46, 47), especially if an oversized post space is prepared (48). Overall, there is agreement post and core systems do not serve to improve retention of the final restoration (49). In the event a post is to be placed, Goodacre and Spolnik recommended a post length equal to 3/4 of root canal length (50). Sorensen and Martinoff reported a 97% success when the post length at least equaled the crown height (51). Overall, post length is the most important factor in retention. To establish a post space, at least 4mm of gutta-percha should remain as Abramovitz et al. demonstrated that 3 mm thickness of remaining gutta-percha provides an unreliable apical seal (52). A post space can be easily made in an obturated canal using a heated instrument, rotary, or hand instruments (53). Fabricating a post space requires knowledge of root anatomy for successful endodontic post placement. Most teeth are wider faciolingual than are mesiodistal (54). The natural root morphology may be at risk of perforation during post space fabrication of the apical portion or lateral portion of the root. Literature suggests that the lingual root of the maxillary first premolar may be a better option to place a post due to the occurrence of the palatal groove found on the lingual aspect of the buccal canal (55, 56). In the event a post is to be placed in a maxillary first molar, the facial curvature of the palatal root needs to be taken into account as it to curves greater than 10° facially 85% of the time (57). Mandibular molars have a “danger zone” commonly found on the furcal side of both the mesial and distal roots of mandibular molars that requires consideration when placing a post as this area has minimal dentin thickness (58, 59). There is also a “danger zone” on the furcal side of the coronal portion of the root in the mesiobuccal root of both the maxillary first and second molars (60). When evaluating roots for post, radiographs may not be a reliable method to assess post diameter as root morphology is difficult to appreciate for residual wall thickness (61).

Many post systems are available in the marketplace to restore endodontically treated teeth. Historically, posts were metallic and either prefabricated or laboratory fabricated by casting. Since fabricating a cast post involves an indirect technique, cast posts likely require multiple appointments for fabrication, may be expensive, and the canal is typically prepared to fit the post. The advantages of a cast post are that indirect fabrication allows for custom alignment as needed for restorative purposes. However, casts posts tend to be very rigid (62). Insertion of a prefabricated post typically involves less appointments, can be bonded to composite, and the post can be fitted to the canal which may conserve dentin more than indirect posts. Example types of prefabricated posts include stainless steel, titanium, quartz fiber, glass fiber and zirconia. Prefabricated fiber reinforced composite posts tend to be favored due to modulus of elasticity similar to dentin lessening the likelihood of root fracture (63, 64). Fiber reinforced composite posts also have bonding potential to root dentin (65) and are esthetic. Findings from Kurtz et al. 2003 suggest that eugenol based root canal sealers do not affect the ability of adhesive resin bonding to the canal wall (66). Bonding of a fiber post to root canal dentin can be accomplished with luting cements, such as Rely X Unicem (3M ESPE, St. Paul, MN), with favorable results (67) and with better sealing (68). After insertion of a prefabricated post, a composite core buildup can then be completed.

Restoring the Endodontic Access of a Crown

Performing endodontic therapy through a crown and then restoring the access is common. There are *in vitro* studies that have evaluated the endodontic access and subsequent restoration on crown retention. To assess crown retention, a study by McMullen et al. discussed preparing extracted tooth samples and then fabricating respective crowns that were cemented with zinc phosphate (69). The crowns were removed with a vertical vector using a tensile testing machine. The results showed that endodontic access of maxillary central incisor PFM crowns significantly decreased the retention of the crown, likely because of the access compromising the lingual axial wall. Moreover, it was shown that each tooth can be used as its own control for further study because the same crowns can be recemented (after dissolving the zinc phosphate cement with 30% nitric acid) without a change in retention or the crown's intaglio surface. In the second part of the McMullen et al. study, it was found that crowns recemented and restored with amalgam had a 126% increase over the original retention (70). Other researchers used the same study design where tooth samples and crowns were their own respective control by using zinc phosphate as the cementing agent. Yu and Abbott also found that the crown retention decreased following the access of maxillary incisor teeth, but was not found to be significant. However, restoring the access with amalgam increased the retention of the crown; especially if the restoration was a metal Parapost and amalgam flush to the lingual cavosurface (71). Mulvay and Abbott evaluated the use of displacing full gold crowns of molar teeth and found that the displacement force was significantly lower in accessed crowns than with intact crowns. From that study, restoration with either glass ionomer or amalgam each with or without a bevel showed an increase of the original value for retention, but retention only significantly increased with amalgam. Beveling of the restorative material was shown to decrease the retention (72).

A crown with sound margins allows for a permanent restoration to be placed following the root canal therapy. Since a rubber dam is the standard of care for endodontic treatment, restoring of the crown access immediately following root canal therapy lessens the risk for contamination as supported by Heling et al. (73). Recently, a retrospective study by Goldfien et al. suggested that placement of a post using a rubber dam was considered to have a higher radiographic success (93.3% vs. 73.6%) compared to those posts placed without use of a rubber dam (74). Also, the practice of placing a permanent restoration immediately may provide the patient with fewer appointments, decrease the contamination risk, and allow for a period for evaluation prior to a new crown being placed if the patient desires one. In a clinical environment, the extent of restoration and remaining dentin beneath the pre-existing crown is unknown and the type of material selected to restore the access may aid in crown retention. There may be scenarios where, after endodontic access, the amount of remaining tooth structure is compromised and certain materials are chosen to improve strength and dimensional stability. This study seeks to evaluate different materials used for restoring endodontic access of a PFM crown and to assess each materials effect on crown retention.

OBJECTIVE

To our knowledge, no study has identified 1) whether light-cured composite increases PFM crown retention when used to restore endodontic access; 2) effect on PFM retention after placing an amalgam core and bonded composite; or 3) effect on PFM retention after placing a fiber post and bonded composite. This study sought to assess PFM crown retention following restoring the endodontic access using amalgam, bonded composite, amalgam placed as a core material then veneered with composite, or composite with a fiber post placed flush to the PFM crown surface of mandibular molar teeth *in vitro*.

HYPOTHESIS

The null hypothesis is that no retention difference will be found between materials used to restore a PFM with an endodontic access.

MATERIALS AND METHODS

Study protocol was approved by the institutional Review Board (IRB HSC: 1212E25806) of University of Minnesota, Minneapolis, MN.

Freshly extracted teeth collected from the Veterans Affairs dental clinic of Minneapolis, Minnesota were stored in sodium azide 0.5% and kept moist at all times. Sodium azide was chosen as it has been shown to preserve the physical characteristics of teeth (75).

Pilot study

Sample Selection and Preparation

For a pilot study, similar intact caries free mandibular human molar teeth were selected and visually examined to be free of cracks and to have no restorations. All samples were cleaned of debris, and then digitally radiographed using an RVG 6100

Kodak sensor and software (Carestream, Rochester, NY) to ensure that a pulp chamber existed with attempt to standardize the samples (**Figure 1**).

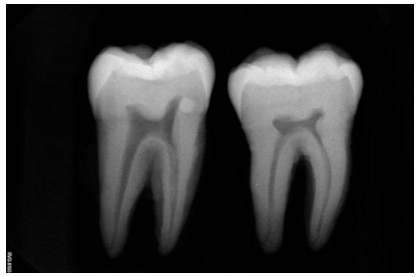

Figure 1. Example radiograph of teeth used.

Superficial horizontal undercut grooves were placed into the roots of the teeth before embedding into clear orthodontic acrylic resin blocks (Lang Dental, Wheeling, IL) along the tooth's long axis. Each sample was then stored in 0.01 M phosphate buffered saline (Sigma-Aldrich, St. Louis, MO) medium throughout the experiment.

A surveyor was modified to affix a highspeed hand piece (Midwest Dental, Wichita Falls, TX) to maintain taper throughout samples (**Figure 2**).

Figure 2. Modified surveyor with affixed highspeed hand piece.

All teeth were standardized for a PFM preparation with a 6º taper, a flat 2mm occlusal reduction, and axial wall height appropriate for each specific tooth. Each preparation was performed with a new diamond bur (**Figure 3**) (801 and L16, BrasslerUSA, Savannah, GA).

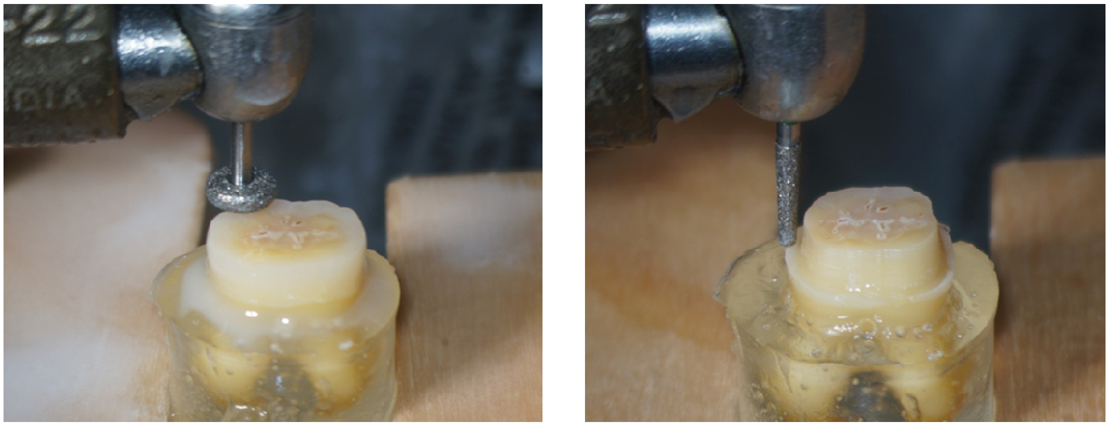

Figure 3. Sample preparation of teeth for PFM with affixed highspeed hand piece and surveyor.

An impression of each prepared sample was made with Aquasil Ultra LV and XLV vinyl polysiloxane material (Dentsply Caulk, Milford, DE).

MTS Attachment Apparatus and Jig

A "go by" crown wax pattern was designed for fabrication of a tensile force attachment apparatus (**Figure 4**).

Figure 4. "Go by" crown pattern for fabrication.

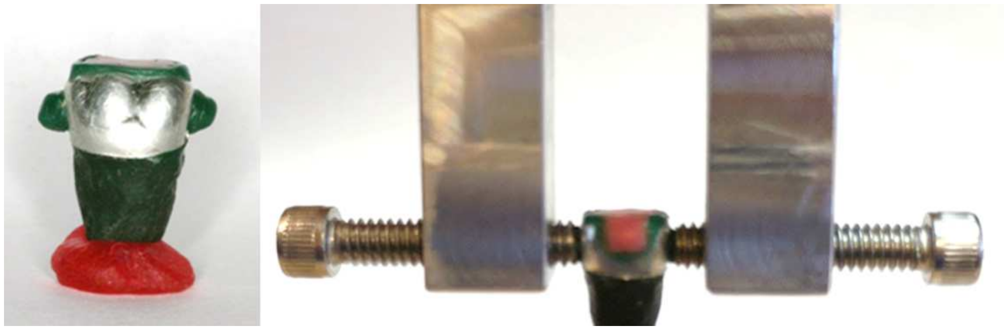

Figure 5. Aluminum attachment device to engage “go by” crown.

Engineering services at the University of Minnesota designed and fabricated a fully adjustable custom aluminum attachment device which engaged both the “go by” crown and upper vertical hydraulic ram of a material testing machine (MTS 858 Mini Bionix II, Eden Prairie, MN) (**Figure 5**).

Figure 6. Customized aluminum adjustable attachment device to attach MTS, tooth sample, and lower mounted specimen.

A customized aluminum mounting apparatus was designed and fabricated to attach to the lower device of a material testing machine and position a mounted tooth specimen **(Figure 6)**. A custom jig was also made to replicate the material testing machine attachment device for tooth positioning and mounting purposes.

PFM Crown Fabrication

The "go by" crown wax pattern and custom attachment device and impressions were then sent to Hermanson Dental Laboratory (St. Paul, MN) for a preliminary wax coping fabrication. A wax coping was made by the lab using computer aided design and computer aided milling (CAD/CAM) with the intent to standardize the occlusal table and attachment areas between all experimental samples with the following characteristics (**Figure 7**):

- 1.5 mm thickness of porcelain + 0.5mm thickness of coping =2mm
- Retentive tabs level with the occlusal plane and with each other in the occlusal 1/3rd on the mesial and distal surfaces
- The spherical retentive tabs (4.75mm diameter) to engage the attachment device

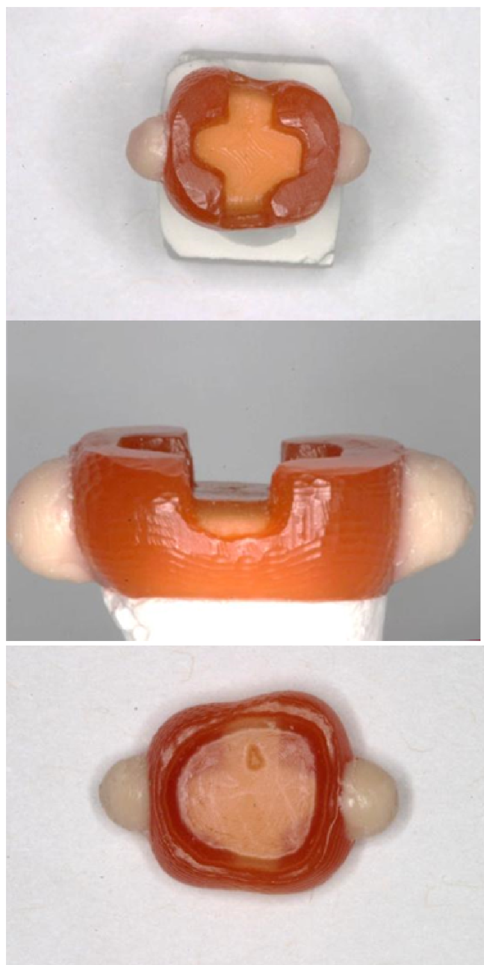

Figure 7. CAD/CAM wax coping with approved PFM characteristics.

The wax coping was approved and returned to the laboratory for crown fabrication. PFMs copings were made by the lab using nonprecious metal with 0.5mm thickness of metal and 1.5mm thickness of Vita 9 (Vident, Brea, CA) porcelain on the occlusal surface near the intended access area. To aid in removing the crown from the tooth, attachment devices were casted on mesial and distal surfaces to be used for the tensile test machine (**Figure 8**).

Figure 8. Casted PFMs coping with attachment devices.

Sample Area Measurements

Aluminum foil (Bakers Choice, Beacon Falls, CT) adaptation was used to measure the preparation surface area of all samples by fitting the foil on the stone die then placing the appropriate crown on the die and trimming the excess (**Figure 9**). The foil adaptation was done in triplicate, measured with an enclosed research lab R200D scale (Sartorius Co., Bohemia, NY) then averaged to determine a difference in weight as a proportion of area between samples as described by Lorey and Myers (76).

Figure 9. Aluminum foil fitted to internal coping for surface area measurement.

Each crown stone die was secured to the base of an Olympus MVX10 stereomicroscope (Olympus America, Melville, NY) and images were taken using acquisition software (MicroSuite Five, Olympus America, Melville, NY) with an Olympus DP71 CCD Camera (Olympus America, Melville, NY) attached to the microscope at 10x magnification. Images were saved in .jpg format at a resolution of 4080x3072 at 300dpi and the occlusal table area and axial wall height was measured in duplicate and recorded (**Figure 10**).

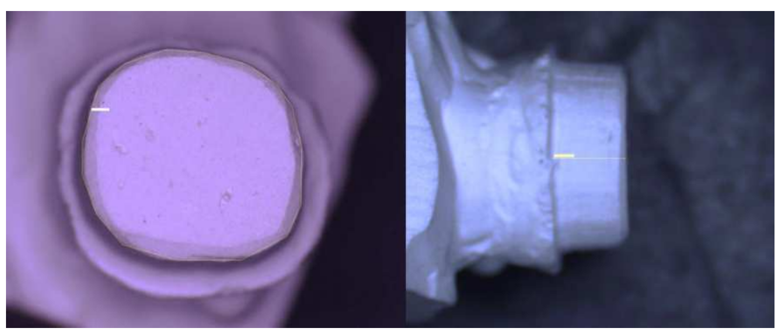

Figure 10. Example of surface area and axial wall height measurements of stone die.

Crown and Sample Preparation for Tensile Force Test

Each crown was held in place on the respective sample using an elastic band, placed in the custom mounting jig, and each mounted tooth was again embedded in a custom indexed and tapered mounting ring with orthodontic acrylic resin to orient the crown and sample to the crown's path of draw (**Figure 11**).

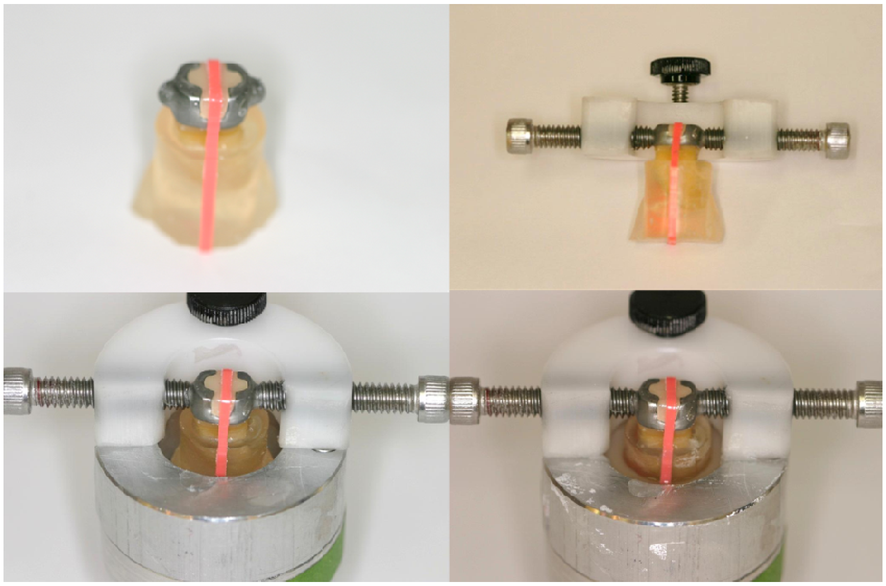

Figure 11. Mounting of the sample preparation and crown long axis in the custom indexed tapered jig.

The crown and specimen were separated, dried, and Fleck's zinc phosphate cement (Keystone Industries, Myerstown, PA) was mixed on a glass slab between 72-75˚F according to manufacturer's instructions. Zinc phosphate was placed in the intaglio surface of the crown with a microbrush (Microbrush International, Grafton, WI) and the crowns were cemented to the appropriate sample. Excess cement was removed from the margin and the crown/tooth was subjected to a 10 kg vertical static load for 10 minutes (**Figure 12**) (77).

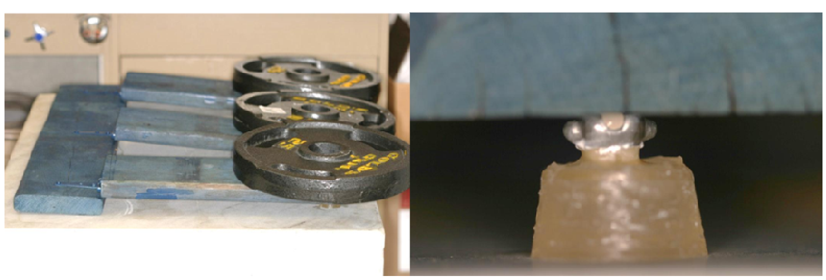

Figure 12. Sample subjected to a 10kg vertical load.

The samples, along with gauze moistened with 0.01 M phosphate buffered saline, were then secured in a plastic storage bag. The bag was submerged in a circulating Imperial

IV water bath (Lab Extreme, Kent City, MI) at 37ºC and 100% humidity for 24 hours to mimic the intraoral environment (**Figure 13**).

Figure 13. Samples stored and submerged in a circulating water bath at 37ºC for 24 hours.

Tensile Force Test

A tensile testing machine (MTS 858 Mini Bionix II, Eden Prairie, MN) was used to displace and measure force to remove crowns from samples. Prior to removing any crown from a sample, the MTS underwent a 20 minute "warming phase" set at 0.5 Hz with amplitude of 5cm. The MTS software station manager setup was specified for" galyna.cfg" and "calibrated.GL" between all tensile force tests. This software was chosen for vertical displacement. The tooth and cemented crown were placed in the indexed mounting device and attached to the lower portion of the MTS. The fully adjustable aluminum apparatus was attached to the vertical arm of the MTS machine then manually positioned so the casted crown attachment devices could be connected (**Figure 14**). The MTS with a crosshead speed of -5mm/min was used to remove copings from each tooth while forces to displace the crowns were measured using the MTS software.

Figure 14. Sample mounted in customized aluminum apparatus attached to MTS machine for measurement of displacement.

Crown and Sample Preparation After Tensile Force Test

After the crowns were separated from the samples, the crowns were cleaned with a 30% nitric acid solution (Thermo Fisher Scientific Inc.,Waltham, MA) for 20 minutes between samples under a class II fume hood. Any cement remaining on the tooth sample was removed with a cavitron (Dentsply Professional, York, PA) ultrasonic with water prior to re-cementation (**Figure 15**). According to McMullen et al. 1989, each crown can be used as its own control since retention is kept relatively constant after clearing each crown with nitric acid (78).

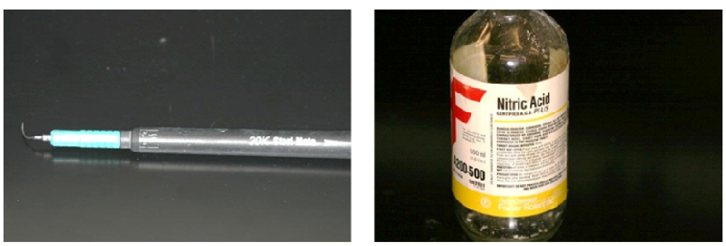

Figure 15. Cavitron and 30% nitric acid solution to remove cement on sample and crown.

Endodontic PFM Access

Standard straight line molar endodontic access was prepared under continuous water spray using a new bur in a highspeed hand piece (BrasslerUSA, Savannah, GA). A Neodiamond diamond round bur (Microcopy, Kennesaw, GA) was used to access the porcelain and a new cross cut transmetal fissure bur (Dentsply-Maillefer, Johnson City, TN) to penetrate the metal coping. The preparations were done with the hand piece as parallel to the tooth's long axis as possible without being divergent (**Figure 16)**. Each access was prepared under 5.1x magnification using a Global G6 microscope (Global Surgical Co. St. Louis, MO).

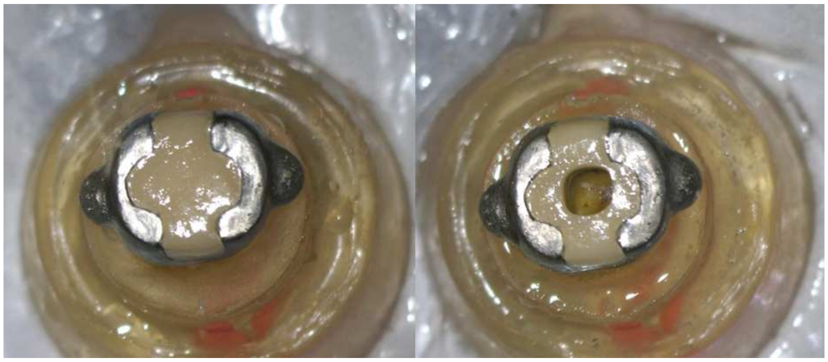

Figure 16. Endodontic access of a PFM crown.

PFM Area Measurements

Crown access was visualized with an Olympus MVX10 stereomicroscope (Olympus America, Melville, NY) and images were taken using acquisition software (MicroSuite Five, Olympus America, Melville, NY) with an Olympus DP71 CCD Camera (Olympus America, Melville, NY) attached to the microscope at 10x magnification. Images were saved in .jpg format at a resolution of 4080x3072 at 300dpi and the PFM access was measured in duplicate and recorded (**Figure 17).**

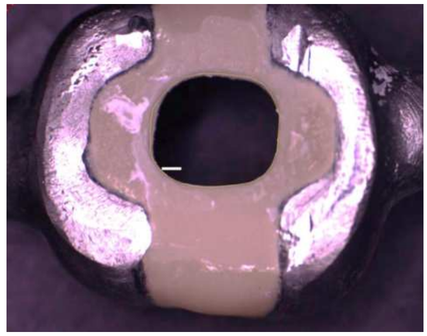

Figure 17. Measuring surface area of the PFM endodontic access.

Tensile Force Test and Crown/Sample Preparation After Access

The crowns were cemented then displaced and forces measured as before. The crowns and samples were both again cleaned and crowns were then recemented as described earlier.

Endodontic Root Canal Therapy After Access

The teeth were prepared for root canal therapy by first establishing a glide path to a #25 K flex-O hand file (Dentsply-Maillefer, Johnson City, TN). Endodontic instrumentation was then performed on each sample up to a 30.06 Twisted File (SybronEndo, Orange, CA) in a ProMark rotary 8:1 ratio hand piece at 600 RPM. Canal irrigation was completed using 5.25% NaOCL via a Maxi I probe 27 gauge side vented needle set 2 mm from the apex of each canal. A final irrigation sequence consisted of 17% REDTA (Roth LTD, Chicago, IL) 1ml/min soak per canal, 3ml 5.25% NaOCL (79), and 1ml 95% ethanol (80). Canals were dried with sterile paper points and Roth's 801 sealer (Roth LTD, Chicago, IL) was placed using a gutta-percha cone. Themoplasticized gutta-percha was placed in the canals and condensed to the level of each root orifice (Obtura II, SybronEndo, Orange, CA). Excess sealer in the pulp chamber was removed with 95% ethanol and microbrushes (Microbrush International, Grafton, WI) (**Figure 18**).

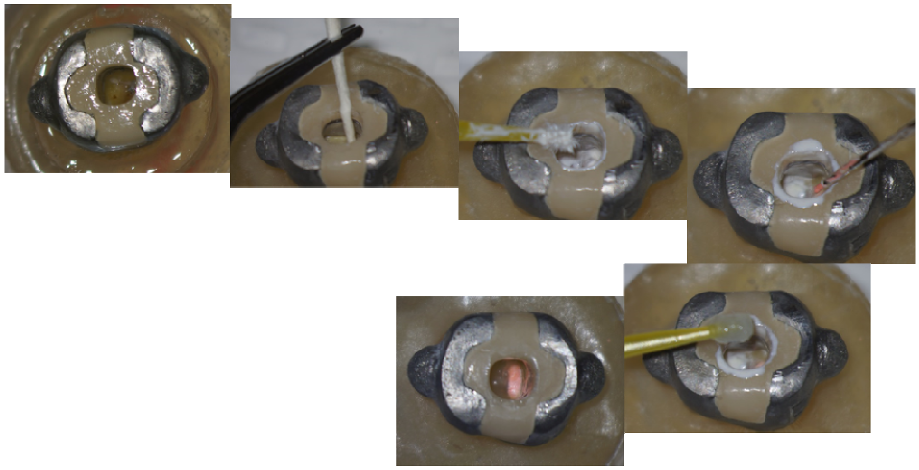

Figure 18. Endodontic sequence of root canal therapy of the PFM access: Access dried following irrigation, Roth's 801sealer applied, obturation with gutta-percha, excess sealer removed with 95% ethanol, cleaned PFM access.

Restoration of the PFM Access

The samples were randomly assigned to groups using software (*www.randomizer.org*); Group 1 amalgam, Group 2 composite with porcelain etch using hydrofluoric acid/silane treatment, and Group 3 composite without porcelain etch/ silane treatment. The restorations were placed using 5.1x magnification Global G6 microscope (Global Surgical Co. St. Louis, MO) with an illuminating filter to prevent material from premature cure (when appropriate).

Group 1 (Amalgam): Two (2) spill Dispersalloy amalgam (Dentsply, Caulk, Milford, DE) was mixed using a Promix Model 400 (Dentsply, Caulk, Milford, DE) amalgamator at 10 seconds using the "turtle" setting then condensed in the access cavity to the occlusal cavosurface of the porcelain (**Figure 19**).

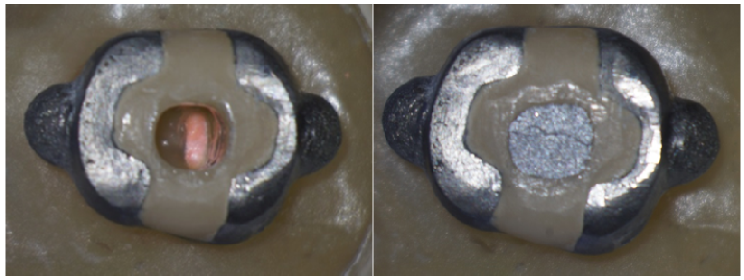

Figure 19. Amalgam restoration of the PFM access.

Group 2 (Composite): The crown porcelain was etched with Pulpdent Porcelain Etch Gel (Pulpdent Co. Watertown, MA) 9.6% hydrofluoric acid for 30 seconds, rinsed for 15 seconds, then silanated with Silane Bond Enhancer (Pulpdent Co. Watertown, MA) for 1 minute and air dried. Intrapulpal access was etched with 35% Ultra Etch phosphoric acid (Ultradent, South Jordan, UT) for 15 seconds, rinsed for 15 seconds, coated with Adper Single Bond Plus (3M ESPE, St. Paul, MN) to manufacturer's specifications, and light cured for 30 seconds with an LED SmartLite (Dentsply, Caulk, Milford, DE). Paracore White (Coltène/Whaledent Inc., Cuyahoga Falls, OH) composite buildup material was placed as an intrapulpal barrier to within 5mm from the crown occlusal cavosurface then light cured for 30 seconds. Filtek Z250 A2 (3M ESPE, St. Paul, MN) composite was added in increments (to reduce the C-factor) to the crown occlusal cavosurface then light cured for 30 seconds. The composite material was finished flush and polished with an FG 8 carbide (BrasslerUSA, Savannah, GA) to the cavosurface (**Figure 20**).

Figure 20. Composite restoration of the PFM access.

Group 3 (Composite without HF/Silane): Samples were restored as in Group 2 only that the treatment of the porcelain (hydrofluoric acid etch and silane) was not performed.

Tensile Force Test

The crowns were then displaced and forces measured as before. The observational results of the pilot study suggest that following displacing forces, restorative material remains both in the access cavity of the crown and in the tooth preparation in all groups. The tensile forces of the pilot study suggested no difference regarding porcelain etch silane steps. Results of the pilot study are included in **Table 1**. A power analysis was then conducted to determine a possible experimental sample size based on data from the Mulvay and Abbot 1996 article (72):

> "A sample size of 17 in each group will have 80% power to detect a difference in means of -14, assuming that the common standard deviation is 14 using a two group t-test with a 0.05 two-sided significance level."

Experimental Study

Following the results of the pilot study, 34 more teeth were then randomly selected, mounted, prepared, impressioned, with crowns fabricated, and samples/ crowns area measured exactly as described for the pilot study as above. The crowns were then displaced and forces measured as before without the endodontic access and then with the access opening. The crowns and samples were both again cleaned, crowns were then recemented, and endodontic root canal therapy performed as described earlier.

Phase I

Teeth were then randomly allocated to into groups (*www.randomizer.org*) **–** Group 1 Amalgam and Group 2 Composite, with 17 teeth allocated to each group. The teeth were restored by two independent calibrated clinicians who were blinded to the study purpose. The independent clinicians assisted and rotated with one another while restoring each PFM access. The restorations were placed using 5.1x magnification Global G6 microscope (Global Surgical Co. St. Louis, MO) with an illuminating filter to prevent material from premature cure (when appropriate). The clinicians were limited to no longer than 1.5 hours of working time before being mandated to take a 15-minute break to reduce fatigue. They were also limited to no more than 3 hours of working time.

Group 1 (Amalgam): Two (2) spill Dispersalloy amalgam (Dentsply, Caulk, Milford, DE) was mixed using a Promix Model 400 (Dentsply, Caulk, Milford, DE) amalgamator at 10 seconds using the "turtle" setting then condensed in the access cavity to the occlusal cavosurface of the porcelain.

Group 2 (Composite): The crown porcelain was etched with Pulpdent Porcelain Etch Gel (Pulpdent Co. Watertown, MA) 9.6% hydrofluoric acid for 30 seconds, rinsed for 15 seconds, then silanated with Silane Bond Enhancer (Pulpdent Co. Watertown, MA) for 1 minute and air dried. Intrapulpal access was etched with 35% Ultra Etch phosphoric acid (Ultradent, South Jordan, UT) for 15 seconds, rinsed for 15 seconds, coated with Adper Single Bond Plus (3M ESPE, St. Paul, MN) to manufacturer's specifications, and light cured for 30 seconds with an LED SmartLite (Dentsply, Caulk, Milford, DE). Paracore White (Coltène/Whaledent Inc., Cuyahoga Falls, OH) composite buildup material was placed as an intrapulpal barrier to within 5mm from the crown occlusal cavosurface then light cured for 30 seconds. Filtek Z250 A2 (3M ESPE, St. Paul, MN) composite was added in increments (to reduce the C-factor) to the crown occlusal cavosurface then light cured for 30 seconds. The composite material was finished flush and polished with an FG 8 carbide (BrasslerUSA, Savannah, GA) to the cavosurface.

Tensile Force Test

Crowns were stored for 24 hours as described earlier, then displaced and forces measured as before.

Phase II

Following the results of the experimental phase I study, the crowns and samples were both again cleaned as presented earlier. The crowns were then placed without cementing on each appropriate sample and reaccessed to remove the restorative material until gutta-percha was exposed. The study experimental phase II included the corresponding four pilot study samples. The restorations were removed using 5.1x magnification Global G6 microscope (Global Surgical Co. St. Louis, MO). Each crown access was visualized with an Olympus MVX10 stereomicroscope (Olympus America, Melville, NY) and images were taken using acquisition software (MicroSuite Five, Olympus America, Melville, NY) with an Olympus DP71 CCD Camera (Olympus America, Melville, NY) attached to the microscope at 10x magnification. Images were saved in .jpg format at a resolution of 4080x3072 at 300dpi and the PFM access was measured in duplicate and recorded. The crowns were then recemented as described earlier.

Under 5.1x magnification using a Global G6 microscope (Global Surgical Co. St. Louis, MO), each sample was then again subjected to a final irrigation sequence in the pulp chamber consisting of 3ml 5.25% NaOCL, 17% REDTA 1ml/min soak, 3ml 5.25% NaOCL, and 1ml 95% ethanol rinse. The pulp chamber was dried with paper points and Roth’s 801 sealer was placed. Excess sealer in the pulp chamber was removed with 95% ethanol and microbrushes.

The teeth were restored again by the same two independent calibrated clinicians who were blinded to the study purpose. The independent clinicians assisted and rotated with one another while restoring each PFM access. The restorations were placed using 5.1x magnification Global G6 microscope (Global Surgical Co. St. Louis, MO) with an illuminating filter to prevent material from premature cure (when appropriate). The clinicians were limited to no longer than 1.5 hours of working time before being mandated to take a 15-minute break to reduce fatigue. They were also limited to no more than 3 hours of working time.

Each sample maintained their respective previous restoration material type and allocated to the appropriate group (ie. Group 1 amalgam became Group 3 Amalgam + composite veneer).

Group 3 (Amalgam + Composite Veneer): Two (2) spill Dispersalloy amalgam (Dentsply, Caulk, Milford, DE) was mixed using a Promix Model 400 (Dentsply, Caulk, Milford, DE) amalgamator at 10 seconds using the "turtle" setting then condensed in the access. The amalgam was condensed to within 3mm from the crown occlusal cavosurface and allowed to set for 3-5 minutes.

The crown porcelain was etched with Pulpdent Porcelain Etch Gel (Pulpdent Co. Watertown, MA) 9.6% hydrofluoric acid for 30 seconds, rinsed for 15 seconds, then silanated with Silane Bond Enhancer (Pulpdent Co. Watertown, MA) for 1 minute and air dried. Intrapulpal access was etched with 35% Ultra Etch phosphoric acid (Ultradent, South Jordan, UT) for 15 seconds, rinsed for 15 seconds, coated with Adper Single Bond Plus (3M ESPE, St. Paul, MN) to manufacturer's specifications, and light cured for 30 seconds with an LED SmartLite (Dentsply, Caulk, Milford, DE). Filtek Z250 A2 (3M ESPE, St. Paul, MN) composite was added in increments in the remaining 3mm to the crown occlusal cavosurface then light cured for 30 seconds. The composite material was finished flush and polished with the cavosurface (**Figure 21**).

Figure 21. Amalgam + composite veneer restoration of the PFM access.

Group 4 (Fiber Post + Composite): A 12mm post space was made in the distal canal using a RelyX fiber post system in sequence to size 2 (3M ESPE, St. Paul, MN). The fiber post fit passively in the canal and also extended beyond the occlusal surface of the crown. Each post was cleaned using 95% ethanol and a single coat of Adper Single Bond Plus added and light cured.

The crown porcelain was etched with Pulpdent Porcelain Etch Gel (Pulpdent Co. Watertown, MA) 9.6% hydrofluoric acid for 30 seconds, rinsed for 15 seconds, then silanated with Silane Bond Enhancer (Pulpdent Co. Watertown, MA) for 1 minute and air dried. Intrapulpal access was etched with 35% Ultra Etch phosphoric acid (Ultradent, South Jordan, UT) for 15 seconds, rinsed for 15 seconds, coated with Adper Single Bond Plus (3M ESPE, St. Paul, MN) to manufacturer's specifications, and light cured for 30 seconds with an LED SmartLite (Dentsply, Caulk, Milford, DE). A single RelyX fiber post size 2, 1.6 mm diameter (3M ESPE, St. Paul, MN) was cemented with RelyX Unicem 2 self-etching resin (3M ESPE, St. Paul, MN) without contacting the crown access margin. The post was inserted and cement was allowed to set for 5 minutes. Paracore White (Coltène/Whaledent Inc., Cuyahoga Falls, OH) composite buildup material was placed as an intrapulpal barrier to within 5mm from the crown occlusal cavosurface then light cured for 30 seconds. Filtek Z250 A2 (3M ESPE, St. Paul, MN) composite was added in 2mm increments, light cured for 30 seconds between increments, and added until flush to the crown occlusal cavosurface. The composite material and post were finished flush with the cavosurface using an L16 diamond bur (BrasslerUSA, Savannah, GA) as recommended by Grandini et al. 2002 (81) then polished with an FG 8 carbide (**Figure 22**) (BrasslerUSA, Savannah, GA).

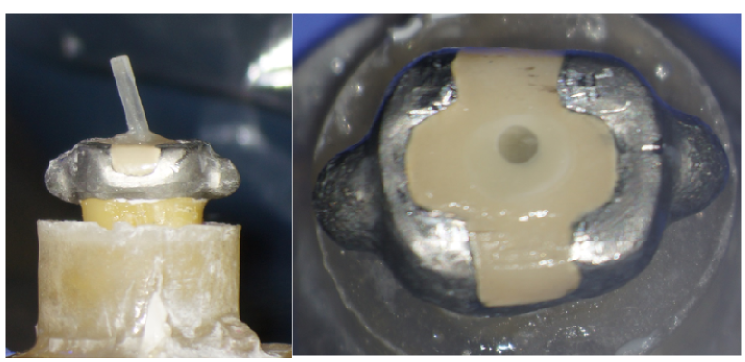

Figure 22. Fiber Post + composite veneer restoration of the PFM access.

Tensile Force Test

Crowns were stored for 24 hours as described earlier, then displaced and forces measured as before.

Phase III

Five (5) crowns and samples from the pilot study and 8 randomly (*www.randomizer.org*) chosen experimental samples and respective crowns were again cleaned as presented earlier (13 total samples). The crowns were then placed without cementing on each appropriate sample and reaccessed to remove the restorative material 3mm below the crown cavosurface using 5.1x magnification Global G6 microscope (Global Surgical Co. St. Louis, MO). The crowns were then recemented, stored for 24 hours, then displaced and forces measured as before.

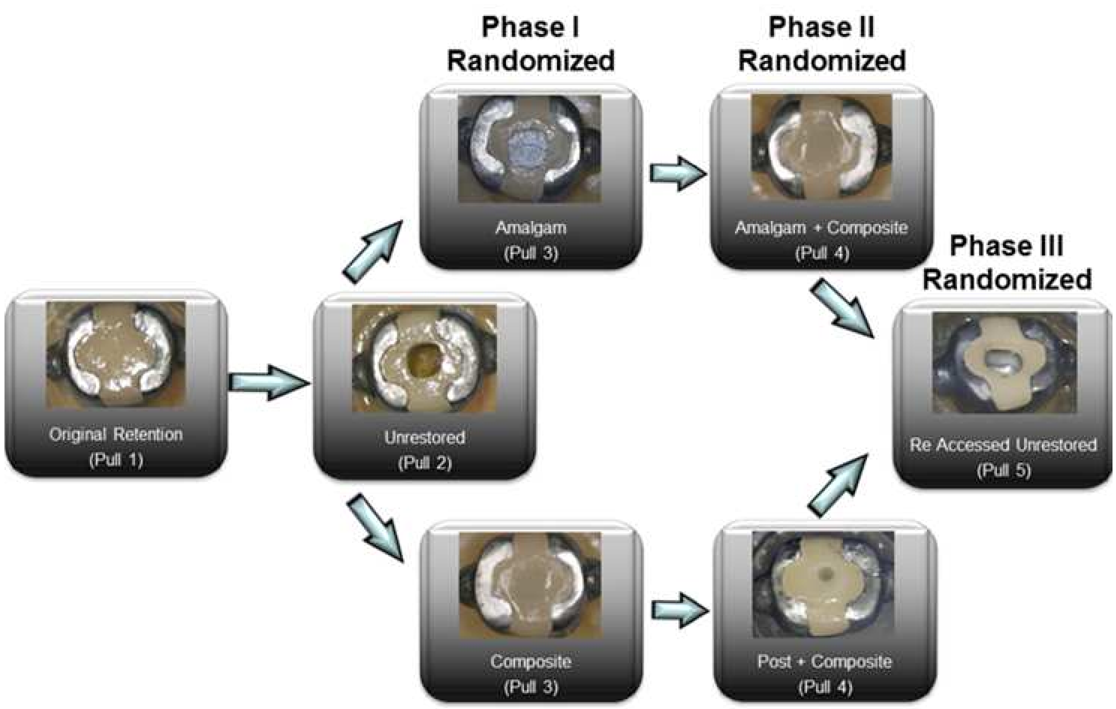

Figure 23. Flow chart indicating experimental phases.

Data Analysis

Data collected from each tensile force test were recorded and saved as a DAT file. The DAT file was imported into statcrunch (*www.statcrunch.com*) and the range of minimum to maximum axial force was calculated for the whole data set. The range was then recorded, converted to Kg of force, then transcribed into a Microsoft Excel document for analysis.

Statistical Analyses

Descriptive statistics (means, standard deviations) were calculated for occlusal table area, axial wall height, access area prior, access area after, and foil weight of preparation. Pearson correlation coefficients (r) and simple linear regression models were conducted to analyze predictive factors for displacement force. Paired T test was used to compare the means of displacement between groups. One-way analysis of variance (ANOVA) was used to compare the mean outcome measure within the groups. This was done by using intercept models to compare the mean force between the 5 pulls for each group. These models take into account potential within-sample correlation. Pairwise comparisons were made using a Tukey-Kramer adjustment for multiple comparisons. P-values less than 0.05 were considered statistically significant. SAS V9.3 (SAS Institute, Inc., Cary, NC) was used for the analyses.

RESULTS

Pilot Study

Quantitative Results

No formal data analysis was performed on the pilot study data at the pilot phase. The mean displacement force was calculated and found to decrease following the endodontic access, increased following subsequent restorations, and decreased again after removing the restorative material. Sample F was fractured under load at the restoration phase and the displacement force was unable to be measured further.

Displacement data for each sample are demonstrated in **Table 1**. Original retention, access unrestored, restored (amalgam or composite), tertiary restoration (amalgam +composite veneer or fiber post + composite), and reaccessed unrestored are designated as Pull 1,2,3,4, and 5 respectively.

	Pull 1(Kg)	**Pull 2 (Kg)**	**Pull 3 (Kg)**	**Pull 4 (Kg)**	**Pull 5 (Kg)**
SAMPLE	**Original Retention**	**Access Unrestored**	**Restored**	**Tertiary Restoration**	**Re-access Unrestored**
A Comp	61.94	52.94	67.76	92.03	56.26
B Comp	63.83	61.65	88.11	71.2	60.61
C Comp w/out HF/Silane	34.98	39.66	56.52	X	46.6
D Amalgam	53.88	40.04	108.33	93.57	50.28
E Amalgam	57.32	44.11	86.86	84.18	49.64
F Comp w/out HF/Silane	22.33	21.33	X	X	X

Table 1. Pilot study PFM displacement force for each pull.

Qualitative Results

All pilot study samples (A-F), regardless of restorative material or treatment, resulted in restorative material remaining in the access hole following displacement. The remaining material was found within the tooth at the preparation occlusal table crown interface. Although sample F was fractured under load and unable to be used for further analysis, visually the restorative material remained in the access (**Figure 24**).

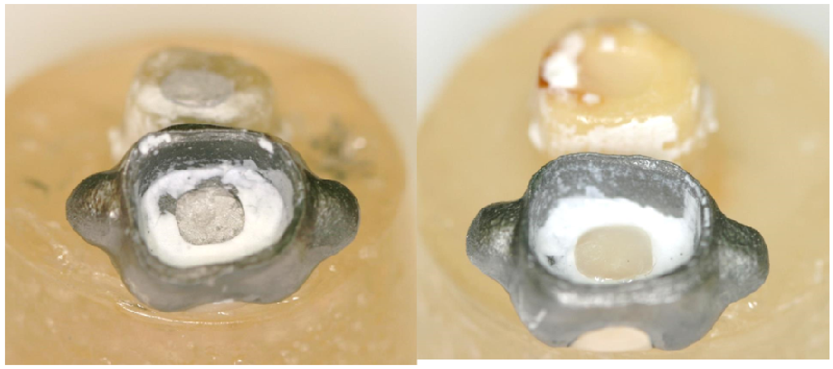

Figure 24. Following displacement, a portion of the restorative material remained in the access.

Experimental Study

NOTE: Corresponding pilot study data were pooled and included with the experimental data for analysis.

Quantitative Results

n=40	Occ Table Area (mm^2)	Axial Wall Height (mm)	Access Prior (mm^2)	Access After (mm^2)	Foil Weight of Prep(g)
Mean	53.662	2.702	12.121	14.352	0.00635
SD	7.593	0.377	1.618	2.143	0.00067

Table 2. Sample means of: occlusal table area (mm^2), axial wall height (mm), access area prior to restoration (mm^2), access area after restoration (mm^2), foil weight of preparation (g).

Table 2 shows the means of: occlusal table area as 53.66mm^2, axial wall height as 2.702mm, access area prior as 12.12mm^2, access area after as 14.35mm^2, and foil weight of preparation as 0.006359 (grams). The means were from each sample corresponding to the phase of the study. Pearson Correlation Coefficients (r) for predictive displacement factors are shown below in **Table 3** and **Table 4**.

n=40	Occlusal Table	Axial Wall	Foil Weight
Pull 1	r=0.33 (p=0.0372)	r=0.50 (p=0.0009)	r=0.68 (p<.0001)
Pull 2	r=0.32 (p=0.0417)	r=0.48 (p=0.0016)	r=0.57 (p=0.0001)

Table 3. Occlusal table, axial wall, and foil weight as a means to determine correlation between displacement and predictor. All correlations are statistically significantly different than 0 ($p < 0.05$). Correlation between the difference of Pull 1 and Pull 2 (Pull 1 minus Pull 2) and the area difference (occlusal table minus access area prior): r=0.11 (p=0.5082). This was not statistically significant.

	Estimate (SE)	P-value
Intercept	-79.84 (22.10)	0.0009
Occlusal Table	0.38 (0.48)	0.4385
Axial Wall	3.91 (12.81)	0.7621
Foil Weight	13366.97 (8485.26)	0.1239

Table 4. Results of a multiple linear regression model, with Pull 1 as the outcome and occlusal table, axial wall, and foil weight as predictor variables.

Predictors of retention based on foil weight, axial wall height, or occlusal table area were correlated and shown in **Table 3**. Each predictor were found to correlate with retention, such that as foil weight, axial wall height, and/or occlusal table area increased, so did the likelihood of the force needed for displacement. None of the predictors are statistically significant; however, this is likely due to correlation between the predictors (e.g. axial wall and foil weight are highly correlated; r=0.80). Because of this, it is not necessary to include all these predictors. Removing axial wall from the model, results in foil weight becoming significant (p<0.0001) while occlusal table remains insignificant (p=0.3786). So foil weight is the best predictor for Pull 1. **Figure 25**, **Figure 26**, **Figure 27**, each show Pull 1 as a function of each predictor separately. An increase in the area of occlusal table, foil weight, or axial wall height, increases the displacement force to remove the crown.

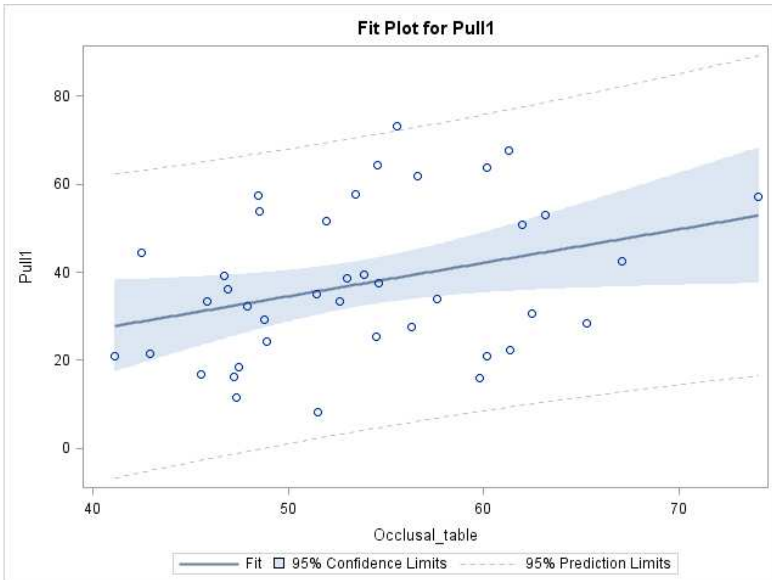

Figure 25. Simple linear regression of Pull 1 and Occlusal Table area. r=0.33

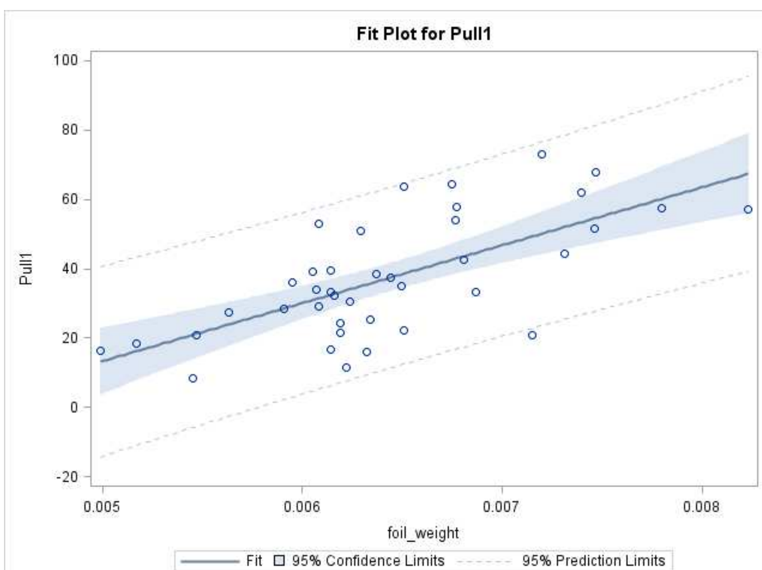

Figure 26. Simple linear regression of Pull 1 and Foil Weight. r=0.68

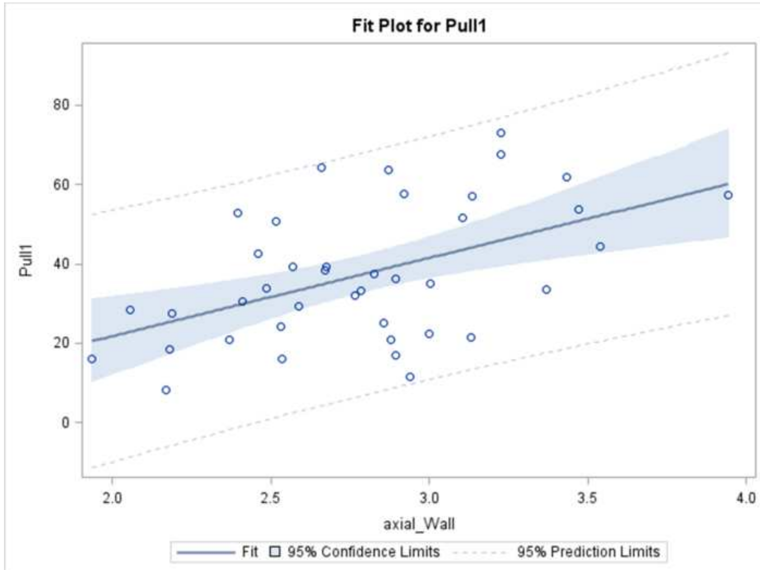

Figure 27. Simple linear regression of Pull 1 and Axial Wall Height. r=0.5

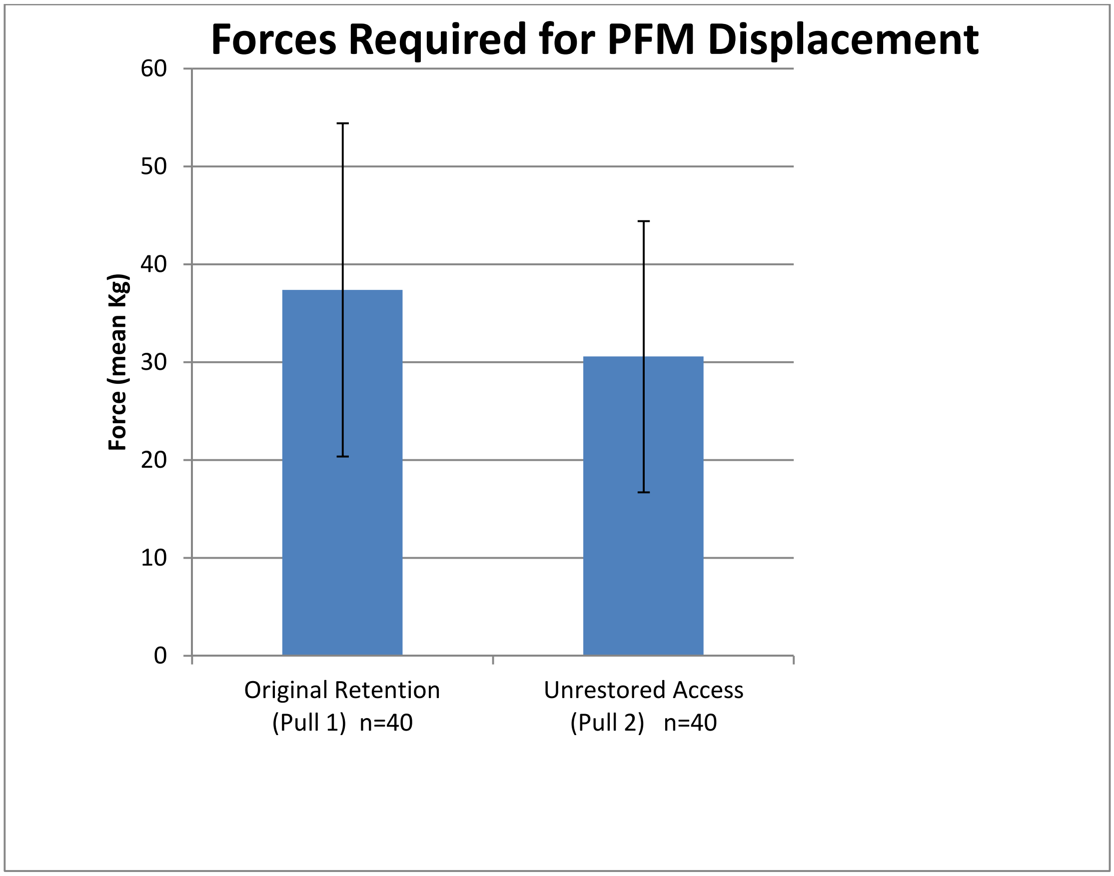

Figure 28. PFM displacement without an access (Pull 1) and PFM displacement with an unrestored access (Pull 2) for all 40 samples. As a group, making an endodontic access decreased the retention force significantly. Paired *t* test $p = 0.0002$*: Error bars = SD*

Overall, Pull 1 vs Pull 2 (n= 40) the endodontic access in the crown (Pull 2) resulted in a 6.82 kg decrease in displacement force compared to the original crown without access opening (Pull 1), which was found significant using a paired *t* test ($p = 0.0002$) as shown in **Figure 28.**

PHASE I	AMALGAM (Group 1) Mean (SD)	COMPOSITE (Group 2) Mean (SD)	T-test p-value
Pull 1: Original Retention (n=21, 19)	36.96 (16.39)	37.89 (18.15)	0.8654
Pull 2: Unrestored (n=21, 19)	32.17 (13.48)	28.83 (14.42)	0.4534
% of Pull 1	***91.19 (23.33)***	***82.46 (28.66)***	
Pull 3: Restoration (n=18, 18)	58.95 (23.34)	61.06 (12.57)	0.7384
% of Pull 1	***180.94 (74.66)***	***194.92 (94.08)***	
PHASE II	**AMALGAM+COMPOSITE (Group 3)**	**POST+COMPOSITE (Group 4)**	
Pull 4: Tertiary Restoration (n=17, 17)	46.32 (26.63)	49.73 (16.45)	0.6567
% of Pull 1	***134.27 (65.06)***	***155.20 (78.38)***	
PHASE III			
Pull 5: Re-access Unrestored (n=7, 6)	41.67 (14.39)	40.63 (14.31)	0.8986
% of Pull 1	***90.44 (23.13)***	***78.30 (21.08)***	
Pull 3 minus pull 2 (n=18, 18)	26.43 (18.3)	31.97 (11.56)	0.2854

Table 5. PFM displacement for Phase I, II, III of the experimental study groups as mean (SD). Comparisons were not statistically significant. Each phase was also calculated as a % of Pull 1. *Note*: pilot study samples C and F were not included for Pull 3 or 4.

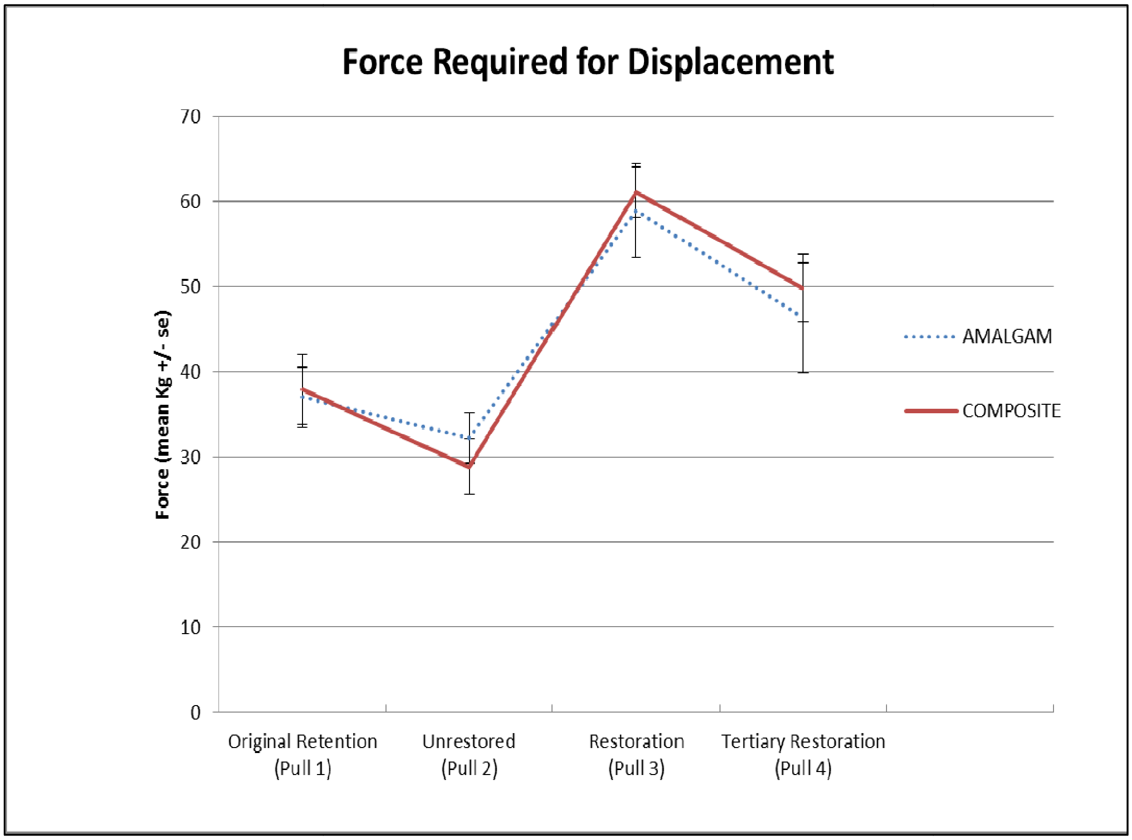

Figure 29. Line graph of mean force for PFM displacement of samples between groups.

The displacement force was calculated for each phase of the experimental groups. Appropriate pilot data was pooled with the experimental data. There were 2 samples lost from each experimental group at the end of the Phase II due to fracture. The sample means for each group were calculated then compared using a T-test. The data indicate that the placement of restorative material in the access of a PFM will restore and exceed the original retention force regardless of the material. There was found to be no significant difference between amalgam and composite to restore the access as in Phase I. Phase II data indicate that when the restorative material was removed then replaced with an amalgam + composite or post + composite per respective group, no significant difference was found between the groups. Results are shown in **Table 5** and forces required for displacement between groups shown in **Figure 29**.

Overall, there were 5 pilot and 8 randomly chosen samples of which restorative material was removed from the access and crowns cemented and displaced (Phase III). The displacement force was compared to the original displacement force (Pull 2 vs Pull 5) using a paired t-test. The data suggest that following the removal of the restorative material (Pull 5), the displacement force is not statistically different from the original unrestored access (Pull 2) $p = 0.2807$; the mean difference of -1.51kg (4.83) was not statistically significant.

AMALGAM (Group 1 and Group 3): Overall test for a difference (Type 3 test p-value < 0.0001)	
Pull	
3 (Amalgam Restoration)	A
4 (Amalgam + Composite Restoration)	B
1 (Original Retention)	BC
5 (Access Unrestored)	BC
2 (Access Unrestored)	C

Table 6. Comparison of PFM displacement within the amalgam group. Pairs with the same letter are not statistically significantly different.

COMPOSITE (Group 2 and Group 4): Overall test for a difference (Type 3 test p-value < 0.0001)	
Pull	
3 (Composite Restoration)	A
4 (Post + Composite Restoration)	B
1 (Original Retention)	C
5 (Access Unrestored)	CD
2 (Access Unrestored)	D

Table 7. Comparison of PFM displacement within the composite group. Pairs with the same letter are not statistically significantly different.

Table 6 and **Table 7** show the displacement force within each group using a Tukey-Kramer adjustment for multiple comparisons. For the amalgam group, there was a significant difference in displacement forces between pulls for amalgam restored in the access from original retention and access unrestored. There was no significant difference between original retention and the amalgam + composite group. In **Table 7**, there was a significant difference in displacement force between each pull for the composite restoration, post + composite, and original retention groups.

Qualitative Results:

The loss of two samples from each experimental group was due to occlusal porcelain fracture or the root separating from resin base.

Phase I restoration: All experimental study samples and pilot samples, regardless of restorative material placed resulted in restorative material remaining in the access hole following displacement (**Figure 30**).

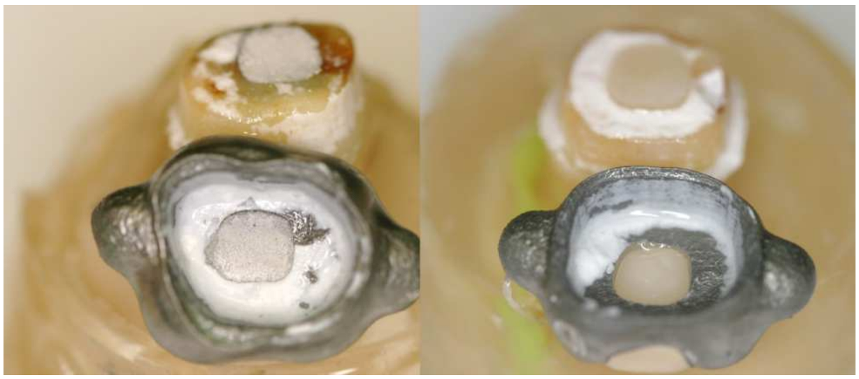

Figure 30. Following displacement, a portion of the restorative material remained in the access of the crown.

Phase II with tertiary restoration for amalgam + composite group, 5 of the 17 samples resulted in a fracture occurring at the amalgam and composite interface. For tertiary restoration in the post + composite group, 17 of the 17 samples resulted in a fracture occurring in composite at the preparation occlusal table crown interface but the post remained intact. Visually, all the samples had composite material present in the crown access and a hole where the post was before displacement (**Figure 31**).

Figure 31. After displacement, samples had composite material present in the crown access and a hole where the post was within the material.

DISCUSSION

In a clinical environment, the immediate placement of the restorative material in the access opening following endodontic treatment is desirable to aid in successful therapy. However, the extent of restoration and remaining dentin beneath the crown is unknown and the type of material selected to restore the access may improve crown retention. A review by Juloski et al. 2012 establishes concepts on ferrule and the effects on outcomes; the presence of a 1.5 - 2mm ferrule has a positive effect on fracture resistance of endodontically treated teeth (82). Identifying if an already cemented crown has an adequate ferrule is difficult. There may be scenarios where after endodontic access the amount of remaining tooth structure is compromised and certain materials are chosen for strength and dimensional stability. This makes the importance of restorative material aiding crown retention that much more important if the crown is to remain in place and provide long-term function.

Phase I experimental results suggest that endodontic access decreases the displacement force of a crown as shown in **Figure 28**. These findings are consistent with past studies (69, 71, 72, 83). The data also suggest that placement of a restorative material in the access can restore and exceed the original retention for a crown cemented with zinc phosphate (69, 71, 72, 83). The original study purpose sought to evaluate the retention of a PFM following restoration with amalgam or composite. The results from this study suggest that composite and amalgam both increased the PFM displacement force beyond the original retention value (**Figure 29**), but there was no difference between the two materials (**Table 5**). The qualitative result in which both materials remained in the convergent/parallel crown access can be explained. Composite resin can be effectively bonded to surface treated leucite porcelain via hydrofluoric acid and a coupling agent like silane (41-44). The amalgam remaining in the crown access may be due to Dispersalloy's inherent slight setting expansion as it is an ad-mixture alloy (84).

Phase II of the experimental study was considered following Phase I qualitative results. The re-irrigation sequence after access (3ml 5.25% NaOCL, 17% REDTA 1ml/min soak, 3ml 5.25% NaOCL, and 1ml 95% ethanol rinse) in Phase II was performed to control for any effect on dentin, which may impact the restorative material and tooth interface. The Phase I qualitative results suggested that the restorative material remains in the crown access following displacement. An attempt was made to increase force for crown displacement by "connecting" the material in the access to that material found in the tooth. For the composite group, the idea was to establish reinforcement between the remaining material in the crown and the core by use of a fiber post. This was established by cementing the fiber post and a subsequent bonded composite buildup. The buildup and post were then reduced flush to the occlusal plane. Visually, the post end was exposed and circumferentially surrounded by composite material, a possible potential interface for leakage clinically. There is a surplus of literature suggesting that posts aid in fracture resistance *in vitro* (85-90). Clinical research suggests that fiber posts also increase tooth longevity *in vivo*. Findings from a 3 year randomized clinical trial by Cagidiaco et al suggest that fiber posts significantly improve the survival rate of endodontically treated restored premolars especially if the coronal walls remained intact (91). In another randomized clinical trial, fiber post placement reduced failure risk for endodontically treated premolars (92). The current study evaluated only crown retention and not resistance. The results suggest that a post and composite when placed in a PFM access increased retention from the original force (**Table 5**). However, the retention force was higher with composite alone as shown in **Figure 29**. The results are not surprising as there is literature that suggests although composite materials form a good adaptation to the post surface, the bond strengths to fiber posts remain relatively weak (93). This is also confounded in that the post used in this study was a RelyX fiber post, which is non-serrated and parallel at the coronal extent offering little mechanical retention. An attempt to maximize resin bonding to the fiber post was done by adding a dentin bonding agent (Adper Single Bond Plus). Applying a dentin bonding agent was clinically relevant because it was readily available. However, previous research suggests there are more effective surface treatments for posts to aid in retention such as sandblasting, silanization, or treatment with peroxide (94-97). Treating the post surface with these agents may have increased crown retention in this study considering the qualitative results in which the failure was at the composite and post interface. However, the use of these materials in the clinical environment may be impractical. A consideration for further study would be the assessment of crown resistance with a post in place.

Phase II also tested the displacement forces with amalgam as an orifice barrier and used alight cured composite veneer placed for esthetic purposes. The results reveal that restoring with an amalgam core combined with a composite veneer is not significantly different from a crown without an endodontic access (**Table 6**). Although, there is indication that restoring the access in this manner may offer original retention, it does not provide the exceeding retentive force that amalgam placed to the occlusal surface did. Yet, from an esthetic point of view it may be desirable. From the qualitative results, it was found that 5 of the 17 samples fractured at the amalgam and composite interface. Further investigation of the samples revealed that this was likely due to minimal dentin exposed for bonding potential as amalgam had formed a meniscus along the access walls. Of samples that fractured at that interface, no dentin was exposed circumferentially within the access cavity, possibly explaining the overall decrease in retention. Research has shown surface conditioning can be a useful mechanism for adhering composite to amalgam (98), although the results of the current study suggest the adhesion with bonding agent alone may be questionable. Had the amalgam been placed with 1mm of dentin exposed in all samples, crown displacement forces may have been higher and found to be significant for this experimental group.

The access area for each sample was measured prior to restoration to compare to the access area after restoration (**Table 2**). Although restorative material was removed using 5.1x magnification Global G6 microscope (Global Surgical Co. St. Louis, MO), the restorative material was challenging to remove without extending the access interface. It was found that the access area had increased significantly from the access prior (mm^2) to access after (mm^2) restoration. However, the retention force of the crown in Phase II of the experiment did not exceed Phase I, but instead a slight decrease was noted (**Table 5**). This suggests that although access increased, the greater bulk of material within the access may have less of an impact on retention than thought.

The use of extracted teeth meant that each tooth would have a custom crown preparation as dictated by the morphology of the tooth. Although the attempt was to fabricate crowns with an ideal 4mm of axial wall height, the mean results show the axial wall height was 2.7mm. A shorter axial wall height may have had an overall impact on crown retention. However, the fact that each sample was its own control may mitigate this. Also, according to **Table 3** and **Table 4**, an overall increase in surface area of the preparation increased the displacement force for the crown (see linear regression **Figures 25-27**). Phase III: Each sample as its own control was verified by removing the access restorative material of random samples and comparing it the unrestored access (Pull 2 vs Pull 5).

An area for improvement in study design may be the use of artificial aging of materials/samples prior to testing. The use of thermal cycling aids to mimic the oral environment for artificial aging by a pattern of heating and cooling over a set period of time. In this study, samples were aged for 24 hours at 37°C at 100% humidity. Studies suggest that thermal cycling results in a decrease in fracture strength of composite compared with the control teeth (99). However, a meta-analysis by Leloup et al. of data from 1992 -1996 concluded that no significant effect was found on bond strengths with the use of thermal cycling (100). The findings from this study were an attempt to evaluate materials at their greatest retentive phase, 24 hours following placement. Thermal cycling of the samples may have provided much different retention results. Another method to age material is by fatigue using compressive forces (101). Within the limits of available resources, however, thermo cycling and fatigue aging was not feasible for the purpose of this study.

Another consideration in study design was the use of the zinc phosphate luting cement. The use of zinc phosphate allowed comparison to previous studies evaluating crown retention prior to, and after access, with subsequent restoration. The fact that zinc phosphate can be dissolved with nitric acid allowed each sample to be its own control without damage to the crown. The manufacturer states that zinc phosphate sets by an acid-base reaction and may vary in its physical properties depending on the powder-liquid ratio and mixing temperature. However, zinc phosphate may have limited clinical use as other more current luting cements have more desirable and improved characteristics. Examples are RMGI and resin which have shown up to 2 - 3 times more crown retention than that of zinc phosphate (102-104); these materials could have been used in place of zinc phosphate to cement the crowns in this study. However, not only would it be challenging to remove the residual cement following crown displacement, but it is possible the sample may have fractured during the testing process rendering further testing impossible. Also, since RMGI and resin are more retentive, it may have been difficult to assess a significant difference for displacement forces at various phases of the experiment from that of restorative material. The results of this study indicate that the restorative material significantly impacts crown retention following endodontic access. However, relative to the cement used for luting of the crown, the material in the endodontic access cavity may have less impact on crown retention provided there is enough ferrule and remaining coronal structure. Regardless, a restorative material will improve the crown retentiveness when properly placed in the endodontic access.

CONCLUSION

The clinician has many choices of materials for restoring an endodontic access of clinically acceptable crowns and the choice of material may be based on biocompatibility, interface, chemical/ mechanical characteristics, esthetics and practicality. In a clinical environment, the extent of restoration and remaining dentin beneath the crown is unknown and the type of material selected to restore the access may aid in crown retention. The results from this study suggest that an endodontic access cavity decreases the displacement force of a PFM. However, subsequent restoration with amalgam, composite, amalgam + composite, or post + composite may meet or exceed the original retention of the crown. To meet the patient’s esthetic criteria, an amalgam with composite overlay may be considered.

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APPENDIX I

Pilot Study Area, Height, Weight, and Access Data

SAMPLE	Mean of Occlusal Table area (mm^2)	Mean Axial wall height (mm)	Mean Foil weight of coping/preparation (grams)	Mean Access area prior to restoration (mm^2)	Mean Access area after restoration (mm^2)
A Comp	56.6	3.435	0.007393333	13.02	13.945
B Comp	60.18	2.87	0.00651	14.245	15.885
C Comp w/out HF/Silane	51.485	3.005	0.006493333	12.42	14.075
D Amalgam	48.51	3.47	0.006763333	11.77	13.785
E Amalgam	48.45	3.945	0.007796667	11.875	12.19
F Comp w/out HF/Silane	61.365	3	0.006506667	12.06	14.04

APPENDIX II

Experimental Displacement Force Data

	Pull 1	Pull 2	Pull 3	Pull 4	Pull 5
SAMPLE	Original Retention (kg)	Access unrestored (kg)	Restored (kg)	Re-Restored (kg)	Access unrestored (kg)
Sample 1 Amalgam	20.96	13.88	38.14	26.19	13.11
Sample 2 Amalgam	30.63	22.29	51.06	16.69	
Sample 3 Amalgam	20.98	19.86	32.02	17.33	
Sample 4 Composite	39.15	19.64	55.32	33.08	
Sample 5 Composite	33.35	10.16	47.76	x	
Sample 6 Amalgam	57.12	55.79	38.14	61	54.33
Sample 7 Composite	16.19	14.55	59.28	30.11	
Sample 8 Composite	16.86	23.16	63.3	42.3	
Sample 9 Composite	38.49	36.99	62.46	45.95	36.33
Sample 10 Amalgam	37.46	42.35	62.9	39.66	
Sample 11 Composite	42.52	30.52	57.73	58.74	32.45
Sample 12 Amalgam	33.88	30.53	57.74	28.61	32.18
Sample 13 Amalgam	52.91	45.18	47.25	x	
Sample 14 Amalgam	67.69	51.8	101.71	87.32	45.54
Sample 15 Amalgam	21.56	26.37	51.51	13.74	
Sample 16 Composite	11.6	14.17	41.6	40.56	
Sample 17 Composite	64.25	19.54	78.25	60.51	25.39
Sample 18 Composite	33.45	19.78	41.82	59.5	
Sample 19 Composite	44.33	38.31	55.13	59.9	32.72
Sample 20 Amalgam	57.82	34.96	55.25	71.34	
Sample 21 Composite	28.35	23.7	60.85	32.43	
Sample 22 Amalgam	18.41	18.14	47.01	31.36	
Sample 23 Amalgam	25.21	23.38	60.03	34.53	
Sample 24 Amalgam	39.42	48.68	82.85	73.64	
Sample 25 Composite	15.92	20.83	43.76	47.43	
Sample 26 Composite	50.82	37.42	72.21	37.92	
Sample 27 Composite	73.17	53.79	72.2	58.84	
Sample 28 Composite	24.33	22.11	67.85	42.01	
Sample 29 Amalgam	8.25	11.05	32.45	28.27	
Sample 30 Amalgam	51.66	29.25	x	x	
Sample 31 Amalgam	27.55	14.68	33.02	32.9	
Sample 32 Composite	29.28	24.21	x	x	
Sample 33 Amalgam	36.14	42.3	74.84	47.18	
Sample 34 Composite	32.12	24.33	63.6	32.91	

APPENDIX III

Experimental Area, Height, and Weight Data

SAMPLE	Mean of Occlusal Table Area (mm^2)	Mean Axial Wall Height (mm)	Mean Foil Weight of Coping/Preparation (grams)
Sample 1 Amalgam	60.19	2.88	0.00715
Sample 2 Amalgam	62.505	2.41	0.00624
Sample 3 Amalgam	41.155	2.37	0.00547
Sample 4 Composite	46.76	2.675	0.00605
Sample 5 Composite	52.675	2.785	0.00614
Sample 6 Amalgam	74.065	3.135	0.00823
Sample 7 Composite	47.25	1.935	0.00499
Sample 8 Composite	45.525	2.895	0.00614
Sample 9 Composite	53.015	2.67	0.00637
Sample 10 Amalgam	54.61	2.825	0.00644
Sample 11 Composite	67.1	2.46	0.00681
Sample 12 Amalgam	57.64	2.485	0.00607
Sample 13 Amalgam	63.195	2.395	0.00608
Sample 14 Amalgam	61.315	3.225	0.00747
Sample 15 Amalgam	42.95	3.13	0.00619
Sample 16 Composite	47.38	2.94	0.00622
Sample 17 Composite	54.56	2.66	0.00675
Sample 18 Composite	45.885	3.37	0.00687
Sample 19 Composite	42.525	3.54	0.00731
Sample 20 Amalgam	53.435	2.92	0.00677
Sample 21 Composite	65.26	2.055	0.00591
Sample 22 Amalgam	47.46	2.18	0.00517
Sample 23 Amalgam	54.485	2.855	0.00634
Sample 24 Amalgam	53.865	2.57	0.00614
Sample 25 Composite	59.835	2.535	0.00632
Sample 26 Composite	62.01	2.515	0.00629
Sample 27 Composite	55.555	3.225	0.0072
Sample 28 Composite	48.935	2.53	0.00619
Sample 29 Amalgam	51.495	2.17	0.00545
Sample 30 Amalgam	51.97	3.105	0.00746
Sample 31 Amalgam	56.315	2.19	0.00563
Sample 32 Composite	48.775	2.59	0.00608
Sample 33 Amalgam	46.915	2.895	0.00595
Sample 34 Composite	47.91	2.765	0.00616

APPENDIX IV

Experimental Access Area Data

SAMPLE	Mean Access Area Prior to Restoration (mm^2)	Mean Access Area After Restoration (mm^2)
Sample 1 Amalgam	13.3	16.205
Sample 2 Amalgam	13.3	13.64
Sample 3 Amalgam	11.16	13.795
Sample 4 Composite	13.715	14.985
Sample 5 Composite	12.545	15.495
Sample 6 Amalgam	12.235	x
Sample 7 Composite	9.81	11.755
Sample 8 Composite	11.59	13.78
Sample 9 Composite	11.085	13.38
Sample 10 Amalgam	13.25	14.41
Sample 11 Composite	14.425	18.075
Sample 12 Amalgam	12.975	14.73
Sample 13 Amalgam	11.785	x
Sample 14 Amalgam	13.07	14.255
Sample 15 Amalgam	11.885	14.27
Sample 16 Composite	11.505	12.175
Sample 17 Composite	12.315	13.96
Sample 18 Composite	9.115	10.69
Sample 19 Composite	10.705	13.205
Sample 20 Amalgam	9.085	9.59
Sample 21 Composite	14.935	18.555
Sample 22 Amalgam	11.515	15.08
Sample 23 Amalgam	11.89	12.72
Sample 24 Amalgam	10.715	15.79
Sample 25 Composite	15.245	19.06
Sample 26 Composite	16.35	18.43
Sample 27 Composite	12.505	15.245
Sample 28 Composite	12.28	14.255
Sample 29 Amalgam	11.96	13.565
Sample 30 Amalgam	12.385	x
Sample 31 Amalgam	11.085	13.225
Sample 32 Composite	9.71	x
Sample 33 Amalgam	10.81	12.865
Sample 34 Composite	11.88	13.385