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Fracture Resistance of Fibrekor, Titanium, and Zirconium Posts to Angular Loading

Aiman Othman Johar

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FRACTURE RESISTANCE OF FIBREKOR, TITANIUM, AND ZIRCONIUM POSTS TO ANGLULAR LOADING

AIMAN OTHMAN JOHAR

D.D.S., King Abdulaziz University Dental School, 1994

A Thesis
Submitted in Partial Fulfillment of the
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I am grateful to Professor Emeritus Comelis H. Pameijer. His genuine ideas for this project were really amazing. I deeply appreciate his dedication, guidance and countless hours of editing. I am indebted to him for materials support and research equipment which made this research come to reality.

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1. Teeth were sectioned 2 mm coronal to cemento-enamel junction. An attempt was made to use teeth of uniform bucco-lingual and mesio-distal diameter. Teeth were also matched for length.

2. Completed root canal obturation of the extracted teeth, showing gutta percha extruding from the access opening.

3. In order to mount the teeth for testing a surveyor analyzing rod friction locked into the root canal treated tooth. The root was notched to improve retention. This assembly was lowered into a mix of acrylic resin poured into a cylindrical opening in a teflon block.

4. Illustration showing a completed post-space preparation in teeth mounted in duralay resin cylinders.

5. A required step in bonding of the posts that were tested in this experiment. The post-space had to be etched with 37% phosphoric acid gel for 15 seconds, followed by thorough rinsing.

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13. This photograph is an example of the mode of failure of a Fiberkor post. Debonding of the core caused subsequent bending of the FiberKore post.
14. This photograph is an example of mode of failure of a Titanium post. Note the bending of the post and coronal fracture of the root and the core.

15. This photograph is an example of the mode of failure of a Zirconium post. Note the complete failure of the post at the access opening of the root.

16. Of all the samples the groups with the Fibrekor post demonstrated the highest mean of displacement (X =1.52). This was due to the flexural properties of the Fibrekor post.

17. This graph shows the behavior of the titanium post when loaded at 90°. The mean displacement of the posts, given the relative softness of Titanium, was in order of 1-1.20 mm.

18. The brittle nature of the zirconium post produced a totally different graph from the Titanium and the FibreKor post samples. Note the abrupt post fracture and minimal displacement (Range: 0.52 - 0.73 mm).
INTRODUCTION

Post and core systems have been used in dentistry for more than 260 years\textsuperscript{1}. In 1728, Pierre Fauchard described the use of tenons which were metal posts screwed into the roots of teeth to retain prostheses. Claude Mouton (1746) described a design of gold crown with a gold post which was inserted in a root canal\textsuperscript{2}.

During the mid 1800’s the use of a wooden post fitted to an artificial crown and into the canal of the root was common practice. Also during this period Richmond developed a post retained crown, commonly referred to as the “Richmond crown”\textsuperscript{2,3}. This one piece post-crown was eventually replaced by a separate cast post - core and crown which has the advantage of improved marginal adaptation and does not limit the path of insertion of the crown.

A severely damaged endodontically treated anterior tooth requires a post and core to retain a crown\textsuperscript{4}. Custom fabricated post and cores made out of yellow gold are frequently used in the esthetically demanding zone. The potential for casting voids, short circular roots and excessively flared canals, are limitations for use of custom posts\textsuperscript{5}.

Selection of the optimum prefabricated post and core system can be a complex task for the restorative dentist, especially for an anterior tooth where esthetics and durability are a primary consideration. The popular use of prefabricated posts can be an easy one appointment procedure, with the use of various composite cores. The durability of using these materials and various systems has not been clearly determined.
OBJECTIVES

The first objective of this study was to compare the fracture resistance of three different prefabricated posts: FibreKor post (Jeneric Pentron Inc., Wallingford, CT), Permapost (Ultradent Inc., South Jorden, UT) and Cosmopost (Ivoclar-Vivadent Est., U Kremer, Germany) to angular loading.

The second objective was to determine the mode of the tooth and the post failure under maximal loading of 100 kg.

The third objective was to determine the effect of the 2mm-ferrule design on the survival of the endodontically treated tooth using these systems.
LITERATURE REVIEW

The purpose of post and core

Providing internal support for endodontically treated teeth prior to making coronal restorations was thought to be of prime importance. It had been a long held belief that a post and core prevented pulpless teeth from fracturing by distributing coronal forces to the root or alveolar bone. However, the goal of a post and core system is to provide retention for a crown that would normally be obtained from sound coronal tooth structure\(^6\).

In 1959, Frank \textit{et al}, recommended the use of a dowel and full coverage restoration in restoring pulpless teeth to assure maximum strength\(^7\).

Rosen (1961) postulated that the brittleness of pulpless teeth was due to deprivation of blood supply\(^8\). To become a useful member of the chewing apparatus, such teeth must be reinforced with an intracoronal “crutch” which is a cast post or dowel.

A method to construct a direct pattern for cast post and cores was described by Silverstein (1964)\(^9\). He mentioned the necessity of providing internal support to restore the integrity of pulpless teeth and to reinforce the remaining tooth structure.

Federick (1974) described a technique by which an immediate dowel and composite resin core was fabricated for an endodontically treated abutment tooth to provide strength and serviceability\(^10\).

A comparison of the fracture resistance of endodontically treated teeth restored with conventional cast gold post and cores, stainless steel posts with composite cores and stainless steel posts alone was done by Kantor and Pines (1977)
using non-reinforced teeth as a control. They concluded that a single post, cemented into a pre-drilled hole and cemented with polycarboxylate cement could double the strength of the tooth when compared to the control.

Trabert et al (1978) investigated the impact resistance of maxillary central incisors to simulated trauma. Maxillary incisors without endodontic treatment were compared to maxillary incisors that received endodontic treatment with and without parallel sided stainless steel posts. They concluded that teeth with stainless steel posts cemented with zinc phosphate cement demonstrated greater resistance to fracture during impact than endodontically treated incisors without posts.

The effect of root canal preparation, post preparation and post placement on a tooth model representing an intact maxillary central incisor, was examined by Hunter et al (1989). The analysis was done using a two-dimensional photoelastic model (photoelasticity using birefringent plastic and polarized light). In their conclusion they stated that a post with a moderate diameter and length substantially reinforces the tooth if considerable enlargement of the root canal has occurred. The authors noted the limitation of applying their in vitro photoelastic model to clinical situations.

The generally recognized belief that a post will provide strength and reinforce a pulpless tooth has been refuted during recent years.

Lovdahl and Nicholls (1977) studied the fracture resistance of endodontically prepared anterior teeth compared to teeth restored with pin retained amalgam cores or cast gold post and cores when a controlled load was applied to the lingual surface. Their results indicate that natural teeth with access preparation only exhibited the
highest failure load and those restored with a cast gold post and core exhibited the weakest.

Guzy and Nicholls (1979) compared in vitro, the breaking loads of 59 endodontically treated teeth, with and without cemented posts\textsuperscript{15}. They concluded that no statistically significant differences could be demonstrated between endodontically treated teeth with or without cemented posts. Thus the reinforcement concept could not be supported.

In (1984 ) Sorensen and Martinoff published a retrospective study of 1273 endodontically treated teeth to determine the clinical significance of post reinforcement and coronal coverage\textsuperscript{16}. They found that intracoronal reinforcement did not significantly increase the clinical success rate regardless of the type of tooth.

A common aspect of most previous studies was that teeth were loaded to failure. In 1987, Leary \textit{et al} evaluated the effect of various post lengths on the strength of the root within the elastic limits of dentin \textsuperscript{17}. Their results showed that as the internal tooth structure was removed, the tooth becomes weaker. Teeth with posts tended to show more reinforcement than teeth without posts, however, the difference was not statistically significant.

Trope \textit{et al} (1985) reported that preparing a post space weakened endodontically treated teeth compared to ones in which only an access opening was made\textsuperscript{18}. They also concluded that cemented paraposts did not increase the fracture resistance.
After a comprehensive review of the literature on post and cores Goodacre et al (1994) concluded that posts do not reinforce endodontically treated teeth. They stated that “The primary purpose of a post is to retain a core that can be used to retain the definitive prosthesis.”

**The purpose of ferrule Design**

A metal band or ring used to fit the root or crown of a tooth is called a ferrule. Kaufman et al (1961) mentioned the importance of the adaptation of the casting to the prepared tooth surface. Rosener first described the function and placement of beveled margins in the literature in 1963. He stated: “Since the marginal fit of the casting is one of the most important criteria in its life expectancy, the beveled surfaces, their placement and their subsequent reproduction in the impression become of prime importance.”

Sheets (1970) stated: “The margins of the core should be covered by the final restoration and not exposed to the environment of the mouth, while the margins of the restoration should be established beyond the margin of the core and in sound tooth structure.”

Tjan et al (1985) investigated the effect of a metal collar (ferrule) on the resistance of roots to fracture. He compared cast dowel and cores cemented with zinc phosphate cement in root canals with a 1mm, 2 mm, and 3mm remaining buccal dentin wall and a 60 degrees bevel. A compressive force was applied on the lingual
surface of the core. He concluded that the addition of a metal collar did not seem to enhance resistance to root fracture.

Barkhordor et al (1989) used the design of the Tjan study.24. He compared 8 mm cast post and cores cemented with zinc phosphate cement in maxillary central incisors with and without a 2 mm ferrule preparation with approximately 30 degree of taper. They reported findings that differed from the previous author. They stated: “The group with a 2 mm metal collar was suitably reinforced and required a higher force to affect failure”.

Sorensen and Engelman (1990) examined in vitro the effect of various ferrule designs on the fracture resistance of endodontically treated anterior teeth 25. Silver-palladium metal cast post and cores were cemented with zinc phosphate cement in 6 different tooth preparation designs:

- Group 1. A 90-degree shoulder and 1 mm of axial tooth structure remained at the shoulder.
- Group 2. A 90-degree shoulder without a coronal dentinal extension.
- Group 3. A 130-degree angle forming a sloped shoulder.
- Group 4. A 90-degree shoulder and 1 mm wide 60-degree beveled finish line.
- Group 5. A 90-degree shoulder, a 1 mm wide, 60-degree beveled finish line and 1 mm coronal dentinal extension.
- Group 6. A 90-degree shoulder, 1 mm wide 60-degree bevel finish line and 2 mm coronal dentinal extension.

An Inston testing machine was used to apply a controlled load to the teeth at a 130-degree angle. Among their findings was that groups with parallel walls of the dentin,
a ferrule, coronal to the shoulder exhibited the highest failure load when compared to the groups without a coronal extension.

In 1991, Hemmings et al, tested in vitro the resistance of various post and core designs to torsional forces\textsuperscript{26}. 6 different cast post and core designs were tested:

1. Parallel sided
2. Paralleled sided with a 3-mm keyway
3. Parallel sided with a 3-mm flare at the coronal part of the preparation hole
4. Parallel sided with a 3-mm depth pinhole,
5. Parallel sided with a 45-degree bevel at the periphery of the root
6. Post flared from the base.

They concluded that a cervical collar was the most favorable design, embracing resistance and reducing tooth fracture.

Libman and Nicholls (1995) investigated maxillary central incisors restored with cast posts and cores and complete cast crowns with four different ferrule lengths, 0.5, 1.0, 1.5 and 2 mm\textsuperscript{27}. Zinc phosphate was used to cement both the post and core and the completed crown. Teeth were subjected to a fatigue load applied at an angle of 135 degrees to the long axis of the tooth. The control group had no cast post and core, but a complete cast crown. The results showed that the 0.5 and 1 mm ferrule lengths failed at a significantly lower number of cycles than the 1.5 mm and 2 mm ferrule lengths and control teeth.

The validity of clinical reports citing the potential of intra radicular reinforcement was investigated by Soupe et al (1996)\textsuperscript{28}. Cast post and cores with and without ferrule were tested. Enforce resin cement was used for cementation. An Instron machine was
used to apply a controlled load to an indentation on the core. They concluded that there was no difference between teeth with a post and core restorations that had a ferrule and teeth without a ferrule when a bonded resin system was used as a luting agent.

**Prefabricated Post Design and Retention**

The prefabricated post is a commercially produced pre-shaped, presized, precious or non-precious anchoring device, which can be threaded or cemented into the root canal.

Commercially available prefabricated posts can be put into the following groups:

1. Parallel sided or tapered post
2. Threaded or smooth surfaced post
3. Vented or non vented post
4. Split post

They are manufactured in gold, stainless steel, aluminum, titanium, zirconium, carbon fiber, glass ceramic and fiber reinforced composite.

In 1978, Standlee *et al*, studied in vitro the concept of dowel retention by using preformed dowel systems incorporating four retentive factors that are normally within the dentist control\(^\text{29}\). The factors were dowel design, length, diameter and type of cement employed. Threaded parallel sided posts showed the greatest retentive
ability, serrated parallel sided provided intermediate retention, and smooth sided tapered post were the least retentive.

In 1979, Ruemping et al, evaluated retention of four commercial dowels under torsional and tensile forces\textsuperscript{30}. They concluded that the threaded screw-in dowels were significantly more retentive than the unthreaded dowels, under tensile force. Under torque both threaded screw-in and serrated dowels were significantly more retentive than the smooth sided dowels.

In 1980, Standlee et al, examined the parallel sided vented dowel with retentive spiral “Redix Dowel” which engaged dentin\textsuperscript{31}. They evaluated the stresses generated during installation and the retentive properties of the system. They concluded that the Radix Dowel System was more retentive than cemented dowels and less retentive than threaded dowels.

In 1984, Caputo et al, examined the retention of parallel sided dowels with axially oriented serrations “Beta Post System” with different diameters\textsuperscript{32}. They concluded that a larger Beta Post is more retentive that a smaller one.

**Prefabricated Post and Stress Distribution**

In 1972, Perel et al, mentioned the danger of cracking a root when using screw type prefabricated post relative to a thin screw type wire in conjunction with amalgam build ups\textsuperscript{33}.

In 1972, Standlee et al, compared three different post designs, smooth sided parallel posts, smooth sided tapered, and threaded parallel sided posts in their ability
to transmit force to their supporting structures\textsuperscript{34}. They concluded that threaded posts generated the highest level of stress when the post was fully engaged.

In 1977, Henry reported in a photoelastic pilot study the influence of post morphology on qualitative stress distribution on the prepared tooth root\textsuperscript{35}. He observed that both tapered and parallel sided cast post and cores are stress free prior to loading and screwed posts showed high stress concentration in the unloaded condition.

In 1990, Burns \textit{et al}, compared the stress distributing characteristics of three different endodontic posts: para-post, para-post plus, and flexi-post\textsuperscript{36}. They concluded that the serrated posts (para-post and para-post plus) produced a similar evenly distributed pattern of stress. Threaded posts (flexi-post) displayed significantly greater stress in an asymmetric pattern.

In 1991, Felton \textit{et al}, compared the potential for root fracture resulting from the tapping and cementation process of nine threaded and three non-threaded endodontic dowel system\textsuperscript{37}. They suggested rotating the dowel one-quarter turn or one half turn counter clock wise to relieve installation stress during cementation process that may cause root fracture. However, they did not report a statistically significant difference between the two systems regarding root fracture.

In 1992, Rolf \textit{et al}, analyzed the stress generated by five prefabricated posts inserted and cemented into a birefringement photoelastic model\textsuperscript{38}. They concluded that the cemented posts were the least stressful while the screw type posts generated the most stress.
Cast and Prefabricated Post Failure

Post loosening is one of the most common reasons cited in the literature for post failure. Several authors have investigated retrospectively the clinical data regarding post and core failure.

Turner, in 1982, retrospectively evaluated 52 posts in 41 patient and he found six have failed due to cement failure and subsequent loosening. The same author reported in another study, 100 posts failure, Fifty nine percent of the recorded failure were due to post loosening.

In 1989, Bergman et al, retrospectively reviewed 96 cast post and cores that had failed over six years. They found six among the nine documented post failures were due to loosening.

A 3-year postoperative clinical evaluation of 154 posts and cores beneath existing crowns were performed by Hatzikyriakos. He found 5 prefabricated parallel-sided posts had failed due to loosening.

IN VIVO AND IN VITRO EVALUATION OF DIFFERENT POST AND CORE SYSTEMS

In 1992, Isidor et al, evaluated in vitro the number of loading cycles required for two different post and core systems to fail. Tapered individual cast post and cores were compared to prefabricated parallel sided titanium posts and composite
resin cores. Bovine teeth were used. All teeth had a chamfer preparation 2.5mm apical to the core for veneer crowns. Cast crowns were luted using zinc phosphate cement. 250 N intermittent load was applied at a 45-degree angle to the long axis of the tooth. The results showed that the teeth with prefabricated posts and composite resin cores had a significantly higher resistance to intermittent loading than teeth restored using tapered individually cast posts and cores.

In 1996, Isidor et al, evaluated the fracture resistance of prefabricated carbon fiber posts under similar test conditions as the previous study. Comparisons of the two studies showed that the failure rate of the two types of post tested in the previous study were significantly higher than those of the carbon fiber posts.

In 1996, Purton et al, compared in vitro the physical properties of carbon fiber posts, with stainless steel posts. Posts were tested with a three point bending test in a universal-testing machine (Instron). They showed that carbon fiber posts exhibited greater rigidity than the stainless steel posts that were tested.

In 1996, Kama, evaluated the recently developed fiber composite laminate post and core (FCL). Teeth were imbedded in acrylic resin, no metal or ceramometal restoration were placed on the specimens. All samples were tested in an Instron machine at a 40 degrees angle to simulate shear stress. Results were compared to other post and core systems reported in the literature. He concluded that the FCL is relatively flexible because none of the specimens exhibited root fractures.

In 1998, Fredriksson et al, evaluated retrospectively the performance of a carbon fiber reinforced epoxy resin post system “composi post” after two to three years of function. A total of 236 treated teeth were followed up clinically and
radiographically. The results showed a 98% success rate over a period of two to three years of evaluation.

In 1998, Martinez-Insua et al., compared the fracture resistance of extracted teeth restored with prefabricated carbon fiber posts and composite cores to cast dowel core restored teeth\textsuperscript{48}. All the teeth had 1mm chamfer preparation for the veneer crowns. A counter bevel of 1mm was also prepared, as a ferrule of the core. A resin and glass ionomer cement was used to cement the posts and the crowns respectively. An Instron universal testing machine was used to apply a force at a 45 degrees to the long axis of the tooth. Higher fracture thresholds were recorded for the cast post and core group when compared to the carbon fiber group.

In 1998, Jung et al., compared the number of cycles to failure of extracted central incisors restored with cast post and cores and full cast crowns luted with three different cements\textsuperscript{49}. Zinc phosphate, a resin modified glass ionomer cement, and resin cement were used. They concluded that the resin cement samples required a significantly higher number of load cycles before failing than for both zinc phosphate and resin modified glass ionomer cement.

In 1999, Sirmai et al., evaluated the resistance to vertical root fracture of extracted teeth treated with six different post and core systems:

1. Cast post and core,
2. Passive titanium post,
3. Polyethylene woven fiber/Heliobond resin post (PWFH),
4. Passive titanium post with (PWFH),
5. Para post plus post with (PWFH),
6. Para post plus post alone,
An Instron universal testing machine was used to apply a controlled load to the core at an angle of 130 degrees to the long axis of the tooth. They concluded that the polyethylene woven fiber group had the lowest failure rate and also resulted in significantly fewer vertical root fractures. Cast posts and cores were the strongest of the six post core systems tested but frequently caused a catastrophic root fracture which rendered the teeth non restorable.

Influence of Post Designs, Materials, and Adaptation on Root Fracture

Stainless steel prefabricated posts used in dentistry are subject to corrosion, which can be defined as a reaction between metallic materials and their environment. It is interesting to note that in reviewing the American literature there were no studies found concerning corrosion of posts and subsequent fracture of roots. On the other hand, the Scandinavian literature has an extensive number of reports of clinical cases, as well as research projects concerned with this aspect of post and core phenomenon.

In 1969, Angmar- Mansson et al, investigated the chemical composition of corrosion products and the combinations of materials used in posts and crowns. Their analysis revealed that the core in most cases consisted of a cast alloy (tin, zinc, and silver) while others consisted of amalgam, silver and gold. Most of the root canal posts were made of steel, some German silver alloy, and a few of brass. The corrosion products frequently contained compounds of tin and less frequently zinc.
Fractures were due to the corrosion of tin that gradually gives rise to products that will exert a pressure on the inside of the root and lead to fracture.

In 1978, Arvidson et al, evaluated in vivo teeth that had been restored with dentatus screw posts, cores of amalgam and gold crowns three to ten years prior to extraction\textsuperscript{52}. They found that copper and zinc migrated not only into dentin but also could be detected in gingiva adjacent to the teeth.

In 1983, Pameijer et al, studied the corrosive potential of some pins commonly used in restorative dentistry by using energy dispersive X-rays analysis\textsuperscript{53}. They observed varying degrees of compositional changes for all the studied situations. In vitro corrosion in fresh saliva is more destructive than in vivo corrosion especially when pins are used to retain amalgam restoration.

In 1985, Tjan et al, compared the resistance to fracture under horizontal force on maxillary central incisors with various thickness of remaining buccal dentin, 1mm, 2mm, and 3mm\textsuperscript{23}. The result showed that dowel channels with 1mm of remaining buccal dentin walls were more prone to fracture.

In 1990, Sorensen et al, examined the effect of different post designs and the amount of post to canal adaptation on the fracture resistance of endodontically treated anterior teeth\textsuperscript{54}. Tapered and parallel-sided cast posts were investigated. They concluded that maximum adaptation to the canal with tapered post significantly increases the mean of fracture threshold, but upon failure renders the teeth non-restorable.

In 1993, Assif et al, compared the effect of four different cast post designs on the fracture resistance of endodontically treated teeth\textsuperscript{55}. The four groups tested were
conventional cast dowel core, cast cylindrical dowel and core, cast cylindrical tapered end dowel and core, and canal closed with ketac fill. Teeth were restored with a complete cast crowns with a 2mm margin on healthy tooth structure. An Instron universal testing machine was used for testing. They concluded that a post design did not influence the fracture of endodontically treated teeth.

**Composition And Mechanical Properties Of Resin Cement**

Most recent resin cements are usually based on the BIS GMA system (they are a combination of bisphenol –A and aromatic dimethacrylate glycidyl methacrylate). This resin matrix contains variable amounts of inorganic filler, silica or glass particles, according to the brand and the curing initiator systems. The fillers are bonded to the matrix via an organosilane coupler. Monomer with functional groups that have been used to induce bonding to dentin are organophosphates bonding mechanism HEMA( hydroxyethyl methacrylate ) and the 4 META (4 methacrylethyltrimellitic anhydride)systems.

When the camphoroquinone amine complex is included in the system, it renders the material light –sensitive. Some resin are self-cured by mean of a peroxide-amine. A dual –cure resin incorporating both components of both polymerization mechanisms.

The film thickness of the resin cement range from 25 –100μm. It’s compressive strength ranges from 125to 205 MPa while the tensile strength is any where from 25to 50 Mpa. The proper use of a dentin bonding agent with the resin
cement will allow for greater bond strength. The dentin bonding agent is generally composed of a primer, a coupling agent and an unfilled resin. The primer may be acetone or alcohol based. After etching dentin HEMA penetrates the demineralized dentin because of its hydrophilic nature, forming a molecular network referred to as the “hybrid zone”, which will subsequently bond to the unfilled resin$^{60,61}$. 
MATERIALS AND METHODS

Teeth collection

Ninety extracted human maxillary central incisors with relatively similar root sizes were selected and stored in 2% sodium azide. The teeth were cleaned and examined under a stereomicroscope using fiber optic light. If root caries, cracks or fractures were present there were disqualified from the study.

Sample preparation

The crowns were sectioned 2mm coronal to the cementoenamel junction with carborundum disk. Four notches were prepared in the roots to prevent dislodgment of the root from the imbedding materials during testing. In preparation for root canal treatment, access cavities were prepared using a rose head carbide bur in a high speed handpiece with copious water irrigation. Root canal therapy was continued using K files (Dentsply Int. Inc L.D. Caulk Division. Milford, DE) From sizes 15 to 40. Each tooth was instrumented to its full working length. Irrigation was used throughout instrumentation to clean debris from the canal. After instrumentation, the roots were dried with paper points and an air syringe. The root canal obturation procedures were accomplished by using gutta percha #4 as a master cone and medium fine accessory cones. (Premier Dental Products Company, Morristown, PA.) with AH26 as a Sealer (Dentsply Int. Inc., L.D. Caulk Division Milford, DE.) Excess gutta percha was removed with a heated spatula.
Mounting Procedures

After root canal therapy was completed, one end of a surveyor metal rod was friction locked into the post space of the tooth while the other end was connected to the surveyor. Thus the teeth could be mounted parallel to the long axis into a cylindrical teflon mold. Auto polymerizing resin (Reliance Dental MFG.Co., Worth, Ill.) was poured into a teflon mold block cylinder (measured 20x25 mm). The tooth rod assembly was lowered into a creamy mix of duralay resin and the tooth was centered by eye as best as possible. During polymerization of the resin the tooth was kept moist with wet tissue paper.

Preparation of post space

After imbedding in the resin, a 9mm-deep post space was prepared in each tooth using a 1.25mm diameter spiral drill (Jeneric Pentron Inc., Wallingford, CT) mounted in a low speed contra angle handpiece. For the zirconium post space a 1.4mm diameter drill (Ivoclar- Vivadent Est., U Kremer, Germany) was used, because it was the smallest diameter available for this type of post. The canals were irrigated with water and dried with air and paper points. The post space was etched with 35% phosphoric acid gel (Jeneric Pentron Inc., Wallingford, CT) applied with a brush and left in place for 15 seconds, then rinsed with water, and again dried with air and paper points while ensuring that the dentin stayed moist.
**Post Cementation**

Two drops of base and catalyst of a bonding agent, Bond It (Jeneric Pentron Inc., Wallingford, CT) were mixed with a brush in a mixing well. The mixture was applied to the post space with a camel hair brush for 15 seconds, followed by insertion of a dry paper point to remove excess bonding agent. Equal amounts of base and catalyst of a resin cement, Cement It (Jeneric Pentron Inc., Wallingford, CT) were mixed and applied to the post and rubbed into the post space with a paper point. The post was seated immediately and the cement allowed to polymerize for ten minutes. During polymerization of the cement a moist paper towel covering the post prevented dehydration of the sample. After ten minutes the teeth were stored in water.

**Core Fabrication**

Z-100 composite resin (3M, Minneapolis, MN) was applied by a composite injector to build an oversized core for each tooth. A diamond bur ISO (800 104) (Brasseler, Savannah, GA) mounted in a milling machine was used to prepare a composite core to a standard taper of 8 degrees. A total of fifteen teeth were prepared for six groups:

- Group 1: Fibrekor post with ferrule design
- Group 2: Fibrekor post without ferrule design
- Group 3: Titanium post with ferrule design
- Group 4: Titanium post without ferrule design
- Group 5: Zirconium post with ferrule design
The ferrule was 2mm in height while the composite core was 4mm. The non-ferrule design preparation had a composite core that measured 5mm in height. A single coat of die spacer was painted on each tooth, followed by a die lubricant. On each tooth a wax pattern coping with a lingual ledge for placement of a blunt chisel in an Instron machine was provided. The wax patterns were cast in a Rexillium III (Jeneric Pentron Inc., Wallingford, CT) using Microfine 1700 (Talladium, Inc., Valencia, CA) investment material and a routine casting technique. After steam cleaning the die spacer from the preparations the copings were cemented using the previously described techniques of acid etch, Bond It, and Cement It. After a cure time of ten minutes the samples were stored in a wet paper towel at room temperature.

**Instron Testing**

The cylinders were placed in a custom made jig which positioned the samples at 45 degrees to the long axis of the teeth. The blunt chisel applied a compressive force while the Instron was programmed to apply a maximum force of 100 Kg. If no fracture occurred the samples were mounted in a jig which applied a shear force at 90 degrees until catastrophic failure occurred. After tabulation of the data the following statistical analysis was done. A Fischer’s exact test was used to determine the frequency of breakage at 45 degrees. No mean and standard deviations were Calculated at 45-degree since the samples that reached 100-KG force did not reflect their true values. Values for shear strength at 90 degrees were tabulated. A mean and
S.D. was calculated and a Kruskal-Wallis non parametric one-way Analysis of Variance, with multiple comparison procedures, to isolate pairwise differences, was used.
RESULTS

Table 1 presents the number of teeth that survived the 100-Kg load at 45 degrees and the mean and standard deviations of the subsequent load at 90 degrees and mean and standard deviation of sample displacement. Table 2 presents the Fischer exacts analysis of the frequency of breakage in the table format. Table 3 presents the statistically significant differences between the values of the six groups at 90-degree load using the Kruskal-Wallis non-parametric ANOVA.

Group 1 (Fibrekor with ferrule), 3 (Titanium post with ferrule), and 5 (Zirconium post with ferrule) all had 2mm ferrule and survived the 100 kg load at 45 degrees without fracture.

Group 2 (Fibrekor Post without ferrule) and Group 6 (Zirconium post without ferrule), both non-metallic posts and both without a ferrule had a significantly high number of samples that broke below 100 Kg at 45 degree load. Only one sample of group 4 (Titanium post without ferrule) broke, reaching a value of 81.61 Kg. At 90 degrees loading the results of the Kruskal-Wallis non-parametric ANOVA were significant in particular for the FibreKor Posts. Both groups, whether with or without ferrule design, had statistically significant higher values than all other groups. On the other end of the scale were the Zirconium posts, especially the group without a ferrule has the lowest values of all other groups. There was no statistical significant difference between the values of the two FibreKor groups at 90-degree load. Values of the Titanium post without ferrule showed no statistical significant difference when compared to the values of Zirconium post with ferrule.
<table>
<thead>
<tr>
<th>Groups</th>
<th>Nos. of Samples</th>
<th>Nos. of Surviving 100 Kg load at 45° w/o breaking</th>
<th>Mean and SD at 90 degree loading</th>
<th>Mean and SD of samples displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr. 1 FP w ferrule</td>
<td>n=15</td>
<td>15</td>
<td>72.56 ± 19.85</td>
<td>1.479 ± 0.390</td>
</tr>
<tr>
<td>Gr. 2 FP w/o ferrule</td>
<td>n=15</td>
<td>10</td>
<td>70.64 ± 04.25</td>
<td>1.520 ± 0.184</td>
</tr>
<tr>
<td>Gr. 3 Ti w ferrule</td>
<td>n=15</td>
<td>15</td>
<td>53.85 ± 18.08</td>
<td>1.097 ± 0.170</td>
</tr>
<tr>
<td>Gr. 4 Ti w/o ferrule</td>
<td>n=15</td>
<td>14</td>
<td>41.94 ± 24.05</td>
<td>1.274 ± 0.192</td>
</tr>
<tr>
<td>Gr. 5 Zir w ferrule</td>
<td>n=15</td>
<td>15</td>
<td>33.44 ± 10.42</td>
<td>0.520 ± 0.220</td>
</tr>
<tr>
<td>Gr. 6 Zir w/o ferrule</td>
<td>n=15</td>
<td>8</td>
<td>18.49 ± 02.91</td>
<td>0.730 ± 0.190</td>
</tr>
</tbody>
</table>

**Table 1.** This table presents the number of teeth tested for each of the six groups, the number of samples that did not break at 100 Kg when loaded at 45 degrees and the Mean and Standard Deviation of the teeth when subsequently loaded at 90 degrees. In addition this table presents the Mean and SD of the displacement of the samples.
<table>
<thead>
<tr>
<th>Groups</th>
<th>Gr. 2</th>
<th>Gr. 3</th>
<th>Gr. 4</th>
<th>Gr. 5</th>
<th>Gr. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr. 1 FP w ferrule</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Gr. 2 FP w/o ferrule</td>
<td></td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Gr. 3 Ti w ferrule</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Gr. 4 Ti w/o ferrule</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr. 5 Zir w ferrule</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Gr. 6 Zir w/o ferrule</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2.** This table represents the Fischer exact analysis of the frequency of breakage of the six experimental groups. See Table 1 for values.
Table 3. This table represents the statistically significant differences between six groups using Kruskal-Wallis non-parametric ANOVA.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Gr. 2</th>
<th>Gr. 3</th>
<th>Gr. 4</th>
<th>Gr. 5</th>
<th>Gr. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gr. 1 FP w ferrule</td>
<td></td>
<td>* p=0.005</td>
<td></td>
<td>* p&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Gr. 2 FP w/o ferrule</td>
<td></td>
<td></td>
<td>* p&lt;0.001</td>
<td></td>
<td>* p&lt;0.001</td>
</tr>
<tr>
<td>Gr. 3 Ti w ferrule</td>
<td>* μ=0.024</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr. 4 Ti w/o ferrule</td>
<td></td>
<td>p=0.035</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr. 5 Zir w ferrule</td>
<td></td>
<td></td>
<td>* p&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gr. 6 Zir w/o ferrule</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>* p=0.042</td>
</tr>
</tbody>
</table>
Three patterns of specimen failure were observed. Fibrekor posts failed due to core detachment and subsequent post bending. Zirconium posts failed due to core detachment and complete post fracture. Titanium posts failed due to core dislodgment as well as the post bending leading to coronal root fracture.
DISCUSSION

The resin reinforced Fiber system known as FibreKor post is a new concept for post and core restoration of endodontically treated teeth. For optimal result when this system is used, resin cement is necessary to bond the post to the post space.

The results obtained in this study may not accurately reflect the *in vivo* situation. Attempts were made to carefully select teeth of similar size and length. Standardized preparations were made using a milling machine to obtain a uniform tapered design. Maximum load catastrophic failure was tested in this study rather than fatigue loading which is more difficult and expensive test to run. This may be more clinically relevant in simulating material failure *in vivo*.

No attempts were made to simulate the periodontal ligaments and tooth supporting structure because of the potential to dislodge the tooth during testing, thus roots were embedded directly into resin. Rigid re-enforcement of the root may alter the root strength and the mode of failure. Whether the thermocycling could have affected the data is an entirely independent study.

This investigation supports earlier studies stating that 1.5- 2mm of ferrule design is necessary for long term clinical success of endodontically treated teeth.\(^{24-27}\) The results of this study are in agreement with the previous investigator, because all the groups with 2 mm ferrule survived 100 kg load under a 45 degree angle without breakage.

It is interesting to note that no difference could be demonstrated between FibreKor post groups with and without ferrule, when loaded at 90 degrees.
The group with ferrule reached 72.56 ±19.85, the group with out ferrule 70.64 ±4.25 kg force. This difference was statistically insignificant. This finding is in agreement with Saupe’s findings\(^{28}\). He concluded that there is no difference between the ferrule and none ferrule groups when the resin cement was used. This might lead to the wrong assumption or conclusion that therefore it does not make a difference whether the post preparation had a ferrule design or not. Apparently the choice of luting agent has an important role.

However the findings were totally different in non ferrule design groups. Group 6 Zirconium post without ferrule had the lowest number surviving at 45 degree angle loading, only 8 samples survived. While Group 4 Titanium post with out ferrule had the highest number surviving at 45-degree angle loading, 14 samples survived. Group 2 Fibrekor post with out a ferrule was in the middle between the Group 6 and 4, 10 samples survived the 100 kg at 45 degree angle loading.

The difference between the two non-metallic posts was statistically significant, in spite of the fact that the Zirconium posts had an added advantage in that the diameter tested was 1.4mm , versus the 1.25 mm for the other two systems.

Of importance is also the statistically significant difference between the FibreKor post and the Titanium post when loaded at 90 degrees. Both FibreKor groups demonstrated a higher value.

Catastrophic failure of the Zirconium post at lower values maybe due to the brittle nature of the post, while, catastrophic failure of the FibreKor post at a higher value may be due to the toughness of the post. Initially conditions in the oral environments in terms of direction of force were simulated. The force was applied to
the completed cast crown at 45 degrees to resemble class 1 occlusion in anterior teeth. However, when samples did not break, a 90 degree angle loading was applied to load unbroken samples using a shear force. All the samples exposed to this shearing force had already been stressed with 100 kg at a 45 degree loading. Microcracks could have happened. However, the samples were still able to sustain further loading and the computer generated paper graph did not indicate a catastrophic failure.

All the groups generated a different mean of displacement. The displacement could be measured in the paper graph that represent the load force until failure occurred. The displacement is the cumulation of movement of the Instron cross head, microcrack at the composite or the cement level, or displacement of the entire assembly of the sample handle.

Cement It resin cement has a compressive strength of 155 MPa, and tensile strength 41 MPa thus the force has to completely offset the bond strength of the cement and allow the core and subsequently the post to move. Clinically, the restorative dentists should follow patients restored with FibreKor posts closely to detect any potential marginal leakage under the restoration before its progression to caries.

Using the Fibrekor post to restore the root canal treated anterior teeth offer the restorative dentist many advantages. The ability of the post to flex will allow it to fail before catastrophic root fracture that will render the tooth unrestorable. Its corrosion resistance properties will prevent graying of the surrounding soft tissue.
In addition, light color of the Fibrekor post will enhance tissue illumination when restoring anterior teeth.
CONCLUSIONS

The following can be concluded from this study:

1- At 45-degree loading the 3 groups without ferrule design scored from the highest to the lowest number of surviving samples as follow:

- Titanium (14 out of 15 survived)
- FibreKor (10 out 15 of survived)
- Zirconium (8 out 15 of survived)

None of the samples with a ferrule design broke at a 45 degree load angle, based on the data above it is recommended to prepare the endodontically treated tooth with a ferrule design to improve it's prognosis and long term success.

2- At 90-degree loading the three groups with a ferrule design scored from the highest to the lowest failure values as follow:

- FibreKor 72.5 kg
- Titanium 53.8 kg
- Zirconium 33.4 kg.

Based on the above data, FibreKor post may offer a viable alternative in strength to the Titanium post with the added advantage that they are tooth colored and particularly suitable when esthetics restorations are indicated.

3- Zirconium posts broke at statistically lower values than the other post systems studied and scored lowest displacement values. This was due to the inherent brittleness of this post system.
The purpose of this in vitro study was to evaluate the fracture resistance of 3 different kinds of prefabricated posts. Zirconium post 1.4 mm in diameter, FibreKor post 1.25mm in diameter, and Titanium post 1.25mm in diameter.

Six groups of 90 human extracted maxillary anterior teeth of similar diameter and length were used. Each tooth was sectioned 2mm coronal to the cementoenamel junction. Endodontic treatment was performed. Teeth were mounted in acrylic resin cylinders at 90° to the horizontal plane using surveyor. 9mm long post of each type was cemented with a resin cement and dentin bonding agent (Cement It and Bond It ). Each tooth had composite build up and an 8° tapered preparation by using a diamond bur mounted in a milling machine.

The First group was FibreKor post with ferrule effect design. The Second group was FibreKor post without ferrule effect design. The Third group was Titanium post with ferrule effect design. Fourth group was Titanium post without ferrule effect design. Fifth group was zirconium post with furrel effect design. Sixth group was zirconium post without ferrule effect design.

Rexillium crowns were made to fit each tooth. Cement-It and Bond-It was used to cement each crown. All specimens were subjected to a 45° load until failure occurred. If failure did not occur at 45° with 100 kg maximum load then the sample was subjected to 90° shearing load until fracture. The force at the failure and the location of the failure was recorded. In general, teeth with a ferrule design failed at higher force than teeth without a ferrule design.
BIBLIOGRAPHY


Figure 1. Teeth were sectioned 2 mm coronal to the cemento-enamel junction. An attempt was made to use teeth of uniform bucco-lingual and mesio-distal diameter. Teeth were also matched for length.
Figure 2. Completed root canal obturation of the extracted teeth, showing gutta percha extruding from the access opening.
Figure 3. In order to mount the teeth for testing, a surveyor analyzing rod was friction locked into the root canal treated tooth. The root was notched to improve retention. This assembly was lowered into a mix of acrylic resin poured into a cylindrical opening in a teflon block.
Figure 4. Illustration showing a completed post-space preparation in teeth mounted in duralay resin cylinders.
Figure 5. A required step in bonding of the posts that were tested in this experiment. The post-space had to be etched with 37% phosphoric acid gel for 15 seconds, followed by thorough rinsing.
Figure 6. This illustration shows the three post systems with bulk composite build-up, before being milled to standard size in a milling machine.
Figure 7. Specimens showing composite core build up on teeth with titanium posts.
Figure 8. The dimensions of the final core were prepared with a diamond bur mounted in a milling machine. The preparations were ground to a standard 8° taper.
Figure 9. This illustration shows a ferrule design. The composite core was milled to a standardized 8° taper. The final dimensions of the preparation were 2 mm of remaining dentin and a 4 mm composite core.
Figure 10. A photograph showing the Instron 4444 testing machine used for this experiment.
Figure 11. Specimen undergoing fracture resistance test at $45^\circ$ loading. An aluminum jig (AJ) was used to seat the sample at $45^\circ$ to the load force, which was applied by the crosshead (CH) in the Instron machine.
Figure 12. Specimen undergoing fracture resistance test at 90° loading. The sample (white arrow) was secured in an aluminum jig (AJ). The cross head (CH) in the Instron was aligned on the ledge on the lingual aspect, thus applying a force at a right angle (90°) to the long axis of the tooth.
This photograph is an example of the mode of failure of a Fibrekor post. Debonding of the core caused subsequent bending of the Fibrekor post.
Figure 14. This photograph is an example of the mode of failure of a Titanium post. Note the bending of the post and coronal fracture of the root and core.
Figure 15. This photograph is an example of the mode of failure of a Zirconium post. Note the complete failure of the post at the access opening of the root.
Figure 16. Of all the samples the groups with the Fibrekor post demonstrated the highest mean displacement (A range of 1.48-1.52 mm). This was due to the flexural properties of the Fibrekor post.
Figure 17. This graph shows the behavior of the Titanium post when loaded at 90°. The mean displacement of the posts, given the relative softness of Titanium, was in the order of 1-1.20 mm.
Figure 18. The brittle nature of the Zirconium post produced a totally different graph from the titanium and Fibrekor post samples. Note the abrupt post fracture and minimal displacement (Range: 0.52-0.73 mm).