UNIVERSITY of the WESTERN CAPE

An *in-vitro* study of the fatigue resistance and structural integrity of different aesthetic posts.

Student name: J Ziegler

Student number: 9017703

Degree: MSc (Thesis)

Department: Restorative Dentistry

Supervisor: Dr. S. Mpungose

Co- Supervisor: Dr. D. Moodley

An in-vitro study of the fatigue resistance and structural integrity of different aesthetic posts.

Keywords:

Fiber posts; Fatigue test

Abbreviations and acronyms:

SEM - Scanning electron microscope

N - Newtons

MPa - Mega Pascal

Table of Contents

LIST OF FIGURES

LIST OF TABLES

Abstract

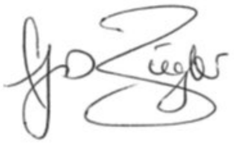
Aim: The aim of the study was to assess and determine the fatigue resistance of different fiber posts and to observe their ultrastructures through scanning electron microscopy (SEM).

Objectives: To assess and compare the fatigue resistance of 4 different types of fiber posts, to analyse and compare the surface morphology using scanning electron microscopy (SEM) and to determine a correlation between the fatigue resistance exhibited by the different types of posts and their structural characteristics. Materials and Methods: Four types of aesthetic posts were selected for this study, namely: Radix Fiber Post (Dentsply Sirona, USA, zirconia glass fiber), ParaPost Fiber White (Coltene/Whaledent, NJ, USA, glass fiber), Edelweiss Composite Posts (Edelweiss Dentistry, Austria, hybrid glass) and GC Fiber Post (GC, Tokyo, Japan, glass fiber). For each group, the 15 largest posts available were used. For the fatigue testing 10 posts were used, the remaining 5 were used for processing in SEM evaluation. The 10 posts from each group were tested using a fatigue test machine (Tinius Olsen, Horsham USA). The surface structure was analysed using a scanning electron microscope (Merlin SEM Gemini II from Carl Zeiss, Oerzen, Germany) Statistical analysis were computed using SPSS, Ver21 (IBM, USA). Results: The flexural strength values ranged from 408 to 664 MPa and flexural load from 78.31 to 154.75 Newton. The study indicated that there were statistically significant differences in the flexural strengths of the 4 fiber post systems. A strong correlation existed between the flexural strength and the fiber diameter and fiber/matrix ratio of the four fiber post systems. The Pearson's correlation coefficients were set at $p<0.05$. The study has shown that the structural characteristics significantly affected the properties of the four fiber posts. A linear correlation between flexural strength and the fiber diameter as well as the flexural strength and fiber/matrix ratio were observed.

Declaration

I declare that an in-vitro study of the fatigue resistance and structural integrity of different aesthetic posts is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name: Jonathan Denis Ziegler Date: 7 December 2022

Signed: 

Acknowledgements

I would like to thank my supervisors, Drs. S.Mpungose and D.Moodley. I want to thank Dr.Mpungose for his academic input. I would like to thank Dr.Moodley for his continuous guidance, inspiration, belief and continued support. I would like to thank Dr.R.Mulder for his help in the Oral and Research Laboratory. Your eagerness to learn is an inspiration for us all. I would like to thank my colleagues, Drs S. Bredenkamp, C. Cloete and C.Peck for your emotional input and inspiration. To Mrs. Z. Smith many thanks for your continuous encouragement and support. To Mrs.Y.Erasmus many thanks for all your help and motivation. To Dr. Karangwa, my statistician, many thanks for all your input and help. It is greatly appreciated. I would also want to thank the Department of Health and South African Dental Association for their financial assistance. To my wife Carmen and daughters, Eden and Rayna, thanks for all your understanding and patience during my period of studies.

CHAPTER I

1.1 Introduction and Literature Review

Introduction

The advancement of technology and techniques in dentistry had given the clinician more alternatives to restore the endodontically treated tooth with less catastrophic dental outcomes. Improvements in the restoration of teeth made it feasible to preserve tooth structure, which otherwise would have had a negative result.

Recent research on endodontically treated teeth has changed contemporary views concerning some of the older principles. Clinical success in restoring endodontically treated teeth depends on our ability to use the latest materials available in conjunction with sound clinical methods. A number of articles have discussed the major factors that play a key role in the long-term survival of endodontically treated teeth and associated restorations.

1.2 Problem statement

Tooth extraction not only may lead to loss of bony tissue, but also clinicians find it difficult to replace lost aesthetics due to bone loss. Clinicians tried to preserve teeth as much as they can to prevent loss of bone and hence aesthetics. Endodontics for the long time have tried to save tooth structure and to prevent tooth loss. Endodontic treatment often involved post and core treatment with subsequent extra-coronal prosthesis. Posts are important to reconstruct and support the coronal prosthesis, but they do not strengthen dental roots. Posts might hinder the mechanical resistance of restored teeth, expediting the chances of further damage of the residual tooth structure. There exists ongoing research into which post material is best for the restoration of the root canal treated teeth. Posts with biomechanical attributes identical to those of dentine had been recommended. This study highlighted four different types of fiber posts systems {Radix Fiber Post (Dentsply Sirona, USA), ParaPost Fiber White (Coltene/Whaledent, USA), Edelweiss Composite Posts (Edelweiss Dentistry, Austria) and GC Fiber Post (GC, Tokyo, Japan) to demonstrate which fiber post system showed the best results with regards to their fatigue resistance and structural integrity. It is important to comprehend that an exact reflection of the fatigue resistance of fiber posts in intra-oral conditions and during functional load was not achievable. The results of this study analysed the fatigue resistance of fiber posts systems and described their surface structure.

1.3 Literature review

Introduction

A dental post is a restoration needed where there is insufficient tooth structure/core left to retain a conventional crown. The post is cemented into the prepared root canal containing a core tooth structure or restoration, which keeps the final restoration or crown. Post and core systems had been part of the researcher's pen for the past 250 years (Smith, Schuman and Wasson et al. 1998). Pierre Fauchard in 1728 talked about "tenons" which were metal posts screwed into the roots of teeth to retain his fixed prosthesis. Claude Mouton, in 1746, presented his gold post and crown to be cemented into the root canal preparation, to the dental world. During the mid-1800's, metal posts were replaced by wooden posts giving rise to the "pivot crown". The pivot crown was a wooden post fitted to an artificial crown and fitted to the root of the tooth (Smith, Schuman and Wasson et al. 1998). One of the drawbacks of the wooden posts were that it would absorb fluid, expand and subsequently cause catastrophic fractures of the root (Smith and Schuman, 1998). In 1880 the "Richmond crown" was presented to the world. The Richmond crown was an all-in-one post retained crown with a porcelain facing manufactured to act as a bridge retainer. It was only in 1930 that the metal post and core was introduced to dentistry in order to substitute the all-in-one post crown. This obviously meant that the crown must be poured independently to the post and core (Smith and Schuman, 1998). This was a two-step procedure which resulted in an enhanced marginal fit. It also improved the clinician's ability and scope to the path of insertion.

Posts for many years had been used to anchor the extra-coronal prosthesis to the root of the tooth. Root canal treatment had been considered to be the last feasible alternative to keep a vulnerable tooth. Root canal treated teeth are unfortunately more prone to fracture due to its compromised nature. In the past, the metallic post had been the post of choice due to its ability to fit snugly into the prepared root canal and its hardness. Kumar and Rao (2015) found that stress distribution in teeth treated with metallic posts were more concentrated in the apical region, whereas fiber posts stress distribution is more concentrated in the cervical region. The metal post caused fractures of teeth in a vertical fashion, rendering the tooth unrepairable. The fiber post on the other hand caused fractures in the cervical region rendering a possibility for repair. Because of this ability to repair, researchers and developers then concentrated on fiber posts to improve its flexural strength. Although fiber posts have been replacing cast posts in recent times, they do fail. Post fracture had been identified as one of the reasons for failure of fiber posts (Barfeie et al. 2015). Post fracture had been regarded as a key component in the clinical success of fiber post placement in dentistry. The clinical reality is that tooth preparations without a ferrule as discussed further in the paper has a poor prognosis and should not be restored.

1.4 Types of posts

1.4.1 The background

Endodontic treatment not also results in the loss of dental tissue and ablation of tooth structure, but also depletion of mechanical resistance of the dental tissue (Reeh, Messer and Douglas, 1989). The principal purpose of an endodontic post is to support a core and provide foundation for the crown in a tooth that has endured considerable loss of crown structure (Schwartz and Robbins, 2004). Posts are used to enhance core retention and to render tooth support (Figure 1). Bandlish et al., 2006 argued that the amount of reduction in tooth strength following root canal treatment is debatable. It is argued that root canal treatment does not strengthen the tooth and hence it is important that tooth structure be preserved as much as possible in restoring non-vital teeth. Furthermore, dental caries together with access opening preparation also resulted in defective tooth structure (Zhu et al. 2015; Valandro et al. 2006 and Plotino, 2007).

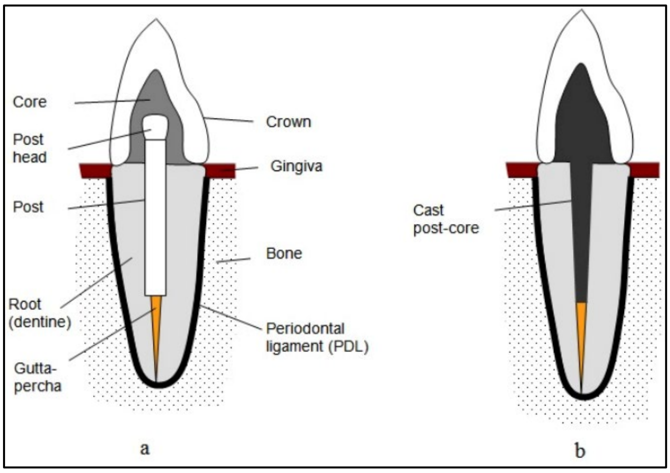


Figure 2. Diagram showing post and core in the root system (Rosenstiel, 2016).

An important factor considered was the size of the lesion that necessitated endodontic therapy. This lesion led to pulp pathology and leakage from the chamber top, which connected the cusps. The chamber top or roof distributed the masticatory and functional stresses over the whole tooth surface (Howe and McKendry, 1990; Helfer et al. 1972). Taking into account dentine dehydration and variance of the alignment and pattern of the collagen fibers, the outcome was the reduction in the strength of the tooth following root canal treatment. (Wagnild and Mueller, 1998; Ferrari et al. 2004).

1.4.2 Post classification

Caputo and Standlee (1987) categorized post designs into three basic combinations:

1. tapered, serrated or smooth-sided, cemented into a post space prepared with a matched-size post drill,
2. parallel-sided, serrated or smooth-sided, cemented into matched cylindrical channels prepared by a post drill and
3. parallel-sided, threaded and inserted into pre-tapped channels.

They stated that the axial form is either tapered or parallel, and the surface can be smooth, serrated with or without vents, or threaded using taps or self-threading.

Dallari et al. (1999) introduced different types of posts for the restoration of the endodontically treated tooth.

He tabled posts to be categorised as:

1. Intrinsically retentive metal posts,
2. Passively retentive metal posts, and
3. Non-metal passive posts.

In general, parallel-sided posts were more retentive than tapered posts, and threaded posts were more retentive than cemented posts. With respect to their installation mode, all posts were referred to as either active or passive. Active posts engaged dentine within the root canal space and transfer more stress to the remaining root structure. Passive posts, even though they did not engage dentine in the root canal space, still transferred stress to the remaining root structure, but to a lesser extent. Scwartz and Robbins (2004) added to the conversation that posts can be classified as active or passive, parallel or tapered and by material composition (Figure 2).

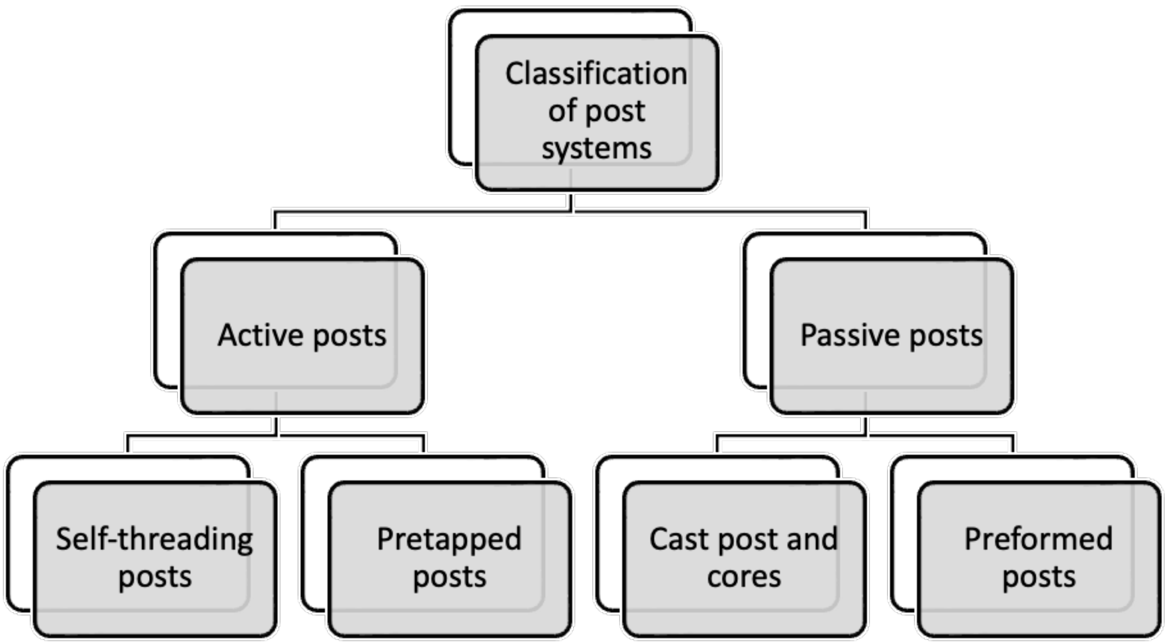


Figure 2: Classification of post systems according to retentive mechanism (Scwartz and Robbins, 2004)

1.4.3 Active and passive post systems

Based on the method on placement of the post and its engagement to the root surface, they can be divided into active or passive posts

1.4.3.1 Active Posts

1.4.3.1.1 Self-threading and pre-tapered posts

Self-threading posts consist of an effective sharp thread that pierces into the endodontic wall as it enters the canal. The shape of the post is such that the diameter is bigger than the canal itself. An instrument with a sharp thread is used to prepare the post for the canal. The post then gets inserted and followed the path that was outlined by the device. One of the benefits of threaded posts is that it grips into dentine wall and produces better retention that passive posts.

In spite of that a lot of pressure is applied on the endodontic wall, which consequently increases the risk of vertical root fracture during the threading action or functional load (Soares et al. 2013).

1.4.3.2 Passive posts

1.4.3.2.1Cast Post and Cores

Metal alloy has a modulus of elasticity ten times higher than natural dentine, which creates stress in the stiff roots which consequently can lead to root fracture (Terry and Swift, 2010). Another drawback is the fact that the metallic post can show through the cervical part of the tooth resulting in discolouration and darkening of the gingiva. This procedure also requires two appointments and the patient also needs to pay the laboratory cost. Researchers also found that custom cast posts rendered better the traditional custom-cast post and core provided a better structural conformation to expanded and ovoid canals with the least tooth structure disposal (Smith, Schuman and Wasson, 1998). Rosenstiel, 2016 wrote that metal post and cores adhere better to tapered, non-circular cross sectional and/or irregular structured canals as well as root with very little coronal tooth structure. The authors concluded in their studies that this system had overall a good outcome with loss of retention the primary reason for failure.

1.4.3.3 Preformed posts

Prefabricated posts are categorised according to their design and contour. They depend heavily on method of retention for success. Their designs include active and passive posts and can be tapered - serrated; tapered – smooth sided; tapered - threaded; parallel - serrated; parallel – smooth sided; and parallel - threaded. Active posts generated stress when placed inside an endodontic canal, because it comes into contact with the canal wall. Passive posts on the other hand does not come into contact with the canal per se, but rely on cement for retention. Clinicians also found that active posts generate more stress during functional load and hence were more susceptible to root fracture. Metallic prefabricated posts are mainly made of titanium alloys and stainless steel. Stainless steel is stronger, but renders the recipient to adverse tissue reactions to the nickel. As a result of the adverse tissue effects titanium had become the material of choice for cast posts (Christensen, 1989). In conclusion the parallel serrated post was found to be more retentive, with the tapered smooth post the least retentive of all the configurations (Terry and Swift, 2010).

1.4.3.4 Non-metallic posts

The non-metallic prefabricated posts had been created as a possible substitute to the metal post and core system. It included ceramic (zirconium oxide) and fiber-reinforced composite resin posts (Figure 3). Zirconium oxide posts showed an enhanced flexural strength, are biocompatible and corrosion resistant. Unfortunately, it has a drawback in the sense that it is difficult to cut intra-orally and retrieval from the endodontic canal seems also a challenge (Asmussen et al. 1999). The fiber-reinforced composite resin post-and-core system rendered some positivity. It provided a one visit method, no laboratory costs, no corrosion, the majority of the time non-catastrophic root fractures, no specified opening size, preservation of tooth structure, enhanced retention due to surface roughness and enhanced aesthetics.

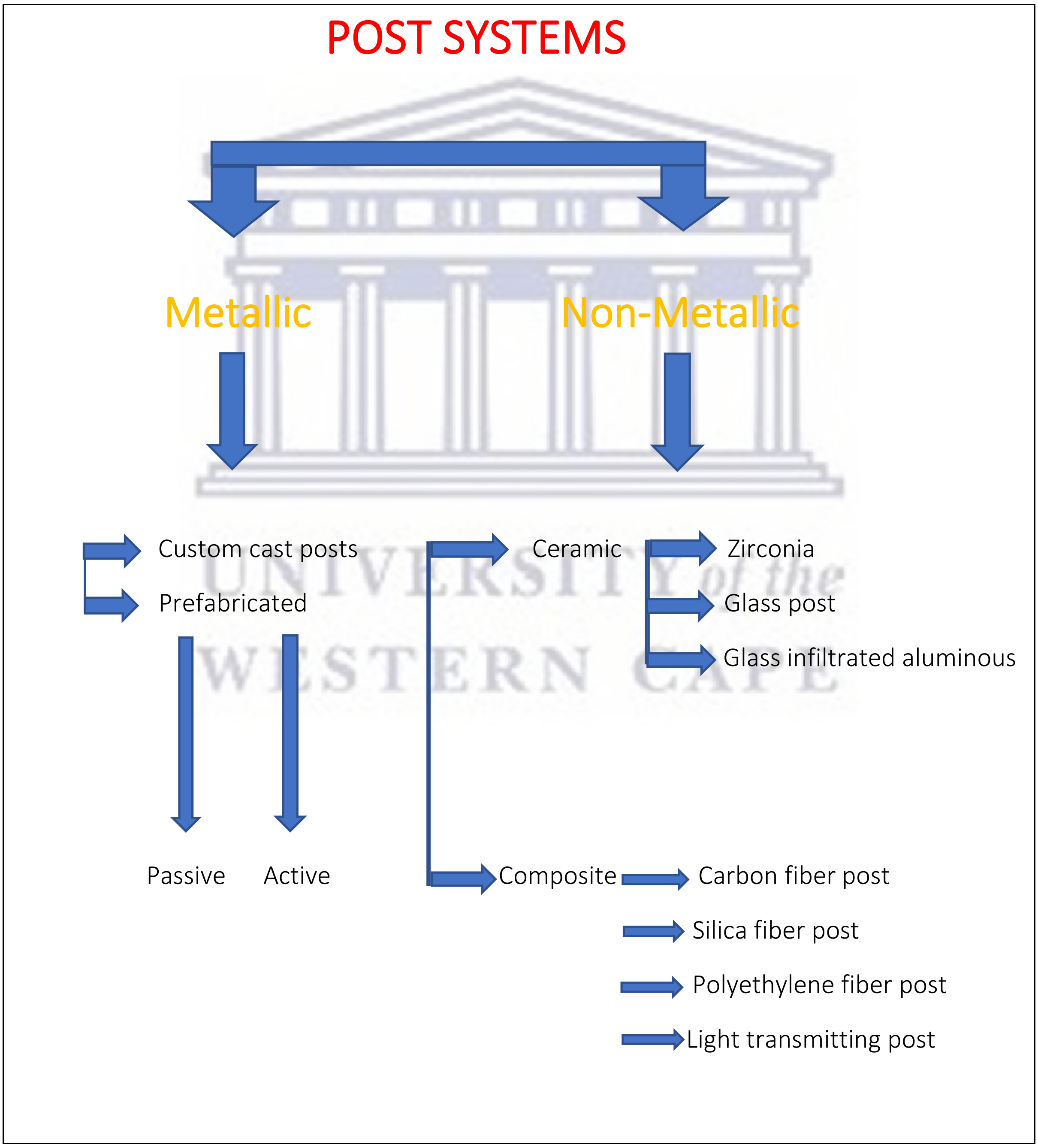


Figure 3. Classification of post systems

1.4.3.5 Ceramic zirconia posts

Partially stabilized zirconium dioxide ceramics was introduced to dentistry towards the latter part of the 1980's. The material presented with superb chemical stability, physical properties and excellent aesthetics. It also showed excellent light transmission capabilities and superior radiopacity (Figure 4). Zirconia posts had a greater elastic modulus, around 200 GPa, which led to many root fractures consequently (Segal, 2001). Zirconia posts were also found to be very stiff and fragile and if the need arose to redo the root canal treatment, the procedure to remove the post would have been a difficult one (Segal, 2007; Mannocci, 1999a and Quintas et al. 2000). Shetty et al. (2013) advocated that zirconium dioxide be used in conditions where there is severe tooth loss and destruction. Zirconia dioxide was the material of choice when the need arose to better the bond strength of the post. The treatment was to be fulfilled with the use of resin cements, pre-treatment of the surface with particle abrasion and finally silanization.

Figure 4. Diagram showing zirconia post and core (Koutayas and Kern, 1999).

1.5 Composite fiber reinforced posts

Recently, fiber posts were introduced and since having been popular in clinical practice. There a variety of posts available based on their composition, as follows:

i) Carbon fiber posts

ii) Prefabricated glass and quartz-fiber posts

iii) Individual glass fiber posts

iv) Polyethylene fiber posts

v) Hollow fiber posts

vi) Monoblock posts

vii) PEEK Posts

1.5.1 Carbon fiber posts

Carbon fiber post are darker in colour (Figure 5), which makes it difficult to camouflage the material under composite restorations or all ceramic prosthesis. It can therefore, not be fully categorised as an aesthetic post. Manufacturers overcame this issue by coating the post. Carbon fiber posts also showed poor radiopacity and adhesion to composite cores (Standlee and Caputo, 1992). Some of the advantages of carbon fiber posts included great mechanical properties, such as high fatigue resistance, increased impact resistance and shock absorption. It showed to have a low modulus of elasticity, close to that of dentine, ranging from 18 to 42 GPa. It has also shown great ease of manipulation.

Figure 5. Diagram showing types of fiber posts: from left to right, carbon fiber post, two quartz fiber posts and glass fiber post on the right of picture (Ricketts et al. 2005).

1.5.2 Prefabricated glass and quartz-fiber posts

These posts are manufactured using quartz-fibers and prestretched silanizated glass which is kept together in an epoxy-polymer or methacrylate resin. It shown to have a great degree of conversion with a structure that is intricately cross-linked that keeps the fibers together (Trabert et al. 1978). The primary function of the fibers was to render stiffness and strength. The polymer matrix served to transmit the load to the fibers and guarded them from wet conditions of the intraoral cavity (Sorensen and Martinoff, 1984). They had shown to be aesthetically pleasing, very good fatigue and flexural strength, shown to have great handling capabilities, it is biocompatible, the modulus of elasticity is close to that of dentine, fairly priced and can be fairly easily removed when it is required (Figure 5). Many clinicians now opt for these posts as a means of prosthetic restoration of endodontically treated teeth. However, more research is still needed as research evidence for carbon-fiber posts far exceeds that for quartz-fiber posts (Bateman et al. 2003).

1.5.3 Individual glass fiber posts

Added to the benefits of prefabricated fiber posts, was the introduction of a new innovation of distinctively formed fiber reinforced composite (FRC) posts shown in figure 6 (Dallari and Rovatti, 1996). This concept allowed clinicians to reduce the unnecessary removal of root dentine, allowing for extension of the amount of FRC material to the coronal part of the endodontically treated tooth. This way of treatment reduced the stress further down at the apex, it saved dentine and allowed fracture resistant and stiff posts with larger diameters to form strong connection with the core. The matrix of the glass fiber posts was very sticky and the fiber were inclined to separate. It is for these reasons that an inexperienced dental clinician found it difficult to use this product. On the positive side individually, manufactured glass fiber posts in contrast with prefabricated glass fiber posts presented with more flexural strength and fracture resistance as well as enhanced interfacial coherence of cement (Paul and Scharer, 1997).

Figure 6. The Parapost Fiber White post. (Courtesy Coltène/Whaledent AG, Altstatten, Switzerland.)

1.5.4 Composition of a Fiber Post

Composite materials seemed to make out the bulk of fiber-based posts currently available on the market. They comprised of prestretched fibers of silica or carbon bounded by a matrix of polymer resin. Fiber-reinforced post systems contained a high-volume percentage of continuous fibers embedded in polymer matrixes, which are commonly epoxy polymers with high degree of conversion and a highly cross-linked structure that bound the fibers (Akkayan and Gülmez, 2002). The predominant of the fiber-reinforced posts contained epoxy resin or bis-GMA matrix along with some fillers (Drummond et al. 2003). Carbon fiber posts were prepared from unidirectional and continuous carbon fibers in an epoxy resin matrix (Hedlund et al. 2003). Some drawback of carbon-fiber posts provided desired aesthetics with all-ceramic restorations resulted in the manufacturing of translucent and tooth coloured silica-fiber posts. These were also called glass-fiber and quartz-fiber reinforced posts. Glass fiber posts could contain different types of glass, such as E-glass (electrical glass), and S-glass (high-strength glass). Electric glass fibers contained silicone dioxide, calcium oxide, boron monoxide, aluminium oxide and a few other oxides of alkali metals in its amorphous phase. Furthermore, glass fiber posts could also be made from quartz fiber, which is pure silica in a crystallized form according to Lassila et al., 2004, providing a better aesthetic result. Manufacturers suggested that these posts could hold similar biomechanical properties as carbon-fiber posts (Cagidiaco et al. 2007).

1.5.5 Resin Base Materials

The production of aromatic monomer bisGMA (bisphenol A glycidyl methacrylate) brought about a transformation in the form of dental resin composites. They had been widely in use as matrix component (Asmussen et al. 1999). BisGMA based material had been placed under the microscope, since many discussions were in progress to determine whether it is safe or not to use in clinical dentistry. Bisphenol A, a contaminant in the bisGMA resin-based materials, is believed to produce allergic reactions or induce estrogenic effects (Söderholm and Mariotti,1999). Nonetheless, as in the case of fiber post, the end product might be spared from the contaminants. BisGMA had been generally used as a resin base material for the glass fiber post. According to Bateman et al., 2003 these glass fiber posts have been reported to have flexure strength in the range of 453-936 MPa.

Epoxy resins are thermosetting polymers mainly utilised as a matrix material in fibrous composites. Various fields as in adhesives, paints, coatings, medical implants, and electrical devices make use of it. Epoxy, also known as polyepoxide, was created by the reaction of an epoxide (base) with polyamine (reactor). Epoxy resin is extensively used as the resin base for the dental fiber posts. Other material used for the resin base, bis-GMA (bisphenol A glycidyl methacrylate), based glass fiber posts were compared by Soares et al., 2008 with epoxy resin-based carbon fiber post. They observed that the glass fibers deformed more than carbon fibers because of their lower modulus of elasticity. Hence, the carbon fiber post system could function superiorly. Over and above that, the matrix took in the advancing stresses right through the post system. The fiber configuration in fiber-reinforced composite posts provided high tensile strength, at the same time the resin matrix stood up to compressive stresses (Ferrari et al., 2000). Conventionally factors such as volume fraction, direction of the fibers, proportion of the fibers impregnated into the matrix resin, the polymerization shrinkage of the resin, the bonding between the matrix resin and the fibers and the individual properties of the fibers and the matrix, played a role in the mechanical strength of the fiber posts (Bateman and Ricketts, 2003). On the contrary, structural defects such as voids, cracks, or micro bubbles in the fibers and the matrix, resulting during the construction process, weaken the post (Soares et al. 2008). In view of the fact that the resin matrix is less resistant to tensile stress, it breaks first. Breakdown of the restoration in root canal treated teeth is reportedly a consequence of the fatigue process.

1.5.6 Polyethylene fiber posts

Polyethylene fiber posts is a composite laminated root canal post and core system held together on an interlaced attachable band. Plasma coated ultra-high molecular weight polyethylene fibers are entwined into a three-dimensional network, triaxial braid or leno wave. The cross-linked strings provided an enhanced mechanical engagement. The fibers were treated with cold gas plasma beforehand reducing the surface tension. This was to ensure better chemical bond to resin products. The polyethylene-reinforced resin rendered ample retention to ensure success for the post and core system. The fracture resistance of the fiber was also very good, which enabled the tooth to withstand occlusal load, which might have led to catastrophic fractures. Polyethylene fibers shown excellent translucency. Producers of this product claimed that it is stronger than fiberglass. Furthermore, the polyethylene fibers had shown to have impenetrable sewn threads prohibiting the fibers from repositioning when handled and conversion before polymerization (Belli and Eskitascioglu, 2006). These properties allowed polyethylene fibers to be deformed and intertwined to allow for dense mechanical mesh from one thread to another. These fibers had been found to demonstrate an enhanced elasticity coefficient and an enhanced resistance to expand, bend and grip. This characteristic allowed them to conform firmly within the endodontic canal, subsequently enhancing the volume of the fiber post. This led to very little usage of bonding cement and polymerization shrinkage. The fibers conformed to the endodontic canal, which subsequently meant there is no longer a need to make the endodontic canal larger. This inevitably meant that more tooth structure could be conserved. The latter could prevent root perforations. One great characteristic of polyethylene fibers was that the polymer was strengthened in all direction rendering the mechanical properties independent of any direction. The interlaced fiber network positively affected the fracture resistance. Occlusal load created breaks, but halted at the node of the leno latch-stitched network. This resulted in the avoidance of the spreading of the crack from the prosthesis to the tooth, assisting in the integrity of the fiber network (Karbhari and Strassler, 2007). Erkut et al. (2008), differentiated between polyethylene fiber and reinforced fiber posts, including glass fiber posts and found that when dual-cured resin cement was used to cement the posts, polyethylene post had shown the smallest number of microleakage in over flared endodontic canals. Polyethylene fiber posts exhibited enough retention for post and core treatment to be successful (Singh et al. 2012). It has enough resistance to fracture to facilitate more non-catastrophic fractures of endodontically treated teeth (Aggarwal et al. 2012). The only drawback of these fibers was their cost. Polyethylene fibers are costly, which restricted their usage in day-to-day dentistry, in spite of their outstanding characteristics (Amizic, P.I and Baraba, A. 2016). Figure 7 shows Ribbond as an example of a polyethylene fiber post.

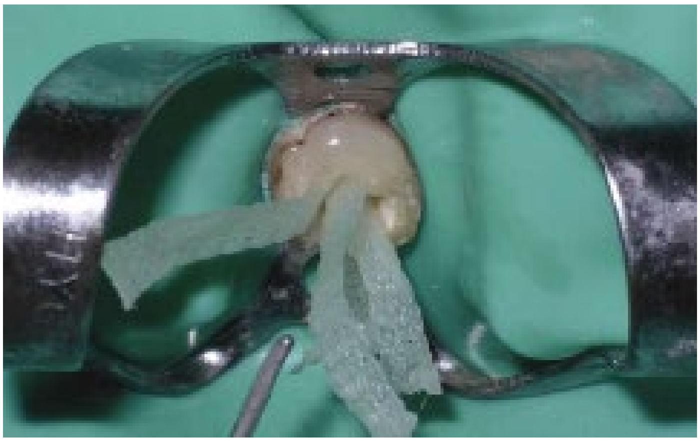


Figure 7. Ribbond above is an example of a polyethylene fiber post. It is introduced into the canal with a resin cement. (Belli and Eskitascioglu, 2006).

1.5.7 Hollow fiber posts

As a consequence of polymerization shrinkage and compression deficiencies, voids and gaps and cavities may occur at the interface between the dentine and restorative material or at the interface between the post and the restorative material. The primary reasons for the development of voids in restorative material is the viscosity of the restorative material, the shape and anatomy of the endodontic canal and the way the post is inserted (Vichi et al. 2002). Inaba et al. (2013) manufactured a new direct core build-up technique, which entailed the preparation of a channelled Fiber Reinforced Plastic (FRP) post. The restorative material was injected into the concavity of the post at the apical part of the root canal. Inaba et al. (2013) studied the distortion properties of the prepared hollowed post and collated it with those of more rigid and commercially accessible fiber posts. They analysed the pull-out strength and the distribution pattern and number of voids in the main body. The researchers reported that their new cylindrical FRP post included a new direct core build up technique, which reduced the number of voids in the emerging build up core body. The hollow root canal post permitted the inversion of the bonding cement preventing the formation of air bubbles (Gallicchio et. al.

2022). This technique improved the bonding strength between the restorative material and the FRP post. The result was that the pull-out strength was enhanced in contrast with the conventional technique. In addition, the number of voids in the restorative material were reduced. This technique shown to be precise and an accurate direct technique of core build up for clinical practice, due to the fact that it was basically unaffected by the viscosity of the restorative materials, the structure of the endodontic canal and the ability of the clinician.

1.5.8 Monoblock posts

Fiber posts can be further divided into two categories: translucent and non-translucent posts based on the material composition and fibers. Quartz fiber posts are highly translucent whereas posts without fibers in the matrix are non-translucent (Pennaaccio et al. 2020). Generally, posts take on the shape of the inner root canal anatomy. This is in order to achieve a better fit within the root canal. Researchers thought it best to even further improve on the fit of fiber posts in the endodontic canal. Recently a new type of post was introduced to the dental world, Edelweiss Post, (Edelweiss Dentistry Products GmbH, Wolfurt, Austria. This post had a shape resembling the coronal part of the abutment pursuing to simplify the steps in building up the core or the tooth (Figure 8). The coronal part resembles the core part of the tooth. The Edelweiss Post is made of a resin composite and does not contain any fibers. The Edelweiss Post and Core material consisted of barium glass, strontium glass and zinc oxide nanoparticles impregnated into a resin matrix. Zinc oxide provided antibacterial properties with the crystals sintered into a monoblock (Srivastva, 2020).

Edelweiss posts have shown to have the following advantages (Paul et al. 2018).:

1. The post is translucent, which allowed for light to polymerize the apical area of the post.
2. The monoblock which formed the post and core could be built up with composite resin allowing for blend of the post and resin material.
3. The monoblock prevented the wedge effect.
4. It had shown to be biocompatible.
5. It had shown to have flexural strength of 20GPa similar dentin (15 - 20 GPa).
6. It is radio-opaque.
7. It had been shown to cut like dentine.
8. It shown good bonding capabilities to the endodontic canal.
9. The usage of monoblock required one session, which in turn reduced operator time,
10. The monoblock had been shown to be time sparing and economical in its usage

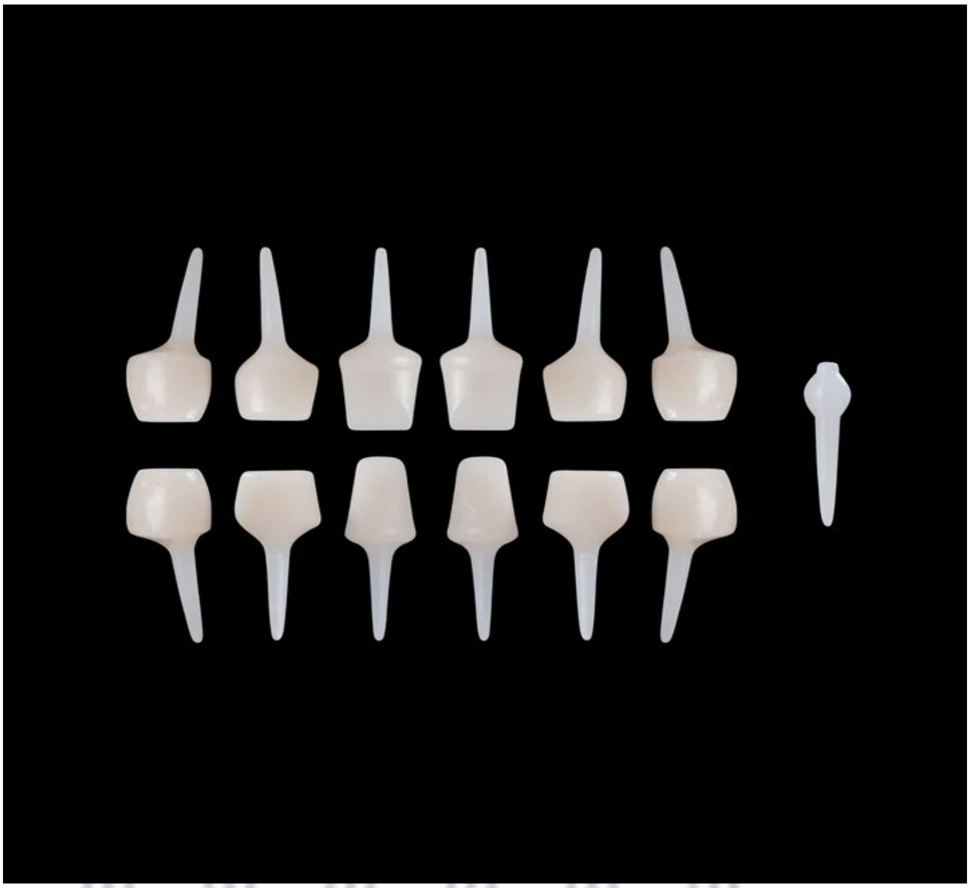


Figure. 8. Edelweiss Posts (Edelweiss Dentistry Products GmbH, Wolfurt, Austria).

The process of sintering occurred when crystals are heated to temperatures near their melting points. The result is a rapid increase of density during the sintering of single phases. The increase of density can be explained by volume diffusion of vacant lattice sites or surface migration of atoms and also involves the macroscopic flow. The driving force for this flow is surface tension, and an equation connecting the rate of shear strain with the shear stress defines the resistance to deformation (Mackenzie et al. 1949). The crystals are fired at intervals ranging from seconds to hours at temperatures ranging from 400 to 1000 degrees Celsius (Cheung and Darvell, 2002). The Edelweiss Composite Post is manufactured via a laser sintering process. The laser sintering process is believed to be advantageous in improving the mechanical properties of the post, including reducing porosity. Pitzer and Brewer in 1961 wrote that porosity lessens with sintering time, and with higher temperatures, as compressed gases escape by diffusion through the resin matrix, driven by the dissolution occurring under the Laplacian excess bubble pressure according to Henry's Law, especially as the viscosity of the matrix declines REF. The sintering process results in a closer bond between the barium and silica glass and the resin matrix.

1.5.9 PEEK Posts

Polyetheretherketone or PEEK is a sophisticated and well-functioning polymer that is the latest addition to the dentistry inventory. PEEK in its adapted state contained 20 percent ceramic fillers and showed enhanced mechanical properties with outstanding biocompatibility (Sarot et al. 2010; Seferis, 1986 and Rivard et al. 2002). It had been applied in the manufacturing of removable and fixed dental restorative devices and implant restorative devices (Zoidis, Bakiri and Polyzois, 2017). PEEK had been implemented in the usage and manufacturing of restorations by Computer Aided Design and Computer Aided Manufacturing (CAD-CAM) technology and injection moulding procedures.

Advantages of PEEK posts

1. PEEK had shown to have an elastic modulus of 4 GPa, with elasticity close to bone. It had been shown to act as a decompressor. This allowed for less stress been transferred to the prosthesis and natural tooth structure
2. Eradication of allergic reactions,
3. Excellent wear resistance,
4. Excellent polishing characteristics,
5. Reduced plaque adhesion,

6. It is radiolucent, which could help in caries diagnosis

Disadvantages of PEEK posts

1. Microleakage
2. Management of fatigue loading is uncertain,
3. A need exists for occlusal modifications,
4. PEEK showed difficulty to polish following cementation and produced a lacklustre appearance (El-Damanhoury et.al.2015; Adler et al. 2013 and Rzanny et al. 2013).

1.5.10 Biological posts

Biological posts were introduced as a comparable option to improve intraradicular root canal treated teeth on the account of its natural acquired characteristics (Swarupa et al. 2014). They were produced from naturally removed teeth. Biological posts helped in underpinning intraradicular dentine.

Advantages

1. It attained a monoblock outcome,
2. Dentine load was reduced,
3. The dentinal walls of the endodontic canal were kept intact,
4. Manifested high biocompatibility with enhanced tooth strength and retention of the posts in relation to pre-constructed posts.
5. It showed toughness in relation to the initial tooth.
6. It had shown higher degree of bonding to the tooth structure and composite material and at reduced price (Galindo et al.2000; Kaizer et al. 2008; Osborne, 1985 and Cândido et al. 1999).

Disadvantages

1. It was a laborious task to find a tooth of comparable shade and profile as that of the broken tooth.
2. Patient disapproval to receive a part of a tooth procured from another patient. This ultimately would led to the patient not receiving the prosthesis (Swarupa et al. 2014).

1.6 Indications for post placement

The purpose of a post is to support a core and provide foundation for the crown in a tooth that has endured considerable loss of crown structure. The decision regarding post placement should be made based on the position of the tooth in the arch, the amount of coronal remaining tooth structure, and the functional requirements of the tooth (Figure 9).

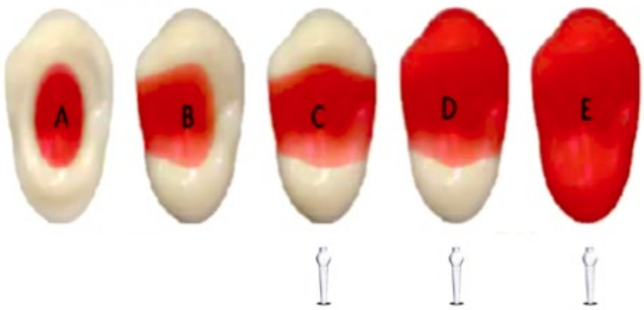


Figure 9. Diagram indicating when a post is needed according to Peroz (2005). In C, D and E where more than 3 walls are missing then a post is needed.

Goodacre and Spolnik (1994) alluded to the fact that posts were selected primarily to retain a core in an endodontically treated tooth which had undergone great loss of coronal tooth structure. Restorative intervention comes with its own risks, which may include root perforations and fractures of the root, that might necessitate further tooth loss or treatment failure. Felton et al., 1991 reported that post retention is affected by the length of the post, taper and diameter, luting material used and whether a passive or an active post is used.

Heydecke et al., 2001 have also shown that posts do not toughen root canal treated teeth. Clinical trials have shown that teeth prepared with ferrules tend to fail in a favourable manner (Stankiewicz and Wilson, 2002 and Al-Hazaimeh and Gutteridge, 2001). Furthermore, metallic or cast posts were stiff and cause a greater percentage of failures producing teeth that are unrestorable (Akkayan and Gülmez, 2002). Post resistance was also affected by the residual tooth structure, the length of the post and rigidity, whether an anti-rotation groove and a ferrule had been placed (Mezzomo et al. 2003). The manner in which the restored tooth failed was affected by the resistance of the post placed. It is with this in mind that fiber posts were created to overcome some of the deficiencies and limitations of metal posts.

It had been reported that teeth restored with fiber post, which have a modulus of elasticity close to dentine, tend to have failures that can be restored (Salameh, 2008). Following the results of the clinical trials, a rapid influx of fiber posts into the dental clinical world had occurred. Hence the need for a systematic assessment of their mechanical properties and clinical performance.

1.7 Contraindications for post placement

- Posts cannot be placed in teeth where root canal treatment had failed.
- Posts cannot be placed in teeth with inferior and problematic restorative outcome. In instances where severe destruction of teeth has occurred and the placement of a ferrule is not possible, the restorative success will be diminished (Peroz et al. 2005).
- Where teeth had shown an enlarged mobility.

▪ Where teeth had shown weakened roots. Anomalies of the roots might give rise to weakened residual dentine. Thicker fiber posts reduced the residual dentine thickness, which in effect enhances the root perforation rate (Qiu et al. 2023).

▪ Teeth that had shown to have had enough residual tooth structure, where placement of a post was unnecessary. This was in instances where all four axial walls are present and the thickness is more than 1mm. It this instance it was not necessary to insert a post (Peroz et al.2005).

1.8 The importance of fiber posts in restoring the endontically treated tooth

Fiber posts have made a significant contribution to dentistry over the recent decades (Duret et al. 1990). Fiber posts were introduced to dentistry in the early 1990's. Santis et al.(2000) added to the investigation by means of Finite Element Analysis (FEA) of three-dimensional models that, high-density materials such as metal posts resulted in an inhomogeneous stress distribution. Bateman et al. (2003), argued that rigid metal posts were able to resist lateral forces without distortion resulting in a significant stress transfer to the less rigid dentine, with subsequent root fracture. Ferrari and Scotti (2002) found the primary advantage of fiber posts to be their modulus of elasticity with reference to their loading direction, especially transverse loading. They found that fiber posts have a modulus of elasticity close to dentine. This was beneficial in the sense that it reduced stress transmission to root canal walls and thus reduced the risk of vertical fractures.

Fiber posts comprise of uninterrupted, unidirectional fibers lodged in a resin matrix. They are manufactured through a semi-automated industrial process named pultrusion (Grandini, 2005). Pultrusion is an uninterrupted process for production of composite materials with constant cross-section. In contrast with extrusion, which pushes the material, pultrusion works by pulling the material. The quality of the posts and its mechanical properties were influenced by the diameter and density of the fibers as well as the adhesion between the fibers and the matrix. Fibers were pre-treated with a silane-coupling agent to expedite a chemical bond with the resin matrix and to connect them smoothly. Silane had been identified to be an important component during the pultrusion process in enhancing the stability of the system. The resin matrix, in many instances epoxy, was introduced into the pre-stressed fiber bundle to pack the spaces between the fibers. Another cause of action was to soak fibers in a bath of resin. Grandini et al (2005) wrote that many differences in manufacturing were related to the quality, mechanical and clinical behaviour of posts. The high density of fibers, lack of internal defects and strong bond between fibers and matrix enhanced the quality and performances. A wide variety of posts are available and include, parallel-sided, smooth, tapered, and serrated types. Carbon, silica, glass fiber and quartz make up the different types of posts available in clinical dentistry. Carbon fiber posts were the first to be used as a replacement for metal posts. Dark fiber posts were replaced by translucent fiber posts (glass or quartz), this also resulted in improved aesthetics (Ferrari et al.2000). Translucent fiber posts today are better accepted than carbon enriched posts. This is particularly true when restoring teeth in the anterior region, where a ceramic crown will be restorative material of choice. They also allow for light to pass through allowing adhesive cement to be polymerized. The newer posts on the market do not seem to differ with regard to mechanical behaviour from carbon posts (Grandini et al. 2005). Adhesive and luting cements will be discussed in more detail under the heading biomechanical considerations.

1.9 Comparing post and core systems

Fiber post have flooded the market, since its inception into dentistry and controversy still exists on the choice of post system to be used and decisions quite often is based on operative experience rather than scientific evidence (Magne, 2017).

1.10 Fracture resistance of post systems

An ideal post and core system should render enough retention to the final prosthesis, providing sufficient fracture resistance and subsequently protecting the remaining tooth structure. Clinicians are looking at fracture resistance of posts seeking for the perfect post and core material. Resistance of post restorations is related to failure mode. Clinical failures occur with all post systems, but some post systems result in a more catastrophic failure of tooth structure. When it comes to failure loads and failure modes fiber post systems are often compared to those of metal and ceramic post systems.

Metal post systems shows a higher failure load than prefabricated fiber reinforced post systems. Ceramic post systems show a lower failure load. Significantly, more failures that are favourable occurred with prefabricated fiber reinforced post systems than with metal post systems. Martinez-Insua et al. (1998) in a study on single rooted premolars restored with custom made cast parallel post and core or carbon fiber post and composite core, showed that the cast post and core withstood higher flexural loads, but a significant amount of fractures involved the teeth. Asmussen et al., 1999 showed that carbon fiber posts have a modulus of elasticity closer to dentine than metal posts. Ferrari et al., 2000 reported on a load that was applied to carbon fiber posts, which yielded a modulus of elasticity of 21GPa compared to dentine of 18GPa. It also had a higher resistance to fracture under repeated loading than metal posts. The author concluded that the less stiff carbon fiber post provides a more even distribution of stresses in the tooth and are thus less likely to cause root fracture. Akkayan and Gulmez (2002) found that metal posts demonstrated the least resistance to flexure loads and the most catastrophic fractures. Higher fracture resistance was observed in teeth when quartz fiber posts were used. The mean flexure load of glass fiber posts and zirconia oxide posts did not differ. However, it was significantly higher than the loads obtained for metal group and lower than the results obtained for the quartz fiber posts. The author noted that all specimens with zirconia oxide posts fractured. The mode of fracture showed that the glass fiber and quartz fiber posts fractured favourably, suggesting that the tooth or fracture could still be repaired. The zirconia oxide and metal posts all rendered catastrophic fractures (Akkayan and Gulmez, 2002).

Drummond and Bapna (2003) suggested that cyclic loading *in vitro* was representative of the forces that occur *in vivo*. Investigations into intermittent loading of quartz fiber, carbon-quartz fiber and zirconium dioxide ceramic root canal posts revealed that more than half of the zirconium dioxide root canal posts fractured. The results of the study also showed that quartz fiber and carbon-quartz fiber posts were able to reduce the risk of root fractures of teeth restored with composite crowns and Empress crowns under cyclic loading in a wet environment. The root fractures observed were all above the resin block simulating the gingival margin. In a clinical scenario, this would be considered a favourable fracture. The researchers concluded their study and said that teeth with prefabricated carbon fiber posts had significantly higher resistance to intermittent loading than teeth with prefabricated parallel-sided titanium posts or tapered, individually cast posts. Investigations might explain why we ended up with these results, as it was reported that poor adaptation of zirconium dioxide ceramic posts to the root canal walls existed following cyclic loading. Furthermore, good adaptation of carbon fiber posts was found and additionally that the difference in modulus of elasticity of zirconium oxide and dentine might have explained the higher fracture rate observed in the zirconium oxide posts group.

In a study done by Fokkinga et al., 2004 on failure loads and failure modes on fiber, metal and ceramic post and core systems, custom cast post systems showed higher failure loads than prefabricated fiber reinforced composite systems. Ceramic post and core systems also showed lower failure loads. The study found that more favourable failures occurred with prefabricated fiber reinforced composite post and core systems than with custom cast metal post and core systems. Fractures with the carbon fiber posts involved the cores only and were repairable. In a study by Santos et al., 2010 on the impact of fiber posts on the root of the tooth it was found that regardless of the shape of the post, metal posts exerted higher stresses along the palateal-buccal plane than glass fiber posts. Stresses at the post/cement interface changed from compressive (post compressing the cement) to tension stresses (post pulled the cement). The metal posts showed the highest peak values when this change happened.

Stress analysis confirmed that the glass fiber posts, with a lower elastic modulus, leads to lower stresses in the post/cement interface compared to the metal post. The lower elastic modulus of glass fiber posts reduced the risk of debonding caused by lower stresses at the post/cement interface. Upon failure of the post/cement bond, the stresses in the glass fiber post were higher than those of the metal post restored tooth. Nonetheless, the root restored by the glass fiber post would be less prone to fracture, due to the fact that the fracture risks of the composite core and post are higher than those of the root. In a review on post systems Goracci et al., 2011 wrote that fiber reinforced composite posts restorations had demonstrated triumphant survival rates over long follow-up periods. The clinical effectiveness of such restorations has been predominantly ascribed to the fact that fiber reinforced composite posts' biomimetic behaviour reduced the risks of vertical root fractures. The most common type of failure when it came to fiber posts was clinical post debonding. It was generally agreed that intraradicular adhesion of posts to dentine was much more challenging than adhesion to coronal dentine. Clinical evidence suggested that fiber posts were a very good alternative to the use of metal and other tooth coloured posts, such as zirconia, in post retained restorations (Goracci et al. 2011).

The important factors in the success of posts in post-retained endodontically treated teeth included:

1. The conservation of coronal dentinal tissue,
2. The usage of posts with comparable elastic characteristics of that of dentine and
3. Sound post adhesion.

Goracci et al., 2011 reiterated that more studies were needed to understand the bond strength of luting cements, especially resin cements. This led us to the following section on biomechanical considerations and structure of fiber posts. These biomechanical considerations provided guidelines to assist us in clinical decision making.

1.11 Biomechanical considerations and structure of fiber posts

Fiber reinforced post's mechanical properties were based on the kind of fiber post, the kind of matrix presented, the fiber composition and the trajectory of the fibers. The fibers added strength and stiffness to the commonly flexible matrix (Le Bell-Rönnlöf, 2007). BisGMA and epoxy resin were generally used as a resin based medium of fiber posts (Quintas et al. 2000). Quartz or glass particles made up the silica-based fibers of the post. Quartz existed as a crystalline formation of silica. Glass on the other hand existed as a monocrystalline configuration. Galhano et al., 2005 found that greater flexural strength existed with the quartz fiber post than with the glass fiber post. The most predominantly applied reinforced fiber post were S- (stiff, strong) and E- (electrical application). It had been found that glass fiber extended evenly to their rupture mark. When the bending force was removed prior to breakage, the fibers returned to its initial length. E-glass had shown to comprised good compressive and tensile strength, good electrical insulation, not very expensive, but had shown to have rather terrible fatigue resistance. S-glass, with a dissimilar chemical composition, had shown to have had better wet strength retention, higher tensile strength, but had shown to be very expensive (Trushkowsky, 2008). The resin matrix was believed to have handled compressive strength very well right through the post system and the fibers in the post was to have handled tensile strength. Stresses could occur at the silica/glass fiber and resin matrix bond as the fiber post was loaded. These strain on the fiber post developed micro cracks, voids and air bubbles and weakened the post (Manhart, 2009). Condensed fibers in its most uniform distribution of fibers within the matrix system, together with the excellent blend of fibers within the matrix, and elevated level of polymerization of the organic compound and a solid post structure devoid of voids, cracks and air bubbles led to the best quality fiber post you can imagine. Following polymerization, the gaps or spaces were brought to finish by means of a milling procedure. Different post structures existed, which also meant that fiber post surfaces quality variations existed due to the disparities in the milling process. Trushkowsky, 2008 in his study revealed that composite resins had a modulus of elasticity of 5.7-25 GPa and fiber reinforced posts 16-

40 GPa. These capabilities provided enhanced shock protection, shock absorption, reducing of trembling and expanded fatigue resistance.

1.12 Retention factors

Over the years post and core material had been extensively evaluated to see which are the most retentive and the most favourable material that was the least stressful to the encircled dentine. Sorensen and Martinoff, 1984a in a retrospective study reported that parallel sided serrated post showed to be the most successful, in contrast cast post and cores(tapered) showed to have had a high failure rate. Goodacre and Spolnik, 1994 added that the most retentive post seemed to be the threaded post with the parallel sided post not far behind. Non-serrated parallel sided posts or tapered posts had been found to be the least retentive, whereas serrated parallel sided posts had been found to be the most retentive. Cormier et al., 2001 also reported that teeth that were restored by means of core build-up, made up between 3 to 10 percent of all post and core failures. The most dentinal stress was created by the tapered threaded screw in post. Occlusal loading of these posts caused very high internal dentinal stresses (Standlee and Caputo, 1992). It had been reported that when the post length had been increased, the resistance to fracture was also increased; when the diameter of the post had been increased the resistance to fracture was reduced (Cormier et al. 2001). Cormier et al., 2001 reported that tapered cast post and cores showed to be part of more catastrophic failures. It had been suggested by Dallari and Rovatti, 1996 what a perfect intraradicular restorative system should look like. They proposed that the system should include biomechanical attributes of that of natural tooth structures. New products had been developed mainly due to the amalgamation of adhesive techniques into post and core preparations and design. New products such as the "monobloc", the tooth-post and core-crown, exists on the market. It had replaced the multiple components that makes up the post and core and crown that currently exist. The aesthetic make-up of products used in the preprosthetic phase is an important factor considered by dental clinicians. This was particularly important when restorations had been done in the anterior region. Cast posts had been used as a standard for many years, now non-metallic restorations are substituting cast posts in the anterior zone. The past years saw considerable advances in the manufacturing of fiber-reinforced, bondable and ceramic aesthetic posts to improve the restorative structure of root canal treated teeth. In regions where aesthetics was of importance, as in the anterior region, fiber, light conducting and all ceramic posts were available for construction of prosthesis (Paul and Scharer et al., 1997 and Pissis, 1995). These posts showed more or less the same transparency to natural dentine. This characteristic allowed for superb aesthetics in all ceramic prosthesis. In a randomised clinical trial by Bolla et al., 2007 the researchers contrasted metal to non-metal posts. Two hundred participants took part in this study, which revealed that there is a higher chance of failure with metal cast posts compared to that of carbon fiber posts. The authors studied passive metal custom-cast posts and cores (category I), active or passive prefabricated metal post (tapered, parallel or a parallel-tapered combination) and a core built up from amalgam, glass-ionomer cement, resin-modified glass ionomer or composite resin (category II) and in category III they examined a two-element system comprising of prefabricated non-metal post such as fiber-reinforced post or ceramic post, composite resin, a glass-ionomer cement or a resin-modified glass-ionomer core. The results obtained confirmed technical failures by means of post dislodgment, post and root fracture (Bolla et al. 2007).

1.13 Post length

Researchers had found that the post and core prosthesis were forced out due to deficient retention form of the prepared tooth (Sorensen and Martinoff, 1984b; Turner, 1982). This issue was even further problematical due to the regular convergence of anterior teeth and minute tooth sizes. Clinicians reported that rounded, cross-sectional, long posts provided good retention in anterior teeth, but in posterior teeth with curved roots and oval shaped canals it must be evaded. Two or more short posts are better suited in these cases where root canals are divergent. It had been reported that the distance of the post had always been an important factor in the stress dissemination in the root and consequently influenced its resistance to fracture. The retentive capability was closely related to the length of the post. The retentive capability increased as the length of the post increased (Rosenstiel et al. 2016). A consequence of a short post length meant that a risk developed of possible root fracture or even perforation. Clinicians recommended that the length of the post to have been the same as the length of the crown or even longer as seen in Figure 10. The apical seal had been of a concern. Clinicians recommended that by establishing 4-5mm of endodontic material, an endodontic seal would have been established (Le Bell-Rönnlöf, 2007 and Indzhov, 2006).

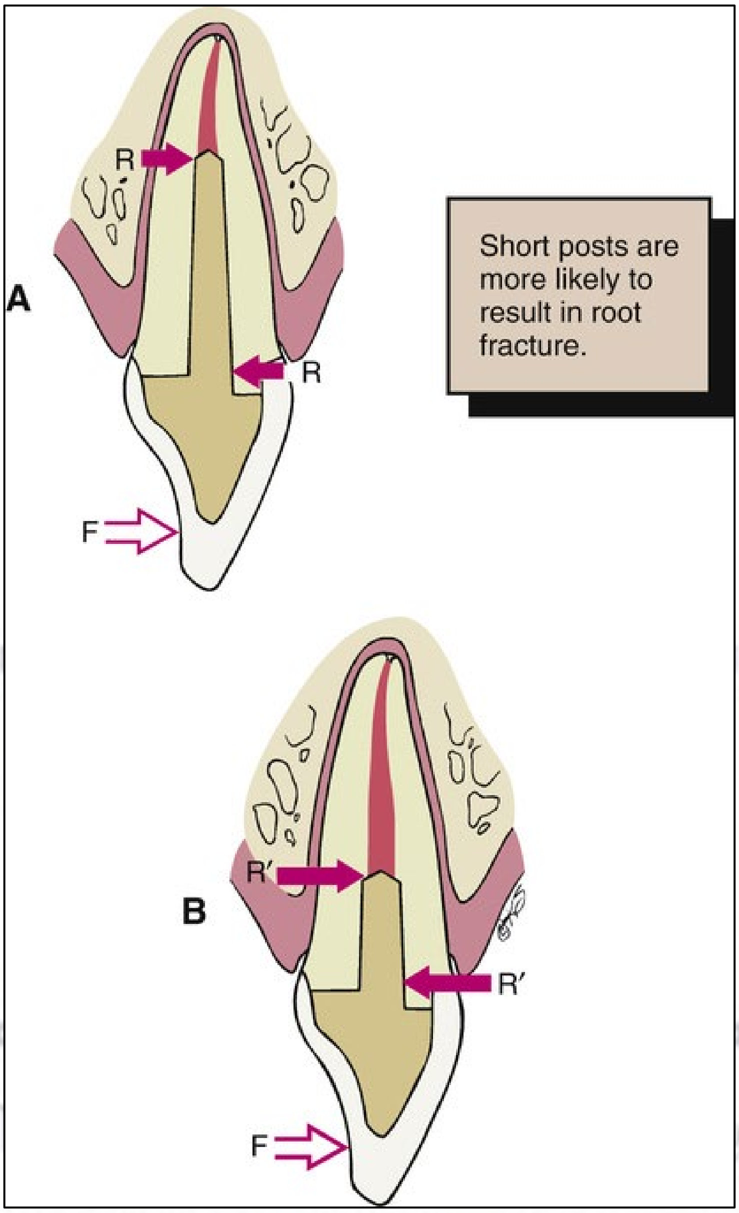


Figure 10. Labiolingual longitudinal slides of a maxillary central incisor. A, a post of the right length, with a force (F) applied near the incisal edge of the crown produces a resultant couple (R). B, If the post is too short, this couple is greater (R′), which increases the possibility of root fracture. (Rosenstiel et al. 2016).

1.14 Post diameter and remaining dentine

Researchers stated that the diameter of the post must be one third of the cross-sectional root diameter as seen at the cemento-enamel junction. Not less than 1mm of dentine must surround the post. Some researchers believed that you get enhanced retention when you increase the post diameter (Krupp et al. 1979). Other researchers had not confirmed the latter (Standlee et al. 1978 and Ruemping et al. 1979). Several factors contributed to reduced dentine thickness of the crown area. These factors included removal of the post, internal resorption and opening needed to attain entry to the apical area. A consequence of diminished thickness of crown wall was a reduction of the ferrule effect. The portion of coronal tooth structure left behind has an effect on the success of restorative dental treatment (Inaba et al. 2013).

1.15 Post surface texture

Ruemping et al.,1979 reported that a serrated or roughened post are more retentive than smooth posts. Researchers also reported that grooving of the post and endodontic canal enhanced the retention of the tapered post (Wood,1983).

1.16 Post design

A successful outcome of the restoration was very much dependable on the design of the post and retention. Parallel-sided posts had been shown to be much more retentive than tapered posts and disseminate stress much more evenly extending across its length during functional load. More taper means a reduction in retention (Le Bell-Rönnlöf, 2007). Post shapes had been found to be conical, cylindrical and combined. Posts had been found to be combined in shape with the cylindrical part more found in the coronal area of the root. The conical part of the post was more found in the apical part of the root, where the tooth structure is smaller in diameter than the upper coronal part (Indzhov,2006).

1.17 The ferrule

The ferrule is a border of cast metal belted and encircling the coronal surface of the tooth. It is believed that it may combat loads resembling dynamic lever forces, also the wedging effect found in tapered posts as well as the lateral stresses produced throughout post positioning (Sorensen and Engelman,1990). Many researchers believe the ferrule to be the dentine on top of the margin, but it is undoubtedly the crown that encircles the natural tooth that defines the ferrule as seen in Figure 11. The existence of a ferrule and excellent structural integrity is a must for clinical application for metal prefabricated and cast posts.

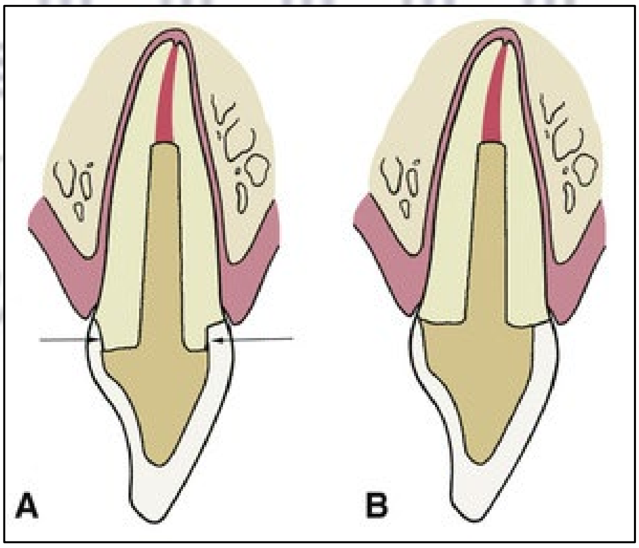


Figure 11. Lengthening of a preparation apically composes a ferrule and aids in the prevention of a fracture of a root canal treated tooth during dynamic movements. A, Construction of a ferrule (arrows). B, Construction without a ferrule.
(Data from Rosenstiel et al. 2016).

Many clinicians noticed the significance of the ferrule in the avoidance of tooth fracture (Isidor et al. 1999). Magne et al., 2017, wrote that the durability of fractured endodontically treated incisors were enhanced by the existence of a ferrule. Kul et al., 2016 reported that prosthetic collapse of root canal treated teeth with a post and lacking a ferrule is probably going to end up in a disastrous fracture. They recommended the ferrule height to be not less than 2mm (Eissmann and Radke, 1987). Researchers evaluated the results of the effects of various ferrule heights (0.5,1.9,1.5 and 2.0mm). The results indicated that 1.5mm ferrule height was the least amount necessary to enhance tooth resistance (Libman and Nicholls ,1995, Stankiewicz and Wilson, 2002). Furthermore, the ferrule effect escalated the post to core ratio, prohibited the bonding cement to corrode and subsequently enhancing post retention. It is believed that the maximum adherence of the post and core to the natural tooth significantly enhanced crown resistance (Hsu et al. 2002). Many considerations existed with regards to the success of the ferrule: ferrule height, ferrule width, number of walls, location of the ferrule, tooth type, lateral loads, type of post and core material type (Jotkowitz and Samet, 2010). The ferrule width is important, since any restorative preparation may jeopardize the dentine wall and contradict the ferrule effect. Walls cannot be less than 1mm in thickness. Furthermore, the caries process may have an impact on interproximal areas as well as abrasion and erosion of dentinal walls. Crown preparation diminished the wall thickness even further with subsequent sectional ferrule effect. Researchers found that a 3mm ferrule on the buccal wall increased the success rate of any preparation and increased the resistance to fracture (Al-Wahadni and Gutteridge, 2003). Ng et al., 2006, suggested that the position of the sound tooth structure to withstand occlusal load was more important than an encircled dentinal wall. Their research indicated that the existence of a palatal wall permitted a maxillary incisor tooth to withstand functional forces. They proved that a maxillary incisor with three walls and without any palatal wall illustrated reduced fracture resistance. This evidence might demonstrate that a sectional ferrule could provide a level of fracture resistance, but might not be absolute as a fully encircled 2mm ferrule.

1.18 Resistance Factors

Post and core prosthesis must be designed in such a way to enhance resistance to lateral aimed forces by spreading them along a huge area as it is viable. Nevertheless, endodontic canal preparation crippled the roots to resulting in a possibility of structural collapse. The primary function of post design should be to disseminate the occlusal load uniformly. Glass fiber posts had shown fewer stress accumulation than metal or ceramic posts, due to the fact that it has shown to have a similar elastic modulus or close to dentine. This concept was named monoblock (Tay and Pashley, 2007). A group of researchers had tested the effects of post design on stress distribution using photoelastic products (Felton et al.1991; Cooney et al. 1986; Mentink et al. 1998; Standlee et al. 1980; Thorsteinsson et al. 1992), strain gauges (Dérand ,1977; Leary et. al. 1989) and finite element analysis (Peters et al. 1983 and Yaman et al.1998). The researchers had concluded

- The most stress focusing were established at the shoulder margins, especially interproximally and the apex. The recommendation was that dentine must be conserved where attainable.
- The expansion of the post length coincided with the reduction of stress.
- Parallel-sided posts might spread stress more uniformly compared to tapered posts, which might have a wedging effect. In contrast parallel-sided posts increased stress at the apical area.
- The creation of sharp angles increased stress during functional loading.

- Parallel-sided posts without serrations or smooth posts were associated with enhanced stress during cementation. This was due to the fact that serrations allow for cement to escape or be vented.
- The cement coating allowed for a uniform spread of stress towards the apical root.
- Glass fiber posts had been shown to involved in less catastrophic fractures. Breakages occurred in the posts rather than the tooth structure (Rippe et al. 2014).

The issue of the post becoming loose or losing retention was also a problem. Preparation of the endodontic canal must prohibit a post with a round cross-section to pivot during functional load. This phenomenon is called rotational resistance. (Figure 12).

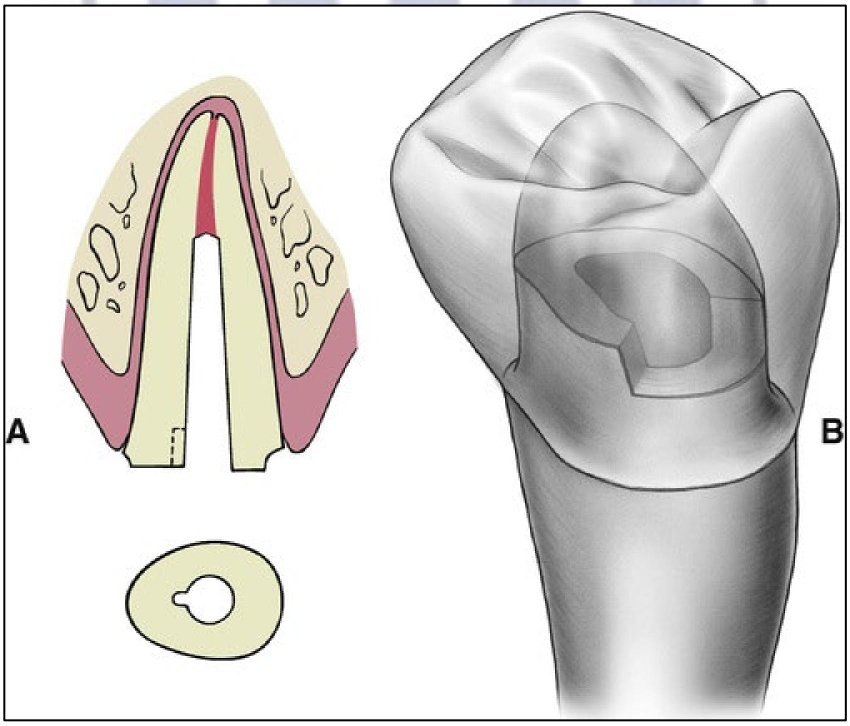


Figure 12. A tiny groove is placed on the inside of the endodontic canal to prohibit rotation of the inserted post (Data obtained from Rosenstiel et.al. 2016).

Rotation of the post does not happen when there is sufficient amount of natural tooth structure left, especially the vertical wall. This tiny groove was placed inside the endodontic canal preparation in cases where coronal tooth structure had been lost. This groove functioned as an antirotational feature and is usually placed in the thicker part of the tooth, namely the lingual surface (Kurer et.al. 1977). Rotational resistance usually does not present a

problem when the remaining coronal tooth structure is sufficient because a vertical coronal wall prevents rotation. The next few paragraphs focused on advantages and disadvantages of fiber posts. This will help us to see whether there exists a biomechanical reason to choose fiber posts as an option for anchorage in endodontically treated teeth.

Advantages of fiber posts

- Fiber posts had been shown to have a high fatigue resistance of 1440 MPa (Quintas et al.2000).
- Low elastic modulus, which is more or less the same as dentine, 18-42GPa. This characteristic helps to fend off catastrophic root fractures (Bru et al. 2013; Vaz et al. 2012 and Asmussen et al. 1999).
- Fiber posts are non-toxic and chemically static. The post can easily be removed in situations where the post placement had failed (Indzhov, 2006 and Cormier et al. 2001).
- Fiber post have excellent light conductivity (11mm) and hence can be cemented with dual-cure resin cements. Zirconia showed excellent light transmission characteristics when compared to other ceramic posts (Michalakis et al. 2004).
- Fiber posts have great translucency, which gives them excellent aesthetic properties and hence they are mainly used in restorations needed in the anterior region (Indzhov, 2006). Prefabricated glass- and quartz-fiber posts together with polyethylene fiber posts showed excellent translucent characteristics (Amizic, P.I. and Baraba, A. (2016).

- Fiber-reinforced post is adhered inside the endodontic canal and dispel functional and parafunctional loads, minimizing the stress on the root.

Disadvantages of the fiber posts

- Fiber posts had become the benchmark in restorative treatment of the root canal treated tooth, but there exist a few disadvantages, which include:
- Fiber post endodontic canal preparation demands supplementary work with cutting of dentine inside the endodontic canal, largely in the apical point of the root.
- Cementing a post is an extra procedure when reconstructing the tooth.
- The post can prevent root canal treatment during retreatment of the tooth.
- The tooth can be placed under severe strain due to forces applied via the post. This may lead to fracture of the tooth (Strassler, 2007).
- Adhesion to intraradicular dentine can be testing for the dental clinician because of the intricacy and sensitivity of the procedure (Ferrari et al. 2000 and Goracci et al. 2006).
- Multiple resin cements and adhesives are employed in clinical dentistry, it is critical to understand their behaviour with reference to discordance between adhesives and resin cements which can open on to potential clinical collapse (Tay, 2003).

Biomechanical collapse linked with post associated treatment had become familiar. Retention loss appeared to have been the most common kind of failure in post treated teeth. The most common drawback seemed to have been root fracture that brought about the most destruction and subsequently led to removal of the tooth (Goodacre et al. 2003). Fracture resistance seemed to have been the greatest factor in the success of root canal treated teeth and its fracture resistance to vertical and horizontal loads were associated with the amount of sound dentine present. It was obvious and stemming from these statements that we should do our outmost to conserve dentine when root canal and restorative treatment were performed. Research had shown that less tooth cutting seemed to have been the best course of action to avoid vertical root fractures. The height of uncut tooth structure between the core and crown margin is crucial to ensure success of the treated root canal tooth. The height of uncut tooth structure should be 1.5-2mm. The ferrule was also important and rendered a bracing or casing role to preserve the integrity of the root (Magne et al., 2017).

1.19 Adhesive cements

Research suggested that adhesive cements such as resin cements had shown to be more reliable with regards to retention and resistance to fatigue (de Moraes et al. 2013). They have improved over time and have shown to do better than luting cements such as zinc phosphate. The modulus of elasticity of resin cements is close to that of dentine and can possibly strengthen thin-walled roots (de Moraes et al. 2013). Resin cements in contrast to zinc phosphate have shown to be technique sensitive in that they possess a short working time, they need a few handling steps and were sensitive to wetness. The recent self-etching resin cements can vanquish and reduce the procedural issues of traditional bonded resin cements. An enhanced surface roughness of the endodontic canal space help to boost the retention of various cements. (de Moraes et al. 2013; Amaral et al. 2009 and Le Bell-Rönnlöf, 2007).

1.20 Fiber post placement and core build-ups

It is important for the clinician to select an appropriate post and core system to preserve optimal root structure and prevent fracture of the root. Build-ups are important from a microbiological aspect. It should be done after endodontic treatment to create a coronal seal. Core build-ups are important since it provides retention and resistance form for the final restoration. Core build-ups must be able to withstand occlusal load, since they are the link between the extra coronal prosthesis and the root canal treated tooth. The success of the prosthesis depends on the strength of the core material as well. In a study done by Burke et al., (2000) on the fracture resistance of pin-retained core build-up materials on teeth that presented with or without extra coronal preparations, it was found that amalgam core build-ups presented an enhanced fracture resistance than composite resin and glass ionomer cement materials. Amalgam however showed a reduction in fracture resistance when the cores were reduced during crown preparation. Cores built with composite resin presented with the most enhanced fracture resistance. The glass ionomer material presented with the least resistance to fracture in both cores build up and crown preparation situations. Bonilla et al., (2000) also tested the fracture toughness of various core material. Fracture toughness of amalgam, titanium-reinforced composite resin, glass ionomer, resin modified glass ionomer material and composite resin with fluoride were tested under loading conditions. All the materials tested presented with fractures starting at the apical region moving towards the loading position. The researchers found that glass ionomer and resin modified glass ionomer were more prone to fracture. Composite resin showed the highest fracture toughness with the titanium reinforced composite resin showing a lower fracture toughness value than composite resin material. Amalgam fracture toughness value however, showed to be between glass ionomer modified and titanium reinforced composite material. The authors concluded that the that fracture toughness is directly associated with the amount of resin in the material and inversely associated with glass ionomer and amount of metal particles in the material (Bonilla et al. 2000). Panitiwat and Salimee (2017) studied the flexural strength of forty teeth that were built up by composite resin material. All teeth were previously root canal treated and restored with fiber reinforced composite posts. A full metal crown was placed on each specimen with core materials including nano hybrid resin composite, light cured core build-up hybrid composite, self-cured core build-up composite with light cure option and dual-cured core build-up composite was used. The results obtained showed that the fracture resistance was higher in cores build-up with light cured hybrid composite than those with self-cured composite. The dual-cured composite as well as the nano hybrid resin composite showed the least resistance to fracture. The composite core with the most filler composition tended to enhance fracture resistance of teeth restored with fiber posts more than others (Panitiwat and Salimee, 2017).

The execution of endodontic treatment does not mean the end of dental health treatment. Endodontic treatment requires complex treatment options with its aim to evade destructive endodontic canal preparations. In today's world of modern and aesthetically pleasing dentistry, patients demand functional prosthesis without negative consequences. Herein lies the conundrum of selecting the best post for post root canal treatment of teeth. The clinician must choose the most appropriate, less complicated post, delivering the best technique and design. Dentistry had undergone a metamorphism with regards to post and core systems. Metal cast posts were regarded the treatment material of choice and now were replaced by fiber posts. The benefits of fiber posts presented seem to be superior to that of metal posts. Biomechanical testing and fatigue strength were considered to be controlled variables and were considered important factors when choosing materials and techniques used in the restoration of root canal treated teeth. Fatigue research showed that biomechanical factors improved the performance of posts. Finally, where a post is required to improve the solidity of the under structure, resin fiber posts were the most fitting choice due to its resemblance of its physical properties to that of dentine.

However, the market seems flooded with various types of posts. Hence, the purpose of this study was to assess and determine the fatigue resistance of various fiber posts and to observe their ultrastructures through scanning electron microscopy (SEM) and to determine if the fiber density would influence the fatigue resistance.

CHAPTER 2

2.1 Aims and Objectives

2.1.1 Aim of the study

The aim of the study was to assess and determine the fatigue resistance of different fiber posts and to observe their ultrastructures through scanning electron microscopy (SEM).

2.2 Objectives

To assess and compare the fatigue resistance of 4 different types of fiber posts,

To analyse and compare the surface morphology using scanning electron microscopy (SEM) and

To determine if there is a correlation between the fatigue resistance exhibited by the different types of posts and their structural characteristics.

2.2.1 Study design

This was an *in vitro* study quantitative study comparing different types of fiber posts, comparing the mechanical and physical properties.

2.3 Null Hypothesis

The null hypotheses tested were:

1. There are no differences in fatigue resistance among the different kinds of fiber posts.
2. There are no significant differences in the structural integrity of the fiber posts.

2.4 Statistical analyses

Data was Data will be entered into a excel spreadsheet and then transferred to statistical programme SPSS, Ver 21 (IBM, USA). Data will be analysed in consultation with a statistician.

2.5 Ethical clearance

Ethical clearance for this study was granted by the Senate Research Committee of the University of the Western Cape. Ethics Reference Number: BM19/4/13

No biological specimens were used in this study.

CHAPTER 3

3.1 Materials and Methods

Four types of aesthetic posts were selected for this study (Table 1), namely:

1. Radix Fiber Post (Dentsply Sirona, USA, zirconia glass fiber, tapered post)

2 ParaPost Fiber White (Coltene/Whaledent, NJ, USA, glass fiber, parallel-sided post),

3 Edelweiss Composite Posts (Edelweiss Dentistry, Austria, hybrid glass, tapered post),

4 GC Fiber Post (GC, Tokyo, Japan, glass fiber, parallel-sided post).

Table 1. The four groups of fiber posts tested in the study and their characteristics

Group	Type of post	Post diameter (mm)	Composition	Characteristics
1 2 3 4	Dentsply Sirona X Posts ParaPost Fiber White Edelweiss Composite Posts GC Fiber Post	1.35 1.4 1.4 1.4	Zirconia Glass Glass Hybrid Glass Glass	Tapered Parallel-sided Tapered Parallel-sided

For each group, 15 posts of the largest available size were used. Post diameters in the different groups ranged from 1.35 mm to 1.4 mm. A micrometer (Swiss American Mfg, Co.) was used to determine the diameter and length of each post (Figure 15). The length of the posts was uniform at 14mm. Ten of the fifteen posts were randomly chosen to be used for fatigue resistance testing. The remaining five posts were used for processing for SEM evaluation.

3.2 Fatigue resistance test

Ten posts from each group were tested using a fatigue resistance Universal Testing Machine (Tinius Olsen, Horsham USA, Figure 13).

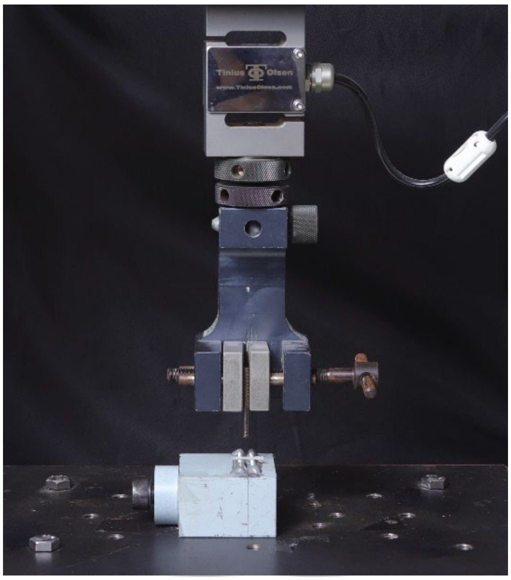


Figure 13. The post ready to be tested

The three-point bending test of loading was done based on ISO 4049and a load was applied to each post, with a loading angle of 90° and a crosshead speed of 1mm/min until fracture (Figure 14).

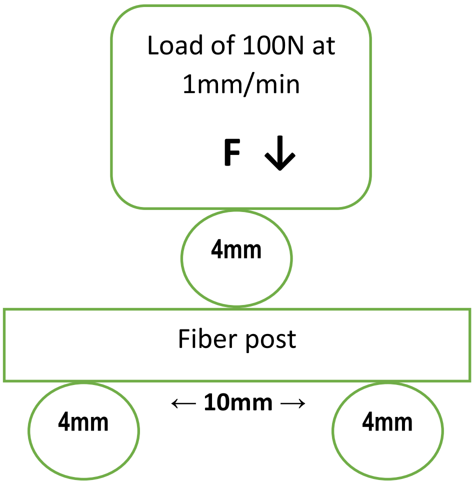


Figure 14. Schematic diagram of the 3-point bending test used to test the mechanical properties of fiber posts.

All posts were exposed to the same loading parameters.

A punching action was delivered onto the fiber posts, which was done at 100 Newtons. The punch and two supports had a diameter of 4mm with the span between the two supports being 10mm as prescribed by the American Society for Testing Materials, 1999. The loading punch was placed on the middle section of tapered posts. This was the case with Edelweiss Composite posts. All other fiber posts that were conical and straight were also punched at equidistance at the midpoint of the post length as reported also by Cooper, 1977. The diameter of each fiber post at the point of loading was confirmed using a micrometer (Swiss American Mfg, Co, Figure 15).

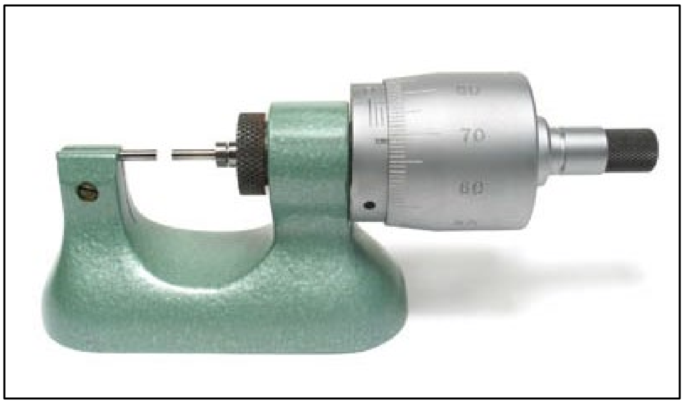


Figure 15. The Swiss American Micrometer used in the study

The load deflection curves were stipulated with PC-software (QMat TestZone,Tinius Olsen, Horsham USA). Flexural load and flexural strength of the studied posts were measured together with the maximum extension indicating when the fiber post will fracture. Furthermore, the proportional limit and energy spent to break the fiber post were also determined. All the tests were carried out at room temperature of approximately 22°C.

3.3 Statistical analysis

Differences among the tested posts were analysed by using the one-way ANOVA Test (Excel, Microsoft Corporation, Redmond, Washington,USA). This was followed by the Bonferroni Test for multiple comparisons to reveal statistical differences between the four fiber post systems (SPSS, IBM, New York, NY, USA). The level of significance was set at $p<0.05$ verifying whether any differences that occur in the post structure as a result of loading. Following the fatigue testing, the fiber posts were prepared for SEM evaluation. Detected modifications or changes that occurred during the loading of the fiber posts have been documented and verified through microphotographs.

3.4 SEM analysis

Individual specimens or posts were cross-sectioned using a high precision diamond cut-off wheel (Struers Minitom, Cleveland, Ohio, Figure 16).

Figure 16. High precision diamond cut-off wheel

The groups were studied for the exposed surface created by the cross-sectional cut. The outside surface of five individual sliced fiber posts were also studied. The samples were mounted on metallic stubs (Figure 17).

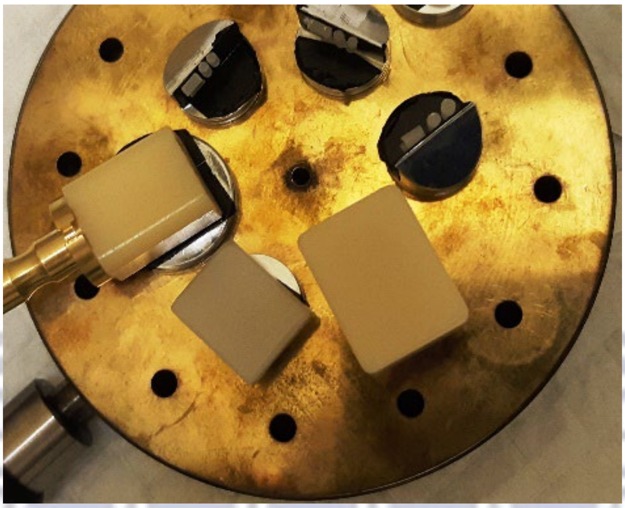


Figure 17. The specimens on metallic stubs.

This was then observed using a scanning electron microscope (Merlin SEM Gemini II from Carl Zeiss, Oerzen, Germany) as shown in Figure 18.

Figure 18. The scanning electron microscope used in the study

The specimens were sputtered with gold in an ion-sputtering device (Leica Microsystems,Wetzlar,Germany, Figure 19). Microphotographs were taken to record the morphologic features of the fiber posts. The fiber diameter, the amount of fibers per mm^2, and the surface occupied by fibers per mm^2 of post surface were analysed.

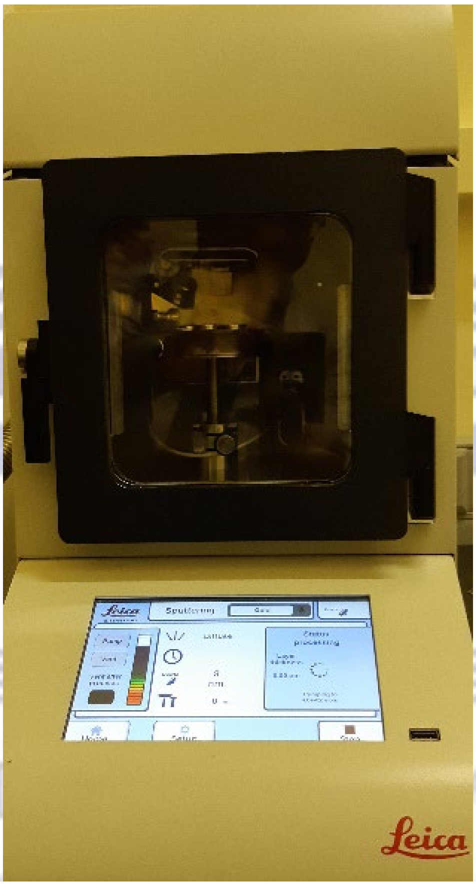


Figure 19. The ion-sputtering device used in the study

Microphotographs were taken to analyse each fiber post from 36X magnification to magnification of 4370X. The results attained were used to derive the mean of the scores allocated to the individual microphotographs.. Two examiners were used for this part of the study.

Where disagreement arose on the score that was assigned to a specimen, a third examiner was chosen if there were to be any dissimilarity between the two examiners with regards to a score given to a fiber post sample. If no agreement could be reached, the most unsatisfactory score was used for the statistical analysis. The examination was repeated twice to confirm interexaminer credibility.

All specimens were coded so as to blind the observer to eliminate any bias. Scoring was based on the standard protocol as discussed by Grandini et al., 2008. Briefly, scanning electron microscopy specimens were observed for presence or absence of voids and graded accordingly as shown in Table 2.

Table 2. Scoring method to quantify the structural integrity of posts, as assessed under scanning electron microscope (Grandini et al., 2008).

Score 0	Score 1	Score 2
No Voids/bubbles	Microvoids /bubbles (diameter <20 microns	Microvoids/bubbles (diameter >20 microns) and/or fiber detachment

To calculate the percentage of fibers occupied in a specific section the surface area was measured and the numbers of fibers occupied in that space were counted using the scanning electron microscope images. Then the amount of resin was calculated as remaining amount occupied in that space.

Correlation analyses

A linear-regression test was used to measure the possible correlations between the physical properties measured in the fatigue test and the structural characteristics of the SEM analysis (SPSS, IBM, New York, USA). One of the aims was to verify the correlation between the mechanical properties (flexural load and flexural strength), and the structural characteristics namely number of fibers per mm^2, the fiber/matrix ratio percentage for all fiber posts, fiber diameter and fiber density. To evaluate possible correlations between the mechanical properties and physical characteristics of fiber posts the Pearson's correlation coefficients test were used. The statistical significance of the correlations will also be assessed ($p<0.05$). A statistician was consulted for this part of the study.

CHAPTER 4 - RESULTS

4.1 Fatigue resistance test

Table 3 shows the summary of the mean flexural strengths and mechanical characteristics of the tested fiber post systems

Group	Type of post	Maximum Extension (mm)	Flexural Load (Newton)	Flexural Strength (MPa)	Proportional Limit (mm)	Energy Between (Joule)
Group 1	Dentsply Sirona X Posts	0.43	132.1 (43.3)	494 (158.3)	0.22	0.025
Group 2	ParaPost Fiber White	0.32	146.8 (22.7)	411 (41.7)	0.14	0.025
Group 3	Edelweiss Composite Posts	0.18	78.31 (12.3)	408 (58.8)	0.05	0.023
Group 4	GC Fiber Post	0.27	154.75 (28.8)	664 (107.6)	0.17	0.024

Figure 20 shows a bar graph of the mean values for flexural strength (MPa) for the 40 tested fiber posts. Each bar represents 100 percent of the tested fiber posts for reach group tested. The maximum of each bar represents the mean flexural strength for each group of fiber posts tested.

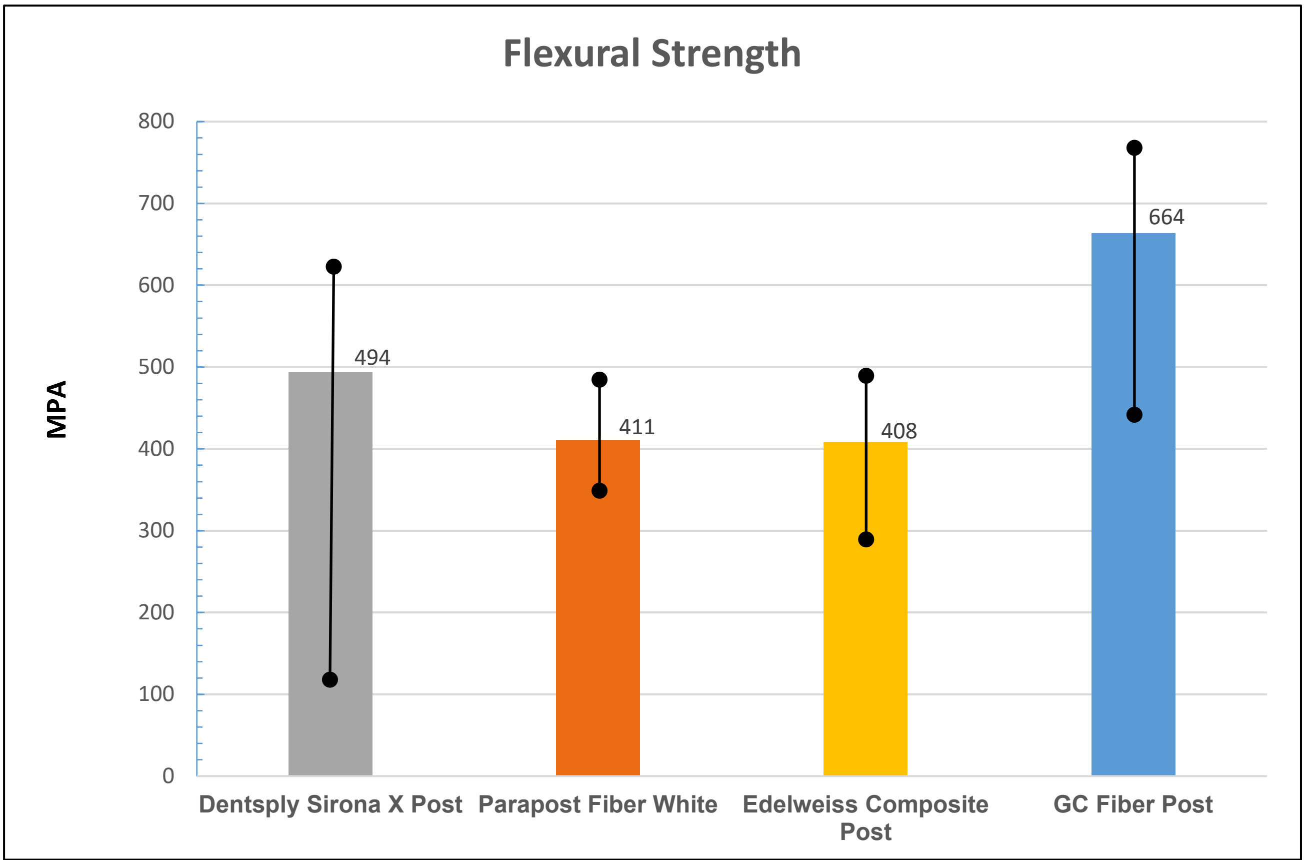


Figure 20. Mean flexural strengths of the four tested fibre post systems. Standard deviations are displayed as vertical lines. Statistical significance was set at $p<0.05$.

The results of the analysis on flexural strength showed a differentiated distribution of four fiber post systems with the highest values obtained by GC Fiber Post with 664 MPa, Dentsply Sirona X Posts 494MPa, ParaPost Fiber White 411MPa and the fourth best value for Edelweiss Composite Post with 408 MPa. The mean values for flexural load for GC Fiber Post (Group 4) recorded 154.75 N, ParaPost Fiber White (Group 2) recorded 146.8 N, Dentsply Sirona X Posts

132.1N and Edelweiss Composite Post 78.31 N. Figure 20 shows the outcome of the statistical analysis on flexural strength with the standard deviation spread out. Figure 20 showed that there is a large variance in the Dentsply/Sirona X Post group which standard deviation value around the mean flexural strength value of 158.3.

The one-way ANOVA test revealed that enough evidence exists to reject the null hypothesis, which states: There are no differences in fatigue resistance among the different kinds of fiber posts. Differences in fatigue resistance among the different kinds of fiber posts exist as experienced by the fatigue test and confirmed by the one-way ANOVA test. The one-way ANOVA tests were used to determine whether there are any statistically significant differences between the means of the four fiber posts groups. The F statistical shown to be 13.86 for flexural strength and the F critical value was 2.86. The F statistical shown to be 15.77 for flexural load and the F critical value was 2.86 as well.

4.2 SEM Analysis

Table 4 shows the structural characteristics revealed by the SEM evaluation of the cross-sectional fiber post surfaces for the four post systems. The outcome is based on the evaluation of five posts (unbroken) per group.

The fiber diameters for the posts were 1.25 micrometer for the Edelweiss Composite Post, 1.4 micrometer for the ParaPost Fiber White Post, 17.65 micrometer for the Dentsply Sirona X Post and 18.6 micrometer for the GC Fiber Post. The fiber diameter, fiber density and surface occupied by the fibers were measured and documented using PC software (Merlin SEM Gemini

II from Carl Zeiss, Oerzen, Germany). The study revealed a significant variation in the fiber/matrix ratio of the different post systems.

Table 4. Summary of the mean physical properties and structural characteristics of the tested fiber post systems.

Group	Type of post	Post diameter (mm)	Fiber diameter (um)	Fiber density (number of fibers per mm^2)	Surface occupied by fibers per mm2 of post surface (um/mm^2)	Fiber/ Matrix Ratio (%)
1	Dentsply Sirona X Posts	1.35	17.65 um	416	758	68.5/31.5
2	ParaPost Fiber White	1.4	1.4 um	581	1139	67.1/32.9
3	Edelweiss Composite Posts	1.4	1.25 um	882	1378	88.1/11,9
4	GC Fiber Post	1.4	18.6 um	456	894	87.8/12,2

Dentsply Sirona X Post presented with around 68.5% fiber count and 31.5% of resin matrix per square mm. Parapost Fiber White presented with approximately fiber count of 67.1% and 32.9% of resin matrix per square mm. Edelweiss Composite Post presented with around 88.1% fiber count and 11.9% of resin matrix per square mm. GC Fiber Post presented with approximately 87.8% fiber count and a resin count of 12.3% per square mm. These findings were illustrated in the SEM images of Figure 21, in which the surfaces of the four posts shown the fiber diameter and matrix of the posts.

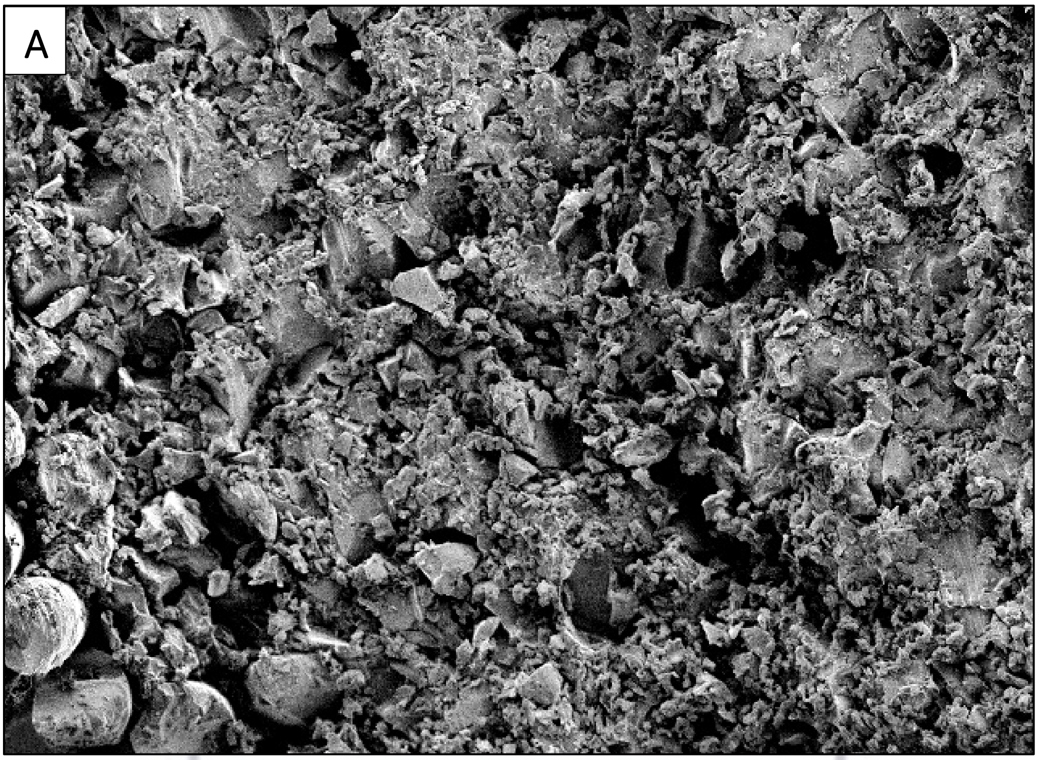


Figure 21(A) - SEM micro-image of Sirona X Post showing the differences in fiber diameter and matrix of the post.

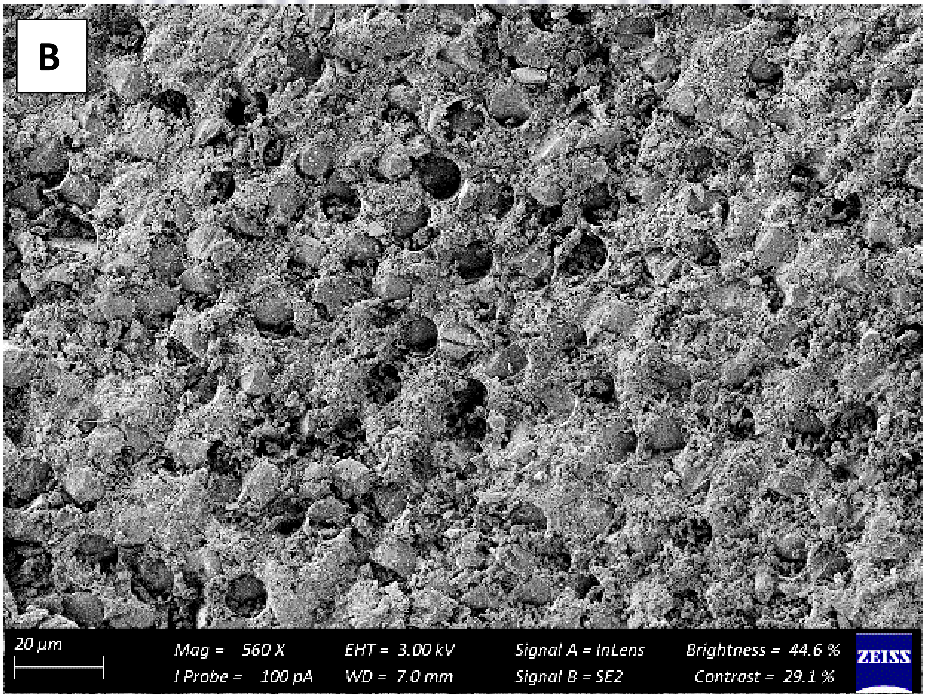


Figure 21(B) - SEM micro-image of Para Post Fiber White showing the differences in fiber diameter and matrix of the post. Edelweiss Composite Post

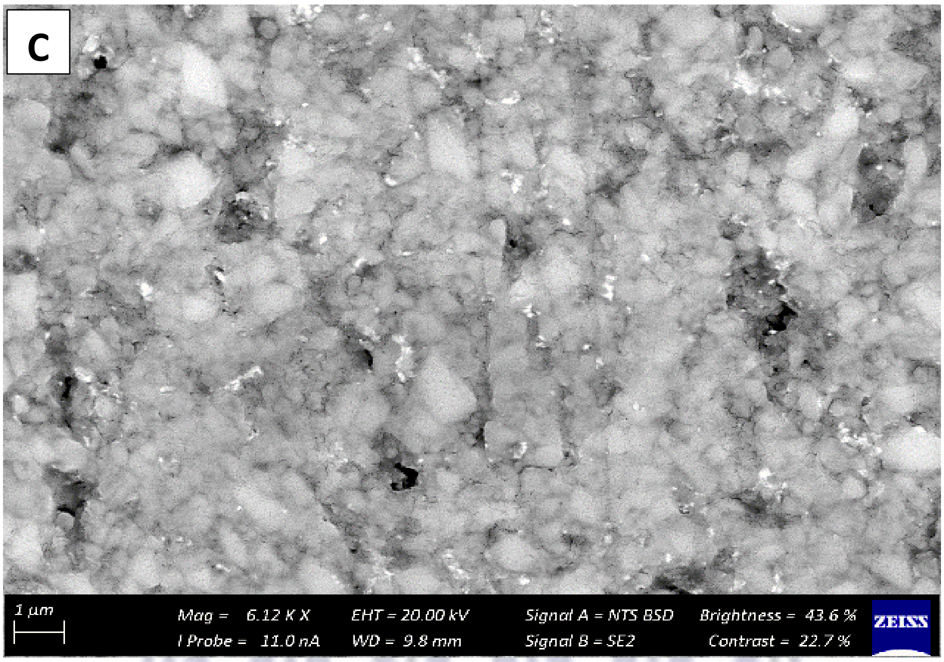


Figure 21(C) - SEM micro-image of Edelweiss Composite Post showing the differences in fiber diameter and matrix of the post.

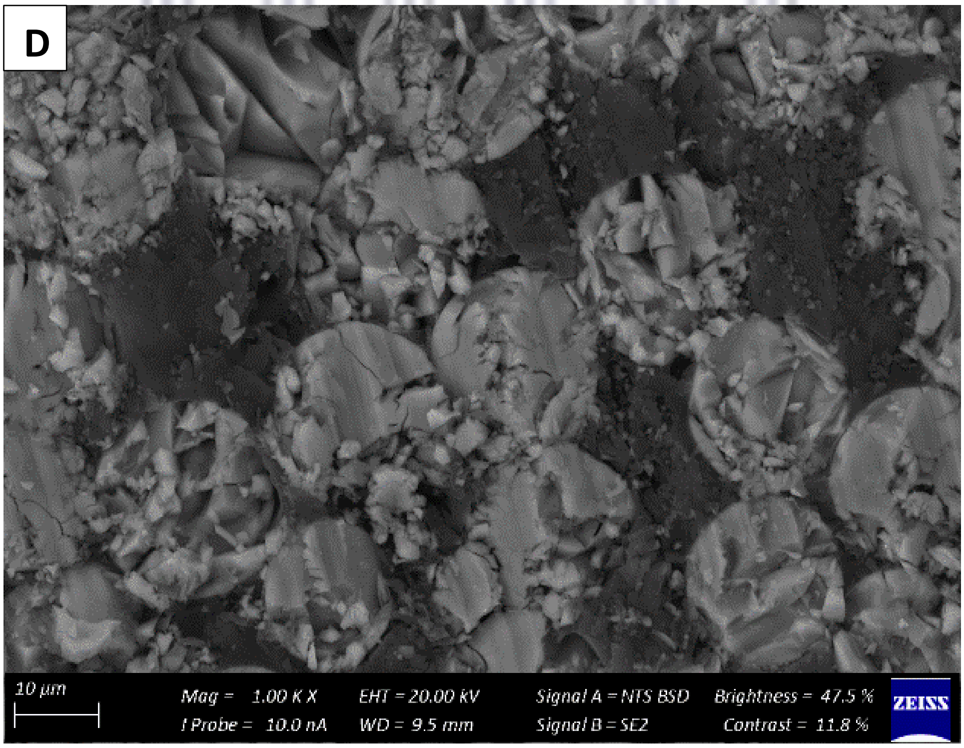


Figure 21(D) - SEM micro-image of GC Fiber Post showing the differences in fiber diameter and matrix of the post.

4.3 Structural integrity

Table 5 summarises the scores given to the various types of fiber posts in order to determine their structural integrity, as expressed by scanning electron microscopy.

Table 5 Median values of the scores given to the different types of fiber posts, providing an indication of each post's structural integrity, as observed by scanning electron microscopy

Group and Type of post	Scores		
	Cross section of post	Longitudinal section of post External	External surface of post
Group 1 Dentsply Sirona X Post	2	2	0
Group 2 Para Post Fiber White	1	2	1
Group 3 Edelweiss Composite Post	1	1	2
Group 4 GC Fiber Post	1	1	0

Cross sectional cut as well as the longitudinal section of the Dentsply Sirona X Post (Group 1) showed voids and/or bubbles within the post structure (Figure 22 and Figure 23). Figure 24 shows a 3D Image of Dentsply Sirona X Post (cross-sectional cut). The Para Post Fiber White Post (Group 2) showed voids and/or bubbles within the post across its longitudinal section. Figure 25 showed an image of the cross sectional cut of a ParaPost Fiber White Post.

Figure 26 showed a 3D Image of ParaPost Fiber White Post longitudinal section. Edelweiss Composite Post (Group 3) showed voids and/or bubbles on the external surface of the post.

Figure 27 showed the image of Edelweiss Composite Post after the cross-sectional cut.

Figure 28 showed a 3D Image of Edelweiss Composite Post depicted the post seen from a longitudinal perspective. Specimens from Dentsply Sirona X Post (Group 1) seen in Figure 23, together with GC Fiber Post (Group 4) seen in Figure 30 showed no visible structural defects on the external surface. The results obtained from GC Fiber Post (Group 4) showed significant lower scores than those of Dentsply Sirona X Post, Para Post Fiber Post and Edelweiss Composite Post. 3D images of fiber posts were also included to assist in the comparison and structural analysis of the posts. Figures 29 to 32 showed cross-sectional, external and longitudinal images of GC Fiber Post.

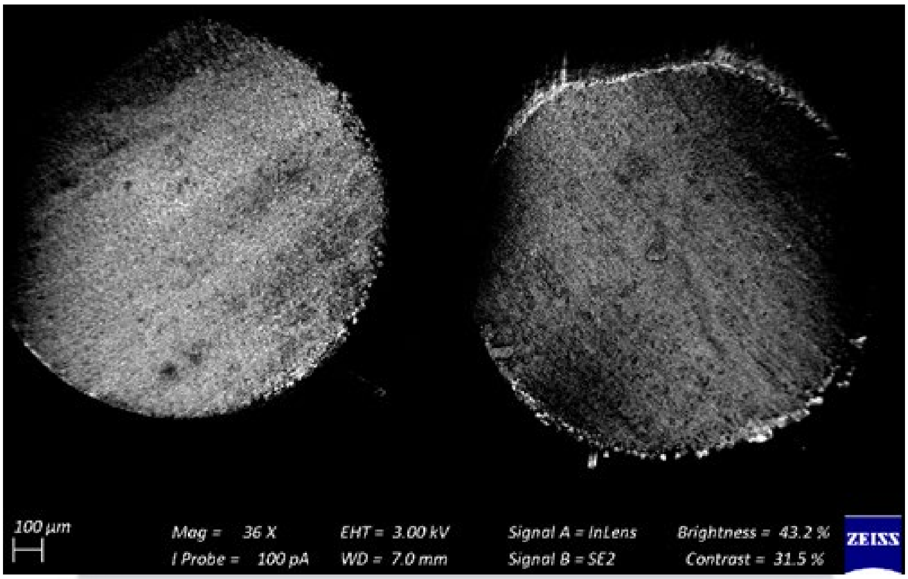


Figure 22. Sirona X Post: Surface following the cross-sectional cut.

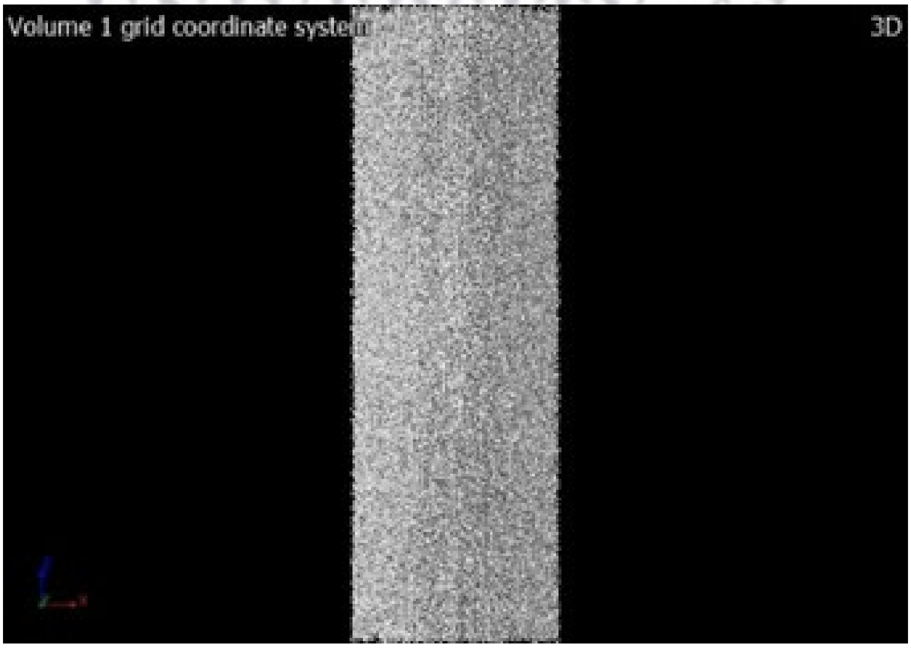


Figure 23. 3D Image of Dentsply Sirona X Post showing the external surface of the post

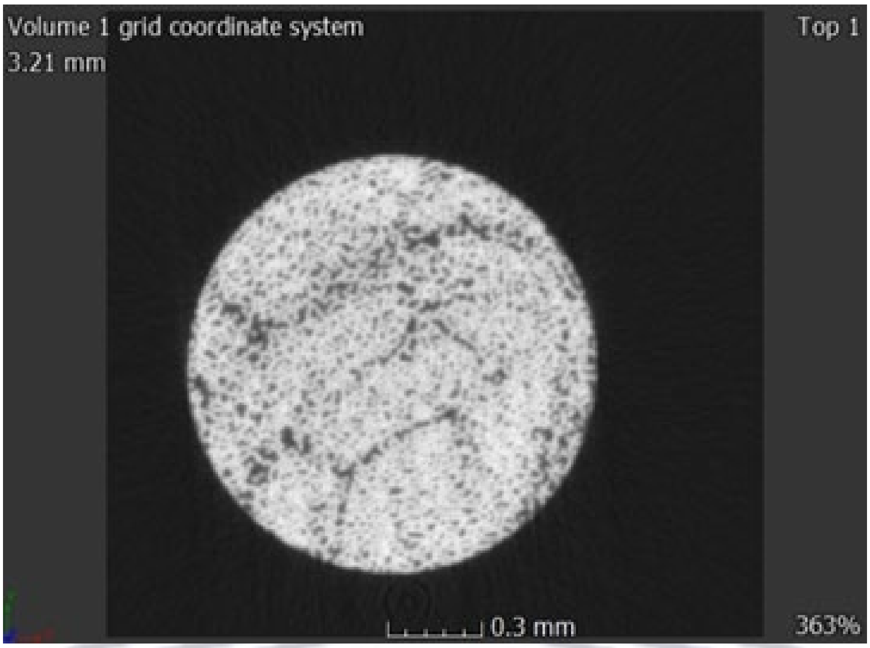


Figure 24. 3D Images of Dentsply Sirona X Post cross-sectional cut.

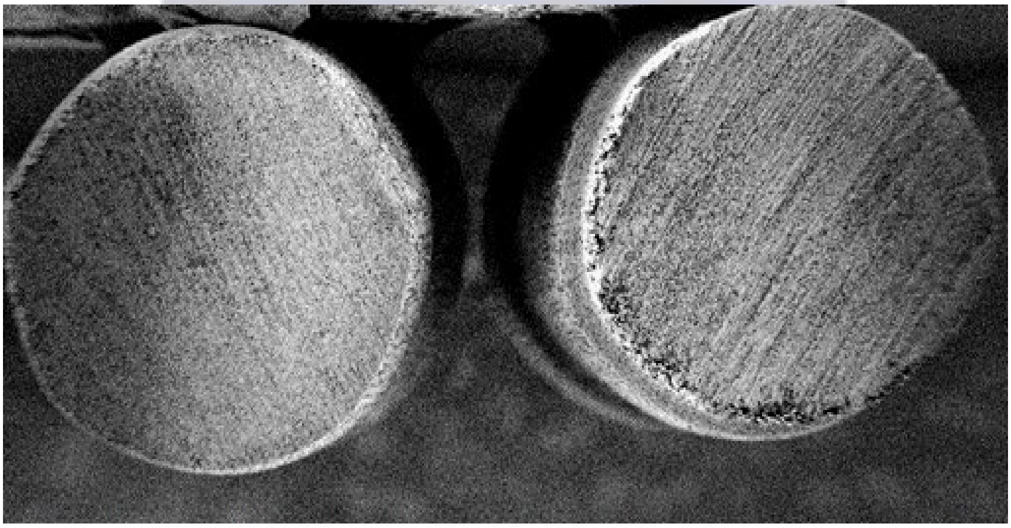


Figure 25. Para Post Fiber White: Surface following the cross-sectional cut.

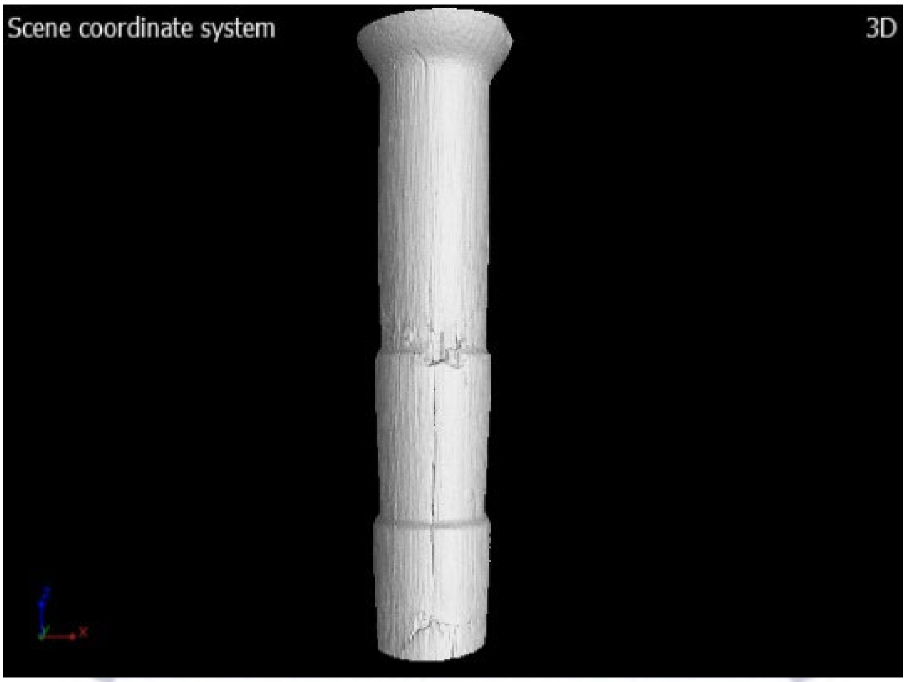


Figure 26. 3D Image of ParaPost Fiber White Post longitudinal section.

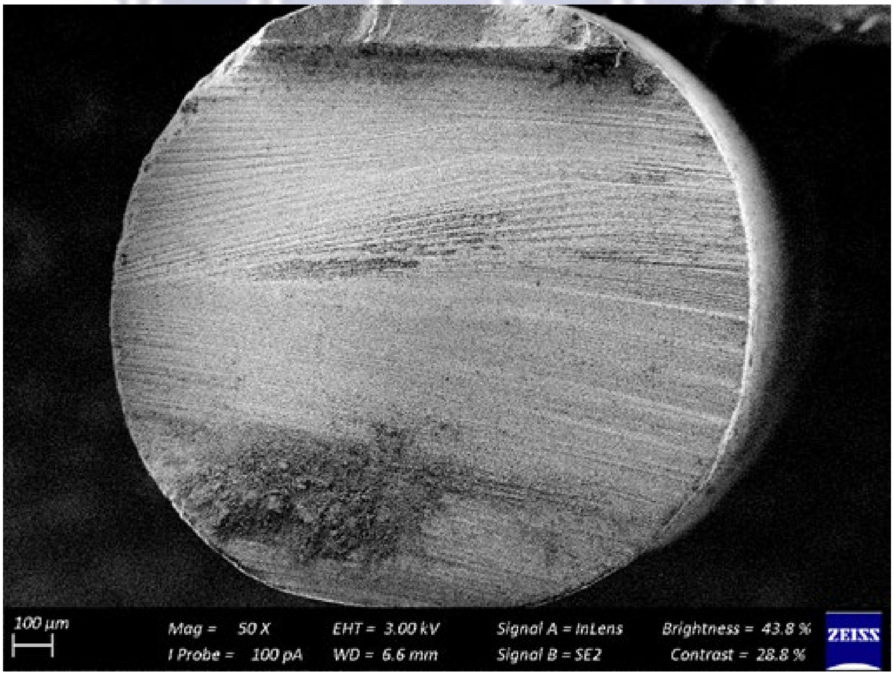


Figure 27. Edelweiss Composite Post: Surface following the cross-sectional cut.

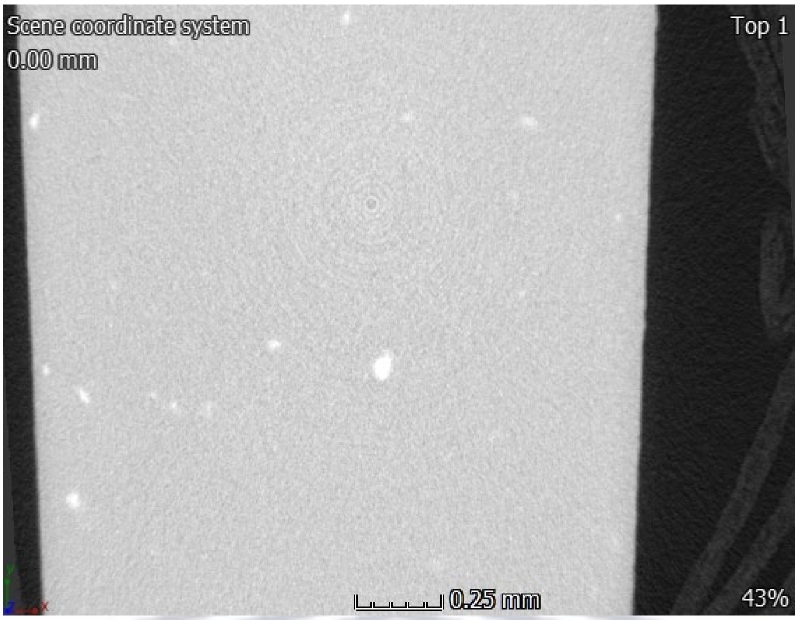


Figure 28. 3D Image of Edelweiss Composite Post. The image depicts the post seen from a longitudinal perspective.

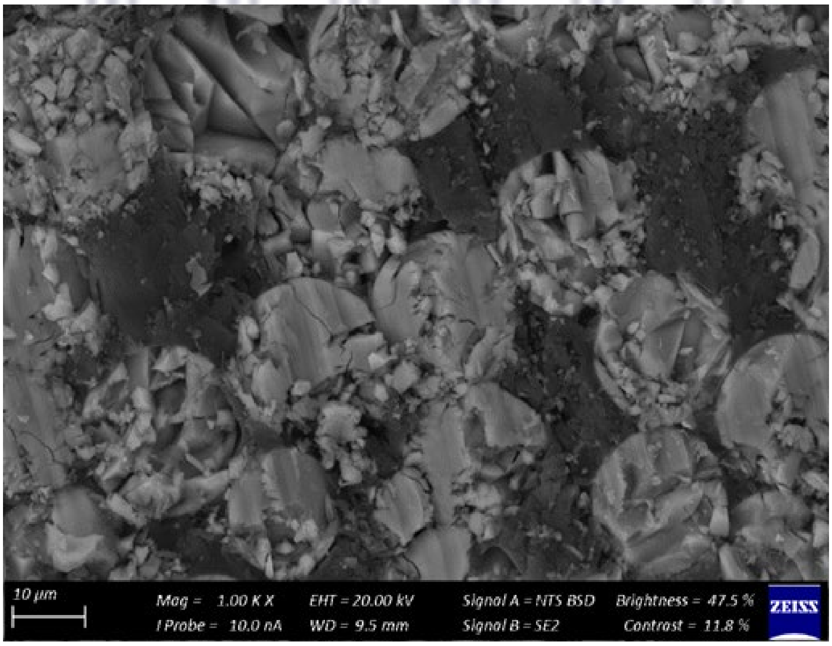


Figure 29. GC Fiber Post: Surface following the cross-sectional cut at 10micrometers

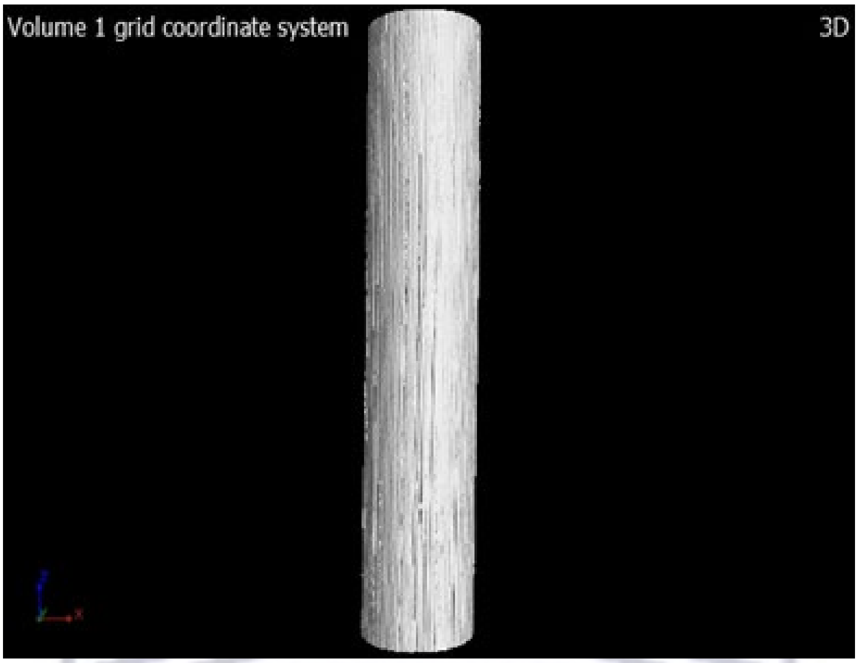


Figure 30. 3D Images of GC Fiber Post of the external surface.

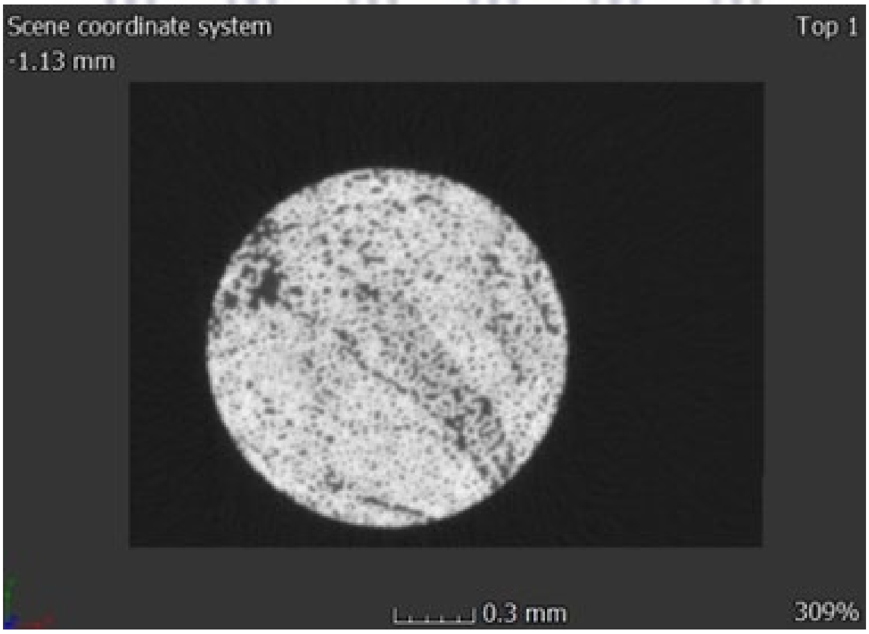


Figure 31. 3D Images of GC Fiber Post images after the cross-sectional cut.

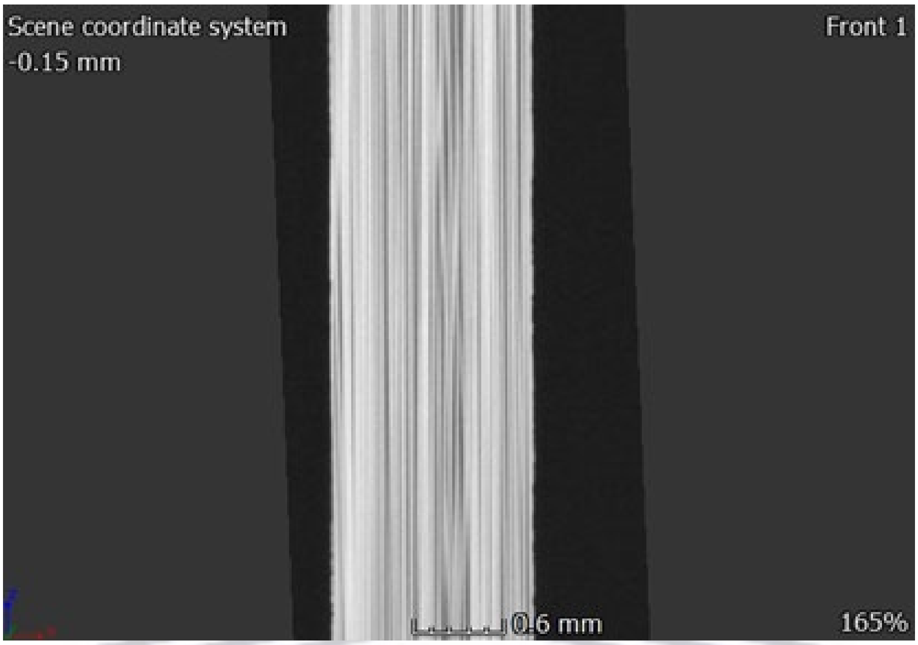


Figure 32. 3D Images of GC Fiber Post images after the longitudinal cut.

4.4 Correlation analysis

A linear regression test was used to show the relationship between the physical properties documented in the fatigue resistance test and the structural characteristics of the SEM analysis. The linear regression model was used to show or predict the relationship between flexural strength and the four variables in this case, fiber diameter, fiber density, fiber/matrix ratio and surface occupied by fibers per square mm of post surface of the four fiber posts systems. The linear regression test showed 664 MPa (x-value/flexural strength) of GC Fiber Post to be 21.09 um. The y-value, which was very close to the value measured for GC fiber post was 18.6 um. The Pearson's correlation - coefficient(r) was found to be 0.84 for flexural strength and the diameter of the fiber. It showed a strong correlation between the flexural strength and the fiber diameter. The Pearson's correlation - coefficient(r) was found to be -0.62 for flexural strength and the fiber density per square mm. It showed an insignificant correlation between the flexural strength and the fiber density. The Pearson's correlation -

coefficient(r) for flexural strength and the surface occupied by the fibers per square mm was recorded as -0.63. It showed a negative value and indicated very little evidence that suggested a correlation between the flexural strength and the surface occupied by the fibers per square mm of the overall post surface.

The Pearson's correlation - coefficient(r) for flexural strength and the fiber/matrix ratio was recorded as 0.41. It showed a moderate correlation between the flexural strength and the fiber to matrix ratio. The level of statistical significance was set at $p<0.05$. Of the four structural characteristics investigated the fiber diameter presented with the strongest and most significant correlation with the flexural strength. The standard deviation for fiber diameter was found to be 9.7um. The standard deviation for fiber density was found to be 210 fibers per square mm. The standard deviation for surface occupied by the fibers per square mm of post surface was found to be 273 fibers per square mm of post surface. The standard deviation for fiber matrix ratio was found to be 11.6%. Results indicating the strength of correlation between fatigue resistance (flexural strength) and structural characteristics of the fiber posts are set out in Table 6.

Table 6. Strength of correlation between fatigue resistance and structural characteristics

	Variable			
	Fiber Diameter	Fiber Density	Surface occupied by fibers per mm2 of post surface	Fiber/Matrix Ratio (%)
Pearson's correlation coefficient	r=0.84	r= -0.62	r= -0.63	r= 0.41
Standard deviation	9.7	210	273	11.6

CHAPTER 5

5.1 DISCUSSION

This study compared four different types of fiber posts systems {Radix Fiber Post (Dentsply Sirona, USA), ParaPost Fiber White (Coltene/Whaledent, USA), Edelweiss Composite Posts (Edelweiss Dentistry, Austria) and GC Fiber Post (GC, Tokyo, Japan)}to demonstrate which fiber post system showed the best results with regards to their fatigue resistance and structural integrity. The fiber posts were loaded onto a three-point bending test machine to determine the fatigue resistance. Fatigue resistance of a material, in this case fiber posts, indicated the resistance to crack initiation under cyclic loading, generally concerning the fatigue limit or the flexural strength. The flexural strength of fiber posts is determined by the resistance to fracture of a specimen (Plotino et al. 2007). The higher values presented in this study is a reflection that a post was more resistant to fracture. Lower values indicated that the post was less resistant to fracture. The results of the analysis on flexural strength showed the highest mean values obtained by GC Fiber Post with 664 MPa. The second highest value were Dentsply Sirona X Posts 494MPa and third highest ParaPost Fiber White 411MPa. The fourth best value was Edelweiss Composite Post with 408 MPa. The flexural strength was calculated by the highest load a post could resist and it highly relied on the structure of the post. The mean values for flexural load for GC Fiber Post (Group 4) recorded 154.75 N, ParaPost Fiber White (Group 2) recorded 146.8 N, Dentsply Sirona X Posts 132.1N and Edelweiss Composite Post 78.31 N. This study showed comparable mechanical characteristics for two of the fiber posts both with regards to their resistance to fracture (flexural strength), namely ParaPost Fiber White(411MPa) and Edelweiss Composite Post(408MPa). Their fiber diameter also showed to be comparable, namely 1.4 micrometer for ParaPost Fiber White and 1.25 micrometer for Edelweiss Composite Post. Dentsply Sirona X Posts and GC Fiber Post also showed comparable mechanical characteristics with regards to their flexural strength, namely 494MPa and 664MPa. Their fiber diameter also showed to be comparable, namely 17.65 micrometer for Dentsply Sirona X Posts and 18.6 micrometer for GC Fiber Post.

What is noteworthy is that higher fracture strengths were documented for fiber posts with the greatest diameter in contrast to that of fiber posts with the least diameter, this for each post group tested. In contrast to this study previous research reported that when flexural strengths were compared, fiber posts with lesser diameter faired remarkably better (Seefeld, 2007). This study's results revealed that flexural strength of fiber posts varied on post make and diameter. Taking a clinical scenario into consideration, the flexural strength should be measured against the flexural load when a post is chosen. The results in this study shown that with a reduced flexural load, the flexural strength decreased, which might result in a failed restoration. Dentsply Sirona X Posts and GC Fiber Post faired very well in this study. Zicari et al.,2013 wrote that the exceptional performance of Dentsply Sirona X Posts might be due to the strengthening effect of zirconia fillers that are interspersed between the fibers. The authors went further and reported that the two-step manufacturing process of Dentsply Sirona X Posts resulted in the curing of the composite resin matrix by chemical and thermal means. The ParaPost Fiber White post presented with inverse ledges or serrations across its post length. These inverse ledges might have created areas of stress concentration and as a result weakened the post. This could have been one of the reasons for the ParaPost Fiber White post being the post with the third highest flexural strength. Grandini et al.,2005 in previous research validated that the inclusion of a notch for retention reasons did not aid to the fatigue resistance of a post. Edelweiss Composite Post recorded a value of 408MPa for flexural strength.

Figure 21c showed an image of Edelweiss Composite Post with compacted filler particles and very little resin in between. The structural integrity of each post was observed by scanning electron microscopy. Edelweiss Composite Post (Group 3) showed voids and/or bubbles on the external surface of the post. These voids and/or bubbles could lead to the formation of cracks within the fiber post. Edelweiss Composite Post was the only post that fractured cleanly during the resistance test. Zicari et al., 2013, reported that when complete fracture of fiber posts occurred, as in the case of Edelweiss Composite Post, this might have been because of delamination, which might be attributed to a reduced interfacial bonding between the filler particles and the resin matrix. Correlation between the mechanical properties of the fiber posts and each of the structural variables was determined by Pearson's correlation coefficients ($p<0.05$). The study revealed that the Pearson's correlation - coefficient(r) was found to be 0.84 for flexural strength and the diameter of the fiber. This indicated that a strong correlation existed between the flexural strength and the diameter of the fiber posts. This study rejected the idea for the hypothesis that no differences in fatigue resistance among the four fiber posts existed.

In addition to the fiber diameter, numerous factors might have been affected the flexural strength of fiber posts. This included fiber density, the type of resin matrix, the orientation of the fibers, interfacial bonding of fibers and resin and the curing process (Callister, 1997). With reference to the structural analysis as demonstrated by the scanning electron microscopy

(SEM), all four fiber post systems showed differences with regards to the variables studied, namely fiber diameter, fiber density, surface occupied by the fibers and fiber/matrix ratio.

This study revealed that no correlation existed between the flexural strength and the fiber density and the surface occupied by the fibers. The Pearson's correlation - coefficient(r) for flexural strength and the fiber density was recorded as -0.62, indicated a negative correlation between the flexural strength and the fiber density. The Pearson's correlation - coefficient(r) for flexural strength and the surface occupied by the fibers was recorded as -0.63, indicated a negative correlation between the flexural strength and the surface occupied by the fibers.

Grandini et al., 2008 tested the hypothesis that the diameter of the fibers and the surface populated by fibers per square millimetre of the post surface, the fiber/matrix ratio, were interconnected to the physical properties of a fiber post. The showing of voids/bubbles within the fiber post and on its external surface was also evaluated and revealed through a score system based on Grandini et al., 2008 seen in Table 2. The results of the scoring of fiber post voids, were expressed in Table 4: 0=no voids or bubbles are visible; 1=microvoids or bubbles can be detected (diameter20 microns) were evident and/or fiber detachment due to a loose bond with the resin matrix (Grandini et al., 2008). We were not only doing a quantitative analysis of the structural integrity of the fiber posts, but at the same time recorded and evaluated statistically the fundamental differences between these posts.

Fiber density and the surface occupied by the fibers seemed not to have had an impact on flexural strength of the fiber posts. The results of the structural analysis showed the highest values obtained for fiber density was Edelweiss Composite Post with 882 fibers per square millimetre. The second highest value were obtained by ParaPost Fiber White Post with 581 fibers per square millimetre. GC Fiber Post presented with 456 fibers per square millimetre and Dentsply Sirona X Posts with 416 fibers per square millimetre. The highest values obtained for surface occupied by fibers was Edelweiss Composite Post with 1378 fibers per square millimetre of post surface. The second highest value were obtained by ParaPost Fiber White Post with 1139 fibers per square millimetre of post surface. GC Fiber Post presented with 894 fibers per square millimetre of post surface and Dentsply Sirona X Posts with 758 fibers per square millimetre of post surface. These results supported earlier studies that demonstrated that higher fiber content does not produce better mechanical properties (Grandini et al. 2005). This study however, revealed a correlation between the flexural strength and the fiber to matrix ratio. The Pearson's correlation - coefficient(r) for flexural strength and the fiber to matrix ratio was recorded as 0.41, indicated a moderate significance between the flexural strength and the fiber to matrix ratio. The results of the analysis on fiber to matrix ratio showed the highest values obtained by Edelweiss Composite Post with 88.1/11.9%. The second highest value were GC Fiber Post with 87.8/12.2%. Dentsply Sirona X Posts was the third highest with 68.5/31.5% and the fourth best value was ParaPost Fiber White with 67.1/32.9%. In support of the findings in this study Seefeld et al., 2007 also found a strong correlation between flexural strength and fiber to matrix ratio. The hypothesis that no differences in structural integrity of the four fiber posts existed was rejected.

Furthermore, GC Fiber Post recorded the second highest value of fiber to matrix ratio, 87.8/12.2%, and the highest value of flexural strength, 664 MPa. Edelweiss Composite Post for instance recorded the highest fiber to matrix ratio, 88.1/11.9%, but recorded the lowest value for flexural strength, 408MPa. Despite the fact that a simple analysis of these results was difficult, one could surmise that other factors such as the mechanical properties of resin matrix and the interfacial adhesion of fibers and the resin matrix might have assisted in the flexural strength of fiber posts. In addition, it was important to have looked at the composition of fiber posts. Fiber-reinforced post systems contained a high-volume percentage of continuous fibers embedded in polymer matrixes, which were commonly epoxy polymers with high degree of conversion and a highly cross-linked structure that binds the fibers (Akkayan and Gülmez, 2002). Composite materials seem to make out the bulk of fiber-based posts currently available on the market. They comprise of prestretched fibers of silica or carbon bounded by a matrix of polymer resin. The predominant of the fiber-reinforced posts contain epoxy resin or bis-GMA matrix along with some fillers (Drummond and Bapna, 2003). Carbon fiber posts are prepared from unidirectional and continuous carbon fibers in an epoxy resin matrix (Hedlund et al.2003). Carbon-fiber posts provided desired aesthetics with all-ceramic restorations resulted in the manufacturing of translucent and tooth coloured silica-fiber posts. These were also called glass-fiber and quartz-fiber reinforced posts. Glass fiber posts could contain different types of glass, such as E-glass (electrical glass), and S-glass (high-strength glass). Furthermore, glass fiber posts could also be made from quartz fiber, which is pure silica in a crystallized form according to Lassila et al., 2004.

With reference to this study, the compositions of the fiber posts evaluated revealed the following:

1. Dentsply Sirona X Posts composes of zirconium enriched glass fiber (68.5%) in an epoxy resin matrix (31.5%). The posts consist of S-glass fibers as the dominant constituent (Internal data: Maillefer Instruments Holding, 2020).
2. ParaPost Fiber White Posts consist of glass fiber and filler particles (67.1%) within a resin matrix (32.9%), (Internal data. Coltène/Whaledent, 2020).

3. Edelweiss Post and Core consists of barium glass, silica glass for aesthetics and aluminium oxide for strength (Mehta, 2020). It also contains zinc oxide for its antibacterial properties and fluoride for regenerative properties (88.1%), embedded in a resin matrix of BisGMA (11.9%). The crystals are sintered which is believed to improve the mechanical properties of the post.
4. GC Fiber Posts consist of glass fibers (87.8%) within a methacrylate resin matrix (12.3%). The glass fibers consist of barium glass, silica glass for aesthetics, aluminium oxide and calcium for strength, zinc oxide for its antibacterial properties and fluoride for regenerative properties, embedded in a resin matrix of methacrylate.

Although researchers over the years had given us an idea of the composition of resin matrix and mechanical properties the precise composition remains a state secret. In conclusion we know that fiber was responsible for resistance against flexure and the resin matrix provided resistance against loads from compression. It also might attach to functional monomers within the adhesive cements (Mannocci et. al. 2001).

CHAPTER 6

6.1 CONCLUSION

Within the limitations of this study, it is evident that, a significant correlation between the fiber diameter and the flexural strength of the four fiber post systems as well as the fiber matrix ratio and their flexural strengths have been established. In this study the following significance could be noticed:

1. Statistically significant differences exist between the flexural strengths of the four fiber post systems tested.
2. Strong correlation was found between flexural strength and fiber/matrix ratio of four fiber post systems as well as the flexural strength and fiber diameter of the four fiber post systems.
3. More data about the clinical outcome of specific fiber post systems are needed before they can be proposed for application clinically.

References

Adler, S., Kistler, S., Kistler, F., Lermer, J. and Neugebauer, J. (2013). Compression-moulding rather than milling: a wealth of possible applications for high performance polymers. Quintessenz Zahntechnik, 39,376-384.

Aggarwal, V., Singla, M., Miglani, S., Kohli, S. (2012). Comparative evaluation of fracture resistance of structurally compromised canals restored with different dowel methods. Journal of Prosthodontics, 21(4), 312-316.

Akkayan, B. and Gülmez, T. (2002). Resistance to fracture of endodontically treated teeth restored with different post systems. The Journal of Prosthetic Dentistry, 87, 431-437.

Al-Hazaimeh, N., Gutteridge, D.L. (2001). An in vitro study into the effect of the ferrule preparation on the fracture resistance of crowned teeth incorporating prefabricated post and composite core restorations. International Endodontic Journal, 34,40-46.

AL-Omiri, M.K., Mahmoud, A.A. and Rayyan, M.R. (2010). Fracture resistance of teeth restored with post-retained restorations: an overview. Journal of Endodontics, 9,1439-1449.

Al-Wahadni, A., Gutteridge, D.L. (2003). An in vitro investigation into the effects of retained coronal dentine on the strength of a tooth restored with a cemented post and partial core restoration. International Endodontic Journal. 35, 913–918.

Amaral, M., Santini, M.F., Wandscher, V., Amaral, R. and Valandro, L.F. (2009). An in vitro comparison of different cementation strategies on the pull-out strength of a glass fiber post. Journal of Operative Dentistry, 34(4), 443-451.

American Society for Testing Materials. (1999). 100 Barr Harbor Drive West Conshohocken, Pennsylvania USA. Available at www.astm.org.

Amizic, P.I. and Baraba, A. (2016). Esthetic Intracanal Posts. Acta Stomatologica Croatica, 50(2), 143-150.

Asmussen, E., Peutzfeldt, A. and Heitmann, T. (1999). Stiffness, elastic limit, and strength of newer types of endodontic posts. Journal of Dentistry, 27, 275–278.

Bandlish, R.B., McDonald, A.V. and Setchell, D.J. (2006). Assessment of the amount of remaining coronal dentine in root-treated teeth. Journal of Dentistry, 34,699-708.

Barfeie, A., Thomas, M.B., Watts, A. and Rees, J. (2015). Failure mechanisms of fibre posts: a literature review. The European Journal of Prosthodontics and Restorative Dentistry, 23(3), 115-127.

Bateman, G., Ricketts, D.N. and Saunders, W.P. (2003). Fibre-based post systems: a review. British Dental Journal, 195,43-48.

Belli, S. and Eskitascioglu, G. (2006). Biomechanical properties and clinical use of a polyethylene fibre post-core material. International Dentistry Journal of Southern Africa, 8, 20-26.

Bolla, M., Muller-Bolla, M., Borg, C., Lupi-Pegurier, L., Laplanche, O. and Leforestier, E. (2007). Root canal posts for the restoration of root filled teeth. Cochrane Database of Systematic Reviews, Issue 1.

Bonilla, E.D., Mardirossian, G. and Caputo, A.A. (2000). Fracture toughness of various core build-up materials. Journal of Prosthodontics, 9(1), 14-18.

Bru, E., Forner, L., Llena, C. and Almenar, A. (2013). Fibre post behaviour prediction factors. A review of the literature. Journal of Clinical and Experimental Dentistry, 5(3), 150-153.

Burke, F.J.T., Shaglouf, A.G., Combe, E.C. and Wilson, N.H. F. (2000). Fracture resistance of five pin-retained core build-Up materials on teeth with and without extra-coronal preparation. Journal of Operative Dentistry, 25, 395-400.

Cagidiaco, M.C., Radovic, I., Simonetti, M., Tay, F. and Ferrari, M. (2007). Clinical performance of fiber post restorations in endodontically treated teeth: 2-year results. International Journal of Prosthodontics, 20, 293-298.

Callister, W.D. (1997). Material science and engineering: an introduction. In: Composites. 3rd ed. New York: Wiley.

Cândido, M.S., Pozzobon, R.T. and Porto Neto, S.T. (1999). Esthetic resolution through heterogeneous bonding root-coronal, laminate and recontourn. J Bras Odontol Clin.,15, 29-33.

Caputo, A.A. and Standlee, J.P. (1987). Restoration of endodontically involved teeth. biomechanics in clinical dentistry, Quintessence, 185-203.

Cheung, K.C. and Darvell, B.W. (2002). Sintering of dental porcelain: effect of time and temperature on appearance and porosity. Dental Materials, 18, 163-173.

Cheung, W. (2005). A review of the management of endodontically treated teeth: Post, core and the final restoration. The Journal of the American Dental Association, 136, 611-619.

Christensen, G.J. (1989). Posts and cores: state of the art. Journal of the American Dental Association, 129, 96-97.

Coltène/Whaledent AG. (2020). Feldwiesenstrasse 20 9450 Altstätten/ Switzerland. Available at www.coltene.com.

Cooney, J.P., Caputo, A.A. and Trabert, K.C. (1986). Retention and stress distribution of tapered-end endodontic posts. Journal of Prosthetic Dentistry, 55, 540.

Cormier, C.J., Burns, D.R. and Moon, P. (2001). In vitro comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post systems at various stages of restoration. Journal of Prosthodontics, 10, 26–36.

Dallari, A. and Rovatti, L. (1999). Il Sistema Composipost perni endocanalari di terza generazione. Martina Ed., Bologna.

Dallari, A. and Rovatti, L. (1996). Six years of in vitro/in vivo experience with Composipost. Compendium for Continuing Education in Dentistry, 17, 57-63.

de Moraes, A.P., Cenci, M.S., de Moraes, R.R. *et al.* 2013 Current concepts on the use and adhesive bonding of glass-fiber posts in dentistry: a review, Applied Adhesion Science, 1, 4.

DeLong, R. and Douglas, W.H. (1983). Development of an artificial oral environment for the testing of dental restoratives: bi-axial force and movement control. Journal of Dental Research, 62,32–36.

Dérand, T. (1977). The principal stress distribution in a root with a loaded post in model experiments. Journal of Dental Research, 56,1463.

Dietschi, D., Romelli, M. and Goretti, A. (1997). Adaption of adhesive posts and cores to dentin after fatigue testing. International Journal Prosthodontics, 10, 498–507.

Drummond, J.L. and Bapna, M.S. (2003). Static and cyclic loading of fiber reinforced dental resin. Dental Materials, 19,226-231.

Duret, B., Reynaud, M. and Duret, F. (1990). Un nouveau concept the reconstruction corono-radiculaire: le composipost (2). Le Chirurgien-Dentiste de France, 542, 69–77.

Edelweiss Dentistry Products (2020). Dammstraße 68, 6922 Wolfurt, Austria. Available at edelweissdentistry.com.

El-Damanhoury, H.M., Haj-Ali, R.N. and Platt, J.A. (2015). Fracture resistance and microleakage of endo-crowns utilizing three CAD-CAM blocks. Operative dentistry,40(2),201-210.

Eissmann, H.F. and Radke, R.F. (1987). Post endodontic restoration. In: Cohen, S., Burns., R.C. (eds). Pathways of the Pulp, 4th edition. St Louis: Mosby, 640–643.

Erkut, S., Gulsahi, K., Caglar, A., Imirzalioglu, P., Karbhari, V.M. and Ozmen, I. (2008). Microleakage in overflared root canals restored with different fiber reinforced dowels. Journal of Operative Dentistry. 33(1),96-105.

Felton, D.A., Webb, E.L., Kanoy, B.E. and Dugoni, J. (1991). Threaded endodontic dowels: effect of post design on incidence of root fracture. Journal of Prosthetic Dentistry, 65,179-187.

Ferrari, M., Mannocci, F., Vichi, A., Cagidiaco, M.C. and Mjor, I.A. (2000). Bonding to root canal: structural characteristics of the substrate. American Journal of Dentistry, 13, 255–260.

Ferrari, M., Mason, P.N., Goracci, C. and Tay, F.R. (2004). Collagen degradation in endodontically treated teeth after clinical function. Journal of Dental Research, 83,414-419.

Ferrari, M. and Scotti, R. (2002). Fiber posts: characteristics and clinical implications. Masson Ed., Milano.

Ferrari, M., Vichi, A., Mannocci, F. and Mason, P.N. (2000). Retrospective study of the clinical performance of fiber posts. American Journal of Dentistry, 13,9B-13B.

Fokkinga, W.A., Kreulen, C.M., Vallittu, P.K. and Creugers, N.H.J. (2004). International Journal of Prosthodontics, 17, 476-482.

Galhano, G.A., Valandro, L.F., de Melo, R.M., Scotti, R. and Bottino, M.A. (2005). Evaluation of the flexural strength of carbon fiber-, quartz fiber-, and glass fiber-based posts. Journal of Endodontics, 31(3), 209-211.

Galindo, V.A., Nogueira, J.S., Yamasaki, E., Kós Miranda, D. (2000). Biological posts and natural crowns bonding alternatives for anterior primary teeth restoration. J Bras Odonto Pedodontol bebe, 16,513-520.

Gallicchio, V., Lodato, V., De Santis, R. and Rengo, S. (2022). Fracture strength and failure modes of endodontically treated premolars restored with compact and hollow composite posts subjected to cyclic fatigue. Materials, 15, 1141.

GC Corporation (2020). 3-2-14 Hongo, Bunkyo-ku Tokyo Japan. Available at www.gc-dental.com.

González-López, S., De Haro-Gasquet, F. (2006). Journal of Operative Dentistry, 31 (1), 33–38.

Goodacre, C. J and Spolnik, K.J. (1994). The prosthodontic management of endodontically treated teeth: a literature review. Part I. Success and failure data, treatment concepts. Journal of Prosthodontics, 3,243-250.

Goodacre, C.J., Bernal, G., Rungcharassaeng, K. and Kan, J.Y.K. (2003). Clinical complications in fixed prosthodontics. Journal of Prosthetic Dentistry, 90, 31-34.

Goracci, C., Fabianelli, A., Sadek, F.T., Papacchini, F., Tay, F.R. and Ferrari, M. (2005). The contribution of friction to the dislocation resistance of bonded fiber posts. Journal of Endodontics, 31, 608–612.

Goracci, C., Cury, A.H., Cantoro, A. (2006). Microtensile bond strength and interfacial properties of self-etching and self-adhesive resin cements used to lute composite onlays under different seating forces. Journal of Adhesive Dentistry, 8, 327-335.

Goracci, C., Ferrari, M. (2011). Current perspectives on post systems: a literature review. Australian Dental Journal, 56, 77–83.

Grandini, S., Goracci, C., Monticelli, F., Tay, F.R. and Ferrari, M. (2005). Fatigue resistance and structural characteristics of fiber posts: three-point bending test and SEM evaluation. Dental Materials, 21, 75–82.

Grandini, S., Chieffi, N., Cagidiaco, M. C, Goracci, C. and Ferrari, M. (2008). Fatigue resistance and structural characteristics of different types of fiber posts. Journal of Dental Materials, 27(5), 1–8.

Hedlund, S.O., Johansson N.G. and Sjogren, G. (2003). A retrospective study of pre-fabricated carbon fibre root canal posts. Journal of Oral Rehabilitation, 1365-2842.

Helfer, A.R., Melnick, S. and Schilder, H. (1972). Determination of the moisture content of vital and pulpless teeth. Oral Surgery, Oral Medicine and Oral Pathology, 34(4), 661-669.

Heydecke, G., Butz, F. and Strub, J.R. (2001). Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems. Journal of Dentistry, 29, 427-433.

Howe, C.A. and McKendry, D.J. (1990). Effect of endodontic access preparation on resistance to crown-root fracture. Journal of the American Dental Association, 121(6), 712-715

Hsu, Y.B., Nicholls, J.I., Phillips, K.M. and Libman, W.J. (2002). Effect of core bonding on fatigue failure of compromised teeth. International Journal Prosthodontics, 15,175–178.

Inaba, Y., Teraoka, F.,Nakagawa, M. and Imazato, S. (2013). Development of a new direct core buildup method using a hollow fiber reinforced post, Dental Materials Journal, 32(5), 718–724.

Indzhov, B., (2006). Basics in cavity preparation, 354-357.

Isidor, F., Odman, P. and Brondum, K. (1996). Intermittent loading of teeth restored using prefabricated carbon fiber posts. International Journal of Prosthodontics, 9, 131–136.

Isidor, F., Brøndum, K., and Ravnholt, G. (1999). The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. International Journal of Prosthodontics, 12, 78-82.

Jotkowitz, A. and Samet, N. (2010). Rethinking ferrule: a new approach to an old dilemma. British Dental Journal, 209, 25–33.

Karbhari, V.M. and Strassler, H. (2007). Effect of fiber architecture on flexural characteristics and fracture of fiber-reinforced dental composites. Dental Material, 23(8), 960-968.

Kaizer, O.B., Bonfante, G., Pereira, Filho, L.D., Lucas, C. and Reis, K.R. (2008). Utilization of biological posts to reconstruct weakened roots. Rev Gaucha Odontol., 56, 7-13.

Koutayas, S.O. and Kern, M. (1999). All-ceramic posts and cores: the state of the art. International, 30(6), 383-392.

Kul, E., Yeter, K.Y., Aladag, L.I. and Ayranc, L.B. (2016). Effect of different post space irrigation procedures on the bond strength of a fiber post attached with a self-adhesive resin cement. Journal of Prosthetic Dentistry, 115, 601-605

Kumar, P. and Rao, R.N. (2015). Three-dimensional finite element analysis of stress distribution in a tooth restored with metal and fiber posts of varying diameters: An in-vitro study. Journal of Conservative Dentistry, 18(2), 100–104.

Kurer, H.G., Combe, E.C. and Grant, A.A. (1977). Factors influencing the retention of dowels. Journal of Prosthetic Dentistry, 38(5), 515-525.

Krupp, J.D., et al. (1979). Dowel retention with glass-ionomer cement. Journal of Prosthetic Dentistry, 41, 163.

Lassila, L.V., Tanner, J., Le Bell, A.M., Narva, K. and Vallittu, P.K. (2004). Flexural properties of fiber reinforced root canal posts. Dental Materials, 20, 29-36.

Leary, J.M., Jensen, M.E., Sheth, J.J. (1989). Load transfer of posts and cores to roots through cements. Journal of Prosthetic Dentistry, 62, 298.

Le Bell-Rönnlöf, A.M. (2007). Fibre-reinforced composites as root canal posts. Medica Odontologica, 780.

Libman, W.J. and Nicholls, J.I. (1995). Load fatigue of teeth restored with cast posts and cores and complete crowns. International Journal Prosthodontics, 8, 155–161.

Mackenzie, J.K. and Shuttleworth, R. (1949). A phenomenological theory of sintering. Section B. Available at iopscience.iop.org.

Magne, P., Lazari, P.C., Carvalho, M.A., Johnson, T. and Del Bel Cury, A.A., 2017. Ferrule-Effect Dominates Over Use of a Fiber Post When Restoring Endodontically Treated Incisors: An In Vitro Study. Operative Dentistry, 42 (4), 396–406.

Maillefer Instruments Holding. (2020). Sàrl Chemin du Verger, 3 CH-1338 Ballaigues Switzerland. Available at www.maillefer.com.

Manhart, J. (2009). Fiberglass reinforced composite endodontic posts, Endodontic Practice.

Mannocci, F., Ferrari, M. and Watson, T.F. (1999). Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber and zirconium dioxide ceramic root canal posts. Journal of Adhesive Dentistry, 1(2), 153–158.

Mannocci, F., Innocenti, M., Ferrari, M. and Watson, T.F. (1999). Confocal and scanning electron microscopic study of teeth restored with fiber posts, metal posts, and composite resins. Journal of Endodontics, 25, 789–794.

Mannocci, F., Sherriff, M. and Watson, T.F. (2001). Three-point bending test of fiber posts. Journal of Endodontics, 27, 758–761.

Martinez-Insua, A., da Silva, L., Rilo, B. and Santana, U. (1998). Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core. Journal of Prosthetic Dentistry, 80, 527-532.

McComb, D. (2008). Restoration of the endodontically treated tooth. Journal of Dispatch.

Mehta, D. (2020). Internal data: R&D and QM Department Edelweiss Dentistry, GMBH Austria. Available at www.edelweissdentistry.com.

Mezzomo, E., Massa, F. and Libera, S.D. (2003). Fracture resistance of teeth restored with two different post-and-core designs cemented with two different cements: an in vitro study. Part I, Quintessence International, 34, 301-306.

Mentink, A.G., Creugers, N.H., Hoppenbrouwers, P.M. and Meeuwissen, R. (1998). Qualitative assessment of stress distribution during insertion of endodontic posts in photoelastic material. Journal of Dentistry, 26, 125.

Michalakis,K.X., Hirayama, H., Sfolkos, K. (2004). Light transmission of posts and cores used for the anterior esthetic region. Journal of Periodotics and Restorative Dentistry.

Nathanson, D. and Moin, K. (1980). Metal-reinforced anterior tooth replacement using acid-etch-composite resin technique. Journal of Prosthetic Dentistry, 43, 408-413.

Ng, C.C., Dumbrigue, H.B., Al-bayat, M.I., Griggs, J.A. and Wakefield, C.W. (2006). Influence of remaining coronal tooth structure on the fracture resistance or restored endodontically treated anterior teeth. Journal of Prosthetic Dentistry, 95, 290–296.

Osborne, J.W. and Lambert, R.L. (1985). Reattachment of fractured incisal tooth segment. General dentistry, 33(6), 516.

Panitiwat, P. and Salimee, P. (2017). Effect of different composite core materials on fracture resistance of endodontically treated teeth restored with FRC posts. Journal of Applied Oral Science, 25(2), 203-210.

Paul, S.J. and Scharer, P. (1997) Post and core reconstruction for fixed prosthodontic restoration. Practical Periodontics and Aesthetic Dentistry, 9, 513-520.

Paul, R., Nagpal, A. and Sharma, A. (2018). Restoration of badly broken teeth using edelweiss post and core. Guident.

Pennaaccio, M.C., Pontoriero, D.I.K. and Ferrari, M. (2020). Influence of different posts's composition and shape on bond strength to radicular dentin. Journal of Osseointegration, 12(3), 209-214; 50(2),143-150.

Peroz, I., Blankenstein, F., Lange, K.P. and Naumann, M. (2005). Restoring endodontically treated teeth with post and cores- A review. Quintessence International.

Peters, M.C.R.B., Poor H.W, Farah, J.W. and Craig, R.G (1983). Stress analysis of a tooth restored with a post and core. Journal of Dental Research, 62, 760.

Pissis, P. (1995). Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Practical Periodontics Aesthetic Dentistry Dent, 7, 83-93

Pitzer, K.S. and Brewer, L. (1961). Thermodynamics, 2nd ed. McGraw-Hill, New York.

Plotino, G., Grande, N.M., Bedini, R. Pameijer, C.H. and Somma, F. (2007). Flexural properties of endodontic posts and human root dentin. Dental Materials, 23, 1129-1135.

Qiu, S., Chen, Y., Tsauo, C., Wu, W., Huang, D., Zhou, X., Peng, L., Gao,Y. (2023). Microcomputed tomography analysis of the radicular residual dentin thickness in mandibular second molars after virtual fiber post placement: Identification of danger zones. Journal of Prosthetic Dentistry, 130, 109.

Quintas, A.F., Dinato, J.C. and Bottino, M.A. (2000). Aesthetic posts and cores for metal-free restoration of endodontically treated teeth. Journal of Practical Periodontics and Aesthetic Dentistry, 12(9), 875-884.

Rantanen, T. (1970). A control study of crowns and bridges on root canal filled teeth. Suomen Hammaslaakariseuran Toimituksia, 66, 275-288.

Reeh, E.S., Messer, H.H. and Douglas, W.H. (1989). Reduction in tooth stiffness as a result of endodontic and restorative procedures. Journal of Endodontics, 15, 512-517.

Reichen-Graden, S. and Lang, N.P. (1989). Periodontal and pulpal conditions of abutment teeth. Status after four to eight years following the incorporation of fixed reconstructions. Schweiz Monatsschr Zahnmed, 99, 1381.

Ricketts, D.N.J., Tait, C.M.E. and Higgins, A.J. (2005). Post and core systems, refinements to tooth preparation and cementation. British Dental Journal, 198, 533–541.

Rippe, M.P., Santini,M.F., Bier, C.A.S., Baldissara, P., Valandroet, L.F. (2014). Effect of root canal preparation, type of endodontic post and mechanical cycling on root fracture strength. Journal of Applied Oral Science, 22, 165.

Rivard, C.H., Rhalmi, S. and Coillard, C. (2002). In vivo biocompatibility testing of peek polymer for a spinal implant system: a study in rabbits. Journal of Biomedical Materials Research, 62, 488-498.

Rosenstiel, S.F., Land, M.F. and Fujimoto, J. (2016). Contemporary Fixed Prosthodontics, 5th edition, Elsevier, 282-317.

Rosentritt, M., Plein, T., Kolbeck, C., Behr, M. and Handel, G. (2000). In vitro fracture force and marginal adaptation of ceramic crowns fixed on natural and artificial teeth. International Journal of Prosthodontics, 13, 387–391.

Roulet, J.F. (1990). Degradation of dental polymers. Basel: Karger AG, 108–110.

Ruemping, D.R., Lund, M.R., Schnell R.J. (1979). Retention of dowels subjected to tensile and torsional forces. Journal of Prosthetic Dentistry, 41, 159.

Rzanny, A., Gobel, F. and Fachet, M. (2013). BioHPP summary of results for material tests. Research Report. Jena, Germany, University of Jena, Department of Materials and Technology.

Salameh, Z. (2008). Mechanical behaviour of endodontically treated teeth restored with fiber posts and full coverage restorations. Siena.

Santis, R.D., Prisco, D. and Apicella, A. (2000). Carbon fiber post adhesion to resin luting cement in the restoration of endodontically treated teeth. Journal of Materials Science, Materials in Medicine, 11, 201–206.

Santos, A.F.V., Meira, J.B.C. and Tanaka, C.B. (2010). Can fiber posts increase root stresses and reduce fracture? Journal of Dental Research, 89(6), 587-591.

Sarot, J.R., Contar, C.M., Da Cruz, A.C. and de Souza Magini, R. (2010). Evaluation of the stress distribution in CFR-PEEK dental implants by the three-dimensional finite element method. Journal of Materials Science, Materials in Medicine, 21(7), 2079-2085.

Schwartz, R.S. and Robbins, J.W. (2004). Post Placement and Restoration of Endodontically Treated Teeth: A Literature Review. Journal of Endodontics, 30, 289-301.

Seefeld, F., Wenz, H.J., Ludwig, K. and Kern, M. (2007). Resistance to fracture and structural characteristics of different fiber reinforced post systems. Dental Materials, 23, 265-271.

Seferis, J.C. (1986). Polyetheretherketone (PEEK): Processing-structure and properties studies for a matrix in high performance composites. Polymer composites, 7(3), 158-169.

Segal, B.S. (2001). Retrospective assessment of 546 all-ceramic anterior and posterior crowns in a general practice, Journal Prosthetic Dentistry, 85(6), 544-550.

Sharma, A., Paul, P., Nagpal, A. (2018). Restoration of badly broken teeth using Edelweiss post and core. Dentistry and Oral Sciences, 11(12), 32-36.

Shetty, P.P., Meshramkar, R., Patil, K.N. and Nadiger, R.K. (2013). A finite element analysis for a comparative evaluation of stress with two commonly used esthetic posts. European Journal of Dentistry, 7(4), 419-422.

Sidoli, G.E., King, P.A. and Setchell, D.J. (1997). An in vitro evaluation of a carbon fiber-based post and core system. The Journal of Prosthetic Dentistry, 78, 5-9.

Singh, A., Logani, A. and Shah, N. (2012). An ex vivo comparative study on the retention of custom and prefabricated posts. Journal of Conservative Dentistry, 15(2), 183-186.

Smith, C.T., Schuman, N.J. and Wasson, W. (1998). Biomechanical criteria for evaluating prefabricated post-and-core systems: a guide for the restorative dentist. Quintessence International, 29, 305-312.

Smith, C.T. and Schuman, N. (1998). Prefabricated post-and-core systems: an overview. Compendium Continuing Education in Dentistry Journal, 19, 1013-1020.

Soares, C.J., Santana, F.R., Pereira, J.C., Araujo, T.S. and Menezes, M.S. (2008). Influence of airborne-particle abrasion on mechanical properties and bond strength of carbon/epoxy and glass/bis-GMA fiber-reinforced resin posts. Journal of Prosthetic Dentistry, 99, 444-454.

Soares, P.V., Reis, B.R., Verissimo, C. and Soares, C.J. (2013). Effects of threaded post placement on strain and stress distribution of endodontically treated teeth. Dental Materials, 27 (4).

Söderholm, KJ. and Mariotti, A. (1999). BIS-GMA based resins in dentistry: are they safe? The Journal of the American Dental Association, 130,201-209.

Sorensen, J.A. and Engelman, M.J. (1990). Ferrule design and fracture resistance of endodontically treated teeth. Journal of Prosthetic Dentistry, 63,529–536.

Sorensen, J.A. and Martinoff, J.F. (1984a). Clinically significant factors in dowel design. Journal of Prosthetic Dentistry, 52, 28-35.

Sorensen, J.A. and Martinoff, J.T. (1984b). Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. Journal of Prosthetic Dentistry, 51, 780.

Srivastva, J. (2020). Restoration of traumatically fractured maxillary central incisor with Edelweiss post and core followed by PFM crown. Guident. Vol. 13 Issue 7, 28-30.

Standlee, J.P., et al. (1978). Retention of endodontic dowels: effects of cement, dowel length, diameter and design. Journal of Prosthetic Dentistry, 39, 401.

Standlee, J.P., Caputo, A.A, Holcomb, J., Trabertet, K.C. (1980). The retentive and stress-distributing properties of a threaded endodontic dowel. Journal of Prosthetic Dentistry, 44, 398.

Standlee, J.P. and Caputo, A.A. (1992). The retentive and stress distributing properties of split threaded endodontic dowels. Journal of Prosthetic Dentistry, 68, 436-442.

Stankiewicz, N.R., and Wilson, P.R. (2002). The ferrule effect: a literature review. International Endodontic Journal, 35, 575-581

Strassler, H.E. (2007). Fiber Posts: A Clinical Update, Inside Dentistry, 3(3).

Swarupa, C.H., Sajjan, G.S., Bhupahupathiraju, V.L. and Anwarullahwarullah, A. (2014). Biological dentin post for intra radicular rehabilitation of a fractured anterior tooth. Journal of Clinical and Diagnostic Research, 8(2), 242-243.

Tay, F.R., Pashley, D.H., Yiu, C.K., Sanares, A.M. and Wei, S.H. (2003). Factors contributing to the incompatibility between simplified-step adhesives and chemically-cured or dual cured composites. Part I. Single-step self-etching adhesive. Journal of Adhesive Dentistry, 5, 27–40.

Tay, F.R., Pashley, D.H. (2007). Monoblocks in Root Canals: A Hypothetical or a Tangible Goal. Journal of Endodontics, 33, 391-398.

Terry, D.A. and Swift, E.J. (2010). Post-and-cores: Past to present. Journal of International Dentistry, 12(2).

Thorsteinsson, T.S., Yaman, P., Craig, R.G. (1992). Stress analysis of four prefabricated posts. Journal of Prosthetic Dentistry, 67, 30.

Trabert, K.C., Caputo, A.A. and Abou-Rass, M. (1978). Tooth fracture—A comparison of endodontic and restorative treatments. Journal of Endodontics, 4, 341-345.

Trushkowsky, R. (2008). Fiber Post Selection and Placement Criteria: A Review, Inside Dentistry, 4(4).

Turner, C.H. (1982). Post-retained crown failure: a survey. Dental Update, 9, 221.

Valandro, L.F., Ozcan, M., de Melo, R.M., Galhano, G.A., Baldissara, P. and Scotti, R. (2006). Effect of silica coating on flexural strength of fiber posts. International Journal of Prosthodontics, 19, 74-76.

Vaz, R.R., Hipólito, V.D., D'Alpino, P.H. and Goes, M.F. (2012). Bond strength and interfacial micromorphology of etch-and rinse and self-adhesive resin cements to dentin. Journal of Prosthodontics, 21(2), 101-111.

Vichi, A., Grandini, S., Davidson, C. and Ferrari, M. (2002). An SEM evaluation of several adhesive systems used for bonding fiber posts under clinical conditions. Dental Materials, 18(7), 295-502.

Wagnild, G.W. and Mueller, K.I. (1998). Restoration of endodontically treated tooth. Pathways of the Pulp, 7th ed., Mosby, St Louis.

Wood, W.W. (1983). Retention of posts in teeth with nonvital pulps. Journal of Prosthetic Dentistry, 49, 504.

Yaman, S.D., Alaçam, T., Yaman,Y. (1998). Analysis of stress distribution in a maxillary central incisor subjected to various post and core applications. Journal of Endodontics, 24, 107.

Zicari, F., Coutinho, E., Scotti, R., Van Meerbeek, B. and Naert, I. (2013). Mechanical properties and micro-morphology of fiber posts. Dental Materials, 29, 45-52.

Zhu, Z., Dong, X.Y., He, S., Pan, X. and Tang, L. (2015). Effect of post placement on the restoration of endodontically treated teeth: A systematic review. International Journal of Prosthodontics, 28, 475-483.

Zoidis, P., (2021). The use of modified Polyetheretherketone post and core for an esthetic lithium disilicate anterior ceramic restoration: a clinical report. International Journal of Prosthodontics, 34(1), 120-125.

APPENDIX

TURNITIN REPORT

Submitted online