A Comparative Evaluation of Root Fracture Resistance of Endodontically Treated Teeth Using Two Fiber Posts with Two Ferrule Heights

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Master Thesis by Khadiga.I.Elfallah, BDS

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Abstract:

Purpose:

The purpose of this project was to evaluate the difference between fracture resistance of the endodontically treated teeth restored with glass fiber posts, and fracture resistance of teeth restored with quartz fiber posts and metal posts with different ferrule heights (1 mm vs. 2 mm).

Materials and Methods:

Sixty extracted human teeth were investigated in the study. Sample criteria included single root teeth; maxillary central incisors, canines, and lower premolars, absence of crown and root decay, cracks, and/or previous endodontic treatment and root length of at least 14 mm. Samples were collected from the Oral and Maxillofacial Surgery Clinic at Tufts University School of Dental Medicine. Samples were disinfected by thymol solution, cleaned and sectioned at 2 mm above the cemento-enamel junction. Root canals were prepared with Gates-Glidden burs. Working length was estimated at 0.5mm short of the apex and all apical seals were preserved about 6 to 7 mm apically. The coronal gutta-percha was removed with the system B heating and then post preparations were established by sequenced sizes of drills until reaching the desired diameter.

Post spaces in groups A and C were prepared according to the Parapost system (Coltene /Whaledent Inc, MA) and in group B according to Bisco system (Bisco, Inc, MA). All posts had 10 mm height and 1.5 mm diameter. All posts were cemented with Rely- X -Ultimate

cement with acid etch and bonding agent followed by a light cure for 20 Sec per surface. Paracore composite build-up (Coltene /Whaledent Inc, MA) was used for all sixty samples using paraforms (Coltene /Whaledent Inc, MA). All ceramic preparation with deep chamfer finish line of 0.7 MM was performed in all samples with a difference in ferrule height. The hand piece was fixed in a surveyor with angulation of 10° using diamond bur #850c-018. A rubber stop was used in the bur to differentiate the ferrule height for 1mm and 2 mm so that groups (A1-B1-C1) had 1 mm ferrule height while groups (A2-B2-C2) had 2 mm ferrule height. All ceramic crowns of (Empress CAD LT A2/C14) were fabricated using E4D CAD/CAM system by scanning the abutments and milling the crowns then all crowns were cemented with Rely-X-Ultimate cement. The compression test was done by subjecting the specimens to a load while using a universal machine for testing (Instron model 5566A, Norwood, MA) with a crosshead speed 0.5mm/min, load cell of 10K Newton with direction of 135° towards the long axis of a tooth and the mean of maximum compression loads were recorded for each group. The Kruskal-Wallis test was used to compare the three post types twice, once with ferrule height of 1 mm and second with ferrule height of 2 mm. Post-hoc test analyses were conducted via the Mann-Whitney U test with Bonferroni correction ($p < 0.05// 3 \approx 0.017$) when the Kruskal-Wallis test was statistically significant. We also used the Mann-Whitney U test for each post type to compare the two ferrule heights.

Result:

This study revealed that the difference in root fracture resistance was statistically significant among the post types (p-value = .021) with 2 mm ferrule. No statistically significant difference was found between the three post types with 1 mm ferrule heights. The metal posts had the highest fracture resistance compared to the quartz posts and the difference was statistically significant (p-value < .005). No statistically significant difference was reported with glass posts comparing with any other post. The difference in ferrule heights within quartz fiber post groups were statistically significant with (p-value < .019) where the 1 mm ferrule group had higher fracture resistance than the 2 mm ferrule group.

Conclusion:

Endodontically treated teeth that have been restored with metal posts had the highest fracture resistance followed by those restored with glass fiber posts and quartz fiber posts. Within quartz fiber posts groups, teeth with ferrule height of 1 mm have an enhanced fracture resistance as compared with those of 2 mm ferrule height and that is explained by the thickness of the remaining dentin structure, which is thicker with 1 mm ferrule groups.

Dedication:

“In the name of Allah, Most Gracious, Most Merciful”.

This dissertation is devoted to my parents: to my best man in the word, my father, Ibrahim Elfallah. He is the foremost reason for my success, without his continuing support and prayers; my goal would never be reached. To my mother, Zahra, for all the unconditional love, guidance, and support. My appreciation and love goes to my brother and sisters. My heartfelt thanks to my delightful 4 year-old son, Ayad, although this may made me miss a lot of important times in his life, but I hope my success will affect his life as well. After this is done, I will make sure that I will never miss a moment with him again and with his future coming sister/brother. My appreciation and recognition to my husband Anas for staying with me in the USA and taking good care of our child during my study

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1. Introduction

Restoring an endodontically treated tooth has become a controversial subject from many aspects because of the structural integrity loss that is associated with access preparation, which leads to a higher occurrence of a fracture in an endodontically treated teeth[1]. Thus the aim of the post is mainly to keep the tooth core, in tooth, which has excessive loss of its structure[1-3]. Prefabricated posts were introduced in the 1970s. Early products were made of metal, mostly stainless steel and then followed by titanium alloys[4]. Metal was chosen because of its intrinsic high mechanical properties, which were intended to increase the effectiveness of the remaining dental structures[5]. Metal posts, however, presented shortcomings such as the propensity to undergo corrosion (if not a noble alloy) and also not being esthetic, so they are likely to compromise the look of the final esthetic restoration[6]. Follow up studies have shown that stiffer metal posts were not ideal for absorbing stress to prevent root fracture. Ideal posts should have mechanical properties and behaviors such as that of the tooth structure[7].

Later on in 1980s prefabricated non-metal posts were introduced, which were chiefly composed of two materials: The first ones were ceramic (alumina oxide or zirconium oxide) and they showed a good strength, but they were more brittle than metal posts. The other material, which is applied widely for post today, is fiber reinforced composite (FRC) [7]. The biomechanical properties of FRC posts have been reported to be close to those of dentin[8]. Clinical prospective and retrospective studies have reported encouraging results[9].

Fiber reinforced posts, like composite posts, owe their mechanical properties not only to the characteristics of the individual components (fibers and resin), but also to the bonding strength in the interface of the two components and to the reinforcing geometry[10]. The addition of fibers to a polymeric matrix causes a significant increase in the material's resistance to fracture, stiffness and fatigue. That is providing a realistic indication of clinical performance[11]. Prefabricated fiber reinforced composite posts flex with the tooth structure and are easy to remove in case of retreatment without affecting the esthetic outcome. Their adaptation to the root canal wall is important for retention, but in most of the cases the canal must be expanded to accommodate the shape of the selected post, thus resulting removal of more tooth structure to achieve optimal adaptation. These prefabricated posts have optimal adaptation and function in teeth with small circular canals. They are contraindicated in root canals with irregularly shaped flared canals because of the improper adaptation and the required thickness of the resin cement[12].

The most popular types of fiber reinforced composite posts are glass fiber posts, which were introduced to dentistry in 1992 [13]. They consist of unidirectional glass fibers embedded in a resin matrix that strengthen the post without compromising the module of elasticity (MOE indicates the material stiffness and how it remains constant over a range of stress). They offer many benefits such as esthetics[14, 15] biocompatibility, MOE similar to dentin, distribute the stress evenly throughout the root, favorable retention[16], high resistance to fracture, easy handling and placing, and less time consuming. Then again, they have some disadvantages such as poor radiographic visibility, cost and technique sensitivity[17].

The ferrule effect has been considered as one of the important factors. It is a collar encircling the cervical portion of the crown, not less than 1.5 mm to 2 mm height above the margin to reinforce the endodontically treated teeth and act as a mean of anti rotation[18]. Dr. Jotkowitz suggested that the minimum acceptable height is 1mm, and although this is a very short height, it resulted a double fracture resistance compared with non-ferrule restored teeth[19]. Restoring a crown without a ferrule on a post and core restored tooth is resulting to a greater chance of fracture [20]. However, an in vitro study by Al-Hazaimeh and Gutteridge reported no difference in fracture resistance, with or without a 2.0mm ferrule, using prefabricated posts and resin cement [21].

A study showed that the fracture resistance of teeth restored with metal posts was significantly higher than zirconia and glass fiber posts. However, there is no statistically significant difference between the glass fiber and zirconia posts [22]. Another study showed that composite resin posts demonstrated similar fracture resistance capacity to those reinforced with fibers. The presence of ferrule around the tooth increased the load bearing capacity significantly [23]. The fracture resistance test measured with Instron[14].

This study will be the first to assess the root fractural resistance of two different non-metal posts, quartz fiber posts and glass fiber posts, with different ferrule heights (1 mm vs. 2 mm) as most of dentists prefer using non metal posts when the esthetic is essential but they are concerned about the fracture resistance of both types.

2. Literature Review:

2.1.The difference between the vital and an endodontically treated tooth:

Teeth may be exposed to a wide range of injuries that put the vital functions of the pulp at risk [24]. Sometimes the influences are non infectious and include trauma from accidents that interfere with the tissue's neuro-vascular supply [25]. Other injuries and diseases produce defects in the tooth structure [26]. Common etiological examples include dental caries, abrasion, erosion, and various forms of fracture [27]. In addition to the consequences of dental treatment procedures for managing caries and periodontal disease or for replacing lost teeth, tooth substance is frequently lost [28]. Once the pulp has lost its vital functions, the potential for regeneration is reduced in the tooth as bacteria take over the pulpal space and multiply into large numbers [29]. The ultimate outcome of this development is a continuing release of bacterial products that lead to peri-radicular inflammatory lesions and possibly also to undesirable systemic health effects[30].

In a clinical context the endodontic therapies are carried out, sometimes to prevent but often in attempts to cure painful and non-painful clinical expressions of infections of the vital and the non-vital pulp[31, 32]. After the process of endodontic treatment, the endodontically treated tooth undergoes considerable changes[33], and the fracture of non-vital teeth is the most common outcome, which could lead to extraction [34-40]. Healthy dentin is rich in collagen fibrils, which are responsible for preventing the extension of micro-cracks [41]. Even so, the changes do not significantly affect the main physical properties of dentin modulus of elasticity, tensile strength or compressive strength[42, 43].Therefore, it is hypothesized that cavity access preparation for endodontic treatment is the primary factor causing reduction of tooth strength [44-48]. Caries, trauma and previous restorations also contribute to reducing the tooth structure and fracture resistance. Sodium hypochlorite (NaOCl) and ethylene-diaminetetra-acetic acid (EDTA) are common root canal irrigating solutions, but their prolonged use at high concentrations has adverse effects on the physical properties of root canal dentin[53, 54]. Dentin of pulpless teeth has a lower elastic modulus and a proportional limit in compression with dentin of normal teeth resulting from dehydration[55].

Arunpraditkul et al, in their study evaluating the amount of remaining dentin walls, showed that teeth with four walls of remaining coronal dentin had significantly higher fracture resistance than teeth with only three walls. However, the site of the missing wall did not have any impact on the fracture resistances of these endodontically treated teeth[56]. Another in vitro study hypothesized that the tooth type significantly increased the chances of a tooth fracture after root canal instrumentation[57]. Complete instrumentation of root canals with excessive removal of dentin, presence of irregular shaped canals and poor gutta-percha condensation increased the risk of root fracture [58-60]. The risk factors for the fracture of an endodontically treated tooth could be: (1) chemical: as result of endodontic irrigating solutions or dentinal medications [54], (2) microbial: caused by bacteria-dentine interaction [6], (3) dentinal: due to tooth structure loss, (4) restorative: depends on post and core restorations[57, 58], (5) and age factors: which include age changes in dentin[62].

2.2.The effect of the post in endodontically treated teeth: Post factors

2.2.1. Posts length:

Post length plays an important role in retention and stress distribution along the root of endodontically treated teeth. Therefore, proper length is required, but in some cases when the root is short or curved a shorter post will be used and that compromises its retention[63]. If the post length is shorter than the crown length, this proportion is not acceptable and will cause fracture of the root [64,65]. The general suggestions of post length are one half, two third, or three quarters of root length[66, 67]. The minimum length should be at least half way between the root apex and alveolar bone crest [68, 69]. A number of studies have evaluated the apical seal of endodontically treated teeth. They suggested leave at least 4-5mm of root canal filling material to preserve a good apical seal[70, 71]. There was a study that hypothesized the maximum apical seal is associated with the maximum length of remaining gutta-percha after post preparation[72].

2.2.2. Post Diameter:

Larger post diameters are not associated with higher retention[47, 73]. Actually, it makes the tooth much weaker because of excessive tooth preparation and dentin loss, which increases the probability of perforation and decrease the root fracture resistance[20, 59,74,75]. The minimum post diameter should not be less than 1.3 mm to provide sufficient rigidity[76]. Studies indicated that the post diameter should not be larger than one third of root diameter[77, 78]. Another study indicated that the canal preparation should be surrounded by at least 1mm of tooth structure from all directions [79].

2.2.3. Post Design:

Posts types are categorized into custom posts and core or prefabricated posts. The custom taper post and core has disadvantages of time consuming and often need for modification to be fit properly[39]. The prefabricated posts designs are classified according to their shape into parallel side posts and tapered posts[80], and according to surface texture into: threaded or smooth surface posts. The threaded posts are more retentive compared to the smooth surface posts and the parallel posts also are more retentive as compared to the taper posts[5]. The parallel posts in addition to their favorable retention, they spread the stress homogeneously. From a different perspective, the taper posts provide optimal tooth structure preservation at the apical end. However, they produce a wedging effect, which compromise the retention. Smooth parallel-sided posts are quite long, but they are difficult to cement because of hydrostatic backpressure[81], whereas the smooth tapered posts are less retentive, but they distribute the cement evenly. Posts are divided according to their retention to either active or passive[82]. The active post engages to the root surface by mechanical friction caused by the threads while the passive posts can fit smoothly into the base and retained by cements. The active posts have showed more retention than the cemented posts[83]**.** However the active post have shown to increase the risk of root fracture due to stress

2.2.4. Type of luting cements:

Common types of luting agents are including zinc phosphate, polycarboxylate, glass ionomer and composite resin. Zinc phosphate cement is composed of zinc oxide and magnesium oxide powders, which are mixed with phosphoric acid liquid. It is commonly used because it is easy to manipulate, in addition to its success in luting procedures [84]. The retention of zinc phosphate cement works by mechanical interlocking into irregularities in the dentin and the prosthetic structure[85]. The main disadvantages of zinc phosphate cement are initial acidifying, solubility in oral fluids and lack of true adhesion. Another cement, which consists of zinc oxide powder and is mixed with a polycarboxylate acid liquid, is called zinc polycarboxylate, and it has a disadvantage of microleakage[86]. Microleakage is also a disadvantage of the glass-ionomer that is constructed of a calcium, strontium and fluroaluminosilicate glass powder base, combined with a water-soluble polymeric acid[87]. These cements also have a much lower modulus of elasticity than zinc phosphate and dentin; the glass-ionomer cement however has advantages of fluoride release[85].

The resin cements, which are made of di-acrylate resins containing 50-80% glass filler particles, have been widely used because of their high retention and resistance to fatigue, compared to zinc phosphate cement[88, 89]. Also they have less leakage than other cements[90, 91]. The elasticity modulus of the resin cements is nearer to the elasticity of dentin, and consequently they succeed clinically to reinforce week roots[92]. Studies have reported less leakage when resin cement is utilized with the stainless steel as well as posts of carbon fiber, compared with glass-monomer or zinc phosphate cements [90,91]. The disadvantages of resin cements including technique-sensitivity because of their short working time, the number of operating steps involved, and sensitivity to moisture, compared to zinc phosphate cements. Some of the newest self-adhesive resin cements may overcome these disadvantages[93]. However, the self-adhesive technique may present less satisfactory adhesion to root canal dentin in contrast with etch-and-rinse and self-adhesive tactics[94]. It also unfavourably affected by inappropriate root canal preparation than other cements [93]. It is also not easy to remove a well-bonded resin cemented metal post in case of failure endodontic treatment[85].

Bonding resin cement to the dentinal wall of the root canal space must be managed cautiously to encourage bonding and diminish microleakage. Any remaining gutta-percha and root canal sealer must be detached from the dentinal walls, to confirm suitable bonding of resin to dentin. Removing gutta-percha using thermal methods, mechanical methods or both, followed by washing the walls using a long pesso brush with pumice slurry, can support this. They used an irrigation syringe should attain thorough rinsing of the canal space. Though, studies have explained no contrary effect on marginal sealant post retention[95], when canals are blocked using a eugenol-containing sealer, and the post is placed with resin cement, provided that the canal walls are cleaned carefully[96].

2.3. Ferrule effect:

Coronal preparation should be constructed so that the borders of the crown extend over the core material and embrace 1.0–3.0 mm of sound tooth structure. Thus, the crown will form a strip, which enfolds the cervical parts of the root, conveying some stresses to the outside of the root rather than to the inside of the canal[97]. A ferrule is known to be the vertical band of a tooth structure at the gingival element of crown preparation. In vitro research depicted that a ferrule having a perpendicular height of 1mm doubles a fracture resistance, when compared to teeth restored without a ferrule [100]. Several studies have suggested that each tooth should have at least 2mm of coronal tooth structure above the cemento-enamel junction to ensure proper resistance form for the prepartion[100-102]. A literature review and prospective studies inferred that the ferrule effect of the crown preparation could be more important than the actual post and core technique[20, 103]. Lack of ferrule of an endodontically treated post-and-core restored tooth is accompanied with superior distinctions of failure load [20]. Another study found that fracture patterns were more restorable when a ferrule is present. The fractures on teeth without ferrule were non-restorable[104, 105]. In case there is not enough coronal structure to provide ferrule effect, orthodontic extruding of the root or crown lengthening will be helpful; otherwise extraction and implant placement is more satisfactory treatment option as an alternative to placing a post and core [106].

2.4. Preparation of the Root Canal post Space

Different methods for post space preparation in endodontically treated teeth were identified in the literature including heated instruments, rotary instruments and solvent techniques[107]. No literature has suggested the superiority to a specific method over the others[108]. The mechanical removal of root canal filling is the most common technique. However, it may result irretrievable damage to tooth structure. If it is done imprecisely it may result excessive removal and weakening of tooth structure, damage to periodontal tissues and perforation [109]. To avoid these problems, non-cutting round bur is used to remove the gutta-percha without removing dentin structure and avoid raising tooth surface temperature, which may damage the periodontium[110, 111]. Regarding chemical removal of gutta-percha, it is believed that these materials such as eucalyptus oil, turpentine oil and chloroform are toxic and possibly carcinogenic[112, 113]. They cause dimensional changes of gutta-percha and subsequence microleakage[114, 115]. A study suggested that solvents for gutta-percha removal should not be employed because of the potential risk of outflow these materials to peri-radicular tissues[106]. Some studies advocated removing gutta-percha by heated instruments leaving at least 4-5mm length of apical seal [116]. The plugger should be selected according to the desired post length, which is estimated from radiographs. The tip of instrument should be heated enough to cut through the gutta-percha within 2-3 seconds because it will cool within 7-10 seconds. A radiograph is important to confirm the apical seal before post cementation[117]. Gutta-percha removal is achieved by preparing the root canal with reamers and rotary instruments to establish the post length. Saliva and bacteria debris are removed by water and alcohol and the canal is dried with absorbent paper points before post cementation[118]. The best technique for post cementation is applying the cement into the prepared space using a lentulo-spiral, covering the post itself with cement, and then inserts it with gentle pumping action inside the canal [119,120]. By applying the cement over the surface of post alone, compromised retention has been experienced [118].

2.5.Types of Root Canal Post Systems:

2.5.1. Metal post:

2.5.1.1. Cast Metal Post:

The custom-made cast post was a standard restoration for endodontically treated teeth for many years ago and is still used today in many clinical situations[46, 121]. It is manufactured in the laboratory from a custom pattern of the prepared canal. A cast post indicated in abnormal shaped canal, oval canal and misaligned tooth because it is based on impressions of the canal resulting in very good fit of the post inside the canal. A cast post has shortcomings. It is time consuming[122], expensive and tedious. Additionally it shows less retentive abilities and the provisional restorations always mandatory[123]. It is also contraindicated in a narrow and short canal where a pin-retained amalgam core is recommended[12]. In this case the preparation of canal should not be conical to avoid reduction in its retention [125]. A ferrule needed on the prepared tooth so that the summit will extend 2mm apical to core-tooth junction [121]. Gold alloys are the most common material used to fabricate cast metal posts. They are considered as the gold standard because of the superior success rate accomplished with physical strength and biocompatibility [121,126,127].

2.5.1.2. Prefabricated Metal Posts:

There are thousands of systems of prefabricated metal posts. Common types include stainless steel and titanium alloy with almost no superiority of one type over the other[128]. Studies found that the parallel titanium post is more rigid than the parallel stainless steel post and it is not recommended in areas where more occlusal loads are anticipated[7, 129]. Prefabricated metal posts are designed as either taper or parallel sides where the parallel side posts are more retentive especially if more retentive means are added to the surface as grooves, serrations and roughness. The taper posts are more conservative in tooth preparation and more consistent with root shape[130]. However, the tapered metal posts exert a wedge effect, which place the root in risk of fracture[13, 134]. Optimum ferrule is required to prevent root fracture caused by occlusal stress in either tapered or parallel posts [93].

2.5.2.Ceramic Posts:

Meyenberg introduced zirconia posts[135]. Zirconia is a broadly used material due of its proper chemical stability, high mechanical strength, high toughness, and small modulus of elasticity similar to that of stainless steel alloy. Zirconia also has the esthetic advantage of possessing a color comparable to that of natural teeth[135, 136]. However, zirconia posts have a major disadvantage as it is almost impossible for it to be removed from the root canal when a failure occurs[137]. It is impossible to grind away a zirconia post, and removal of a fractured zirconia post through ultrasonic vibrations has been realized to cause temperature increment on root surface as well as to the post[138]. Another disadvantage that resulted due to the inflexibility of the zirconia posts included the significant loss of retention and the posts fracture under intra-oral forces[139]. The modulus of elasticity of zirconia posts is 200 MPa [140], which cause stress to be transferred to a less rigid dentin, thus leading to root fractures[141].

2.5.3.Fiber Posts:

Fiber posts that were introduced in 1990 consist of composite reinforced materials and are subdivided according to the kind of fibers. The characters are mainly composed of hard filler particles surrounded by hard matrix to enhance the mechanical properties of the final material[142]. A literature review demonstrated that non-vital teeth restored with composite resin or composite resin combined with fiber posts resisted fatigue well, and now may signify the best treatment option[143]. Advantages of prefabricated fiber posts include: elasticity modulus similar to the tooth structure[144], root fracture resistance[145], easy handling, and good esthetics[146]. On the other hand, they have the low load bearing capacity with small thickness posts[147, 148]. In almost all types of prefabricated fiber posts a circular preparation is required which leads to excessive tooth reduction. Additionally, the adhesion of fiber posts is technique sensitive compared with cast metal posts. Furthermore, most of fiber posts are not radiopaque but this problem started to be solved by adding radiopaque material to the matrix[149].

Fiber posts mainly consist of fibers embedded in a matrix of epoxy resin with helping of interface agent such as silane to link between the two materials. The reason for adding the fibers is to optimize the effectiveness and stability whereas the matrix marries the fibers together and protect the fibers from moisture[150]. The type of fibers used categorized the post such as glass fiber and carbon fiber, where the character embedded in a matrix is usually an epoxy, or a mixture of epoxy and di-methacrylate resins[151].

Based on the reinforced materials, the fiber posts can be classified as follows:

2.5.3.1. Glass fibers:

Glass fibers are the most commonly used as reinforced composite posts because of low modulus of elasticity, excellent tensile and compressive strength, and cost[152]. Because of their translucency they become the choice of restoring teeth in esthetic zone. Glass fibers are created by mixing sand, limestone, kaolin and calumniate and heating them together at1600°C. The resulting liquid will then drain into fibers[142]. E glass is the most common type, but S glass is also used in dental offices. On clinical experience, the glass fiber posts exhibit a high success rate with minimum restorable failures and less root fractures[153]. Studies define some factors that impact the retention of glass fiber posts; these constituents may include dentin bonding agents, luting cements, and polymerization mode[130, 154]. Furthermore, fiber post's retention could be decreased by surface treatments such as roughening or grit blasting[155, 156,157].

2.5.3.2. Carbon Fibers:

Carbon fibers introduced to dentistry in 1970s[158]. They are still widely used despite the fact that they are difficult to manage and they are black in color [50, 127,145,159]. Carbon fibers are made by manipulation of carbon-rich organic precursors as polyacrylonitrile by oxidation, carbonization and finally graphitization at high temperature[142]. They have properties of high intensity, low coefficient of thermal expansion; and exhibit corrosion and fatigue resistance [35,160]. They were the first prefabricated post introduced in 1990s but because of esthetic demands prefabricated quartz and glass fiber is now more commonly used[161, 162]. On vitro studies have stated that a tooth restored using carbon/graphite fiber posts, when intermittently loaded, resist fracture propagation within the roots better than a tooth restored with prefabricated titanium or cast metal posts[145]. A study reported a success rate of 95% for carbon fiber reinforced posts, compared to 84% cast posts and cores[163].

2.5.3.3.Polyethylene Fibers:

Polyethylene fibers uses are restricted because of their poor bonding of fibers to the matrix, although they possess high durability and low modulus of elasticity [142].

2.5.3.4.Quartz Fibers:

Quartz fibers have been recently introduced to dentistry. They have the most esthetic results and light transmission[164]. A study suggested that the quartz fiber posts have the same mechanical properties of carbon fiber posts in addition of highly esthetic result[165]. Malferrari, et al, did a clinical study using quartz fiber posts to restore 180 endodontically treated teeth for a period of 30 months. Three types of failure were resulted about 1.7% among the total sample size although the three types of failure were related to fracture involve the post and core restorations only and non-related to root fracture. And these failures were restorable[166].

6. Principles of Core Build-up:

Core build-up is required to replace the missing coronal tooth structure that is needed to retain the crown[167]. Requirement of a good core materials may include: (1) adequate compressive and flexural strength to resist force[168], (2) biocompatibility, (3) coefficient of thermal expansion close to tooth structure, (4) resistance to leakage[169], (5) being easy to manipulate[170], (6) bonding to the tooth structure[171], (7) dimensional stability[172], and (8) minimum water absorption[170, 173]. Different core materials are available such as amalgam, cast gold, resin-based composite and glass ionomer. Cast gold and amalgam have a high success rate over the decades because of their high strength and less solubility. However the cast gold is time consuming and requires additional visits in addition to compromised esthetic especially with all ceramic restorations. The composite core has shown a successful esthetic result with all ceramic crowns although it has some a drawback such as polymerization shrinkage, hygroscopic expansion and technique sensitive. It has been said that the composite is incompatible with eugenol, which is present in some types of endodontic sealer resulting microleakage[170]. Some studies have suggested excluding glass-ionomer from the core materials because of its weak tensile and compressive strength[174-176], poor condensability, high solubility and low modulus of elasticity[170].

3. Clinical significance of the study:

If there is a significant effect on the fracture of an endodontically treated tooth which is restored with different types of posts (metal, glass or quartz fiber), it would affect the clinical preference of either type since both posts have equal esthetic performance.

As far as the ferrule effect of endodontically treated tooth that is restored using different types of composite posts this study will assess the influence of its different heights on the fracture resistance of the tooth.

4. Specific Aims and Hypothesis:

4.1. Aim of this study:

To evaluate the difference of fracture resistance between endodontically treated teeth that are restored with glass fiber posts and those restored with quartz fiber posts or metal posts with different ferrule heights.

4.2. Hypotheses:

1. The fracture resistance of endodontically treated teeth which are restored with quartz fiber posts is higher than resistance of those restored with glass fiber posts considering teeth with metal posts as control groups since they have the highest fracture resistance.

2. The fracture resistance of teeth that have been restored with 2mm ferrule height is higher than the fracture resistance of those that have 1mm ferrule height.

1. Research Design and Methods:

5.1. Sample size calculation:

A power calculation was performed using nQuery Advisor (version 7.0). Assuming a variance of means of 6309 for the different post types, and a common standard deviation of 87, a sample size of n = 10 per group is adequate to achieve a type I error rate of 5% and a power of 99% to detect a difference between post types.

5.2. Sample Selection:

Roots of approximately similar size and shape have been selected by measuring the buccolingual and mesiodistal widths in millimeters, allowing a maximum deflection of 10% from the determined mean[177]. Sample criteria included single root teeth; maxillary central incisors, canines, and lower premolars; absence of crown and root decay, cracks, and/or previous endodontic treatment; and root length of at least 14 mm. Samples were collected from the Oral and Maxillofacial Surgery clinic at Tufts University School of Dental Medicine. Any specimen with multiple roots and carious or broken roots were kept out. All specimens were examined clinically with a 10X microscope (Busch & Lomb) to eliminate teeth with gaps.

5.3. Sample preparation:

All samples were safely stored in distilled water throughout the study and infection control protocol was followed[178, 179]. We did not use the solution of NaOCl for disinfection as the literature showed that NaOCl affect the bonding ability of resin cement[180]. Specimens were disinfected by thymol solution, which was employed by many researchers as a storage agent because of its antifungal activity for 2 weeks after the extraction. Soft tissue, calculus, and other debris were mechanically removed by ultrasonic (Cavitron SPS; Dentsply Caulk, Milford, Del). The teeth were sectioned horizontally at 2mm coronal above the cemento-enamel junction (CEJ) which was marked by a black fine point permanent marker using a diamond double-faced disk in a slow-speed hand piece, cooled with air/water spray.

5.4. Root Canal Treatment:

Root canals were prepared with the use of Gates-Glidden burs: burs no. 2 (Ø 0.54 mm) and 3 (Ø 0.83 mm) were used in the entire root canal length, and bur no. 4 (Ø 1.10 mm) was used only in the third cervical of the root canal. Working length was estimated at 0.5mm short of the peak, and the apical portion enlarged with k-files (MediDenta; Dentsply Maillerfer, Milford, Del), up to ISO #55. The canals were irrigated with 1% sodium hypochlorite solution followed by Ethylenediaminetetraacetic acid (EDTA) 17% to get rid of that smear layer while using endodontic irrigation syringe and then they were dried with absorbent paper points[181]. Sealer was placed in the root canals using a lentulo-spiral instrument 25mm in length, the sealer obtained from the endodontic department at TUSDM and they were pre-mixed of zinc ozide-eugenol (ZOE). A gutta-percha master cone, size ISO #55, coated with the sealer, was placed in the root canals to the working length, and accessory cones were used to fill the width of the root canals. The lateral condensation technique utilized hand spreaders (Hu- Friedy) was used to finalize the root canal treatment [182] see figure (1).

5.5. Post Space Preparation

A straight line was drawn along the long axis of the external root surfaces using black fine point permanent marker, to assure vertical placement of the post. The top part of gutta-percha was removed with heating system B (SybronEndo 5004; Sybron Dental Specialties Inc, Orange, Calif)**.** Post preparations then completed with the sequenced of dills which they came in a kit with each type of posts. The glass fiber posts and metal posts have the same drills, while quartz posts have their own posts drills which they were matched with the size of the other posts type. The final post spaces were created according to the manufacturer’s instructions. Post spaces in groups of A and C were prepared according to the Parapost system (Coltene/Whaledent Inc,MA). The prepared post spaces were then irrigated with 5.25% NaOCl for 1 minute, and final irrigation was accomplished with distilled water. The post spaces were dried with paper points before cementation of the posts. All post spaces were prepared to the length of 8mm inside the canal and 2 mm in the coronal portion so all specimens received total of 10 mm post length. The roots were embedded perpendicularly in ortho-acrylic resin up to 2.0 mm below the cervical limit to simulate the alveolar bone[183]. The post spaces were prepared with optimum length about 10mm to keep good apical seal with gutta-percha not less than 5-6mm.

5.6. Specimen grouping:

All prepared teeth (n = 60) were randomly divided into three major groups (A, B and C) according to the post types; there were 20 of total samples in each group, which subsequently split into six subgroups (A1, A2, B1, B2, C1 and C2) with 10 specimens in each subgroup. Two of the groups were considered as control groups because their root canals were restored with prefabricated metal posts with 1mm and 2mm ferrule heights (A1, A2). The remaining groups were restored either quartz fiber posts (B1, B2) or glass fiber posts (C1, C2) and had either 1mm ferrule (B1/C1) or 2 mm ferrule height (B2/C2)

The categorization of groups is the following:

Group 1: Teeth restored by prefabricated metal posts (MP) Size #4 with 1 mm ferrule (1F) height (Parapost ® XP™ Titanium Alloy or Stainless Steel Posts;Coltene Whaledent, Hudson, Mass).

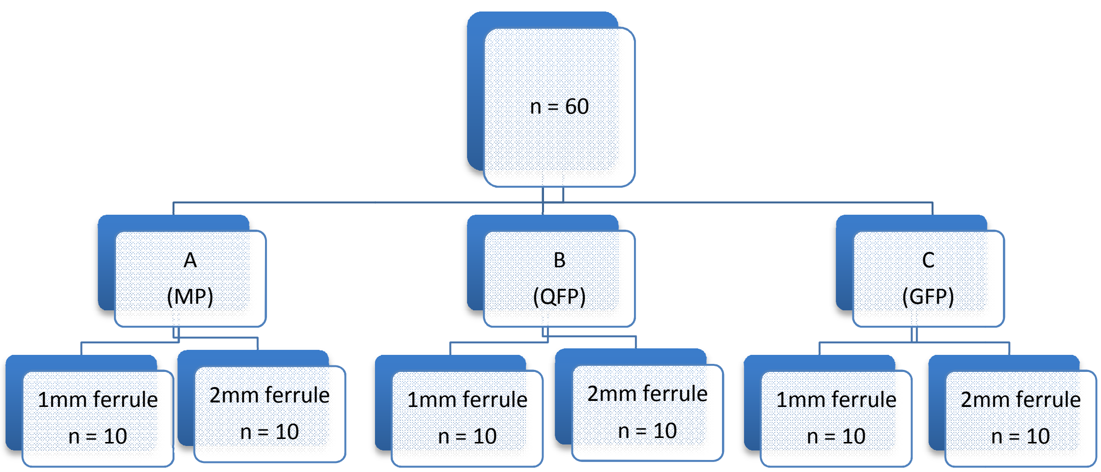
Group 2: Teeth restored by prefabricated metal posts (MP) Size #4 with 2 mm ferrule (2F) height (Parapost ® XP™ Titanium Alloy or Stainless Steel Posts;Coltene Whaledent, Hudson, Mass).

Group 3: Teeth restored with prefabricated quartz fiber posts (QFP) Size #2 with 1 mm ferrule (1F) height (D. T. Light-Post®; Bisco Inc, Schaumburg, Ill).

Group 4: Teeth restored with prefabricated quartz fiber posts (QFP) Size #2 with 2 mm ferrule (2F) height (D. T. Light-Post®; Bisco Inc, Schaumburg, Ill)

Group 5: Teeth restored by prefabricated glass fiber posts (GFP) Size #4 with 1 mm ferrule (1F) height (Parapost Taper Lux®; Coltene Whaledent, Hudson, Mass).

Group 6: Teeth restored by prefabricated glass fiber post (GFP) Size #4 with 2 mm ferrule (2F) height (Parapost Taper Lux®; Coltene Whaledent, Hudson, Mass).



5.7. Post Cementation:

Rely-X-Ultimate cement was used to cement all the posts (3M ESPE adhesive resin cement) according to the manufacturer's instructions. Each Post was marked at a distance of 10 mm from its apical end, to a length of corresponding preparation post space. The post space in the canal was first etched for 30 sec then washed with water then dried with absorbent papers, bonding agent was applied to the canals by intra-canal brush for 20 sec then dried by absorbent paper following by air, after that the cement was applied into the canal by intra-canal auto mix tip. All posts were covered with the cement and were seated to the full depth into the prepared spaces using finger pressure, ensuring that all posts extended to the same length from the orifice of the canals. The cement was light activated for 20 sec from four tooth aspects and from the tip of the posts, using the same halogen light cure unit with the light source at an equal distance from each cemented post. List of materials are listed in table (1).

5.8.Core Build-up:

After post cementation, the cores were built-up with composite resin core material (coltene whaledent). The paraforms were cylindrical, with a slight occlusal taper. The dimensions of the crown forms were 8mm in length, 5mm in diameter at the cervical base, and 4 mm in diameter at occlusal level and gave a height of at least 2-3 mm coronal to the posts. According to the manufacturer instructions, sequences of three parabond were followed then composite was injected by auto mix tip to the top of the paraforms and light cured 20 sec each surface using the same halogen light cure unit with the light source at an equal distance, to standardize the core height. One paraform was cut 3 mm in height and was used for the all specimens as a reference to cut the specimen by precision saw ((Buehler Isomet 1000, Lake Buff, Ill) as shown in figure (2-4) horizontally at the level of paraform, so that all specimens had same diameters of core with 3mm height.

5.9. Ferrule preparation:

All ceramic preparation with deep chamfer finish line of 0 .7 mm each was performed on all samples with a difference in ferrule heights. The handpiece was fixed in a surveyor with angulation in 10° by using the acrylic resin to stabilize in order to make sure the angulations of preparation was standard. With air/water irrigation the preparation was started using diamond bur (#850C-018; SS White Burs Inc, Lakewood, NJ). A rubber stop was used in the bur to differentiate the ferrule height for 1mm and 2 mm. Since we sectioned the teeth 2 mm above the cemento-enamel junction in the beginning of the study, so in the groups of 2 mm the ferrule height the finish line was placed at CEJ level; while in the other groups with 1 mm ferrule height the finish line was placed 1mm above the CEJ. Then to smoothen the surface of preparation and rounding the angles, extra fine diamond bur #881xf-016 was used and extra fine football bur #868xf-022 was used to create the lingual fossa. Circumferential ferrule of 1 mm in height was prepared in groups A1, B1, and C1. Ferrule of 2mm was prepared in groups (A2, B2, and C2). Randomization of the prepared teeth was done using excel windows software 2010. Figures (5, 6).

5.10.All Ceramic Crowns Designing and Cementation:

After preparation was done on all specimens, all ceramic restorations were fabricated using ceramic blocks (IPS Empress CAD for E4D Lt A2 /C14; Ivoclar Vivadent, Amherst, NY). First the prepared specimens were scanned with an E4D scanner (E4D; D4D Technologies, Richardson, Tex), in the continuing education lab at TUSDM, then the design was selected by library (C) for central incisor #8 for the all specimens so they will receive the same design with same crown height of 8 mm and ceramic thickness of 2 mm overall in all directions. Sprue was placed in the lingual surface. We added a layer of ceramic material with standard diameters of 1x1 mm in the lingual surface of 3mm below the incisor edge in the all crowns to make a lingual ledge for standard loading point, so the universal testing machine will apply load at the same point on the lingual surface of the crowns. The cement space was left as 0.12µm thicknesses. Empress CAD blocks were placed in the E4D milling machines and the average time of milling was 16 min for each crown as in figures (7-11).

Using Rely-X-Ultimate cement, all crowns were cemented, first the prepared specimens were acid etched for 30 sec then washed with water then dried with air, bonding agent was applied to the surface for 20 sec then dried by air, after that the cement was applied inside the crown by auto mix tip and crowns were seated with finger pressure and light cured 20 sec each surface, then excess cement was removed. Before testing, all prepared specimens were stored in precision shallow form reciprocal shaking bath for 24 hours, to attain 100% humidity at 37 C°.

6. Testing Equipment and Sequence:

The fracture resistance was assessed by subjecting the specimens to a load while using the testing machine (Instron model 5566A, Norwood, MA) with a crosshead speed 0.5mm/min, load cell of 10K Newton with direction of 135° to the long axis of a tooth[11] as in figure (12). The maximum compression loads were put down in Newton (N), which caused either root or crown fracture for each specimen. The mode of failure then evaluated and categorized as follows: fracture of a post, fracture of tooth, fracture of the core and crown. The mean compression load for each group recorded and tested. The failure threshold was defined as the maximum load samples could withstand until fracture, failure loads, modes of failure and tooth preparation (ferrule design) were recorded and statistically analyzed.

For further investigations, some samples were sectioned horizontally at crown margin and examined under the microscope to measure the thickness of remaining dentin at the ferrule preparation level. The thickness in group B1 (quartz fiber posts with 1 mm ferrule height) at crown margin level is higher than the thickness of the dentin in group B2 (quartz fiber posts with 2 mm height) with an average of dentin diameters (B1=749.33 µm / B2 = 457.49 µm) in general the thickness of dentine were thicker with 1 mm ferrule groups as in figures (13- 15)

7. Statistical Analysis:

The independent variables were the type of posts (glass fiber posts vs. quartz fiber posts vs. metal posts) and ferrule heights (1mm vs. 2mm). The dependent variable was the root fracture resistance (load needed to cause fracture). All analyses including descriptive statistics were performed using SPSS version 19. Originally a two-way ANOVA was conducted but since one of the assumptions was violated, namely the equality of variances, we used the Kruskal-Wallis test to compare the three post types twice, once with ferrule height of 1 mm and second with ferrule height of 2 mm. Post-hoc test analyses were conducted via the Mann-Whitney U test with Bonferroni correction ($p < 0.05/3 \approx 0.017$) when the Kruskal-Wallis test was statistically significant. We also used the Mann-Whitney U test for each post type to compare the two ferrule heights.

8. Results:

Medians and inter-quartile ranges of maximum compression loads of groups are shown in table (1). The highest compression values were reported in the metal posts group and the lowest compression values were reported with quartz post type. Side-by-side box plots are shown in figure (16). The failure mode was presented as restoration fracture or root fracture or both. There was no post fracture in all specimens.

We found that there was not a statistically significant difference in the maximum compression loads between the post types with a ferrule height of 1 mm with p-value = .463. On the other hand, there was a statistically significant difference in the maximum compression loads of the post types with a ferrule height of 2 mm (p-value = .021). In the post-hoc Mann-Whitney U tests, the only statistically significant difference was between metal posts which were higher in compression loads than the quartz posts group with p-value = .005.

When assessing the difference in maximum compression loads between the two ferrule heights for each post type, we found no statistically significant difference between ferrule height of 1 mm and ferrule height of 2 mm except in QFP groups, where QFP, 1F group showed higher compression loads compared to QFP, 2F group with p value = .019.

The dentin thickness in QFP, 1F group at crown margin level was higher than the thickness of the dentin in QFP, 2F group with an average of dentin diameters (QFP, 1F =749.33 µm, QFP, 2F = 457.49 µm) in general the thickness of dentine were thicker with 1 mm ferrule groups as in figures (6,7)

In all tested groups, first fracture occurred on the crowns. Almost half of samples fractured either as one piece with the core or gradually chipped until they ended up with core fracture. The second kind of the fractures occurred horizontally at the apical third of root with or without involvement of crown/core fracture. Only a few number of samples showed vertical root fracture. No post fracture in any of the groups.

9. Discussion:

In the present in vitro study, there has been an attempt done to compare the effectiveness of root fracture and failure mode of endodontically treated teeth that are restored with prefabricated posts made of metal, quartz fiber, and glass fiber. Root fracture of an endodontically treated tooth has been a frustrating complication that leads to extractions. Therefore, the post is used to retain the core material, which reinforce the remaining tooth structure and increase root fracture resistance. Restoring an endodontically treated tooth is affected by many factors like design, diameter and length of a post, the ferrule effect, the cementation, and the quality and quantity of remaining tooth substance.

From that data, it has been noticed that the fracture resistance and the failure mode were different in anterior teeth that have been restored using the non-metal as well as metal posts. This is with an agreement with Fokkinga et al[148] who found that custom-cast post systems showed higher failure loads than prefabricated fiber posts. Glass and quartz fiber reinforced resin groups showed approximately half the fracture strength of teeth restored with cast posts and cores. Our outcome also agreed with an outcome of a study which was comparing the resistance of fracture of metal posts and two fiber posts, for instance glass and quartz posts. The fracture caused by metal posts revealed that only 13.34% is repairable and about 86.66% were deemed as non-repairable fractures. Whereas 100% of the fracture was repairable in cases of both fiber posts but in comparison with our survey, all fractures were non-repairable since they involved root fracture with or without crown fracture but no post fracture. In the previous study, the cast metal posts were used instead of prefabricated metal posts as our groups. Although they found the mean compression loads of the posts of quartz fiber are higher than the glass fiber posts groups which is opposite of our findings, but both their findings and ours were not statistically significant[185].

The fiber posts modulus of elasticity is equal to 18 to 54 MPa. This would be considered more favorable in stress distribution comparison of those of metal posts with MOE equal to 200 MPa when the load is applied. Therefore, the outcome of the study was in agreement with the other studies. We can conclude that the characteristics of fiber posts simulate the natural dentin structure, which adds more elasticity and stress distribution along the root surface and acts as a chock-absorbable medium thus demonstrating higher fracture resistance.

Result of the present study is consistent with Panna, etal[186] and Sirimai[187]. As M. Sadeghi hypothesized, metal posts have the highest root fracture resistance. Fiber posts might possess some benefits over metal posts due to their elasticity modulus being nearer to that of the dentin. They can be a suitable alternative for metal posts. Another study done with Tariq Abdul-Jabbar [22], he hypothesized that rigid post, which sustained the highest modulus of elasticity among the post types tested results in less bending of the post/core unit under load.

The most important anti-rotatory feature for posts and cores is the placement of a ferrule effect circumferentially around the build-up and remaining root stump by extending the crown preparation margins at least 1-2 mm apically to the core tooth structure interface[102].

In vitro studies revealed that the ferrule significantly reduces the incidence of fracture in non-vital teeth by reinforcing the tooth at its external surface and redistributing applied forces. The present study found no statistically significant difference in the root fracture resistance between 1 mm ferrule height and 2 mm ferrule height in two groups. Except within the quartz groups where the teeth with 1 mm ferrule having an enhanced fracture resistance than the tooth having a 2 mm ferrule which in contrast with Mutebi and Osman [189]. They found insignificant differences in the force needed to break teeth with no ferrule and 2 mm ferrule, which is agreed with other researchers [21,190]. This study also reported that the axial tooth width of the crown margin did not significantly increase the fracture resistance or altered the failure threshold.

Clarisse et al evaluated the ferrule effect on root fracture resistance using quartz fiber posts (No. 1 D. T. Light-post; BiscoInc), and the effect of their suggested that 360 degrees of circumferential axial wall with 2 mm height may not be determining feature to increase the fracture resistance. On the other hand, the location of ferrule is more important, accordingly they found higher fracture resistance was in the group where the ferrule located on the palatal surface of the incisors endodontically treated teeth where opposing tooth contact and generate occlusal loads[191].

The most probable explanation of this current study result regarding the ferrule height is that the thickness of the ferrule is playing a more important role than the height of the ferrule in the fracture resistance. The specimens were sectioned horizontally at the crown margin and examined under stereoscopic zoom microscope. We find the thickness of dentine in all teeth with 1 mm ferrule height is larger than the thickness of dentin of the other groups, but the difference in group B1 (quartz fiber posts with 1 mm ferrule height) at crown margin level resulting significantly higher fracture resistance than teeth in group

B2 (quartz fiber posts with 2 mm height) with an average of dentin diameters (B1=749. 33 μm / B2 = 457.49 μm) as in figures (14, 15)

The level of preparation and position of finish line must be given much consideration. In this present study, we considered standard crown diameter and height so the finish lines were positioned differently. In groups of 1mm ferrule height where the finish line placed 1 mm supra cemento-enamel junction. Therefore, there is remaining circumferential 1 mm band of sound tooth structure apical to the finish line which explain the result where the fracture resistance in these groups are higher than the fracture resistance of other groups. For 2 mm ferrule height groups, the finish line was located at the cemento-enamel junction, and then there were no sound tooth structure left above the junction of cemento-enamel junction therefore theses groups have less fracture resistance and that is explained because of the prepared dentin thickness which become thinner as we extended apically as it has been shown in drawn diagram in figure (17).

The failure mode was classified according to where the fracture happened either in the core and crown, post, or root. This classification is different from the most of the other previous studies where the failure mode classified as restorable or non-restorable. The mode of failures in this study was either root fracture which mostly horizontal at the apical third except some few cases were shown a vertical root fracture with or without the crown fracture. A second mode of failures was including the crown fracture with cores and root fractures. Consequently, the fracture in this study was 100% non-restorable regardless the type of posts since the root fractures were involved in all samples. Although zero post was fractured or debonded which illustrated the bond strength of the cement that was used in the study as in shown figure (18).

9.1. Limitation:

This in vitro study has limitations as the tests were carried out in single rooted teeth, with specific dimensions and post preparation, under a static compressive loading applied at a single point at affixed angulation. Testing the compression in one direction, which is unmatched with the masticatory force. Thus dynamic and fatigue behavior cannot be inferred. Other considerations that should be evaluated are occlusion, masticatory force, level of alveolar bone and parafunctional habits. This study limited to certain type of fiber posts so the result cannot be generalized to all kind of fiber posts. Further investigations are needed with different ferrule dentinal thickness.

9.2. Recommendations:

Clinical trail is recommended to test the fracture resistance of different kind of posts with different ferrule height. I recommend a future study testing same of my groups but with the subjection of samples to thermo-cycling and compare the result, I have not considered it in this study because most of the studies I reviewed they didn’t use it. I also suggest comparing the root resistance of teeth restored with quartz posts with two different ferrule heights and two different cements.

10. Conclusion:

Within the limitations of this study we can conclude that:

1. There is no statistically significant difference in root fracture resistance between metal, quartz and glass fiber posts when the preparations have 1 mm ferrule height. With 2 mm ferrule, endodontically treated teeth having metal posts showed the highest fracture resistance followed by glass fiber posts, and then quartz fiber posts. The fracture resistance difference between metal posts and quartz posts was statistically significant.

2. For single rooted endodontically treated teeth, a difference in ferrule height provides no statistically significant improvement when prefabricated metal posts or glass posts are used.

3. Single rooted endodontically treated teeth which are restored with quartz fiber posts and 1 mm ferrule height have more fracture resistance than the teeth restored with the same kind of posts but with 2 mm ferule height and that is because of thinner axial dentinal walls present with the 2 mm ferrule height.

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Tables:

Table 1: List of The Materials that Used in this Study:

Materials	Manufacturer
Prefab Metal Posts	Parapost from Coltene Whaledent
Prefab Glass Fiber Posts	Parapost fiber (taper-lux) Coltene Whaledent
Prefab Quartz Fiber Posts	BISCO's D.L.light posts
Rely -X-Ultimate Cement	(3M ESPE)
Core Build up	Para Core Composite, Coltened Whaledent
All Ceramic Blocks	Empress CAD LT/A2/C14 E4D, Ivoclar Vivadent

Table 2. Fractural strength (in newton’s) of each group under study					
Groups	**Sample Size**	**Medians**	**IQR**	**Minimum**	**Maximum**
Metal (1 mm)	**10**	**462.2**	**384.1**	**137.9**	**960.3**
Metal (2 mm)	**10**	443.3	**196.1**	**307.1**	**705.9**
Quartz (1 mm)	**10**	**409.4**	**216.2**	**272.5**	**538.8**
Quartz (2 mm)	**10**	**261.3**	**170.2**	**120.7**	**515.2**
Glass (1 mm)	**10**	**401.5**	**288.6**	**162.7**	**597.2**
Glass (2 mm)	**10**	**303.3**	**232.6**	**196.6**	**541.4**

Figures:

Figure1: Teeth with Root Canal Filling

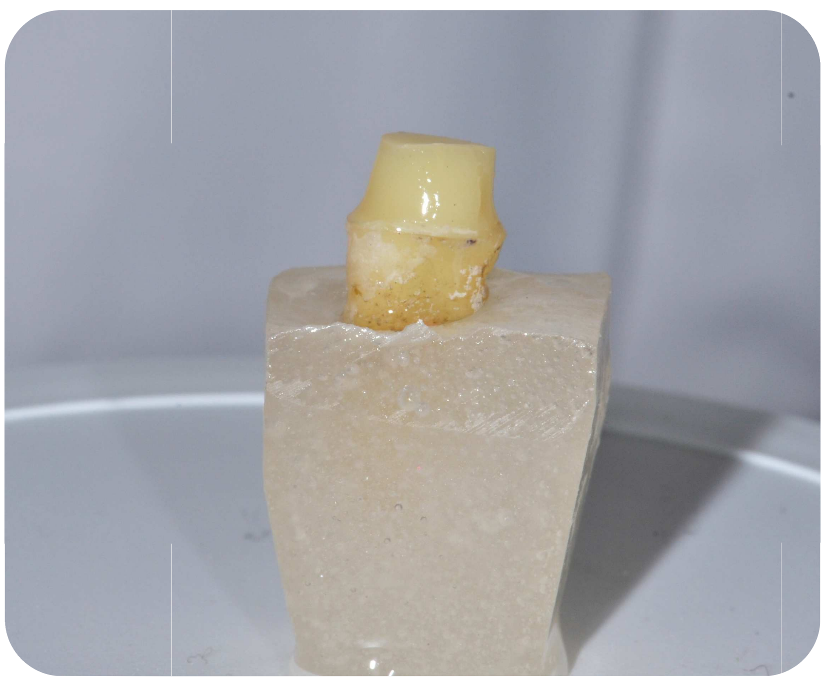


Figure 2: Core build-up

Figure 3: Paraform for core build-up

Figure4: Isomet Sectioning Machine

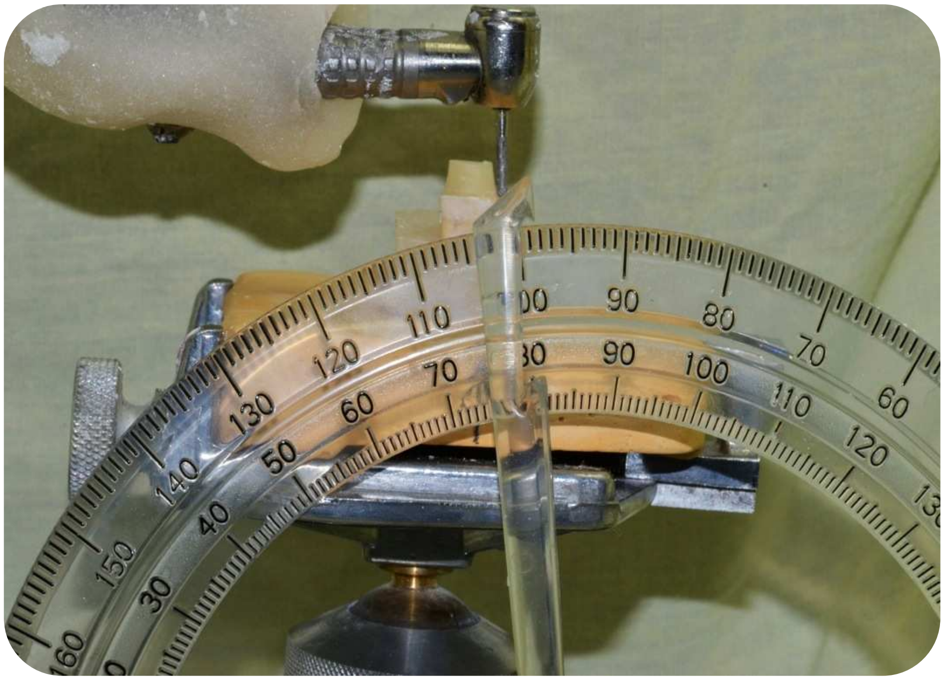


Figure 5: Fixed Handpeice with Angulation of 10°

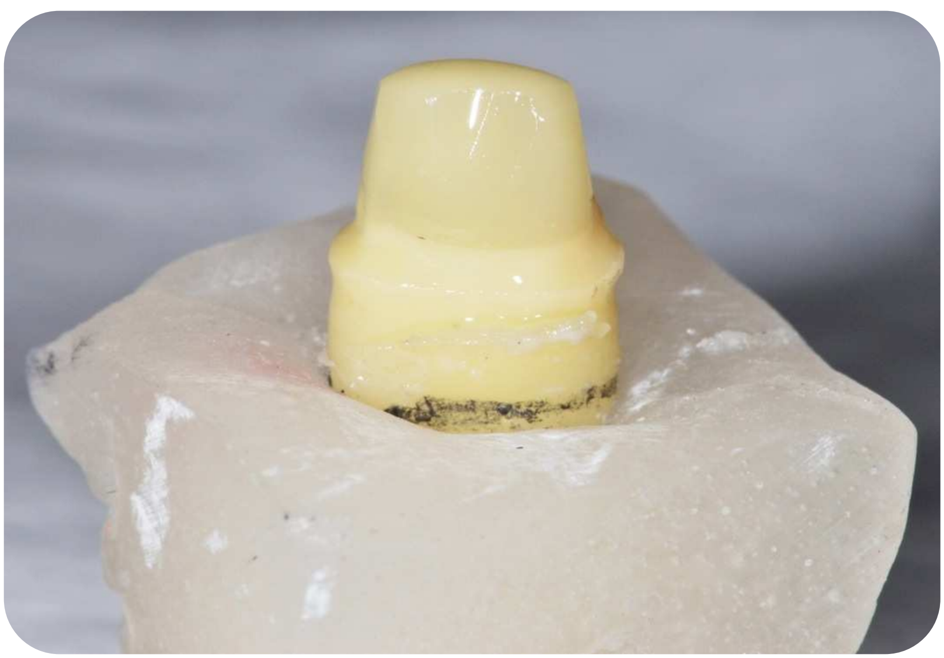


Figure 6: Prepared Abutment

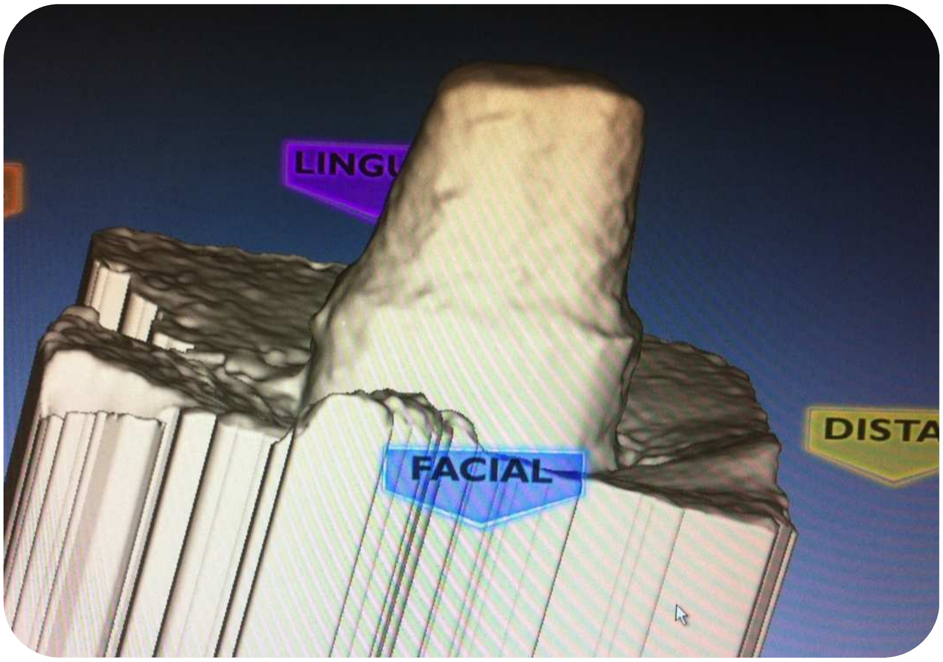


Figure 7: Scanned Abutment by E4D Scanner

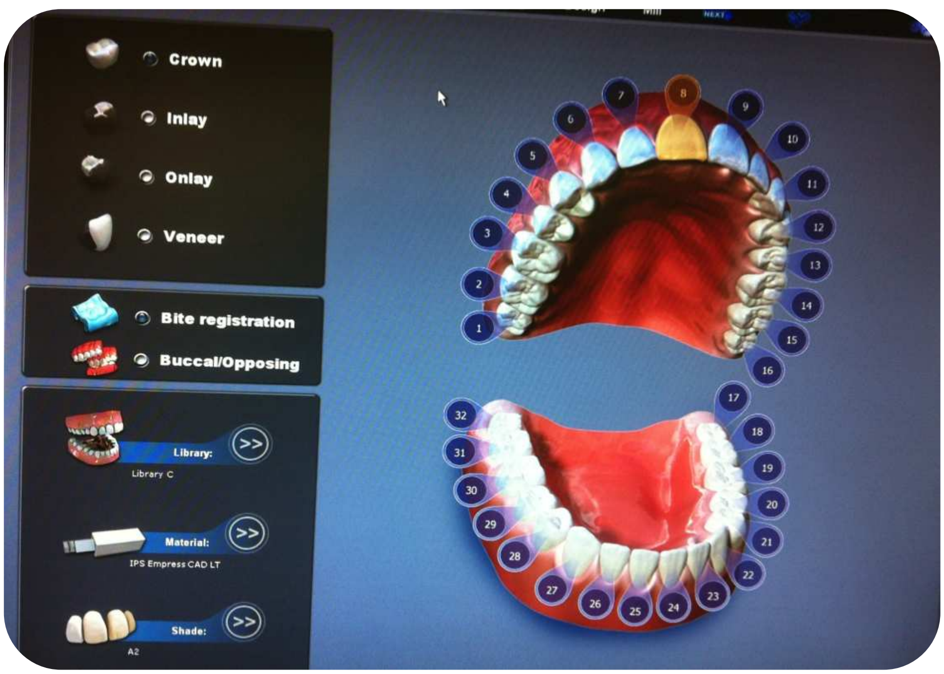


Figure 8: Design Selection

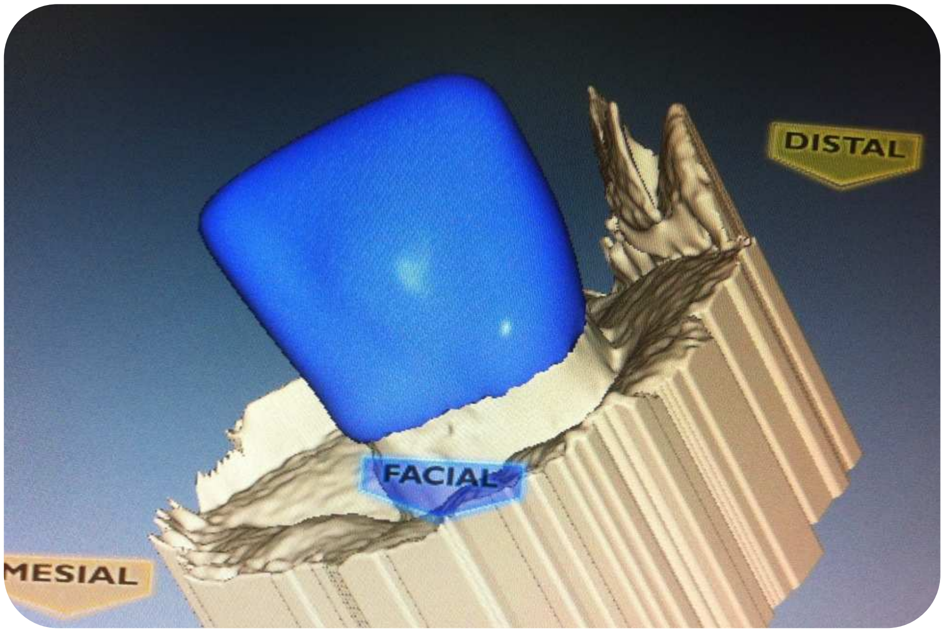


Figure 9: Crown Designed by E4D Designer

Figure 10: Lingual Ledge 1*1 mm

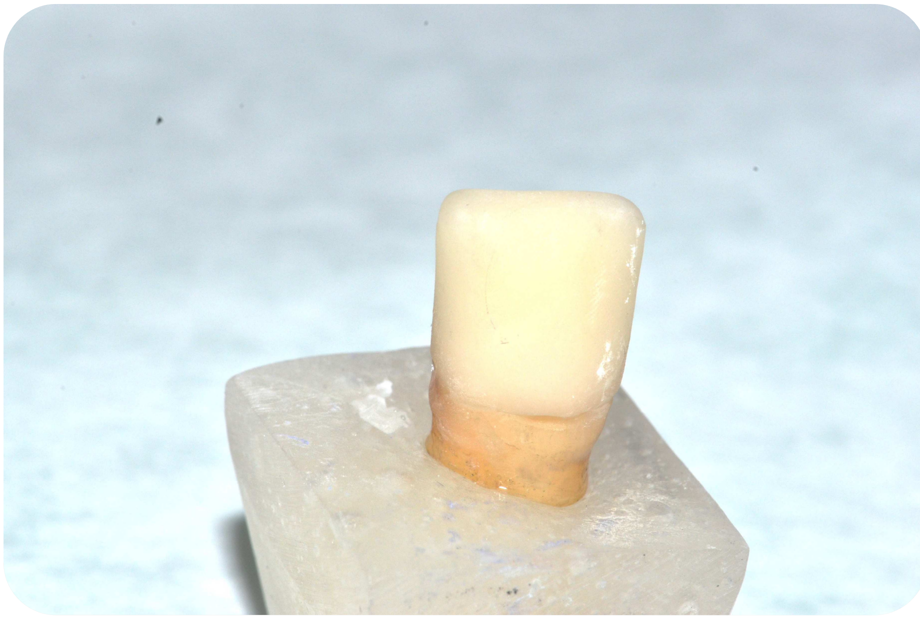


Figure 11: Cemented crown

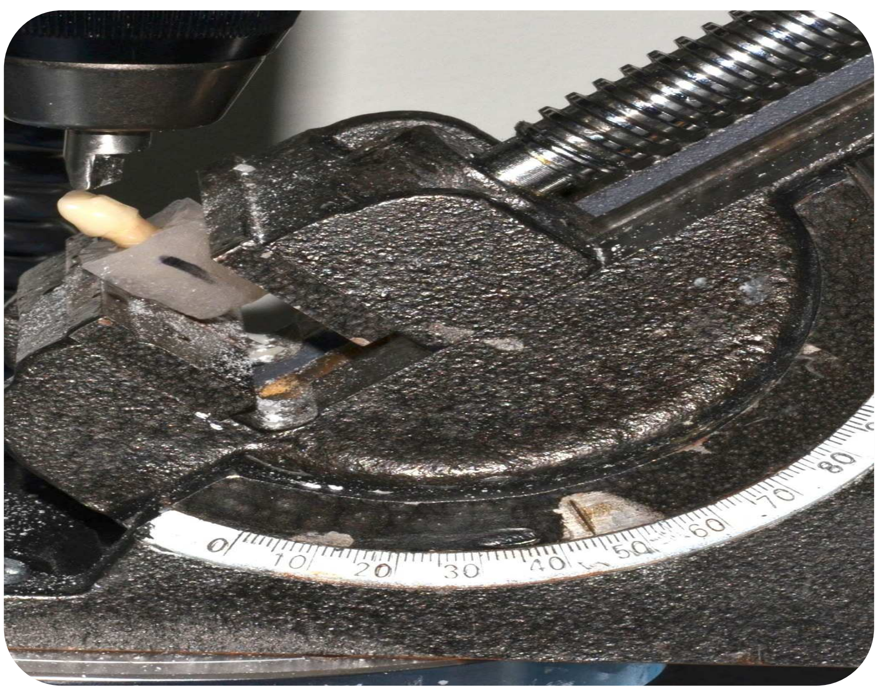


Figure 12: Instron at 135 ° to the Tooth

Figure 13: Stereo Zoom Microscope

Figure 14: Dentin Thickness in 1mm Ferrule Groups

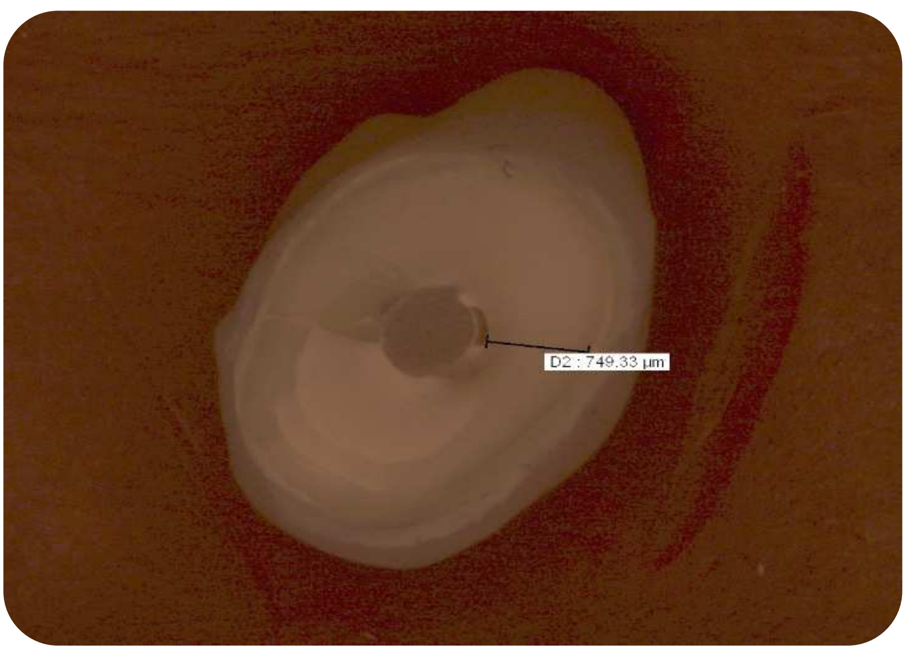


Figure 15: Dentin Thickness in 2 mm Ferrule Groups

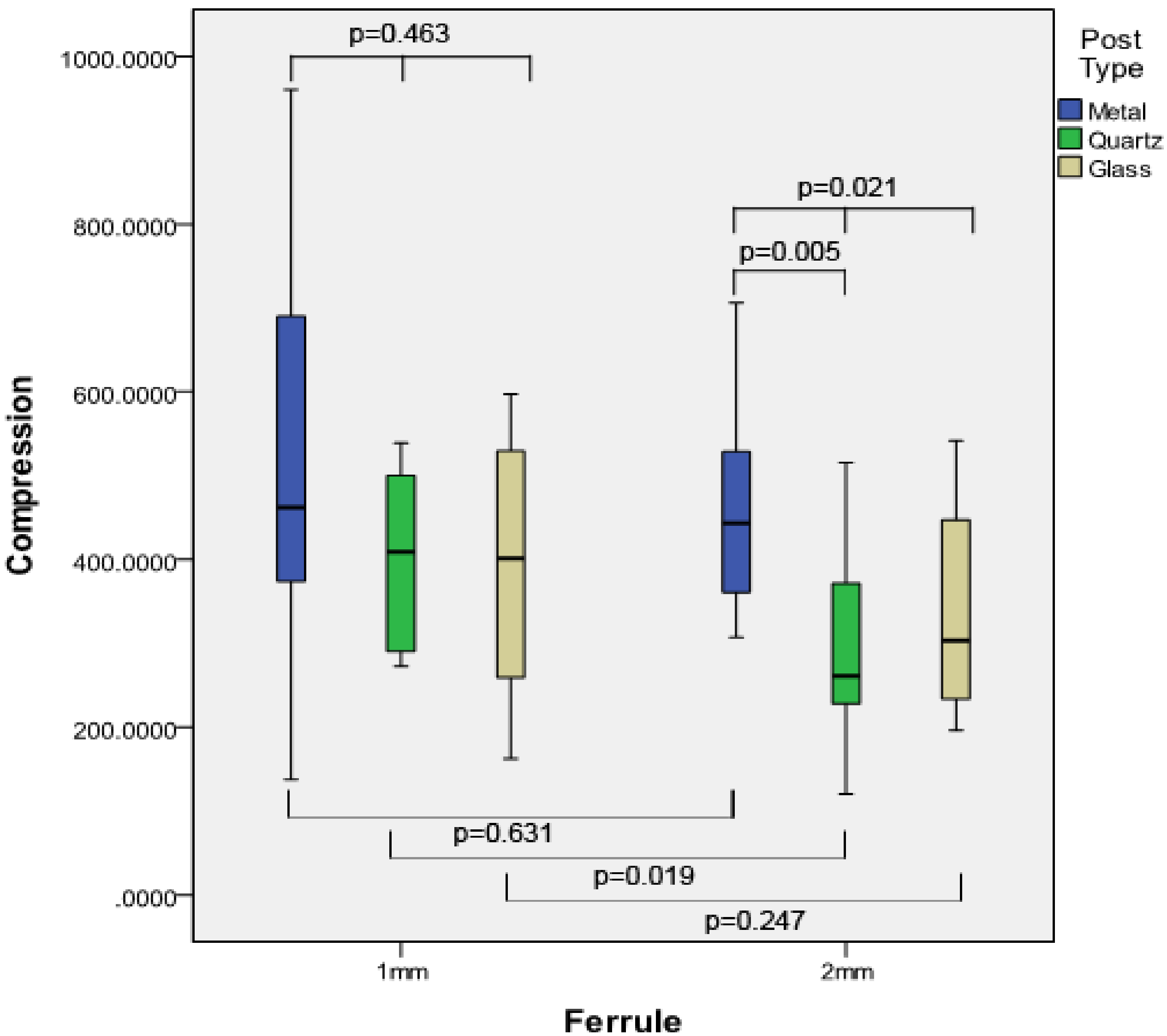


Figure 16: Side- by-Side Box Plot

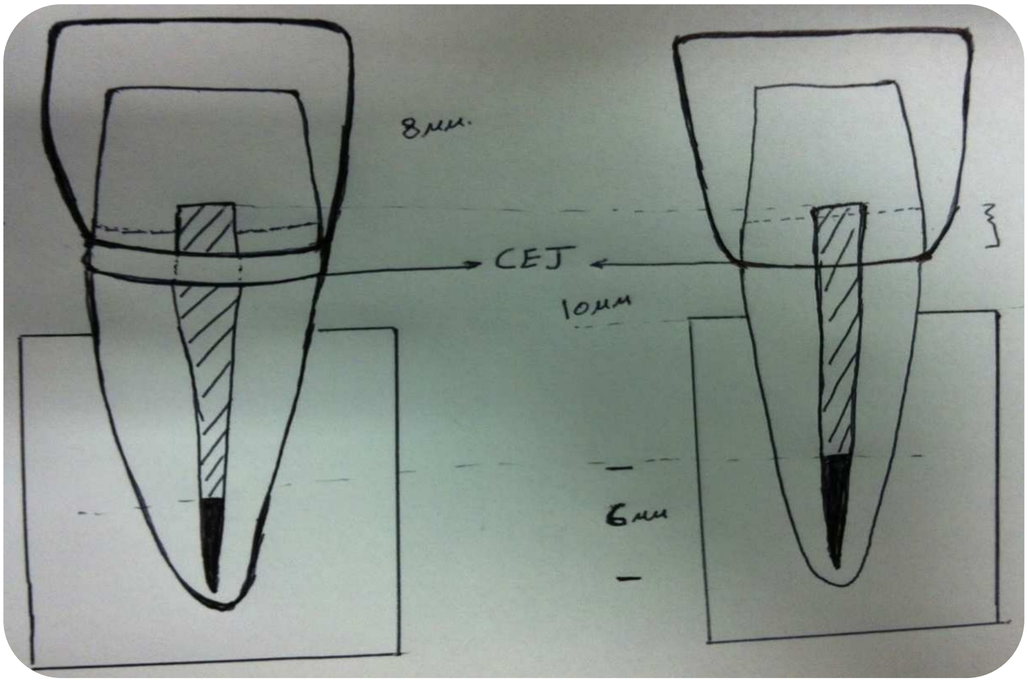
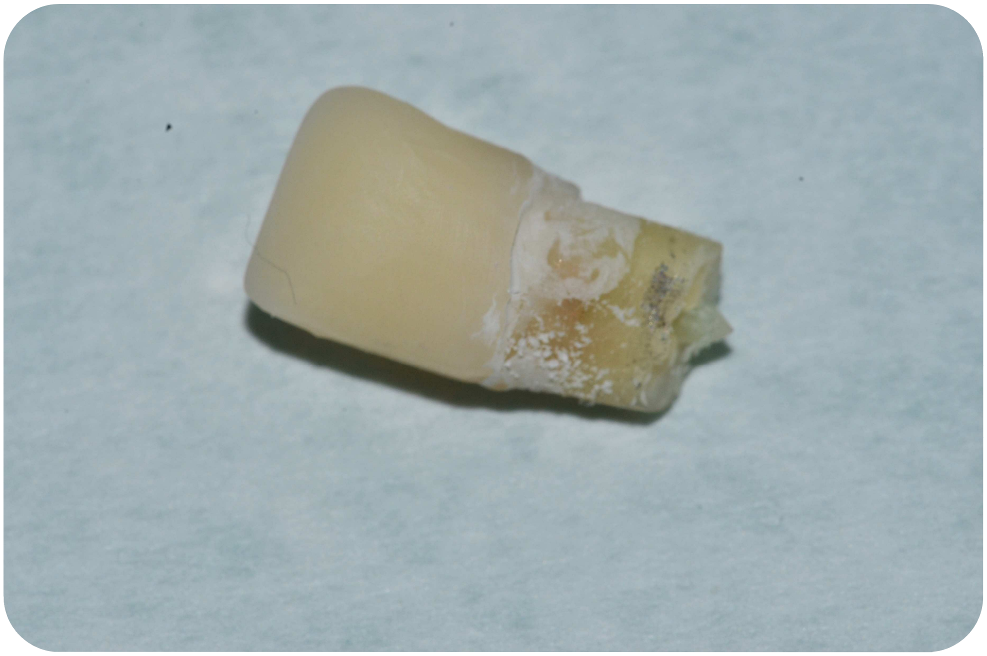


Figure 17:Drawn diagram to show finish line and ferrule heights



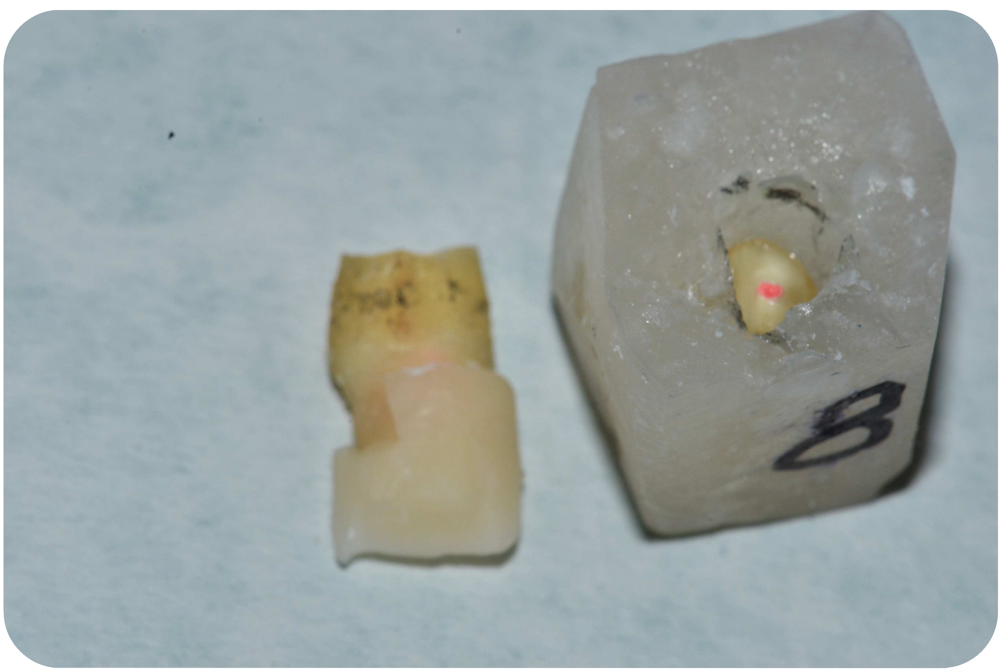


Figure 18,19: failure mode