We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Restoration of Endodontically Treated Teeth

Deepak M. Vikhe

Abstract

A tooth that has been properly treated endodontically should have a good prognosis. It can resume full function and if necessary serve satisfactory as an abutment for a fixed and removable partial denture. However special techniques are needed to restore such a tooth. Traditionally, a pulpless tooth received a dowel or post to “reinforce” it and a crown to “protect” it. Until the introduction of ZnPO₄ cement in the last century. The major problem with their use was that of post retention. Currently, the clinician can use a variety of post and core systems for the different endodontic and restorative requirements. However, no single system provides the perfect restorative solution for every clinical circumstance, and each situation requires individual evaluation.

Keywords: abutment, dowel, endodontically, post, restorative

1. Introduction

Loss of vitality decreases the physical properties, translucency, and fracture resistance of the remaining tooth structure. A load applied on upper teeth makes them move towards labially i.e. up and outwards having no support from adjacent teeth treated endodontically will have no central core of dentine and so the stresses are mainly absorbed by margins. Unless there is bulk in this region simple restoration of the coronal form may be insufficient to reinforce the tooth. So to reinforce the crown, a post is placed in the root canal. By this, the potential point of fracture from the gingival margin can be shifted towards the root apex. Similarly loads on lower teeth cause down and inward movement which closes the arch and also gains support from adjacent teeth. So here reinforcement with the post is not as important compared to upper teeth. But still, as preparation of access cavity may leave little of dentine placement of post may be desirable. Endodontically treated teeth often require partial or complete coverage restorations according to the amount of remaining tooth structure. Endodontic treatment is usually the consequence of caries followed by pulpal infection or traumatic damage to a tooth. Therefore, these teeth also suffer from loss of structural integrity, necessitating restoration of the tooth for esthetic and functional rehabilitation. It was believed that the insertion of a post into an endodontically treated tooth reinforced and increased fracture resistance [1].

- **What is post? (Figure 1)**

It is that part of the prosthesis usually made of metal that is fitted into a prepared canal of a natural tooth

Figure 1.
Schematic illustration of an endodontically-treated tooth restored by the post-core system.

- Depending upon the design of the post the basic designs available are
 1. round ended
 2. tapered ended
 3. parallel ended
- Depending on surface texture it is divided into.
 1. smooth sided
 2. serrated
 3. threaded posts.
- Examples of some posts are
flexi posts, endoposts, plastic impression posts, brasslers ER casting post, weissmans dentatus post, para post, v- lock active post etc.
- Parallel sided posts advantages
Better retention, better distribution of forces.
- Disadvantages are.
Fits only at the apical part of the canal, requires more dentine to be removed.
- Tapered posts advantages are.
Better conforms to the canal, less removal of dentine.
- Disadvantages are.
Less retentive than other posts, causes greater stress concentration and causes wedging affect.
- Here retention can be increased by controlled grooving.
- Of all the posts threaded posts are more retentive but these are well known to cause root fracture due to increase in forces at each coil of the threaded during insertion of the post.

According to Caputo and Standlee the self-threaded pins and friction lock pins should not be used in endodontically treated teeth [2].

According to Johnson and Sakamura, parallel sided posts resist tensile forces 4.5 times greater than tapered posts [3].

- What is parapost?

parallel pins that are added to the prefabricated post, which provides resistance to rotation and some minimal additional retention.

According to Colley parallel sided serrated posts of 5.5 mm long are more retentive than tapered posts of 8 mm long [4].

- The ideal required length of the post is $\frac{2}{3}$ the length of the root or the length of the clinical crown, whichever is longer and the diameter of the post is $\frac{1}{3}$ of the diameter of the root [it is the maximum]

2. Recent advancements in posts

2.1 Fiber reinforced epoxy resin posts

Reinforced with black carbon fibers which are later coated with quartz fibers to mask the black color and to improve the aesthetics. These posts possess inherent flexibility that is similar to that of natural teeth [dentine], allowing the post to behave similar to the radicular dentine, which absorbs stresses and prevents root fracture. At the same time these posts cause failure of the cement seal at the margins of the artificial crown, especially when the ferrule is minimum [5].

2.2 Zirconia posts

These contain zirconium oxide, a medicine for orthopedic implants. These should be used along with composite cores. These have less tensile strength and may fracture when subjected to shear stresses [5].

2.3 Woven—fiber composite materials

These include cold—glass. Plasma treated poly ethylene woven fibers embedded in conventional resin composites. These are weaker than cast metal posts and cores. These have inferior strength combined with undesirable flexibility [5].

- **What is core? (Figure 1).**

It is the centre or base of the structure.

- core materials used for anterior teeth are:

1. Plastic materials like amalgam or glass ionomer cement or composites.
2. Resin or wax.

- core materials used for posterior teeth are.

1. Cast gold core.

2. Resin core or composite core with metal post.

3. Resin or composite core with a cast pins.

In vitro studies states that, when load is applied on a tooth, root fracture is less in teeth restored with resin core, compared with amalgam and cast gold cores [6].

Trauma and decay are often associated with an extensive loss of tooth structure, requiring a restoration for esthetic and functional rehabilitation of the tooth. Often caries leads to loss of tooth structure and vitality of the pulp. Endodontic treatment is necessary in such cases. Adequate anchorage for restoration cannot be achieved if a significant amount of coronal section of the tooth is lost i.e. when only one wall or no wall is remaining. To increase the retention of the restoration post and core treatment is required.

Endodontic treatment influences the strain values and fracture resistance of the remaining tooth [7]. Most of the endodontic treatment failures are influenced by masticatory load. In general, failure rates tend to increase concomitantly as occlusal load increases. Failure loads have been shown to increase as parallelism approaches the load angle between the long axes of the teeth i.e. under lateral loading, failure tends to occur more readily [8]. Teeth which are nearer to transverse horizontal axis are subjected to increased amount of load as compared to anterior teeth. The fracture resistance of the tooth is also directly proportional to remaining bulk of dentin. Post space preparation can increase the amount of dentin removed thus affecting the load bearing capacity of the tooth. To prevent the major tragedy of vertical root fracture (VRF) cases, researchers have been focusing on materials used for post fabrication, designs of the post, luting agents, and the ferrule effect.

Various types of post and core systems have been introduced in dentistry. Endodontic post and core may be cast using material such as gold and nickel-chromium (Ni-Cr), or they may be prefabricated, such as titanium, stainless steel posts and fiber posts. For many years, the custom made posts have been the choice of restoration for endodontically treated teeth. However custom-made posts are technique-sensitive. The elution of the metal ions from these posts can cause metal allergy [9]. Another disadvantage of cast post being higher modulus of elasticity than dentin, which increases the risk of catastrophic failure [10]. Due to these disadvantages, these posts are progressively being replaced by titanium post. Use of a straight titanium posts requires excessive post space preparation in the curved canals [11]. This disadvantage of straight titanium post can be overcome by bendable titanium posts due to its flexible nature. Bendable titanium post can be used for various purposes, for instance, it can be included in preparation of the core when the axis of the crown of the tooth being restored has to be altered to place two or more posts, if necessary, or they can be placed in curved root canals since they can be contoured to follow the canal anatomy, thus bending internally, creating a mechanical lock for the resin core and increasing the retention surface.

Evidence remains controversial regarding the most efficient form of post for restoring endodontically treated teeth. The reduced load bearing capacity of the endodontically treated teeth being the one of the major concerns; fracture resistance provided by different posts needs to be compared.

3. Review of literature

Standlee J, Caputo A, Collard E (1972) [12], compared three post systems in regard to their design, methods of insertion, their length and their abilities to

transmit forces to their supporting structures. According to the photoelastic stress analysis, post design affects stress distribution. Stresses tended to concentrate under the post shoulder, especially if sharp angles were present. Also ascertained was the fact that the post length should approximate the length of the anatomic crown.

Guzy G, Nicholls J (1979) [13], compared the breaking loads of endodontically treated teeth, with and without cemented posts, to determine if the post reinforces the root against fracture. Study was performed using maxillary central incisors and maxillary and mandibular canines. Load was applied at an angle of 130 degrees to the long axis of tooth with a speed of 5 cm/min. It was concluded that teeth without posts fractured through the middle or coronal one third of the root whereas teeth with posts fractured through the body of the post and there was no statistical significant reinforcement with cementation of posts.

Davy D, Dilley G, Krejci R (1981) [14], compared a series of designs for endodontic dowel posts, using maxillary central incisor. The tooth was examined under two load conditions, lateral load and compressive load. Both loads were treated as being concentrated along the incisal edges. They concluded the effect of taper was found to be slight if the local tapered-post diameter was comparable to the cylindrical post diameter in the high-stress region. The tapered-post design experienced slightly higher tensile and slightly lower shear stresses than the cylindrical post. Using the peak stresses in the dentin and at the dentin-post interface as a criterion, the cylindrical post with the largest diameter was the best design.

Eshelman E, Sayegh F (1983) [15], compared three post systems for fracture resistance. He concluded that between three post systems, ParaPost (stainless steel), custom made gold dowels and custom made composite dowels, the materials used for fabrication were not necessarily significant, but the angle of the load influenced the amount of force required to cause fracture and its location.

Reinhardt R, Krejci R, Stannard J (1983) [16], studied the effect of alveolar bone loss on the magnitude and distribution of stress in dentin of post-reinforced teeth. Dentin stresses from simulated functional loads to post-reinforced tooth models with four levels of periodontal support were calculated using finite element analysis. As bone levels diminished, stresses increased dramatically and were found to concentrate in the small amount of dentin remaining near the post apex.

Sorensen JA, Martinoff JT (1984) [17], evaluated 1273 endodontically treated teeth and compared the clinical success rate of six coronal-radicular stabilization methods, recorded the failure of dowel systems and the effect on endodontically treated teeth, and determined the effect of dowel length on the clinical success rate. Authors concluded the cast parallel-sided serrated dowel and core and the parallel-sided serrated dowel with an amalgam or composite resin core recorded the highest success rate. The tapered cast dowel and core displayed a higher failure rate than teeth treated without intracoronar reinforcement.

Kersten H, Fransman R, Velzen T (1986) [18], studied the effect of shape of the root canal in the success of the root canal treatment, apart from the efficiency of different root canal filling techniques especially in oval shaped canals. It was shown that close canal adaptation with minimal tooth structure removal provides a conservative and long lasting treatment for the restoration of endodontically treated teeth.

Plasmans PJJM, Visseren GH, Vrijhoef MA, Iyser AKF (1986) [19], evaluated the failure resistance of some restoration methods utilizing amalgam under an oblique load. The results suggested that intracoronar reinforcement with a prefabricated dowel did not significantly increase the in vitro resistance. Hence, the authors concluded that this in vitro study supports the approach of not removing too much remaining tooth structure to adapt the tooth for a cast dowel and core. Preservation of sound dentin and adapting the amalgam core to the teeth leaves

more tooth structure and makes easy rebuilding possible with a restoration which is strong enough to resist forces of about 1,000 N.

Leary J, Aquilino S (1987) [20], evaluated the effect of various post lengths on the strength or rigidity of the root within the elastic limit of dentin. Extracted maxillary centrals, maxillary and mandibular canines were the specimens selected for study. For the study the minimum root length acceptable was 12 mm measured from the cemento-enamel junction on the facial surface. This length allowed three incremental increases in post length of 3 mm, still leaving a 3 mm minimum for the apical seal. Load was applied 10 mm from the CEJ at 90 degrees to the long axis of the test specimen. They concluded that as internal tooth structure is removed from the tooth the tooth becomes weaker, that teeth with posts do show more reinforcement than teeth without post with the same manipulation characteristics, and that some load transfer appears to exist with cemented posts.

Hunter A, Feiglin B, Williams J (1989) [21], examined the effect of root canal preparation, post preparation, and posts on the relative stresses in the cervical and apical regions of tooth models representing an intact maxillary central incisor. The authors concluded that removal of internal tooth structure during root canal therapy is accompanied by a proportional increase in stresses at the cervical area, particularly on the tension side. Post length appeared more important than post diameter in determining relative stresses at the cervical region. However, short wide posts led to elevated stress concentrations in this region. Post placement beyond two thirds of the root depth did not further decrease cervical stresses but usually increased stresses in the apical region.

Greenfeld R, Roydhouse R, Marshall F, Schoner B (1989) [22], compared a new parallel-tapering, threaded, split-shank post with a well-accepted parallel serrated post under applied compressive-shear loads. The posts were placed in paired, contralateral human teeth to attempt to minimize variation in the tooth model. Both initial and ultimate failure modes were observed, and the clinical significance was reported. The Flexi-post system compared favorably with the Para-Post system under the conditions of this research.

Burns DA, Krause WR, Douglas HB, Burns DR (1990) [23], compared the stress distribution during insertion and function of three prefabricated endodontic posts with different designs using the criteria of post length and diameter. It was reported that larger diameter posts at increased depths distributed stress more efficiently than the smaller, shorter posts when loaded obliquely.

Hatzikyriakos A, Reisis G, Tsingos N (1992) [24], conducted a longitudinal clinical study of patients treated with three traditional techniques (1) screw post and light-curing composite resins, (2) cemented post with parallel sides and light-curing composite resins, and (3) a cast and core technique. All post and core fabrications demonstrated remarkable success in the 3-year period regardless of the technique. The posts and cores with the techniques described performed for patients with existing prosthodontics, were satisfactory. The statistical analysis revealed that only the factor "type of abutment" (RPDs and FPDs) had some effect on the failure of the restorations.

Sedgley C, Messer H (1992) [25], compared the biomechanical properties of endodontically treated teeth. It was concluded that Vital dentin was 3.5% harder than dentin from contralateral endodontically treated teeth ($p = 0.002$). The similarity between the biomechanical properties of endodontically treated teeth and their contralateral vital pairs indicated that teeth do not become more brittle following endodontic treatment.

Assif D, Bitenski A, Pilo R, Oren E (1993) [26], examined the effect of post design on the fracture resistance of endodontically treated premolars restored with cast crowns. The experimental model used cast posts and cores to test the effect of

post design in a post-core system with identical rigidity. Samples were loaded on an Instron testing machine until failure revealed that post design did not influence the fracture resistance of endodontically treated premolars restored with complete cast crowns. In their study they concluded that endodontically treated teeth having a dowel-core system of identical rigidity and restoration with a complete cast crown having a 2 mm margin on healthy tooth structure. The selection of a dowel should be based on a system that preserves the most tooth structure and possesses suitable retention of the core for restoration of the tooth. If the anatomic crown is sufficiently preserved and core retention can be achieved from within the natural crown, or if completion of the coronal surface is unnecessary, a dowel is not required.

Mentink A, Creugers N, Meeuwissen R, Leempoel P, Kayser A (1993) [27], conducted a clinical trial to assess the clinical performance of several post and core systems. During the period 1974–1986, 112 post and core build-ups were inserted in 74 patients. The build-ups consisted of a metal prefabricated post in combination with a composite core. After an average follow-up period of 7.9 years, they concluded that the Dentatus post in combination with composite tends to yield a high failure rate. The results of the Unimetric and Radix posts in combination with composite appear to be acceptable.

Goodacre C, Spolink K (1994) [28], reviewed the management options of endodontically treated teeth and concluded that crowns should generally be used on endodontically treated posterior teeth but are not necessary on relatively sound anterior teeth. The primary purpose of post is to retain a core that can be used to retain the definitive prosthesis. Loosening of the post and tooth fractures were the two most common failures reported. Considering the post design threaded posts are the most retentive followed by cemented parallel sided posts, cemented tapered post is least retentive posts. Threaded post forms are the most likely to cause root fracture and split, and threaded flexible posts do not reduce stress concentration during function. Cemented posts produce the least root stress.

Torbjorner A, Karlsson S, Odont D, Odman P (1995) [29], evaluated the dental records of 638 patients treated with 788 posts and cores to analyze failure rate and failure characteristics for two post designs. Frequency of the technical failures, loss of retention, root fracture, and post fracture were recorded 4 to 5 years after post cementation. Two types of posts were compared: custom-cast tapered posts and parallel-sided serrated posts. The cumulative failure rate was 15% for 456 tapered posts and 8% for 332 Para-Post posts. Loss of retention was the most frequent reason for failure for both types of posts, whereas root fractures had the most serious consequences, and all resulted in extraction. A significantly higher success rate was recorded for parallel-sided serrated posts, compared with custom-cast posts, regarding the total failure rate and the severity of the failure.

Purton D, Love R (1996) [30], compared the properties in two different 1-mm diameter root canal posts — smooth carbon fiber posts (Endopost) and serrated stainless steel posts (Parapost). Ten posts of each type were tested for rigidity in a three point bend test. Ten posts of each type were cemented with resin cement into the roots of endodontically treated, extracted teeth. The tensile force required to remove the posts was recorded. The Paraposts proved to be significantly more rigid under load and significantly more strongly retained in the tooth roots. The Parapost appears to be a mechanically superior post for the restoration of root-filled teeth with narrow diameter root canals.

Mendoza D, Eakle W, Kahl E, Robert H (1997) [31], evaluated the ability of resin-bonded posts to reinforce teeth that are structurally weak in the cervical area against fracture. Forty canine roots were endodontically treated and randomly distributed into four groups of 10. Parallel-sided preformed posts were cemented

into the roots of these teeth after their crowns were removed. The cervical third of the canals were flared to simulate teeth weakened in this area as a result of caries or endodontic therapy. Three resin cements and a zinc-phosphate cement, which was used as the control, were used to secure the posts into the roots. Cemented posts were loaded with a gradually increasing force at a 60-degree angle to the long axis of the root until the root fractured. Authors concluded that the roots in which the posts were cemented with Panavia were significantly more resistant to fracture than those where zinc phosphate was used.

Asmussen E, Peutzfeldt A (1999) [32], investigated the direction of shrinkage of a light-curing resin composite in relation to the attachment and the thickness of the material. The resin composite was applied in cylindrical brass molds in such a manner that a flash, serving as attachment, was produced at one side of the specimens, while the material was flush with the mold at the other side. The specimens were now irradiated from either the flash or the flush side, and the convexity or the concavity of the specimens was measured. At a material thickness of 3 mm, the shrinkage was towards the light source, irrespective of the position of the flash. At 4 and 5 mm thickness of the molds, the direction of shrinkage could be directed towards or away from the light source, depending on the position of the flash. The number of light quanta emitted from the light source and passing through the material was compared with the number of molecules of camphorquinone present in a resin composite of 3, 4, or 5 mm thickness. It was concluded that under the conditions of the present study, the direction of shrinkage was the result of an interplay between the direction of the light, the attachment of the material, and the thickness of the material.

Hazaimah N, Gutteridge D (2001) [33], investigated the effect of a ferrule preparation on the fracture resistance of crowned central incisors incorporating a prefabricated post (Parapost) cemented with Panavia-Ex and with a composite core. The test group consisted of 10 post crowned natural central incisor teeth with a 2-mm wide ferrule preparation, whilst the control group of 10 teeth had no ferrule. The specimens were mounted on a Lloyd universal testing machine and a compressive load was applied at an angle of 135 degrees to the palatal surface of the crown until failure occurred. He concluded that when composite cement and core materials are utilized with a Parapost prefabricated system in vitro the additional use of a ferrule preparation has no benefit in terms of resistance to fracture.

Cormier C, Burns D, Moon P (2001) [34], evaluated 6 post systems over 4 simulated clinical stages of tooth restoration to (1) determine quantitatively the fracture resistance strength at each stage when a static loading force is applied to cause failure; (2) determine the failure mode for each post system at each simulated clinical stage 12 and (3) determine the feasibility of removing failed post systems. Ten post systems made with various materials and designs were tested at the following 4 stages of simulated clinical treatment: stage #1: posts only, loaded using a 3-point loading model to failure, to determine transverse strengths and failure modes for each post system; stage #2: posts alone, bonded into teeth; stage #3: posts bonded into teeth with core build up; stage #4: post and core build up and full veneer restoration. For stages #2 through #4, the coronal portion of 60 mandibular premolars was amputated at the cemento-enamel junction, the canals were treated endodontically, and the specimens were mounted in acrylic blocks. A testing force was applied to the posts at 90° to the long axis of the tooth, 4 mm from the cemento-enamel junction. The fiber posts evaluated provided an advantage over a conventional post that showed a higher number of irretrievable posts and unrestorable root fractures. At the stage of final restoration insertion, there was no difference in force to failure for all but the FibreKor material, which continued to be

weaker than all other tested materials. The fiber posts were readily retrievable after failure, whereas the remaining post systems tested were non retrievable.

Raygot C, Chai J, Jameson L (2001) [35], evaluated the fracture resistance and mode of fracture of endodontically treated incisors restored with cast post-and-core, prefabricated stainless steel post, or carbon fiber-reinforced composite post systems. Ten endodontically treated teeth restored with each technique were subjected to a compressive load delivered at a 130-degree angle to the long axis until the first sign of failure was noted. The fracture load and the mode of fracture were recorded. They concluded that the use of carbon fiber-reinforced composite posts did not change the fracture resistance or the failure mode of endodontically treated central incisors compared to the use of metallic posts.

Akkayan B, Dent M, Gulmez T (2002) [36], compared the effect of 1 titanium and 3 esthetic post system on fracture resistance and fracture patterns of crowned endodontically treated teeth. A total of 40 recently extracted human maxillary canines with their crowns removed were endodontically treated. Four groups of 10 specimens were formed. Teeth were restored with titanium, quartz fiber, glass fiber, and zirconia posts and numbered as groups 1, 2, 3, and 4, respectively. All posts were cemented with Single Bond dental adhesive system and dual-polymerizing RelyX ARC adhesive resin cement. All teeth were restored with composite cores, and metal crowns were fabricated and cemented with glass ionomer cement. Each specimen was embedded in acrylic resin and then secured in a universal load-testing machine. A compressive load was applied at a 130-degree angle to the long axis of the tooth until fracture, at a crosshead speed of 1 mm/min. He concluded that significantly higher failure loads were recorded for root canal treated teeth restored with quartz fiber posts. Fractures that would allow repeated repair were observed in teeth restored with quartz fiber and glass fiber posts.

Pontius O, Hutter J (2002) [37], evaluated the survival rate and fracture resistance of maxillary central incisors restored with different post and core systems. The post and core systems investigated were a prefabricated high precious metal post with cast core (group A), zirconia post with a prefabricated bonded ceramic core (group B), and a resin-ceramic interpenetrating phase composite post (experimental) with a prefabricated bonded ceramic core (group C). The all-ceramic copings were cemented using Panavia 21 TC. In the group without coronal radicular reinforcement, the access cavity was closed with a light-cured composite in combination with a dentine-bonding agent (group D). Each specimen was intermittently loaded and thermocycled before final stress tests. With the help of results they concluded that the samples restored with a cast post and core demonstrated more vertical root fractures and the preservation of both internal and external tooth structure is of utmost importance when restoring endodontically treated teeth.

Nergiz I, Schmager P, Platzer U, Ozcan M (2002) [38]; investigated the effect of length and diameter on the retentive strength of sandblasted tapered prefabricated titanium posts. The results of the study were that retention was affected strongly with the increase in the length (approximately 100%) than with the increase in the diameter (approximately 60%).

Kishen A, Kumar GV, Chen N (2004) [39], evaluated biomechanical perspective of fracture predilection in post-core restored teeth using computational, experimental and fractographic analysis. These experiments aided in correlating the stress-strain response in structural dentine with cracks and catastrophic fractures in post-core restored teeth. They observed that the inner dentine displayed distinctly high strains, while the outer dentine demonstrated high stresses during tensile loading. Hence they concluded that energy fed into the material as it is extended will be spread throughout the inner dentine, and there is less possibility of local increase in stress at outer dentine, which can lead to the failure of dentine structure.

During post endodontic restoration with increase in loss of inner dentin the fracture resistance factor contributed by inner dentine is compromised, which in turn disposes the tooth to catastrophic fracture.

Tan PL et al (2005) [40], investigated the resistance to static loading of endodontically treated teeth with uniform and nonuniform ferrule configurations. Fifty extracted intact maxillary human central incisors were randomly assigned to 1 of 5 groups: CRN, no root canal treatment (RCT), restored with a crown; RCT/CRN, no dowel/core, restored with a crown; 2 FRL, 2-mm ferrule, cast dowel/core and crown; 0.5/2 FRL, nonuniform ferrule (2 mm buccal and lingual, 0.5 mm proximal), cast dowel/core and crown; and 0 FRL, no ferrule, cast dowel/core and crown. The teeth were prepared to standardized specifications and stored for 72 hours in 100% humidity prior to testing. Testing was conducted with a universal testing machine with the application of a static load, and the load (N) at failure was recorded. With the help of their results they demonstrated that central incisors restored with cast dowel/core and crowns with a 2-mm uniform ferrule were more fracture resistant compared to central incisors with nonuniform (0.5 to 2 mm) ferrule heights. Both the 2-mm ferrule and nonuniform ferrule groups were more fracture resistant than the group that lacked a ferrule.

Ng CC, Dumbriague HB, Al-Bayat MI, Griggs JA, Wakefield CW (2006) [41], investigated the fracture resistance of restored endodontically treated teeth when residual axial tooth structure was limited to one half the circumference of the crown preparation. Fifty extracted maxillary anterior teeth were sectioned 18 mm from their apices, endodontically treated, and divided into 5 groups of 10 teeth each. Four groups were prepared with full shoulder crown preparations having axial wall heights of 2 mm around the preparation circumferences. In 3 of the groups with axial tooth structure, one half of the axial tooth structure was removed, palatally, labially, or proximally, and groups were identified according to the site of retained coronal tooth structure. For the fifth group, all axial tooth structure was removed to the level of the preparation shoulder. Thus, in 1 group the axial walls were circumferential, 360 degrees around the preparations (Complete group), in 3 groups the axial walls were continuous for 180 degrees (Palatal, Labial, and Proximal groups), and the last group had no retained coronal tooth structure incisal to the finish line (Level group). All 50 prepared teeth were then restored with quartz fiber posts (Bisco), composite resin (Bisco) cores, and metal crowns. A universal testing machine compressively loaded the tooth specimens from the palatal at a crosshead speed of 0.5 cm/min at an angle of 135 degrees to the long axis of teeth until failure occurred. Authors observed that for restored endodontically treated teeth that do not have complete circumferential tooth structure between the core and preparation finish line, the location of the remaining coronal tooth structure may affect their fracture resistance.

Dietschi D, Ardu S, Gerber A, Krejci I (2006) [42], evaluated the influence of post material physical properties on the adaptation of adhesive post and core restorations after cyclic mechanical loading. Composite posts and cores were made on endodontically treated deciduous bovine teeth using 3 anisotropic posts (made of carbon, quartz, or quartz-and-carbon fibers) and 3 isotropic posts (zirconium, stainless steel, titanium). Specimens were submitted to 3 successive loading phases – 250,000 cycles at 50 N, 250,000 at 75 N, and 500,000 at 100 N – at a rate of 1.5 Hz. Restoration adaptation was evaluated under SEM, before and during loading (margins) and after test completion (margins and internal interfaces). With the help of results they concluded that regardless of their rigidity, metal and ceramic isotropic posts proved less effective than fiber posts at stabilizing the post and core structure in the absence of the ferrule effect, due to the development of more interfacial defects with either composite or dentin.

Salvi GE, Siegrist Guldener BE, Amstad T, Joss A, Lang NP (2007) [43], assessed the survival rates and complications of root-filled teeth restored with or without post-and-core systems over a mean observation period of 4 years. A total of 325 single- and multirooted teeth in 183 subjects treated in a private practice were root filled and restored with either a cast post-and-core or with a prefabricated titanium post and composite core. Root-filled teeth without post-retained restorations served as controls. The restored teeth served as abutments for single unit metal-ceramic or composite crowns or fixed bridges. Teeth supporting cantilever bridges, overdentures or telescopic crowns were excluded. In their observation they concluded that the, provided that high-quality root canal treatment and restorative protocols are implemented, high survival and low complication rates of single- and multirooted root-filled teeth used as abutments for fixed restorations can be expected after a mean observation period of ± 4 years.

Maccari PC, Cosme DC, Oshima HM, Burnett LH Jr, Shinkai RS (2007) [44]; evaluated the fracture strength of teeth with flared canals and restored with two fiber-reinforced resin systems and one custom cast base metal (Ni-Cr) post and core system. The results suggested that teeth restored with cast posts had fracture strength twice that of teeth restored with resin posts. Fiber-reinforced resin posts failed at a compressive force comparable to clinical conditions, but all failures were repairable. While with the cast posts involved with root fractures.

Hinckfuss S, Wilson P (2008) [45], evaluated the fracture resistance of bovine teeth restored with one-piece cast core/crowns and no ferrule, compared to teeth restored with amalgam cores and full coverage crowns, with and without a dentine ferrule. In this study thirty bovine incisors were selected and modified to ensure all teeth had axial dentine walls of similar size. The teeth were then randomly allocated to one of the three groups: control group restored with amalgam core and cast crown without ferrule; ferrule group restored with amalgam core and cast crown with a 2-mm dentine ferrule; one-piece group restored with one-piece cast core/crown without ferrule. Each tooth was loaded to the point of fracture. It was observed that the maximum load resistance was significantly enhanced by a 2-mm ferrule compared with teeth with no ferrule and teeth restored with one-piece cast core/crowns. Teeth restored with one-piece cast core/crowns were significantly more resistant to loading than teeth restored with amalgam cores and crowns without a ferrule.

Kivanc B, Gorgul G (2008) [46], investigated the fracture strength of three post systems cemented with a dual cure composite resin luting cement by using different adhesive systems. Sixty three extracted anterior teeth with single roots were endodontically prepared and filled. Teeth were randomly assigned to one of three post systems placed into the prepared canals: Group I - titanium posts, Group II - glass fiber posts and Group III zirconia posts. Each group was again randomly divided into three subgroups according to the bonding materials used [Single Bond ($n = 7$), Clearfil SE Bond ($n = 7$), and Prompt L Pop ($n = 7$)]. A dual cured resin cement (Rely X ARC) was used for bonding the posts into the root canals. Standard cores were made by a composite resin (Clearfil Photocore) using core build-ups. The samples were tested in the compression test machine for 1 mm/min and fracture resistance of the teeth were recorded. This study concluded that endodontically treated anterior teeth restored with glass fiber posts exhibited higher failure loads than teeth restored with zirconia and titanium posts. Self-etching adhesives are better alternatives to etch-and rinse adhesive systems for luting post systems.

Alikhasi M, Dorriz H (2009) [47], compared the fracture resistance of endodontically treated teeth restored with different post and core systems in combination with complete metal crowns in teeth with no coronal structure. Fifty extracted

mandibular premolars were divided into five groups. The coronal portion of each tooth was removed at the cemento-enamel junction (CEJ) in all groups except Group 1. In this group the teeth were sectioned 1 mm above the CEJ to create a ferrule. After root canal preparations, cast posts were placed in the first four groups. Prefabricated glass fiber posts and composite cores were placed in the fifth group. An opaque porcelain layer was applied to the metal post surfaces in the third group and an alloy primer was applied to the posts in the fourth group before using Panavia F2 resin cement. No bonding agent or surface treatments were used for the first and second groups. It was concluded that either a ferrule preparation or bonding with the use of an opaque porcelain layer can increase the fracture resistance of teeth with little remaining tooth structure that are restored with cast crowns following endodontic therapy.

Ma P, Nicholls J, Junge T, Phillips K (2009) [48], correlated different ferrule lengths with the number of fatigue cycles needed for failure of the crown cement for an all-ceramic crown cemented with a resin cement. Fifteen maxillary central incisors were divided into 3 groups ($n = 5$), with ferrules of 0.0 mm, 0.5 mm and 1.0 mm respectively. Each tooth was restored with a 0.050-inch glass-filled composite post) and a composite resin core. The posts were cemented with resin cement, and the composite resin cores were bonded to dentin using a dentine bonding agent. Each specimen was prepared with a 7-mm total preparation height, a 1.5-mm lingual axial wall, and a 1.0-mm shoulder around the tooth. The crowns for all specimens were pressed with a pressable ceramic material and cemented with resin cement. Load of 6-kg cyclic test was applied to each specimen at 135 degrees to the long axis of the tooth. After looking at the result they concluded that specimens with a 0.0-mm ferrule survived few fatigue cycles despite the fact that both the post and crown were bonded with resin cement. Teeth with a 0.5-mm ferrule showed a significant increase in the number of fatigue cycles over the 0.0-mm group, whereas teeth with the 1.0-mm ferrule exhibited a significantly higher fatigue cycle count over the 0.0-mm but not the 0.5-mm group.

Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G (2009) [49], compared the long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. Authors stated that the choice of appropriate definitive restoration of endodontically treated maxillary anterior teeth should be guided by the amount of remaining hard tissues as well as functional and esthetic considerations. However, in cases of inadequate remaining coronal tooth structure, post-retained cores are often required to support complete crown restorations. The preparation of a post space significantly weakens endodontically treated teeth. A post did not significantly strengthen endodontically treated teeth.

Silva NR, Raposo L, Versluis A, Julio A, Neto F, Soares C (2010) [50], evaluated the effect of post, core, crown type, and ferrule presence on the deformation, fracture resistance, and fracture mode of endodontically treated bovine incisors. One hundred and eighty bovine incisors were selected and divided into 12 treatment groups ($n = 15$). The treatment variations were: with or without ferrule, restored with cast post and core, glass fiber post with composite resin core, or glass fiber post with fiber-reinforced core, and metal- or alumina-reinforced ceramic crown ($n = 15$). The restored incisors were loaded at a 135-degree angle, and the deformation was measured using strain gauges placed on the buccal and proximal root surfaces. Specimens were subsequently loaded to the point of fracture. It was concluded that core type did not affect the deformation and fracture resistance of endodontically treated incisors restored with alumina-reinforced ceramic crowns. The presence of a ferrule improved the mechanical behavior of teeth restored with metal crowns, irrespective of core type.

Jang JH et al (2012) [51], examined the stress distribution in endodontically treated maxillary central incisors restored with various lengths of either titanium or fiber reinforced composite (FRC) post-and-core systems, using two-dimensional finite element analysis models. Eight models of the maxillary central incisor were formed, surrounded by cortical bone, cancellous bone, and the periodontal ligament. Two different post-and-core systems, titanium and FRC posts (D.T Light Post), were modeled. In each restorative system, four models were designed by changing the post lengths cemented to the root at 10 mm, 9 mm, 8 mm, and 7 mm. A 100-N load was applied at a 45 angle to the long axis of each model. In the end they observed that the possibility of fracture of the FRC post is relatively low, compared to the titanium post, even for a short post. The same criteria for installation of a metal post should not be applied to an FRC post.

Hegde J, Ramakrishna, Bashetty K, Sreekha, Lekha, Champa (2012) [52], evaluated the fracture strength and mode of failure of endodontically treated teeth with flared canals restored with two fiber reinforced systems (glass fiber and quartz fiber) and one base metal cast post and core system. Forty five anterior teeth were decoronated at cemento-enamel junction and were endodontically treated. Post space was prepared and randomly divided into three groups according to the post system. Specimens were loaded at 45° in a universal testing machine at a cross head speed of 0.5 mm/min until failure. The mode of failure was classified as repairable or non-repairable. They concluded that the results of this study showed that fracture strength and mode of failure in anterior teeth with flared canal varied according to the type of post used to support a crown.

Juloski J, Radovic I, Goracci C, Vulicevic JR, Ferrari M (2012) [53], summarized the results of research conducted on different issues related to the ferrule effect. They said that presence of a 1.5- to 2-mm ferrule has a positive effect on fracture resistance of endodontically treated teeth. If the clinical situation does not permit a circumferential ferrule, an incomplete ferrule is considered a better option than a complete lack of ferrule. Including a ferrule in preparation design could lead to more favorable fracture patterns. Providing an adequate ferrule lowers the impact of the post and core system, luting agents, and the final restoration on tooth performance. In teeth with no coronal structure, in order to provide a ferrule, orthodontic extrusion should be considered rather than surgical crown lengthening. If neither of the alternative methods for providing a ferrule can be performed, available evidence suggests that a poor clinical outcome is very likely.

Santos-Filho P, Verissimo C, Soares PV, Saltarello RC, Soares CJ, Martins LR (2014) [54], evaluated the influence of post system, length, and ferrule on biomechanical behavior of endodontically treated anterior teeth. The investigation was conducted by using laboratory tests and 3-dimensional finite element analysis. Eighty bovine incisors were selected and divided into 8 treatment groups (n = 10) with absence of ferrule and 2.0 mm of ferrule, restored with glass fiber post or cast post and core, and 12.0 and 7.0 mm of post length. The specimens were loaded at 135 angle, and the strain was measured by using strain gauge method. Specimens were subsequently loaded until fracture. Three-dimensional models of a maxillary central incisor were generated with the same treatment variations used in laboratory tests. Each model was subjected to 100 N oblique loads. They concluded that the post length influenced only the cast post strain and stress distribution. The ferrule groups always showed more satisfactory stress distribution and fracture resistance.

Maroulakos G, Nagy W, Kontogiorgos E (2015) [55], investigated the fracture resistance and mode of failure of severely compromised teeth restored with 3 different adhesively bonded post and core systems. Thirty extracted endodontically treated maxillary anterior teeth were randomly divided into 3 groups, CPC, gold

cast post and core; TPC, titanium prefabricated post/composite resin core; and FPC, quartz fiber reinforced post/composite resin core. All posts were adhesively cemented. All cores resembled a central incisor preparation with no remaining tooth structure above the finish line. Cast gold crowns were fabricated and cemented adhesively. The specimens were aged with thermocycling and cyclic loading. Two specimens per group were randomly selected for micro-computed tomographic imaging before and after aging. Failure was induced with a universal testing machine. The mode of failure was characterized by the interface separation. They observed that the severely compromised endodontically treated teeth restored with bonded gold cast post and cores showed significantly higher fracture resistance.

Upadhyayal V, Bhargava A, Parkash H, Chittaranjan B, Kumar V (2016) [56], evaluated the effect of design and material of post with or without ferrule on stress distribution using finite element analysis. A total of 12 three-dimensional (3D) axisymmetric models of post retained central incisors were made, six with ferrule design and six without it. Three of these six models had tapered posts, and three had parallel posts. The materials tested were titanium post with a composite resin core, nickel chromium cast post and core, and fiber reinforced composite (FRC) post with a composite resin core. The load of 100 N at an angle of 45° was applied 2 mm cervical to the incisal edge on the palatal surface. In their study they concluded that a rigid material with high modulus of elasticity for the post and core system creates the most uniform stress distribution pattern. Ferrule provides uniform distribution of stresses and decreases the cervical stresses.

Kim AR, Lim HP, Yang HS, Park SW (2017) [57], evaluated the fracture resistance with regard to ferrule lengths and post reinforcement on endodontically treated mandibular premolars incorporating a prefabricated post and resin core. One hundred extracted mandibular premolars were randomly divided into 5 groups (n = 20): intact teeth (NR); endodontically treated teeth (ETT) without post (NP); ETT restored with a prefabricated post with ferrule lengths of either 0 mm (F0), 1 mm (F1), or 2 mm (F2). Prepared teeth were restored with metal crowns. A thermal cycling test was performed for 1,000 cycles. Loading was applied at an angle of 135 degrees to the axis of the tooth using a universal testing machine with a crosshead speed of 2.54 mm/min. In their study they observed fracture resistance of ETT depends on the length of the ferrule, as shown by the significantly increased fracture resistance in the 2 mm ferrule group (F2) compared to the groups with shorter ferrule lengths (F0, F1) and without post (NP).

Marchionatti A, Wandscher V, Rippe M, Kaizer O, Valandro L (2017) [58], compared the clinical performance and failure modes of teeth restored with intra-radicular retainers. Evaluated retainers were fiber (prefabricated and customized) and metal (prefabricated and cast) posts, and follow-up ranged from 6 months to 10 years. Most studies showed good clinical behavior for evaluated intra-radicular retainers. In their review they concluded that the metal and fiber posts present similar clinical behavior at short to medium term follow-up. Remaining dental structure and ferrule increase the survival of restored pulpless teeth.

Onofre R, Fergusson D, Cenci MS, Moher D, Cenci P (2017) [59], assessed the influence of the number of remaining coronal walls, the use or disuse of posts, and their type on the clinical performance of these restorations. Randomized controlled trials and controlled clinical trials for ETT restored with a combination of post/crown or no post/crown were searched for in MEDLINE, Embase, and the Cochrane Library. In their review they concluded that the restoration of ETT should focus on the maintenance of the coronal structure. Until more studies with longer follow-up periods are available, posts with a high elastic modulus appear to present with better performance when restoring ETT with no ferrule.

Naumann M, Sterzenbach G, Dietrich T, Bitter K, Frankenberger R, Lausnitz MS (2017) [60], evaluated the dentin-like glass fiber posts (GFPs) compared with rather rigid titanium posts (TPs) for post-endodontic restoration of severely damaged endodontically treated teeth with 2 or fewer remaining cavity walls. Ninety-one subjects in need of post-endodontic restorations were randomly assigned to receive either a tapered GFP (n = 45) or TP (n = 46). Posts were adhesively luted by using self-adhesive resin cement, followed by composite core build-up and preparation of 2-mm ferrule design. Primary endpoint was loss of restoration for any reason. Hence they concluded that when using self-adhesively luted prefabricated posts, resin composite core build-up, and 2-mm ferrule to reconstruct severely damaged endodontically treated teeth, tooth survival is not influenced by post rigidity. Survival decreased rapidly after 8 years of observation in both groups.

Lazari P, Carvalho M, Altair A, Curry D, Magne P (2018) [61], investigated the restoration of extensively damaged endodontically treated incisors without a ferrule using glass-ceramic crowns bonded to various composite resin foundation restorations and 2 types of posts. Sixty decoronated endodontically treated bovine incisors without a ferrule were divided into 4 groups and restored with four different post-and-core foundation restorations. NfPfB = no-ferrule (Nf) with glass-fiber post (Pf) and bulk-fill resin foundation restoration (B); NfPfP = no-ferrule (Nf) with glass-fiber post (Pf) and dual-polymerized composite resin core foundation restoration (P); NfPt = no-ferrule. They concluded that the survival of extensively damaged endodontically treated incisors without a ferrule was slightly improved by the use of a fiber post with a bulk-fill composite resin core foundation restoration. However, none of the post-and-core techniques was able to compensate for the absence of a ferrule. The presence of the posts always adversely affected the failure mode.

Meng Q, Ma Q, Wang T, Chen Y (2018) [62], evaluated the effect of ferrule design on the fracture resistance of endodontically treated mandibular first premolars after simulated crown lengthening and orthodontic forced eruption methods restored with a fiber post-and-core system. Forty extracted and endodontically treated mandibular first premolars were decoronated to create lingual to-buccal oblique residual root models, with a 2.0 mm height of the lingual dentine wall coronal to the cemento-enamel junction, and the height of buccal surface at the cemento-enamel junction. The roots were divided randomly into five equal groups. With the help of results they concluded that increased apically complete ferrule preparation resulted in decreased fracture resistance of endodontically treated mandibular first premolars, regardless of whether surgical crown lengthening or orthodontic forced eruption methods were used.

Zarow M et al (2018) [63], reviewed the status of root filled teeth to analyze the most important factors in decision-making and discuss the current restorative concepts and classified both the evidence and clinical practice in a way that seeks to be clear, understandable and helpful for clinicians. They concluded that the decision-making process in the restoration of root filled teeth is complex and should consider the following factors: amount and quality of tooth structure, tooth position in the arch and anatomy and function. Fiber posts are recommended in anterior teeth and premolars with compromised tooth structure (<50%) and/or with high tooth length over bone crest. A ferrule is highly beneficial for the prognosis of root filled teeth. If a ferrule cannot be provided and the patient still prefers to save the tooth, a gold cast could be a possible option.

Fadag A et al (2018) [64], evaluated the fracture resistance of endodontically treated maxillary central incisors with different post systems. Fifty-six extracted intact maxillary permanent central incisors were used, treated endodontically

(except for the control group), and distributed into the following seven test groups (n = 8) depending on the post type: UHT (control group: root-filled teeth without endodontic post), ZRP (prefabricated zirconia post), GFP (prefabricated glass fiber post), CFP (prefabricated carbon fiber post), CPC (custom-made cast post and core), TIP (prefabricated titanium post), and MIP (prefabricated mixed post). The specimens were loaded in a universal testing machine until fracture occurrence. In their, they observed endodontically treated teeth restored with zirconia post, glass fiber post, titanium post, or mixed post were more resistant to fracture loads compared with those that were not restored (control group) or restored with either carbon fiber post or cast post and core.

Pinto CL et al (2019) [65], evaluated the influence of different post systems on the biomechanical behavior of teeth with a severe loss of remaining coronal structure. Fifty standardized bovine teeth (n = 10 per group) were restored with: cast post-and-core (CPC), prefabricated metallic post (PFM), parallel glass-fiber post (P-FP), conical glass-fiber post (C-FP), or composite core (no post, CC). The survival rate during thermomechanical challenges (TC), the fracture strength (FS), and failure patterns (FP) were evaluated. Hence they concluded that the type of intracanal post had a relevant influence on the biomechanical behavior of teeth with little remaining coronal structure.

Bakirtzoglou E, Kamalakidis S, Pissiotis A, Michalakis K (2019) [66], evaluated the retention and resistance form of complete coverage restorations supported by two different cast post and core designs. Forty extracted maxillary central incisors were randomly divided into four groups of 10 specimens each. All specimens were endodontically treated and a uniform post space of 9 mm was created. All prepared teeth had a 360 degree chamfer ferrule of 2 mm in axial height measured 0.5 mm coronally from the cemento-enamel junction (CEJ) and an axial wall thickness of 1.5 mm. Both cast post and core designs offer equal retention.

Veeraganta S et al (2020) [67], evaluated the influence of post material and post diameter on the fracture resistance of endodontically treated mandibular premolars. In addition, the influence of tooth substance loss was evaluated by comparing 1 with 2 residual dentinal walls. Sixty-four extracted mandibular first premolars were endodontically treated and divided into 8 test groups based on the number of residual walls (1 or 2), post material (glass fiber or titanium) and post diameter (International Standards Organization [ISO] 70 or ISO 90). After luting the posts, the specimens received a composite resin core and a crown preparation with a 2-mm ferrule. Cast Co-Cr crowns were cemented with glass ionomer cement. After 1200000 mastication cycles with a load of 49 N and simultaneous thermocycling (5–55°C), specimens were loaded at 30 degrees to the longitudinal axis of the tooth until fracture. In their study they observed that fracture loads ranged from 954 ± 35 N (1 residual wall glass fiber ISO 70) to 1286 ± 202 N (1 residual wall glass fiber ISO 90). Titanium posts showed a statistically significant higher fracture resistance than glass fiber posts. A statistically significant increase in fracture resistance was also observed with increasing post diameter. However, no significant difference was found with respect to the number of residual walls. Hence they concluded that teeth restored with titanium posts exhibited higher fracture resistance than teeth restored with glass fiber posts, especially when smaller diameter posts were used.

One of the most frequent procedures of restorative dentistry is the restoration of mutilated and endodontically treated teeth. It is also difficult to repair these teeth since significant quantities of the coronal tooth structure is lost as a result of decay, prior restorative treatment, endodontic access and fractures. Restoration of an endodontically treated tooth needs a good understanding of its physical as well as biomechanical properties, along with sound knowledge of its anatomy as well as

endodontic, periodontal, restorative and occlusal principles. Even though the availability of various restorative materials for endodontically treated teeth has increased over few years, the principle of restoring it remains the same [68]. When a significant coronal section has been lost, resulting in the presence of one wall or no wall remaining, then adequate anchorage for the restoration cannot be achieved [69].

With the aid of a post, anchorage can be gained in such conditions. A post is described as the restoration segment inserted into the root canal to help maintain a core component. It can be made of metal or non-metallic compounds. The main objective of the post is to provide retention for the core and the coronal restoration [29, 70]. Sorensen in 1984 stated that the reason for placing a post in the root canal is to retain a crown and not to reinforce the tooth. Posts should not be positioned arbitrarily because post space preparation introduces a degree of risk to a restorative operation by disrupting the seal of the root canal filling, which can lead to micro-leakage. The risk of perforation increases due to the removal of sound tooth structure. Tooth fracture can also occur because of weakening of roots due to removal of sound tooth structure.

It is preferred that physical properties of the tooth i.e. the dentin should match with the physical properties of post system. An ideal post should distribute the functional stresses along the root surface in such a manner that minimum stresses are developed. Esthetics of the post should be compatible with the surrounding tissue. An ideal post should have easy retrievability, good retention and should be compatible with core material. They should also be available at a reasonable cost and should be easy to use. The indications for a post have been modified over the years based on the advantages of the adhesive restoration principles, which may obviate the need for the posts [71]. The remaining amount of tooth structure determines the stability for the restoration. In addition, the tooth's prognosis is influenced by different factors such as occlusal contacts, its location in dental arch and ferrules [71].

1.5 to 2 mm height of ferrule is the minimum requirement to obtain sufficient fracture resistance. 20 The ferrule with the help of core and dentin reduces the stress on the entire restoration. However, researchers have indicated that it is possible to overcome the lack of fracture protection that may occur in the absence of ferrules using adhesive agents [70, 71].

A further benefit of flexible posts is that dentine elimination is reduced by following the morphology of the channels in curved channels, while direct positioning in the post increases dentine elimination as the length (surface area) increases. Another explanation for this is that the curvature region starts after the 7 mm mark. This is where the thickness of the dentine decreases and there is a very high chance of strip perforation [72].

3.1 Considerations [anterior teeth]

It's not always necessary to have a complete coverage except when a plastic restoration has limited prognosis. Teeth which are badly destructed due to caries, which can be used for RPD or FPD.

Posterior teeth are subjected to greater stresses because of their position i.e. closer to the insertion of the muscles of mastication. This combined with their morphologic characteristics makes them more susceptible to fracture.

Complete coverage is recommended on teeth with a high risk of fracture especially maxillary premolars as they have long, thin and curved roots which gives best protection against fracture but at the same time considerable tooth reduction must be done and in these cases a post and core foundation is needed for better retention of the prosthesis.

- Its commonly believed that endodontically treated teeth are weak than normal teeth which may be due to low moisture content.[not proved experimentally]. so attempts have been made to increase strength by adding posts.

Studies reveal that no significant reinforcement results with the post, because teeth when loaded, stresses are more at the facial and lingual aspects of the root and post being at centre is minimally stressed and does not help prevent fracture. However some contradicts this assumption.

Disadvantages of placement of the post:

It requires an additional operative procedure. Additional tooth structure must be removed. if post fails it is difficult to restore the tooth later for a complete crown. Post can prevent future endodontic treatment.

when a complete coverage is not necessary, post is contraindicated in that tooth. when there is extensive loss of tooth structure which can be used for a FPD or RPD a complete coverage is mandatory.

3.2 Preparation aspects

All most all the principles of normal tooth preparation applies to the endodontically treated teeth. Ideally coronal half of the post hole will have been left open at the time of obturation. if not care must be taken not to deviate from the canal while opening. Guidance can be achieved by softening the guttupurcha with an heated instrument. A reamer can then be inserted to remove the guttupurcha and the direction of the canal is identified. Use of magnifying lens and fiber optic light is helpful in this process. After opening to the required length it is reamed to the appropriate size to accept a post. The minimum length required for a post hole is either the size of that tooth crown or two-thirds the length of the root whichever is longer.

3.3 Conservation aspects

- Root canal- as the thickness of the remaining is the prime variable in fracture resistance of the root, care should be taken only to remove minimal tooth structure from the canal. Over enlargement can perforate or weaken the root which may split while cementing the post.
- Studies reveal that post of 1.8 mm diameter fracture more easily than those with 1.3 mm and also internal stresses are less with thinner posts. It is recommended to enlarge the root only the amount required because most of the roots are narrow mesio distally and also have proximal concavities where the remaining dentine is thin which can favor perforation by the post or acts as a fracture point.

Enlargement seldom needs to exceed once or twice additional file sizes beyond that used for endodontic treatment. so it is wise to check the treatment record of endodontic therapy for proper and limited enlargement of the canal.

3.4 Crown aspect

In most of the endodontically treated teeth the coronal part has been lost from caries, previous restoration or during access cavity opening so most tooth structure should be conserved as it helps in reducing the stress concentration at the gingival margins.

Indeed if more than 2 mm of coronal tooth is left the post design probably plays little role in the fracture resistance of the restored tooth. 1 mm of the vertical height of the crown provides FERRULE EFFECT.

FERRULE EFFECT: It is defined as a metal ring or cap put around the end of tool, cane etc. to give added strength. This effect is used in the dowel preparation in the form of a circumferential contrabevel which reinforces the coronal aspect of the dowel preparation. It also aids in affecting a positive occlusal seat and acts as antirotational device [73].

FERRULE EFFECT: If the artificial crown extends apical to the margin of the core and encircles sound tooth structure for 360 degrees, the crown serves as a reinforcing ring or ferrule to help protect the root from vertical fracture.

SECONDARY FERRULE: A contrabevel has been advocated when preparing a tooth for a cast post and core to produce a cast core with a collar of metal that encircles the tooth and serves as a secondary ferrule, independent of the ferrule provided by the cast crown [5].

3.5 Retention aspects

3.5.1 Anterior teeth

Retention is mainly two types.

1. Active retention.: It is due to threads or the serrations or any irregularities present on the post surface.
2. Passive retention: It is due to the sealer or the cement used for the luting of the post.

Retention of the post is affected by preparation geometry, post length, post diameter, surface texture and luting agent.

Preparation geometry: Taper should be restricted to 6 degrees or nearly parallel walls should be attained. Under cuts should be removed

Studies reveal that threaded posts are most retentive of all provided the post fits the canal properly.

1. **Length:** Increase in length increases the retention and post that is too long may damage the apical seal or may perforate the apical third of the root that is curved. In general normal crown length is 10.5 mm and root length is 13 mm. so leaving a 4 mm of guttapercha at the apex for better seal is impossible and a compromised situation may require a serrated post which is more retentive at shorter lengths. Increase in the length of the post, shifts the point of fracture from gingival part to apical part of the root, so that the horizontal force required to get fracture is more when compared to shorter post.
2. **Diameter:** One group says increase in diameter increases the retention while others do not confirm this. But increase in diameter in an attempt to increase the retention may weaken the remaining root.- caution..the commonly used diameter ranges from 0.8 mm to 2 mm and different types used are boston, dentatus, flexi, kerr, parapost, v lock passive post etc.
3. **Surface texture:** Roughened post is more retentive than a smooth one.
4. **Luting agent:** This has little effect in retention aspects. But recent advancements like adhesive resin shows an increase in retention of the post which are dislodged due to lack of retention. new generation luting agents like adhesive resins and tubule-seal promises the role of this, in retention.

3.5.2 Posterior teeth

- Usual cause of loss of vitality of the posterior teeth is extensive caries, micro leakage beneath a large restoration. Therefore much of the central core of dentine is missing and the remaining enamel is undermined and weakened. so simple restoration of crown of the tooth with G I C OR COMPOSITE cannot impart sufficient strength to with stand laterally directed occlusal load. so it is desirable to rebuild with amalgam to support the posts before placing crown.
- Ditches and grooves will help in retention but as there is little dentine left it is not possible to place them.
- Relatively long posts with a circular cross section provide good retention and support in anterior teeth but should be avoided in posterior teeth which often have curved roots i.e. elliptical or ribbon shaped canals. so for these teeth retention is better provided by relatively short posts in the divergent canals.
- If more than 4 mm of coronal tooth structure is remaining use of the root canal for retention is not necessary.
- If a cast core is used it can be made in sections that have different paths of withdrawal.

4. Resistance aspects

One of the function of the post and core is to improve resistance to laterally directed forces by distributing them over as large as an area as possible.

According to studies• Stresses are more at shoulder and apex region.

- Stresses can be decreased by increasing the post length.
- Parallel sided posts distributes stresses more evenly than tapered posts[which has wedging effect]
- Sharp angles should be avoided.

5. Rotational resistance

Rotation of the post can be prevented by axial walls.where more coronal tooth structure is present. When most of dentine is destroyed a small groove placed in the canal can serve as an anti rotational element. it should be placed in the bulkiest part of root [usually lingual side]. auxillary pins also acts as anti rotational elements. Alternatively rotation of the threaded post can be prevented by preparing a small cavity, half in the post and half in the root then condensing amalgam in to it after cementation of the post.

6. Procedure

It involves 3 stages:

1. Removal of root canal material to appropriate depth

2. Enlargement of canal

3. Preparation of the coronal tooth structure

A post cannot be placed if the canal is filled with a full length silver point and these should be retreated with gutta purcha.

7. Methods to remove Gutta Purcha

- With a warm endodontic instrument and rotary instrument[some times with a chemical agent chloroform].

However warm method is preferred as it will not disturb the apical seal. before removing the G.P. calculate the length of the post to be placed. Make sure the post length equal to height of the anatomic crown or $\frac{2}{3}$ the length of the root whichever is longer.

- Do not disturb the apical 4 to 5 mm of the G P. if this is not done the prognosis of the tooth is compromised.

If working length of the tooth is known the length of the post can be easily determined.

Then apply rubber dam to prevent aspiration. Select an condenser large enough to hold heat well, mark it at app length W.L minimum 5 mm and place in canal to soften the G P.

- If GP is old and lost its thermoplasticity use rotary instrument. Make sure that instrument does not engage the dentine.
- It was stated that gates glidden drill conforms to the original canal more consistently than the para post drill.
- Choose the rotary slightly narrow than the canals.
- Rotary should follow the centre of the gutta purcha preserving the dentine.
- Rotary should not be used immediately after obturation as it disturbs the apical seal.

After removing, shape the canal as needed. The purpose is to remove the undercuts and prepare the canal to receive the posts. posts should not be no more than $\frac{1}{3}$ the diameter of the root dimension.

8. Enlargement

Prior to enlargement of the canal, decision must be made regarding the type of post used.

Parallel sided prefabricated posts are recommended for conservatively prepared root canals with circular cross section.

Flared canals can best be managed with custom made post.

9. For pre fabricated post

- Parallel sided posts are more retentive and distributes stresses better than tapered, but they do not conform to the shape of the canal. in this situation it may not be possible to enlarge the canal sufficiently for the post, then a tapered custom made post is preferred.
- Tapered post better conform to the canal than parallel post but it is less retentive and will cause greater stress concentration although retention may be improved by controlled grooving.

10. For custom made posts

These are used in canals that have a noncircular cross section or extreme taper. Little preparation is sufficient for custom made post. i.e. removal of undercuts and additional shaping.

CAUTION: Mandibular molars distal wall of mesial root is particularly susceptible. in maxillary molars the curvature of the mesio buccal root makes mesial or distal perforation more likely.

11. Preparation of coronal tooth structure

After post space is prepared then extracoronary restoration is done.

Anterior teeth requiring post and core can be best restored with metal ceramic crown

Prepare the remaining crown as it was an undamaged tooth.

Sufficient reduction in the facial surface gives good esthetics.

Remove the undercuts and undermined enamel

The prepared crown must be perpendicular to the post so that it can act as a positive stop and prevent over seating of tooth.

Rotation of the post can be prevented by preparing a flat surfaces parallel to the post and when little tooth structure remains an antirotational groove should be placed in the canal.

Complete the preparation by giving smooth finish lines.

12. Post fabrication

12.1 Pre fabricated posts

- The only advantage is simplicity of the technique.
- Post is selected to match the canal and minimum adjustments are made to seat it.
- Coronal part may not exactly fit and this is adjusted by adding material to the core while it is fabricated.

Available materials are pt- au- pd. \ p-g-p,cr-co, s.s, ni- cr-ti and non oxidizing noble alloys.

- Studies reveal that corrosion of these base metal leads to root fracture and this is attributed to the electrolytic action of the dissimilar metals used to the post and core which causes a volume change that split the root.

Prefabricated posts have high modulus of elasticity, elongated grain structure which contributes to the physical properties as compared to cast posts and also more rigid.

13. Custom made posts

These can be cast either by direct pattern or by indirect pattern.

In single canals ————— direct pattern is used.

In multiple canals ————— indirect pattern is used.

14. Direct pattern

Lubricate the canal—select a dowel, it should extend full depth of the canal.

Apply resin [bead brush tech,]

Here resin can be applied in two types.

1. Applying at the orifice of the canal only

2. Resin is rolled and placed in canal

Now moisten the dowel with monomer and insert in the canal. Do not allow the resin to set fully and now loosen the dowel and reseat it. Repeat this until the resin sets. Remove the dowel. Trim any excess or undercuts on it... the completed post pattern should not bind the canal.

15. Indirect pattern

Here a wire reinforcement should be done to prevent distortion and to get an accurate impression of the root canal.

An orthodontic wire cut in J shape is selected. It should be loosely fit in canal and must extend to full depth of the canal. Coat it with an adhesive. Lubricate the canal to facilitate removal of the wire.

Fill the canal with impression material using lentulo spiral. Seat the wire in the canal. Syringe more material around the wire and tooth and place the tray. Now remove the tray along with the post pattern. Evaluate it and pour the cast.

Using this cast take a plastic post or toothpick which extends full depth, and apply sticky wax to it and seat it in the canal. Like this wax pattern is fabricated. Which should completely adapt to post space.

16. Core fabrication

Replace the missing coronal tooth structure, restoring its original anatomy. It can be shaped either in resin or wax which is added to the post before the assembly is cast in metal. This prevents failure at the post-core interface.

It can be cast on to the prefabricated post system or make the core with a plastic material like amalgam or GIC or composites.

Advantages with plastic materials.

1. Undercuts need not be removed. so tooth structure can be conserved.
2. Less visits to the patient.
3. Less lab procedure.
4. Good adaptation to the tooth structure.

Disadvantages:

1. No long term success due to corrosion.
2. Temperature fluctuations leads to micro leakage.
3. Difficulty may be encountered with rubber dam or matrix application. [with grossly decayed teeth].

17. Procedure with amalgam

- Rubber dam is applied. Remove the G P cone from the pulp chamber. if crown structure is less than 4 mm remove the G P from the root canal up to 2–4 mm.
- Remove the unfermined enamel and carious dentin.
- When cusps are missing, pins are not usually required because adequate retention can be gained by extending the amalgam into the root canal.
- When pulp chamber is thin, protect the chamber from condensing pressures while inserting the base. When lack of tooth structure makes the application of matrix difficult then apply orthodontic or copper band. Condense the materials into the canals with endodontic plugger.
- Fill the pulp chamber and carve the amalgam to desired shape and make an impression.
- Alternatively the amalgam can be built up to anatomic contour and later prepared for a compedte crown. under these circumstance care must be taken to avoid forces that would fracture the tooth or newly placed restoration.

18. Cast metal advantages

Can be cast directly onto a prefabricated post.

An indirect procedure can be applied making restoration of posterior teeth easier.

High noble alloys can be used.

19. Direct procedure for the single rooted teeth

- Take a pre fabricated post [metal or acrylic]
- By bead technique apply resin to the post, light cure resin can also be used

- Slightly overbuild the core and let it polymerize. shape the core with burs. Use water spray to prevent overheating of resin. if any defects correct it with wax.
- Remove the pattern sprue it and invest it.

20. For multirrooted teeth

Both direct and indirect techniques can be used

- Limited access makes the indirect tech easier.
- Single core with auxiliary post can be used or multisection core can be used. Multisection is preferred in indirect approach.
- Core is cast directly on to the post of one canal., while the other canals already have prefabricated posts that pass through the hole in the core.

20.1 Direct approach

Fit the prefabricated posts in the canals. One of the posts is roughened and others are smoothed. All the posts should extend beyond the preparation. Now build up the core with resin by bead tech. Shape the core and finish it.

Now grip the smoothed posts. With forceps and remove the post, invest and cast the core with the single rough post. After this the holes for the auxiliary posts can be refined with the appropriate twist drill. Verify it and cement the core and auxiliary posts to place.

20.2 Indirect approach

Wax the custom made posts, build part of the core around the first post. Remove the undercuts adjacent to other post holes and cast the first section. Now wax the other section and cast them.

Use of dove tails to interlock the sections makes the procedure more complicated and is probably of limited benefit.

21. Provisional restorations

TO prevent drifting of opposing or adjacent teeth an endodontically treated tooth requires a proper provisional restoration immediately following completion of endodontic treatment

These provide good proximal contacts to prevent tooth migration leading to unwanted root proximity

22. Investing and casting

The prepared prosthesis should fit somewhat loosely in the canal. tight fit may cause root fracture.

Casting should be slightly undersized which can be accomplished by restricting expansion of the investment [by omitting the ring liner or casting at a lower mold temperature.]

A sound casting technique is essential because any undetected porosity could lead to a weakened casting that might fail in function.

23. TRY — IN

Care should be exercised such that casting defects should not interfere with seating of the post, lest root fracture results.

Post and core should be inserted with gentle pressure. no adjustments should be made immediately after cementation because vibration from the bur could fracture the setting cement and cause premature failure.

24. Cementation

It is important that the luting agent should fill all the dead space within the root canal system. a rotary paste filler or cement tube is used to fill the canal. post and core is inserted gently to reduce hydrostatic pressure which could cause root fracture.

It is recommended that a groove placed along the side of the post to allow excess cement to escape, if a parallel sided post is being used.

25. Cements and disadvantages

- Zinc phosphate: Solubility in oral fluids.
- Polycarboxylate: Undergoes plastic deformation
- Glass ionomer cement: Do not reach its maximum strength for many days. Therefore Any recontouring of the core may disturb the set of the cement and weaken the immature cement fibers.
- Resin modified GIC: exhibits delayed expansion of the cement.

26. Removal of existing posts

Occasionally a failed post and core must be removed, then if sufficient post length is exposed coronally, it can be retrieved with thin beaked forceps.

Vibrating the post with a ultrasonic scaler will weaken the cement and facilitates easy removal. Here a thin scaler tip is recommended or alternatively a post puller is used. [post puller cannot be used for fractured post.]

Fractured posts should be drilled out but care should be taken not to deviate from the canal. This is best limited to short fractured posts

27. Masserann 1966 handling

He used a hallow end cutting tubes or trephines to prepare a thin trench around the post. Post retrieved can be facilitated by using an adhesive to attach a hallow tube extractor or by using a threaded extractor.

Newer Concepts:

Zarow, M proposed new classification was to help the clinician to select the most appropriate treatment plan for restoring root filled teeth when choosing between a

composite core alone, a composite core reinforced by fiber post, a gold cast post or implant treatment. **The following is the classification:-** [74]

1. Class 0 (no post – composite core build-up).
2. Class 1 (fiber post).
3. Class 2 (pre-restorative procedures are needed: orthodontic extrusion or crown lengthening).
4. Class 3 (gold cast post).
5. Class 4 (extraction).

The three categories given by Motasum Abu-Awwad in 2019 are [75].

1. Minimally destructed teeth, which could be managed simply through intracoronal composite resin restorations.
2. Moderately destructed teeth, which could be managed through adhesive overlays
3. Severely destructed teeth, which could be managed through fiber post–core–crown combination, or through endocrowns [9].

28. Summary

- Restoration of endodontically treated teeth can be done successfully if the available procedures are performed well.
- Where most of the crown is preserved an anterior teeth can be safely restored with a plastic filling material.
- To prevent fracture of posterior teeth, cast restoration with cuspal coverage is recommended.
- Anterior teeth can best built up with a cast metal post and core or a metal core cast on to a prefabricated wire.
- Amalgam can be used on posterior teeth, although if much coronal tooth structure is missing a casting may be preferred.

29. Conclusion

The rational for the post placement is two folds that is,

1. To retain the restoration, and.
2. To protect the remaining tooth structure.

The success rate will be high if the rationales for the results are understood, appreciated and propagated accordingly. A technique with more advantages and

fewer disadvantages in the given restoration should be chosen. It is important to preserve as much tooth structure as possible, particularly in the root canal. The post should be adequate length for good stress distribution but not as long as to jeopardize the apical seal. In the final analysis the quality of the root canal thereby combined with the quality of its final restoration determines the clinical success of pulpless tooth with post and core.

Acknowledgements

I am thankful to Rural Dental College, Pravara institute of medical sciences, Loni. Dr. Mukund Singh, Dr. Milind Jagdale, Dr. Agey Pathak.

Conflict of interest

None.

Author details

Deepak M. Vikhe

Department of Prosthodontics, Crown and Bridge, Rural Dental College and Hospital, Pravara Institute of Medical Science (DU), Pravara Medical Trust, Loni, Maharashtra, India

*Address all correspondence to: drdeepak_mvikhe@yahoo.com

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

- [1] Suna Toksavul, Muhittin Toman, Mehmet Sankanat, Ibrahim Nergiz and Petra Schmage , Effect of Noble Metal Alloy Post and Core Material on the Fracture Resistance of Endodontically Treated Teeth , *European Journal Of Prosthodontics & Restorative Dentistry*. March 2010, Vol 18, Issue 1.
- [2] Standlee J.P. Caputo A.A. Hanson E.C. Retention of endodontic dowels: Effects of cement, dowel length, diameter, and design. *J Prosthet Dent*. 1978; 39: 401
- [3] Sorensen J.A. Martinoff J.T. Intracoronar reinforcement and coronal coverage: a study of endodontically treated teeth. *J Prosthet Dent*. 1984; 51: 780-784
- [4] Colley IT Hampson EL Lehman ML , Retention of post crown: An assessment of the relative efficiency of posts of different shapes and sizes. *Br Dent J*. 1968; 124: 63-69
- [5] Goodacre CJ. Designing tooth preparations for optimal success. *Dent Clin North Am*. 2004;48(2):v-385.
- [6] Chan, R. W., & Bryant, R. W. (1982). Post-core foundations for endodontically treated posterior teeth. *The Journal of Prosthetic Dentistry*, 48(4), 401–406. doi: 10.1016/0022-3913(82)90074-9
- [7] Valdivia ADCM, Correia AD, Raposo LHA, Simamoto-Junior PC, Novais VR, Soares CJ. The effect of fiber post presence and restorative technique on the biomechanical behavior of endodontically treated maxillary incisors: An in vitro study. *J Prosthet Dent* 2012 Sep;108(3):147-157.
- [8] Rosenstiel SF, Land MF, Fujimoto J. *Contemporary Fixed Prosthodontics*. 3rd edition. Year Book Medical Pub; 2001. p.868.
- [9] Santos-Filho PCF, Veríssimo C, Soares PV, Saltarello RC, Soares CJ, Martins LRM. Influence of ferrule, post system, and length on biomechanical behavior of Endodontically treated anterior teeth. *J Endod*. 2014 Jan; 40(1): 119-123.
- [10] Schwartz R, Robbins J. Restoration of Endodontically treated teeth: A literature review. *J Endod* 2004 May;30 (5):289-301.
- [11] Baba ZN, Goodacre CJ. Contemporary restoration of endodontically treated teeth. Ingle's endodontics 7th edition. PMPH USA, 2019.
- [12] Standlee JP, Caputo AA, Collard EW, Pollack MH. Analysis of stress distribution by endodontic posts. *Oral Surg Oral Med Oral Pathol*. 1972;33 (6):952-960.
- [13] Guzy GE, Nicholls JI. In vitro comparison of intact endodontically treated teeth with and without endo-post reinforcement. *J Prosthet Dent* 1979 Jul;42(1):39-44.
- [14] Davy DT, Dilley GL, Krejci RF. Determination of stress patterns in root-filled teeth incorporating various dowel designs. *J Dent Res*. 1981 Jul;60(7):1301–1310.
- [15] Eshelman EG Jr, Sayegh FS. Dowel materials and root fracture. *J Prosthet Dent*. 1983 Sep;50(3):342–344.
- [16] Reinhardt RA, Krejci RF, Pao YC, Stannard JG. Dentin stresses in post-reconstructed teeth with diminishing bone support. *J Dent Res*. 1983 Sep;62 (9):1002-1008.
- [17] Sorensen JA, Martinoff JT. Clinically significant factors in dowel design. *J Prosthet Dent*. 1984 Jul;52(1):28-35.
- [18] Kersten HW, Fransman R, Thoden Velzen SK. Thermomechanical

compaction of gutta-percha. II. A comparison with lateral condensation in curved root canals. May 1986;19(3): 134-140.

[19] PJJM, P JJ, Visseren LGH, Vrijhoef MMA, Käyser AF. In vitro comparison of dowel and core techniques for endodontically treated molars. J Endod;1989; 12(9):382-387.

[20] Leary JM, Aquilino SA, Svare CW. An evaluation of post length within the elastic limits of dentin. J Prosthet Dent. 1987 Mar;57(3):277-281.

[21] Hunter AJ, Feiglin B, Williams JF. Effects of post placement on endodontically treated teeth. J Prosthet Dent. 1989 Aug;62(2):166-172.

[22] Greenfeld RS, Roydhouse RH, James Marshall F, Schoner B. A comparison of two post systems under applied compressive-shear loads. J Prosthet Dent.1989;61(1): 17-24.

[23] Burns DA, Krause WR, Douglas HB, Burns DR. Stress distribution surrounding endodontic posts. J Prosthet Dent.1990 Oct;64(4):412-418.

[24] Hatzikyriakos AH, Reisis GI, Tsingos N. A 3-year postoperative clinical evaluation of posts and cores beneath existing crowns. J Prosthet Dent. 1992 Apr;67(4):454-458.

[25] Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? J of Endod. 1992 Jul;18(7): 332-335.

[26] Assif D, Bitenski A, Pilo R, Oren E. Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent. 1993 Jan;69(1):36-40.

[27] Mentink AGB, Creugers NHJ, Meeuwissen R, Leempoel PJB, Kayser AF. Clinical performance of different post and core systems - results

of a pilot study. J Oral Rehabil. 1993 Nov;20(6):577-584.

[28] Goodacre CJ, Spolnik KJ. The prosthodontic Management of Endodontically Treated Teeth: A literature review. Part I. success and failure data, treatment concepts. J Prosthodont. 1994 Dec;3(4):243-250.

[29] Torbjörner A, Karlsson S, Dr O, Odman PA. Survival rate and failure characteristics for two post designs. J Prosthet Dent. 1995 May;73(5):439-444.

[30] Purton DG, Love RM. Rigidity and retention of carbon fibre versus stainless steel root canal posts. Int Endod J.1996 Jul;29(4):262-265.

[31] Mendoza DB, Stephan Eakle W, Kahl EA, Ho R. Root reinforcement with a resin-bonded preformed post. J Prosthet Dent. 1997 Jul;78(1):10-14.

[32] Asmussen E, Peutzfeldt A. Direction of shrinkage of light-curing resin composites Acta Odontologica Scandinavica. Jan 2000.57(6):310-315.

[33] Al-Hazaimeh N, Gutteridge DL. 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. Int Endod J. 2001 Jan;34(1):40-46.

[34] Cormier CJ, Burns DR, Moon P. In vitro comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post systems at various stages of restoration. J Prosthodont. 2001 Mar;10(1):26-36.

[35] Christophe G, Chai J, Jameson L. Fracture Resistance and Primary Failure Mode of Endodontically Treated Teeth Int J Prosthodont 2001;14:141-145.

[36] Akkayan B, Gülmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent.2002; 87(4):431-7.

- [37] Pontius O, Hutter J. Survival rate and fracture strength of incisors restored with different post and Core systems and Endodontically treated incisors without Coronoradicular reinforcement. *J of Endod.*2002;28(10): 710-715.
- [38] Nergiz I, Schmage P, Platzer U, Ozcan M. Bond strengths of five tapered root posts regarding the post surface. *J. Oral Rehabil.*2020 ;29(4):330-335.
- [39] Kishen A, Kumar GV, Chen N-N. Stress-strain response in human dentine: Rethinking fracture predilection in postcore restored teeth. *Dent Traumatol.* 2004 Apr;20(2):90–100.
- [40] Tan PLB, Aquilino SA, Gratton DG, Stanford CM, Tan SC, Johnson WT, et al. In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. *J Prosthet Dent.* 2005 Apr;93(4):331–336.
- [41] Ng CCH, Dumbrigue HB, Al-Bayat MI, Griggs JA, Wakefield CW. Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth. *J Prosthet Dent.* 2006 Apr;95(4): 290–296.
- [42] Dietschi D, Ardu S, Rossier-Gerber A, Krejci I. Adaptation of adhesive post and cores to dentin after in vitro occlusal loading: Evaluation of post material influence. *J Adhes Dent.* 2006 Dec;8(6):409–419.
- [43] Salvi GE, Siegrist Guldener BE, Amstad T, Joss A, Lang NP. Clinical evaluation of root filled teeth restored with or without post-and-core systems in a specialist practice setting. *Int Endod J.* 2007 Mar;40(3):209–215.
- [44] Maccari PC, Cosme DC, Oshima HM, Burnett LH, Shinkai RS. Fracture strength of Endodontically treated teeth with flared root canals and restored with different post systems. *J Esthet Restor Dent.*2007;19(1):30-36.
- [45] Hinckfuss S, Wilson PR. Effect of core material and restoration design on strength of endodontically treated bovine teeth: A laboratory study. *J Prosthodont.* 2008 Aug;17(6):456–461.
- [46] Gorgul G, Kivanç BH. Fracture resistance of teeth restored with different post systems using new-generation adhesives. *J Contemp Dent Pract.* 2008 Nov 1;9(7):33-40.
- [47] Alikhasi M, Dorriz H, Mirfazaelian A, Hooshmand T. Effect of ferrule and bonding on the compressive fracture resistance of post and Core restorations. *J Contemp Dent Pract.* Feb 2009;10(1):1-8.
- [48] Ma PS, Nicholls JI, Junge T, Phillips KM. Load fatigue of teeth with different ferrule lengths, restored with fiber posts, composite resin cores, and all-ceramic crowns. *J Prosthet Dent.* 2009 Oct;102(4):229-234
- [49] Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. *J Dent.* 2009 Feb;37(2): 115-121.
- [50] Da Silva NR, Raposo LHA, Versluis A, Fernandes-Neto AJ, Soares CJ. The effect of post, core, crown type, and ferrule presence on the biomechanical behavior of endodontically treated bovine anterior teeth. *J Prosthet Dent.* 2010 Nov;104(5): 306-317.
- [51] Jang J-H, Park S-J, Min K-S, Lee B-N, Chang H-S, Oh W-M. Stress behavior of cemented fiber-reinforced composite and titanium posts in the upper central incisor according to the post length: Two-dimensional finite element

analysis. *Journal of Dental Sciences*. 2012 Dec;7(4):384–389.

[52] Hegde J, Bashetty K, Ramakrishna, Sirekha, Lekha, Champa. An in vitro evaluation of fracture strength of endodontically treated teeth with simulated flared root canals restored with different post and core systems. *J Conserv Dent* 2012 ;15 (3): 223-227.

[53] Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M. Ferrule effect: a literature review. *J Endod*. 2012 Jan;38 (1):11–19.

[54] Santos-Filho PCF, Verissimo C, Soares PV, Saltarelo RC, Soares CJ, Marcondes Martins LR. Influence of ferrule, post system, and length on biomechanical behavior of endodontically treated anterior teeth. *J Endod*. 2014 Jan;40(1):119–123.

[55] Maroulakos G, Nagy WW, Kontogiorgos ED. Fracture resistance of compromised endodontically treated teeth restored with bonded post and cores: An in vitro study. *J Prosthet Dent*. 2015 Sep;114(3):390-397.

[56] Upadhyaya V, Bhargava A, Parkash H, Chittaranjan B, Kumar V. A finite element study of teeth restored with post and core: Effect of design, material, and ferrule. *Dental research journal*. May 2016;13(3):233.

[57] Kim A-R, Lim H-P, Yang H-S, Park S-W. Effect of ferrule on the fracture resistance of mandibular premolars with prefabricated posts and cores. *J Adv Prosthodont*. 2017;9(5):328.

[58] Marchionatti AME, Wandscher VF, Rippe MP, Kaizer OB, Valandro LF. Clinical performance and failure modes of pulpless teeth restored with posts: a systematic review. *Braz Oral Res*. 2017. Jul 3;31-64.

[59] Sarkis-Onofre R, Fergusson D, Cenci MS, Moher D, Pereira-Cenci T.

Performance of post-retained single crowns: A systematic review of related risk factors. *J Endod*. 2017;43:175–183.

[60] Naumann M, Sterzenbach G, Dietrich T, Bitter K, Frankenberger R, Von Stein-Lausnitz M. Dentin-like versus rigid endodontic post: 11-year randomized controlled pilot trial on No-wall to 2-wall defects. *J Endod*. 2017 Nov;43(11):1770–1775.

[61] Lazari PC, de Carvalho MA, Del Bel Cury AA, Magne P. Survival of extensively damaged endodontically treated incisors restored with different types of posts-and-core foundation restoration material. *J Prosthet Dent*. 2018 May;119(5):769-776.

[62] Meng Q, Ma Q, Wang T, Chen Y. An in vitro study evaluating the effect of ferrule design on the fracture resistance of endodontically treated mandibular premolars after simulated crown lengthening or forced eruption methods. *BMC Oral Health*. 2018 May 10; 18(1):83.

[63] Zarow M, Ramírez-Sebastià A, Paolone G, de Ribot Porta J, Mora J. A new classification system for the restoration of root filled teeth. *Int Endod J*. 2018 Mar;51(3):318-334.

[64] Fadag A et al. Fracture resistance of Endodontically treated anterior teeth restored with different post systems: An In vitro study. *Eur Endod J*. 2018;3(3): 174-178.

[65] Pinto CL, Bhering CLB, de Oliveira GR, Maroli A, Reginato VF, Caldas RA. The influence of post system design and material on the biomechanical behavior of teeth with little remaining coronal structure. *J Prosthodont*. 2019 Jan;28(1):350–356.

[66] Bakirtzoglou E, Kamalakidis SN, Pissiotis AL, Michalakis K. In vitro assessment of retention and resistance failure loads of complete coverage

restorations made for anterior maxillary teeth restored with two different cast post and core designs *Journal of Clinical and Experimental Dentistry*. 2019 Mar; 11(3):e225-e230.

[67] Veeraganta SK, Samran A, Wille S, Kern M. Influence of post material, post diameter, and substance loss on the fracture resistance of endodontically treated teeth: A laboratory study. *J Prosthet Dent* ; 2020 Aug 2:S0022-3913 (20)30362-0.

[68] Cheung W. A review of the management of endodontically treated teeth. Post, core and the final restoration. *J Am Dent Assoc*. 2005 May; 136(5):611–619.

[69] Peroz I, Blankenstein F, Lange KP, Naumann M. Restoring endodontically treated teeth with posts and cores—A review. *Quintessence Int* 2005;36:737–746.

[70] Ree M, Schwartz RS. The Endo-restorative Interface: Current concepts. *Dent Clin North Am*. 2010;54(2):345–374.

[71] Valea MC, Pena VA. Titanium posts and bonded amalgam core longevity A 22- year clinical survival retrospective study. *J Am Dent Assoc*. 2017 Feb;148 (2):75-80.

[72] Abou-Rass M, Jaan MJ, Jobe D and Tsutsui F. Preparation of space for posting: Effect on thickness of canal walls and incidence of perforation in molars. *J Am Dent Assoc*, 1982 Jun; 104 (6):834-837.

[73] Delgado MM. The ferrule effect: An important aspect of rehabilitation involving using fiber posts. *Rev ADM*. 2014;71(3):120-123.

[74] Zarow, M, Ramírez-Sebastià, A, Gaetano, P, de Ribot Porta, J, Mora, J, Espona, J, Durán-Sindreu, F, Roig, M. A new classification system for the

restoration of root filled teeth. *International Endodontic Journal*, 51, 318– 334, 2018.

[75] Abu-Awwad M. A modern guide in the management of endodontically treated posterior teeth. *Eur J Gen Dent* [serial online] 2019 [cited 2020 Aug 19]; 8:63-70.