EVALUATION OF VARIED FERRULE GEOMETRY ON THE FRACTURE RESISTANCE OF ENDODONTICALLY TREATED MAXILLARY CENTRAL INCISORS- AN IN VITRO STUDY

Dissertation submitted to

THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY

In partial fulfillment for the Degree of

MASTER OF DENTAL SURGERY

BRANCH I

PROSTHODONTICS AND CROWN & BRIDGE

APRIL 2013

CERTIFICATE

This is to certify that this dissertation titled **"EVALUATION OF VARIED FERRULE GEOMETRY ON THE FRACTURE RESISTANCE OF ENDODONTICALLY TREATED MAXILLARY CENTRAL INCISORS- AN IN VITRO STUDY"** is a bonafide record of work done by **Dr. Vinod Narayanan** under my guidance during his postgraduate study period 2010 – 2013.

This dissertation is submitted to **THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the award of the degree of **Master of Dental Surgery** in **Prosthodontics and Crown and Bridge**. It has not been submitted (partial or full) for the award of any other degree or diploma.

Guide:

Dr. ANJANA KURIEN, M.D.S.,

Professor,

Department of Prosthodontics Including Crown and bridge and Implantology

Dr. V.R.THIRUMURTHY M.D.S.,

Vice Principal,

Professor and H.O.D,

Department of Prosthodontics Including Crown and bridge and Implantology

Dr. V.PRABHAKAR, M.D.S.,

PRINCIPAL,

Sri Ramakrishna Dental College and Hospital,

Coimbatore-641006

Date:

Place: Coimbatore

ACKNOWLEDGEMENT

My utmost gratitude to my ***Prof (Dr).V.R Thirumurthy****, Head of the Department of Prosthodontics for the insights he has shared. His sincerity, quest for perfection and encouragement has made me what I am today.*

I convey my sincere and heartfelt thanks to my Guide ***Prof (Dr).Anjana Kurien,*** *Department of Prosthodontics who has always given me valuable support.*

I avail this opportunity to sincerely and heartfully thank ***Dr. K.S.Limson****, Associate professor, Department of Prosthodontics, for his optimistic attitude towards the profession and life in general.*

Dr.Y.A Bindhoo*, Reader, Department of Prosthodontics, has been my inspiration as I hurdle all the obstacles in the completion of this thesis. It would not have been possible for me to complete this task without her rigorous scientific approach and the dedicating spirit for work.*

I also take this opportunity to express my sincere gratitude to ***Dr. Sunil Joseph Jacob,*** *Senior lecturer and* ***Dr. Sathya Shanker,*** *Senior lecturer, Department of Prosthodontics for being a constant source of encouragement, and support.*

I take this opportunity to thank ***Prof (Dr).V.Prabhakar, Principal*** *for his support and facilities provided in the college.*

I express my sincere thanks to ***Dr.K.Palanivelu,*** *Professor and Head. Central institute of plastic and technology, permitting to use the various testing equipment's available in the institution to conduct the test. I also pay my thanks to* ***Dr.P.T.Saleendran****, Statistician, for his help in this study.*

I would like to thank my colleagues, and department staff for their constant support and help rendered without any hesitation whenever I needed.

Finally, but definitely not the least, I express my gratitude to my family. I am so appreciative for their constant love, understanding and encouragement.

Thank you lord for my imperfections and failures are as much a blessing from you as my successes and my talents and I lay them both at your feet.

CONTENTS

EVALUATION OF VARIED FERRULE GEOMETRY ON THE FRACTURE RESISTANCE OF ENDODONTICALLY TREATED MAXILLARY CENTRAL INCISORS- AN IN VITRO STUDY

ABSTRACT

OBJECTIVE- The aim of this study was to compare the fracture resistance of endodontically treated maxillary central incisors with irregular crown ferrule effect after static loading. MATERIAL AND METHODS- Forty maxillary central incisors were divided into 4 groups (n=10). Endodontic treatment was performed. Teeth were decoronated 3.5 mm above the cemento-enamel junction (CEJ). Group I (control) had uniform 2mm long axial wall. Group II had length of labial axial wall reduced by 1mm .Group III had length of palatal axial wall reduced by 1 mm. Group IV had no coronal dentine 1.5 mm above CEJ. The teeth received fiber reinforced posts and composite core restorations. Metal crowns were cemented with type I glass ionomer cement. The restored teeth samples were loaded on a universal testing machine for fracture testing. The results were subjected to one way ANOVA and HSD TUKEY test to analyze the statistical significance. RESULTS- The mean fracture load values (N) were, Group I 535.29N, Group II 657.34N, group III 426.2N, and group IV 362.6N. Analysis revealed Group II was statistically significant from Group IV (p0.000), Group III (p0.000) and Group I (p0.081). CONCLUSIONS-Uniform ferrule effect and Labial irregular ferrule effect increased the failure threshold. Palatal axial wall had profound effect on fracture resistance and in the absence of uniform 2mm axial wall, maximum 2mm palatal axial wall with minimum 1mm labial axial wall increased the fracture resistance. Insertion of a fiber post could reduce the percentage of catastrophic failure.

KEY WORDS- Ferrule effect, fracture load, post and core, endodontically treated teeth.

INTRODUCTION

INTRODUCTION

Is it better to have second chance to correct the fallacies of the first, it always is… and what if there is no second chance? These scenarios are especially relevant when restoring endodontically treated maxillary central incisor.

Clinicians are confronted with difficult choices regarding whether a nonvital tooth should be saved through endodontic treatment or be extracted and replaced with an implant[96]. The concept of evidence-based dentistry essentially states that treatment plans should be devised based on the best available evidence from the literature using the experience and wisdom of the practitioner and the needs and desires of the patient[73]. Major studies published to date indicate that there is no difference in long-term prognosis between single-tooth implants and restored root canal treated teeth[42]. Therefore, the decision to treat a tooth endodontically or to place a single tooth implant should be based on other criteria such as prosthetic restorability of the tooth, quality of bone, aesthetic demands, cost-benefit ratio, systematic factors, potential for adverse effects, and patient preferences. It can be concluded that endodontic treatment of teeth represents a feasible, practical, and economical way to preserve function in a vast array of cases and that dental implants serve as a good alternative in selected indications in which prognosis is poor[42].

Prosthetic restoration of endodontically treated tooth requires post and core foundation to achieve sufficient anchorage when more than 50% of coronal structure is missing. Currently posts are not believed to function as a reinforcing component of prosthetic treatment but rather as an element supporting and anchoring a core foundation, when there is an insufficient clinical crown[10, 18, 19, 63, 86, 87, 101].

Posts can either be prefabricated or custom made. The most common cause of failure of cast posts and cores is post dislodgment, followed by root or post fractures [63,86].Metallic posts show poor stress distribution because of an elastic modulus very different from that of dentin, which, in turn, lead to root fracture [76].Most of the root fractures in cast posts are catastrophic. Nevertheless, they are still considered as the gold standard in anterior endodontically treated restorations [37, 53, 76].

Since the introduction of the direct post-and-core restoration, [58] associated techniques and materials have improved significantly[1]. The introduction of fiber reinforced composite (FRC) posts helped to improve stress distribution because their elastic modulus was shown to be closer to that of dentin by in vivo [21,15] and in vitro research [1,58]. Adhesively luted resin/ fiber posts with composite cores appear to be the best currently available option in terms of tooth fracture and biomechanical behavior[5]. Prefabricated fiber posts have an advantage that the post space can be prepared and the post directly bonded in one appointment [63].

Restoration of endodontically treated teeth is very demanding, as there is substantial loss of hard tissue by restorative procedures [33, 46, 95]. The main risk factor causing tooth fracture is this hard tissue loss [72]. Loss of moisture or increasing brittleness is not a causative factor for tooth fracture as was believed before [79, 30, 34]. Tooth strength is reduced in proportion to lost coronal tissue and a direct relationship exists between the amount of remaining tooth structure [97]and the ability to resist occlusal forces [69].

Posts may also increase root fracture due to excessive pressures during insertion or because of lateral movement of the post within the root, thus ironically increasing the risk of root fracture[36, 53, 98] and treatment failure[87]. Hence the concept of fracture resistance is of importance.

Fracture resistance in endodontically treated teeth was improved if tooth structure loss was limited and a uniform 2mm ferrule effect was obtained [4, 5 17], a post with similar physical properties to natural dentine was used, and adhesive techniques for post luting and coronal restoration were employed [32].

Ferrule is defined as a metal band or ring used to fit the root or crown of a tooth [93].The ferrule on the restoration braces or hugs 360° axial preparation of a tooth to produce a ferrule effect [45]. The ferrule effect reduces the wedging of tapered post or bending forces during post insertion and helps to improve the marginal integrity of fixed partial dentures [61]. Therefore, the use of a correct ferrule design is of particular importance for fracture resistance and dislodgement in teeth restored with post and cores [90, 91].

The incorporation of the concept of 'ferrule' or 'the ferrule effect' has been accepted as one of the foundations of the restoration of the endodontically treated tooth. The origin of the term is thought to come from the Latin terms 'ferrum' - iron, and 'viriola' – bracelet. The cast restoration encircles the remaining parallel walled tooth structure with a metal band thereby 'bracing' the tooth, providing resistance to dislodgement and preventing fracture [44,45,87,90,91]. Hence ferrule effect is an extension of the restored crown which, by its hugging action, prevents shattering of the root.

The ferrule effect in association with post and core treatment was investigated by many researchers [2, 11, 31, 45, 49, 50, 75, 92]. Most of the previous studies were performed in vitro and generally have accepted that ferrules incorporated within cores or final crowns might increase the fracture resistance of restored teeth by reinforcing their external surfaces to resist stresses accompanied by functional lever forces. Ferrules also help to maintain the integrity of cement seal around the restoration [91].

Under clinical conditions, maxillary incisors are often centrally or laterally damaged [95, 105]. Occlusal overload causes a fracture from palatal to facial, often at a sub-gingival level on the facial side of the tooth. Proximal cavities leave hard tooth tissue only on the facial and palatal side [61]. Traumatic injury results in coronal fracture on the facial side, which extends in cervical-palatal direction. In such cases, a favorable 2-mm ferrule effect is difficult to achieve. Hence the various questions that arise are…

Which direct and indirect factors influences ferrule functionality?

As to what extent the degree of dentin preservation influences the success of the ferruled, endodontically treated anterior restoration?

AIM OF THIS STUDY

AIM OF THIS STUDY

1} To evaluate and compare fracture resistance of endodontically treated teeth, with and without ferrule effect.

2} To evaluate and compare fracture resistance of endodontically treated teeth having uniform 2mm ferrule effect with non-uniform ferrule effect.

3} To evaluate and compare fracture resistance of endodontically treated teeth having nonuniform palatal and nonuniform labial ferrule effect.

The tested null hypothesis was that the amount and location of residual coronal dentin (axial wall for ferrule effect) does not significantly affect fracture resistance of endodontically treated teeth.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

A ferrule or encircling band of cast metal around the coronal surface of the tooth has been suggested to improve the integrity of the endodontically treated tooth. The ferrule as part of core or the crown is purported to prevent tooth fracture. The purpose of the ferrule is to improve the structural integrity of the pulpless tooth by counteracting the functional lever forces, avoiding the wedging effect of tapered dowels and the lateral forces exerted during insertion of the dowel. Several authors have suggested that the crown should extend 2 mm beyond the tooth-core junction to ensure a protective ferrule effect [88].

- Rosen [75] (1961) in a review of literature focused on establishing norms for the correct reconstruction and build-up of root canal treated teeth. He stated that operative procedures following endodontic therapy are as important as the root canal treatment itself. He recommended that such teeth must be reinforced or supported with either an intracoronal “crutch” or an extra coronal “brace,” or both. The intracoronal crutch is a cast post or dowel which extends into a preparation made in the root canal and is continuous with a core. The extra coronal brace is a subgingival collar or apron of gold which extends as far as possible beyond the gingival seat of the core and completely surrounds the perimeter of the cervical part of the tooth. It is an extension of the restored crown which, by its hugging action, prevents vertical shattering of the root. He further stated that by virtue of its exaggerated gingival extension, this apron of gold contributes to mechanical retention- for the restoration as well as prevention of recurrence of decay in mouths which have little or no immunity against caries.

- In 1978, Trabert, Caput and Abou-Rass [98] conducted a study to analyze the strength of teeth treated with stainless steel post. Posts with different diameter, width, and lengths where used. They verified that the post with smaller diameters preserve greater amount of tooth structure thereby significantly increasing the resistance to fracture.

- Hoag and Dwyer [38] (1982) in their vitro study evaluated post and core techniques with and without full crown coverage on extracted mandibular molar teeth. They concluded that the method of post and core technique may not be as significant as the placement of full coverage cast-gold crown restorations and placement of margins beyond the buildup restoration.

- Sorensen and Martinoff [86] (1984) evaluated 1273 endodontically treated teeth for clinical significance by post reinforcement and coronal coverage. After comparing the success and failure of the groups, it appeared that some teeth were more prone to failure regardless of restorative technique. Maxillary anterior teeth are more susceptible to trauma than premolars or molars because of arch position. The difference in direction of forces during function in maxillary anterior teeth vs. mandibular anterior teeth may also account for the discrepancy in the failure rate between the two. Mandibular anterior teeth are subject to more vertical forces closer to their long axis, while maxillary anterior teeth receive more angular forces. Significant loss of tooth structure while obtaining canal access during endodontic therapy may sufficiently weaken the maxillary anterior teeth despite the restoration that is placed. They concluded that the records of 1273 endodontically treated teeth suggest: 1. there was no significant increase in resistance to fracture or dislodgment gained with intracoronal reinforcement for the six anatomic groups of teeth. 2. Coronal coverage did not significantly improve the rate of clinical success for maxillary and mandibular anterior teeth. 3. The rate of clinical success was significantly improved with coronal coverage of maxillary and mandibular premolars and molars.

- Tjan and Whang [94] (1985) investigated 1) resistance to fracture under horizontal force and the failure characteristics of dowel channels on maxillary central incisors with various thicknesses of remaining buccal dentin and (2) studied the effect of a metal collar on the resistance of roots to fracture. They concluded that dowel channels with 1 mm of remaining buccal dentin walls were apparently more prone to fracture under horizontal impact than those that had 2 or 3 mm of buccal dentin walls.

- Assif et al [8] (1989) examined the compressive forces exerted by endodontic posts, using photo elastic models. On the basis of this model, the following observations were made. 1. Intact teeth induce a wedging effect on the supporting structure under vertical loads. Under oblique loads, stresses were equally concentrated.2. The placement of a complete crown changes the pattern of the distribution of externally applied loading to the tooth. Stresses concentrated around the crown margins.3. Vertical loads applied directly to the post and core caused high apical stress concentration with the cylindrical post, while the tapered post design showed equal stress concentration at the cemento enamel junction (CEJ) and the apex. On oblique loading, CEJ stress concentration intensified for both post designs. The tapered post in each loading produced less apical stress than the cylindrical post.4. When a post and core was covered by a complete crown with 2 mm margins on sound tooth structure and subjected to loading, there was no difference between the two post designs. The placement of the crown intensified the CEJ stress concentration. It is possible that the complete crown and 2mm margins on sound tooth structure may be the great equalizer, because it tends to change the distribution of forces to the root, post, and core complex, with the post characteristics becoming insignificant.

- Barkhordar, Radke and Abbasi [11] in the year 1989 examined the effect of a metal collar with approximate 3 degrees of taper on the resistance of endodontically treated roots to fracture. Teeth without copings failed at a load of 49.6 kg whereas teeth with metal collars failed at a load of 65.29 kg. They concluded that reinforcement with a metal collar is necessary to enhance resistance to root fracture.

- Loney, Kotowiez and McDowel [50] (1990) assessed the effect of a metal collar on stress distribution with cast post and cores. This was studied by using three-dimensional photo elastic models of maxillary canine teeth of average dimensions. Standardized parallel post and cores were cemented into the models, with half of the samples incorporating a 1.6 mm metal collar. They suggested that the ferrule may help to unite different portion of tooth and had significant effect on stress distribution.

- Sorensen and Engelman [88] (1990) researched to determine the effect of different post designs and varying amounts of post-to-canal adaptation on the fracture resistance of endodontically treated teeth. They concluded that maximum adaptation of the residual root structure with a tapered post significantly increases the fracture resistance of endodontically treated teeth, but upon failure render the tooth nonrestorable. Tapered posts resulted in fractures that were directed more apically and lingually. Parallel-sided posts had a lower frequency of fracture upon failure, involving less tooth structure. Parallel-sided posts surrounded by large amounts of cement had no significant effect on failure loads.

- Sorensen and Engelman [89] (1990) conducted in vitro study to examine the effect of various ferrule designs on fracture resistance of endodontically treated anterior teeth. They concluded that one millimeter of coronal tooth structure above the crown margin substantially increased the fracture resistance of endodontically treated teeth, whereas a contra bevel at either the tooth-core junction or the crown margin was ineffective. The thickness of axial tooth structure at the crown margin did not appreciably improve resistance to fracture.

- The effect of post design on the fracture resistance of endodontically treated premolars restored with cast crowns was examined in vitro by Assif et al [9] (1993). They concluded that post design did not influence the fracture resistance of endodontically treated teeth. They stated that in such teeth, greater importance must be given to crown having a 2 mm margin on healthy tooth structure.

- Libmen and Nicholls [48] (1995) studied varying ferrule heights from 0.5 to 2.0 mm in 0.5-mm increments. The results of this study showed that the 0.5 mm and 1.0 mm ferrule lengths failed at a significantly lower number of cycles than the 1.5 mm and 2.0 mm ferrule lengths and control teeth. They concluded that to achieve full benefits of ferrule effect, axial wall be minimum of 1.5 mm in height and have parallel dentinal walls; crown must totally encircle the tooth, and end on sound tooth structure.

- In an in vitro study Saupe WA, Gluskin AH, Rake RA [77] (1996) investigated the validity of intraradicular reinforcement for endodontically treated teeth with thin remaining walls. They stated that when tooth structure is compromised, the use of the resin reinforcement system and post adhesion with resin cements can eliminate the time-honored requirements of a ferrule. They further stated that the use of a ferrule, under weakened structural conditions, provides no additional benefit for retention and resistance to fracture and will necessitate additional loss of structure.

- McLean [54] (1998) suggested that for an endodontically treated tooth not requiring a post, the requirements are for biologic width + ferrule length (i.e. 4.5 mm of supra-bony solid tooth, dentin a minimum of 1 mm thick after preparation). A tooth requiring a post needs, in addition, enough root length to allow a 4 mm apical seal and a post length apical to the crown margin, equal to the length of the crown. It is essential to assess the functional loads to which the restored tooth would be subjected. Teeth that are endodontically treated, or are likely to be in future, should be avoided as abutments supporting precision attachment RPDs, distal extension RPDs or cantilever FPDs.

- Isidor, Brondum and Ravnholt [43] (1999) in a vitro study evaluated the influence of post and ferrule length on the resistance to cyclic (fatigue) loading of teeth with prefabricated titanium posts (Para Post) and crowns. Combinations of post lengths of 5 mm, 7.5 mm, and 10 mm, and ferrule lengths (i.e., the vertical dentinal overlap of the crown) of 0 mm, 1.25 mm, and 2mm, 5 mm made up 9 different groups consisting of 10 teeth each. The posts where cemented with zinc phosphate cement. Composite-resin cores were made and crowns were cemented. Each test specimen underwent cyclic loading of 400 N with a frequency of 1 load per second at an angulation of 45 degrees to the long axis of the tooth. They concluded that the ferrule length was more important than post length in increasing fracture resistance to cyclic loading of crowned teeth.

- Gegauff [30] (2000) stated that restoration of mandibular second premolars with completely missing clinical crowns in the Kennedy Class I and II arches is costly and the risk of failure is high. A vitro study was done to determine the combined effect of crown lengthening and placement of a ferrule on the failure resistance to static load of decoronated and restored mandibular second premolar analog teeth. The combination of simulated surgical crown-lengthening and more apical crown margin placement to provide a 2-mm crown ferrule on a decoronated mandibular second premolar analog resulted in a reduction of static load failure for the restored analog tooth.

- In an in vitro study by Al-Hazaimeh N, Gutteridge DL [3] (2001) 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 specimens were mounted on a 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. They concluded that when composite cement and core materials are utilized with a Para post prefabricated system the additional use of a ferrule preparation has no benefit in terms of resistance to fracture.

- Butz et al [14] in 2001studied the survival rate and fracture strength of endodontically treated maxillary incisors with moderate coronal defects restored with different post and core systems after exposure to an artificial mouth. They concluded that in the presence of 2mm ferrule effect, prefabricated titanium posts with composite cores, zirconia posts with heat-pressed ceramic cores, and cast posts and cores yield comparable survival rates for fracture strengths in the restoration of crowned maxillary incisors. Survival rates and fracture strengths for zirconia posts with composite cores are significantly lower, so this combination cannot be recommended for clinical use.

- Al-Wahadni A, Gutteridge DL [6] (2002) conducted in vitro study to examine the fracture resistance of teeth restored with cast post and partial cores supported by different heights of coronal tooth structure. They concluded that, 3 mm of retained coronal buccal dentine improved fracture resistance of teeth restored with partial post and cores when compared to teeth without retained coronal dentine.

- In 2002 Pierrisnard et al [70] analyzed through a study of finite element, the effect of different corono-radicular reconstruction methods on stress transmission to dental tissues. Seven 3-dimensional models were created, each representing a tooth embedded in a bony medium. Within the limitations of this study, it was confirmed that all simulated reconstructed teeth were more subject to stress in the cervical region. The absence of a cervical ferrule was found to be a determining negative factor, giving rise to considerably higher stress levels.

- Zhi-Yue and Yu-Xing [106] (2003) assessed in vitro the effects of post-core design and ferrule on the fracture resistance of root canal treated human maxillary central incisors restored with metal ceramic crowns. Within the limitations of this study they concluded that not all of the post-core structures tested improved the strength of the endodontically treated teeth. Those prepared with a 2-mm dentin ferrule more effectively enhanced the fracture strength of custom cast post-core restored endodontically treated maxillary central incisors.

- Mezzomo, Massa and Líbera [57] (2003) investigated fracture resistance of teeth restored with cast post and cores with and without ferrule using two different luting cements through in vitro study. Their result showed that ferruled specimens had greater resistance than nonferruled ones, regardless of the cement used. They concluded that a 2.00-mm cervical ferrule is important for fracture resistance of restored teeth, and resin cement has a better performance.

- Akkayan [2] (2004) conducted in vitro study to compare the effect of 3 different ferrule lengths, on the fracture resistance and fracture patterns of crowned endodontically treated teeth restored with 4 different esthetic dowel systems. He concluded by stating that increasing the ferrule length of the endodontically treated teeth from 1 mm to 1.5 mm in specimens restored with quartz-fiber and glass-fiber dowels did not produce significant increases in the failure loads .No significant difference was detected between glass-fiber and glass-fiber plus zirconia dowels with 1.5-mm and 2.0-mm ferrules .However, fracture thresholds were higher for all 4 dowel systems when the specimens were prepared with a 2.0-mm ferrule length.

- Melo et al [55] (2005) evaluated the influence of remaining coronal tooth structure on endodontically treated teeth restored with prefabricated posts and two different composites for core build-up. They concluded that remaining coronal tooth structure did not influence the resistance of endodontically treated teeth; however, the change of core build-up was able to modify this resistance. They stated that light cured resin core build up was better than dual cure resin core.

- Creugers et al [20, 21] (2005) conducted a prospective clinical study to explore whether direct composite built up restorations with or without a post and not protected by a covering cast crown can show acceptable durability over a 5-year observation period. None of the post free restorations failed. Two restorations with post failed after almost 5 years. Survival difference was not statistically significant.

- Pereira et al [65] (2005) analyzed the fracture strength of endodontically treated teeth restored with different posts and variable ferrule heights. The results of this study showed that the ferrule in crowns promoted significantly higher fracture strength in the endodontically treated teeth.

- Tan PL et al [92] (2005) conducted an in vitro study investigating the resistance to static loading of endodontically treated teeth with uniform and nonuniform ferrule configurations. The results 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.

- Hu S et al [39] (2005) evaluated the resistance to fracture of endodontically treated teeth with flared canals restored with different post and core restorations under static and cyclic fatigue loadings. The results of this study suggested that resin composite post-and-core prepared with 1-mm ferrule was the most desirable restoration for structurally compromised roots, as they revealed relatively strong resistance to cyclic fatigue and fracture .All resin composite post and core specimens also demonstrated favorable root fracture.

- AL-Omiri MK, AL-Wahadni A M [4] (2006) investigated the fracture resistance and fracture patterns of teeth restored with composite cores supported by different pre-fabricated post systems with different heights of remaining coronal dentine. They concluded stating that fracture resistance of teeth increased with the presence of retained coronal dentine. The use of glass and carbon fiber posts did not improve the fracture resistance or the fracture pattern of teeth when compared with metal titanium posts regardless of the presence of retained coronal dentine. The dominant fracture pattern of teeth was not related to the amount of retained dentine if it was more than 2 mm high.

- Pereira et al [66] (2006) studied the fracture strengths of endodontically treated teeth using posts and cores with variable quantities of coronal dentin located apical to core foundations. Teeth with 1 mm, 2 mm, and 3 mm of remaining coronal tooth structure (1, 2, and 3mm ferrule) were studied. All specimens in 0 mm through 3 mm (non-control) groups were restored with a prefabricated post (Screw-Post) and composite resin (Z100) core located superior to the different tooth structure heights. All teeth were restored with complete metal crowns. The fracture resistance (N) was measured in a universal testing machine at 45 degrees to the long axis of the tooth until failure. The results of this study showed that an increased amount of coronal dentin significantly increases the fracture resistance of endodontically treated teeth.

- Ichim I, Kuzmanovic et al [40] (2006) investigated through finite element analysis the ferrule design on restoration resistance and distribution of stress within a root. An extracted, intact, caries free, maxillary right central incisor was scanned by laser and then reconstructed on a computer to produce a model of the tooth and associated periodontal ligament. A simulated post/core/crown restoration was constructed on conventional tooth preparations with various ferrules. The crown was loaded with a simulated 500 N force. The study confirms that a ferrule increases the mechanical resistance of a post/core/crown restoration. However a ferrule creates a larger area of palatal dentine under tensile stress that may be a favorable condition for a crack to develop. Crown lengthening did not alter the levels or pattern of stress when compared with conventional ferrule preparations.

- Ng CC, Dumbrigue HB et al [63] (2006) Conducted a study about influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth. They concluded, 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.

- Idil dikabas, et al [41] (2007) concluded that different ferrule design did not have any influence on the fracture resistance of teeth with fiber posts. The results of that study indicate fiber posts can safely be used for their reinforcing properties. Furthermore, there is no significant change in the resistance of teeth with fiber posts regardless of which ferrule design is incorporated. The property of these types of posts is an additional advantage in clinical practice

- Ferrari M, Cagidiaco M.C, et al [29] (2007) conducted a study on survival of endodontically treated premolars. Over a two-year observation period, post placement resulted in a significant reduction of failure risk for endodontically treated premolars. With regard to the influence of residual coronal dentin, failure risk was significantly higher for teeth that had lost all coronal walls.

- Didier Dietschi et al [25] (2007) in a systematic review of literature stated that the best current approach for restoring endodontically treated teeth seems to (1) minimize tissue sacrifice, especially in the cervical area so that a ferrule effect can be created, (2) use adhesive procedures at both radicular and coronal levels to strengthen remaining tooth structure and optimize restoration stability and retention, and (3) use post and core materials with physical properties close to those of natural dentin.

- Meng QF, Chen YA et al [55] (2007) in a study investigated the effect of a crown lengthening ferrule on the fracture resistance of endodontically-treated teeth restored with two dowel-core systems. They concluded that crown lengthening with a 2.0 mm apical extended ferrule preparation may result in reduced root fracture strengths for endodontically-treated teeth. A carbon fiber-reinforced dowel-resin core system may reduce the severity of the root fractures.

- Hinckfuss et al [37] (2008) 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. They concluded 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.

- Nissan J et al [64] in 2008 examined the influence of a reduced post length sealed with a titanium-reinforced composite luting agent on the fracture resistance of crowned endodontically treated teeth with a 2-mm ferrule on healthy tooth structure. Posts were luted with a titanium-reinforced composite resin luting agent. Titanium-reinforced composite resin cores were constructed, and cast crowns with a 2- mm ferrule on healthy tooth structure were cemented. They concluded that within the limitations of this study, post length did not influence the fracture resistance of crowned endodontically treated teeth with a 2-mm ferrule on healthy tooth structure. For tooth resistance, prosthesis design is more important than post characteristics.

- Senthil Nathan D, Nayar S [80] (2008) stated, teeth restored with custom cast post core were better resistant to fracture than teeth restored with prefabricated titanium post composite core. Ferrule is more important in custom cast post core than in prefabricated post and composite core.

- Erslan O, Aykent F et al [27] (2009) demonstrated the effect of ferrule with different heights on the stress distribution of dentin and the restoration - tooth complex, using finite element stress analysis method. They observed that the stress value with zirconium oxide ceramic was higher than glass fiber reinforced post system. The use of a ferrule in endodontically treated teeth restored with an all-ceramic post-and-core reduces the values of von Mises stresses on tooth-restoration complex. Zirconium oxide ceramic post system stress levels, both at dentin wall and within the post, were higher than that of fiber posts.

- Arunpraditkul et al [7] (2009) investigated the fracture resistance of endodontically treated teeth between those with four walls and those with three walls of remaining coronal tooth structure. The effect of the site of the missing coronal wall was also studied. They concluded that teeth with four walls of remaining coronal dentine had significantly higher fracture resistance than teeth with only three walls. The site of the missing coronal wall did not affect the fracture resistance of endodontically treated teeth.

- Buttel L et al [13] (2009) investigated (i) the impact of post fit (form-congruence) and (ii) the influence of post length on the fracture resistance of severely damaged root filled extracted teeth. They concluded stating that Post fit did not have a significant influence on fracture resistance, irrespective of the post length. Fracture resistance of teeth restored with FRC posts and direct resin composite crowns without ferrules was not influenced by post fit within the root canal. These results imply that excessive post space preparation aimed at producing an optimal circumferential post fit is not required to improve fracture resistance of roots.

- Ma PS et al [51] (2009) studied different ferrule lengths with the number of fatigue cycles needed for failure of the crown cement for an all-ceramic crown cemented with resin cement. 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 0.5mm ferrule showed a significant increase in the number of fatigue cycles over the 0.0mm group, whereas teeth with the 1.0mm ferrule exhibited a significantly higher fatigue cycle count over the 0.0mm but not the 0.5mm group. They suggested that the clinical implication were that the 1.5mm ferrule has been suggested for a metal crown with a cast gold post and core luted with zinc phosphate cement. However, due to the large standard deviation in the 0.5mm ferrule test group, a minimum 1.0mm ferrule length is recommended when using core bonding and bonding of an all-ceramic crown for restoration of the structurally compromised tooth.

- Erslan O et al [27] (2009) studied the effect of ferrule with different heights on the stress distribution of dentin and the restoration-tooth complex, using finite element stress analysis method. Three-dimensional finite element models simulating an endodontically treated maxillary central incisor restored with an all-ceramic crown were prepared. Three-dimensional models were varied in their ferrule height (NF: no ferrule, 1F: 1-mm ferrule, and 2F:2-mm ferrule). A 300-N static occlusal load was applied to the palatal surface of the crown with a 135° angle to the long axis of the tooth. The stress values observed with the use of a 2-mm ferrule were lower than the no-ferrule design for both the glass fiber reinforced and zirconium oxide ceramic post systems, respectively.

- Schmitter M et al [78] (2010) conducted a study combining the advantages of in vitro tests and finite element analysis (FEA) to clarify the effects of ferrule height, post length and cementation technique used in restoration. All conventionally cemented crowns with a 1-mm ferrule height failed during artificial ageing, in contrast to resin-bonded crowns (75% survival rate). FEA confirmed these results and provided information about stress and force distribution within the restoration. Based on the findings of in vitro tests and computations they concluded that crowns, especially those with a small ferrule height, should be resin bonded and failure loads were higher for resin-bonded crowns than for conventionally cemented crowns.

- da Silva NR et al [21] (2010) conducted a study to evaluate the effect of post, core, crown type, and ferrule presence on the deformation, fracture resistance, and fracture mode of endodontically treated bovine incisors. Result showed that the ferrule presence did not significantly influence the buccal strain and fracture resistance for the ceramic crown groups, irrespective of core and crown type. Ferrule presence resulted in lower strains and higher fracture resistance in the metal crown groups, irrespective of core. The cast post and core showed lower strain values than groups with glass fiber posts when restored with metal crowns. They concluded, 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.

- Jelena Juloski et al [45] (2012) in a literature review on ferrule effect stated that the 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.

MATERIALS AND METHODS

MATERIALS AND METHODS

This study was performed to evaluate the influence of variable ferrule effect geometry on the fracture resistance of 40 endodontically treated teeth restored with Fiber reinforced composite (FRC) post and composite core.

Materials used in this study

TABLE.2: EQUIPMENT

PROCEDURE	S.NO	INSTRUMENT	BRAND, MANUFACTURER
TEETH SELECTION	1	Digital Vernier caliper	Aerospace, India.
	2	Phase contrast microscopy	Olympus CH-20i, New delhi, India.
	3	Ultra sonic scaler	Cavitron ,Densply Int,York,Pa
ROOT CANAL TREATMENT AND OBTURATION	4	Reamer (size-10-40)	Mani Inc, Tochigi, Japan
	5	K- files (size-10-40)	Mani Inc, Tochigi, Japan
	6	Airotor Hand piece	NSK, Japan
	7	Burs	Mani SF-11, Japan.
	8	Lentulospirals	Maillefer, Ballaigues, Switzerland.
POST SPACE PREPARATION	9	FRC Postec Plus Reamer, Size 1	Ivoclar Vivadent AG, Schaan/Liechtenstein,572801 AN
	10	Peeso reamers	Mani,Japan
	11	Contra angled micro motor hand piece	NSK,Japan
AXIAL WALL PREPARATION	12	Loop 2x magnification	
	13	Burs	Mani SF-11,Japan
	14	Periodontal Probe – Willams.	S/E # Williams (GDC-AC-002-W).Hosiarpur, India.
MOUNTING	15	Dental surveyor	Ney, Bloomfield, CT

	16	1 inch x 1 inch Stainless steel Cylinder	
POST AND CORE BUILDUP	17	Light cure unit	Hilux, First medica, USA
REFINING AXIAL PREPRATION WITH CORE	18	Custom made Airotor mounting Jig	
	19	Radiograph	X mind, Germany
WAX PATTERN FABRICATION	20	Electric wax dropper	WaxelectricII, Renfert, Germany
	21	PKT instruments	
	22	Digital weighing machine	Essae
	23	Wax caliper	
INVESTMENT AND CASTING	24	Vacuum mixer	Easymix, Bego, Germany
	25	Furnace	Miditherm 100/200 MP,Bego, Gemany
	26	Induction casting machine	Fornax T,Bego, Germany
	27	Metal trimmers	Edenta, Switzerland
	28	Lathe	Ray foster,CA,USA
	29	Sand blaster	Korostar,Bego Germany
	30	Metal caliper	
CEMENTATION	31	2 kg Weight	
	32	Customized jig for crown cementation	
FRACTURE RESISTANCE	33	Custom made Acrylic block mounting Jig	
	34	Universal testing machine	Instron 3382, London, UK
CAMERA	35	Digital SLR Camera	Nikon D5100 Japan

TABLE.3: MATERIALS

PROCEDURE	**S.No**	**MATERIAL**	**BRAND, MANUFACTURER**
SELECTION OF TEETH	1	Thymol	Nice Chemicals, Cochin, India

ROOT CANAL TREATMENT AND OBTURATION	2	3% Sodium hypochlorite	Vensons ,Bengaluru,India
	3	Apexit plus	Ivoclar Vivadent AG, Liechtenstein.
	4	Gutta percha points	Dentsply, China.
	5	Normal saline	Baxter ,Tamil nadu, India
MOUNTING	6	Autopolymerising resin	DPI–RR Cold Cure, The Bombay Burma Trading Corporation, Mumbai, India.
	7	PVS light body elastomer	Express XT Ultra-Light, 3M ESPE.
	8	Aluminium foil	Hindalco,Dadra, India.
POST AND CORE BUILD UP	9	FRC Postec plus Size1	Ivoclar Vivadent AG, Liechtenstein. 590222 AN
	10	Total Etch	Ivoclar Vivadent AG, Liechtenstein
	11	Excite F DSC	Ivoclar Vivadent AG, Liechtenstein
	12	MultiCore	Ivoclar Vivadent AG, Liechtenstein
	13	Salinating agent	Monobond-S, Ivoclar Vivadent AG, Liechtenstein
WAX PATTERN FABRICATION	14	Putty-PVS impression material	3M, ESPE, Seefeld, Germany
	15	Inlay wax	Geo Classic,Renfert
	16	Die hardener	Surface hardener Renfert
	17	Die Spacer	Pico-Fit ,Renfert
	18	Wax separator	Iso-Stift,Renfert
	19	Sprue wax	Renfert.
INVESTMENT AND CASTING	20	Debubblizer	Bego.
	21	Investment	Bellavest® SH,Bego,Germany
	22	Metal	Wirobond 280 ,Bego, Germany
CEMENTATION	23	Glass ionomer luting cement	Meron VOCO,Germany

METHODOLOGY

1) Selection of teeth.

2) Root canal preparation and obturation.

3) Post space preparation.

4) Grouping of samples.

Group I (Control Group)	- Uniform ferrule effect (UFE).
Group II	- Labial irregular ferrule effect (LIFE).
Group III	- Palatal irregular ferrule effect (PIFE).
Group IV	- No ferrule effect (NFE).

5) Axial wall preparation for groups.

6) Mounting of teeth on acrylic blocks.

7) Bonding FRC post and core buildup.

8) Refining axial convergence.

9) Wax pattern fabrication.

10) Investing and casting

11) Cementation

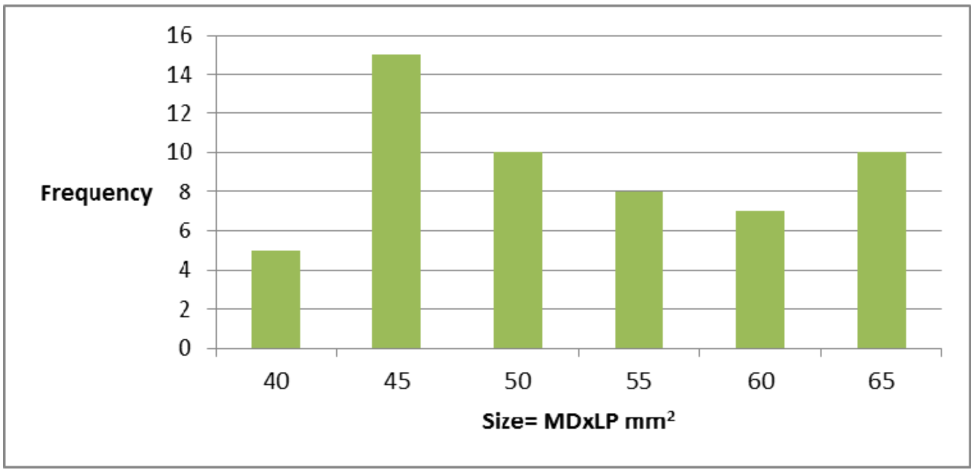
12) Testing of specimens.

1) SELECTION OF TEETH.

Fifty human maxillary central incisors devoid of caries, root canal fillings, restorations, tooth wear and having root length between 11 mm to 13 mm [92,104] were obtained directly after extraction. They were stored in 0.1% thymol solution during the course of the studyv[14, 61]. Hard and soft tissue deposits were removed using ultra sonic instrumentation (Cavitron, Densply Int, York, Pa). All selected teeth were examined under 220x magnifications in a phase contrast microscopy to ensure that they had no abfractions, cracks or fracture lines [7].

The mesiodistal (M-D) and labiopalatal widths (L-P) at the cementoenamel junction (CEJ) were measured with digital vernier caliper (Aerospace, India) and multiplied (Fig-1). This dimension was recorded and used to classify 50 samples according to their “size” [7, 14, 61, 62, 80].

Graph-1 shows the frequency distribution of the sizes, which was used to identify the extreme sizes.



Graph-1

Out of this 40 teeth of sizes between 40 - 60 mm^2 were included for this study.

To ensure functional longevity, endodontically treated teeth must have at least 5 mm of tooth structure coronal to the crestal bone [53, 54, 84]. Three millimeters is needed to maintain a healthy soft tissue complex (2mm connective tissue+1mm Junctional epithelium=Biologic width), and 2 mm of coronal tooth structure incisal to the preparation finish line is necessary to ensure structural integrity [53] (axial wall for ferrule effect). To simulate this, the anatomic crowns of all 40 teeth were removed perpendicular to the long axis of the tooth, 3.5mm above CEJ and 5.5 mm above simulated bone level (Diagram-1), by using water-cooled diamond stone (Mani-SF11) at 300,000 rpm (NSK air turbine Japan).

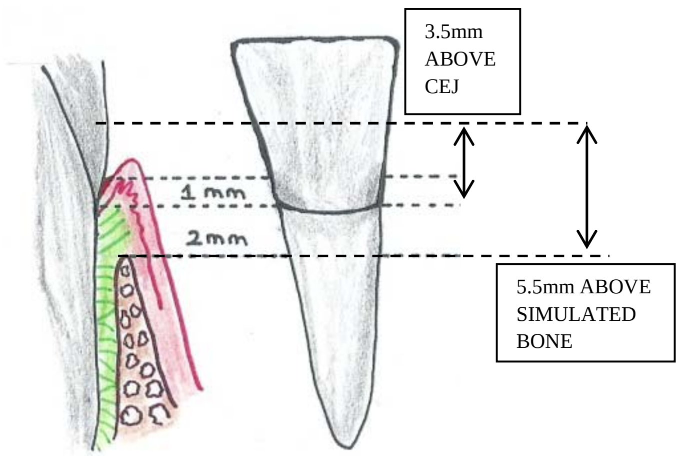


Diagram-1

2) ROOT CANAL PREPARATION AND OBTURATION.

Each canal was prepared to within 1mm of apex with a standard master apical file #25 (Mani, Japan).Master apical files of 3 larger sizes #30, #35, #40 were used for further preparation of the canal [103]. The root canal of each tooth was instrumented with a conventional step back technique. The canals were irrigated with 2.5% sodium hypochlorite solution throughout the preparation followed by normal saline and dried with paper points [7, 81.] Non eugenol sealer (Apexit plus, Ivoclar Vivadent AG, Liechtenstein) was picked up with a lentulo spiral and then used to spin Apexit up the canal to the apical area. Subsequently, the root canal was filled in a conventional manner using gutta-percha points. Each canal was obturated by lateral condensation using gutta percha points (Dentsply, China). The setting time of Apexit Plus is between three and five hours so insertion of endodontic FRC (Fiber reinforced composite) post was done 24 hours following root canal obturation (Diagram-2, Fig-2).

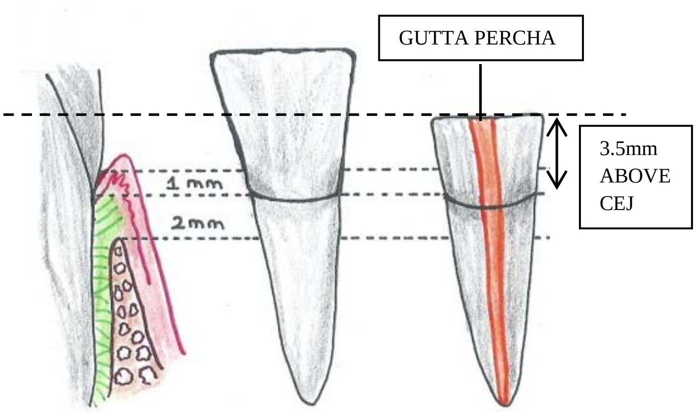


Diagram-2

3) POST SPACE PREPARATION.

FRC Postec Plus size 1(Ivoclar Vivadent AG, Liechtenstein. 590222 AN) suitable for the tooth to be restored was selected (Fig-3). Post space preparation was carried out by Peeso reamer attached with silicon stoppers to maintain 4mm of apical seal [59.] The radicular extension of the post space corresponded to, or was more than, the coronal length of the prosthetic restoration [100]. The root canal filling was removed with Peeso reamer (size 2) at 1000 - 5000 rpm (NSK hand piece) down to the specified depth and rinsed with 3 % H_2O_2 followed by normal saline. The final post space of all 40 samples was prepared using the drill supplied by the manufacturer. For this procedure FRC Postec plus ReamerX, Size 1 [63, 64, 75] (Ivoclar Vivadent AG, Schaan/Liechtenstein, 572801 AN) was used (Diagram-3, Fig-4).

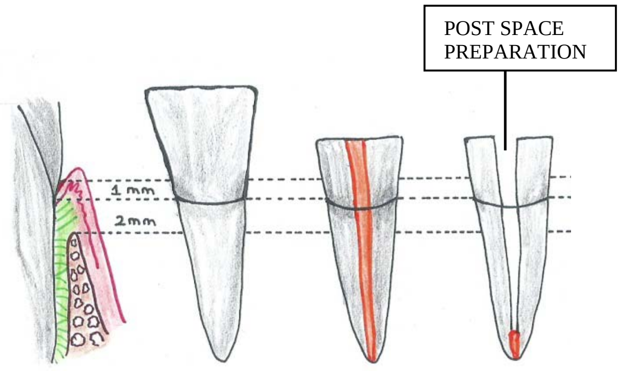


Diagram-3

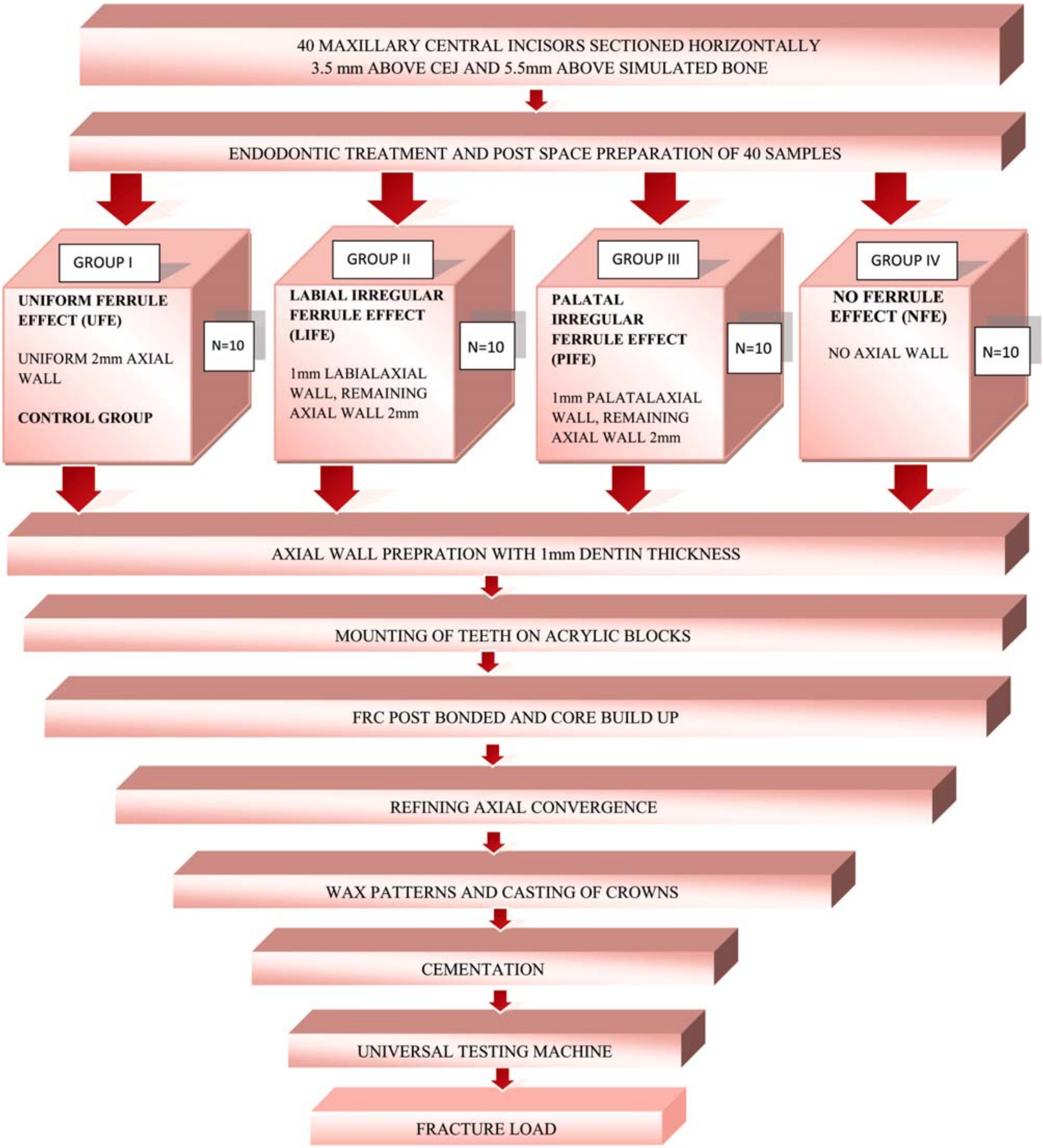
4) GROUPING OF SAMPLES.

Maximum and minimum root length and root size of 40 specimens was measured and randomly distributed into 4 test groups of 10 teeth each (Table-4).

TABLE 4

Test group	Ferrule design	n	Root length [mm] median (min / max)	Root size [mm^2] median (min / max)
I (Control Group)	Uniform ferrule effect (UFE)	10	12.33 (11.54/12.85)	42.35 (39.37/46.58)
II	Labial irregular ferrule effect (LIFE)	10	12.51 (11.62/12.85)	43.94 (40.33/49.77)
III	Palatal irregular ferrule effect (PIFE)	10	12.29 (11.89/12.75)	45.08 (40.32/50.84)
IV	No ferrule effect (NFE)	10	11.91 (11.04/12.95)	55.80 (46.27/59.90)

Study design flow chart.



5) AXIAL WALL PREPARATION FOR GROUPS.

Group I (Control group) - Uniform ferrule effect (UFE).

CEJ was marked. The tooth preparation for this group (10 teeth) was done by using high speed airotor hand piece (NSK) with flat end cylindrical diamond point (Mani SF11) 1.5 mm above CEJ to produce uniform axial wall of 2 mm length and 1mm width [63,64,80,82], with a shoulder finish line (Diagram-4, Fig 5, 6, 7).

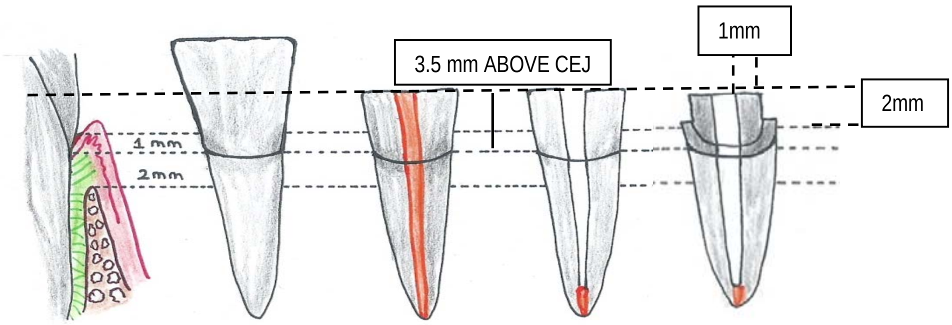


Diagram-4

Group II-Labially irregular ferrule effect (LIFE).

The teeth (10 samples) were prepared similar to Group I. Following this, labial axial wall length alone was reduced by 1mm. This created irregular 1 mm long labial axial wall and 2 mm long remaining axial walls(Diagram-5 and Fig 8, 9,10).

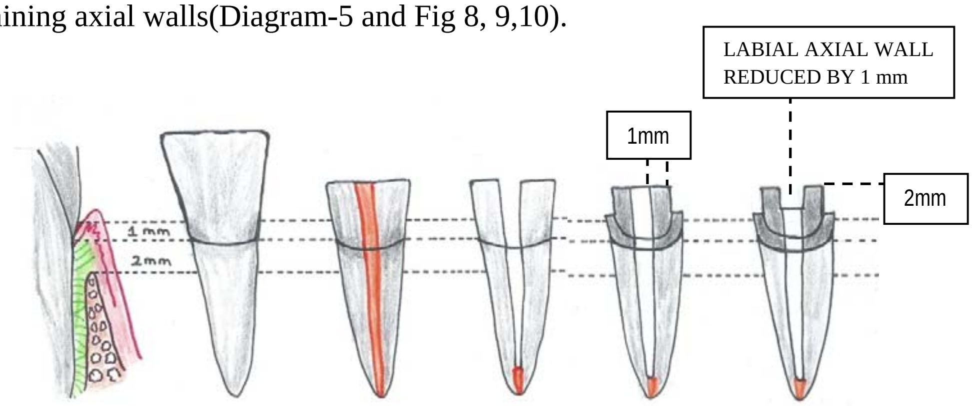


Diagram-5

Group III-Palatal irregular ferrule effect (PIFE).

The teeth (10 samples) were prepared similar to Group I and then only palatal axial wall was reduced by 1mm. This created irregular 1 mm long palatal axial wall and 2 mm long remaining axial walls(Diagram-6 and Fig 11,12,13).

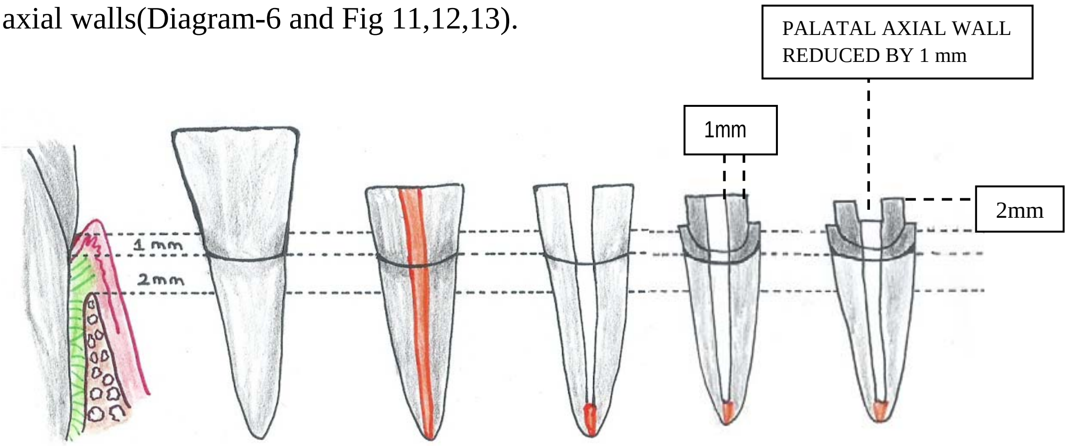


Diagram-6

Group IV- No ferrule effect (NFE).

The coronal portion was removed 1.5mm above the CEJ perpendicular to the long axis of the tooth by using high speed airotor hand piece (NSK) with flat end cylindrical diamond point (Mani SF11). No coronal dentine was remaining 1.5mm above CEJ. 10 teeth were prepared this way [63, 64,80] (Diagram-7, Fig 14, 15, 16).

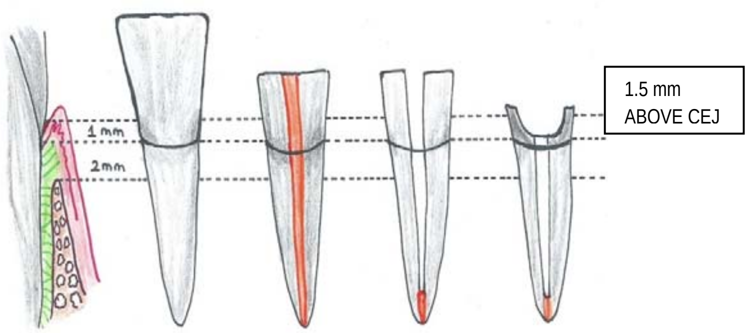
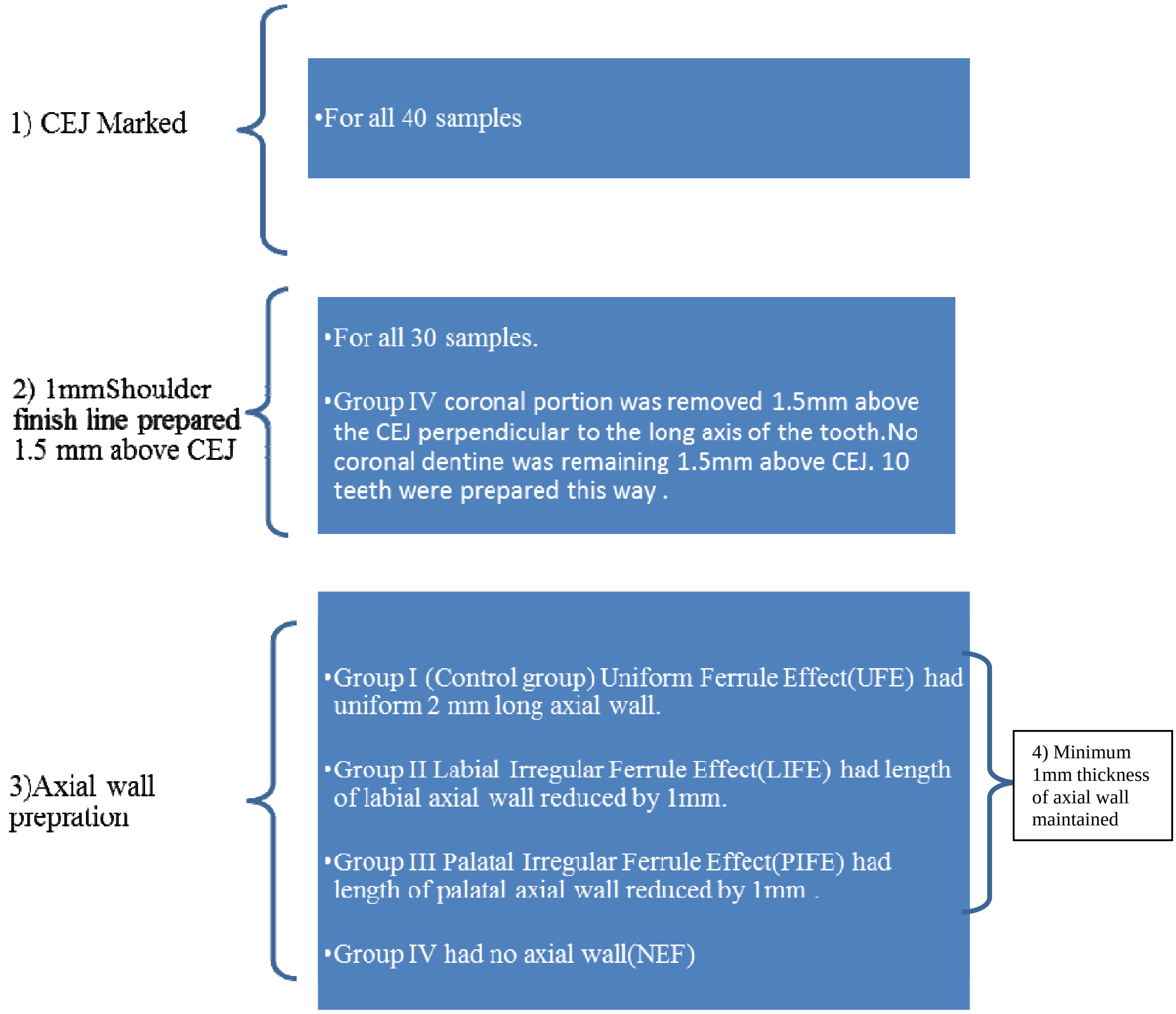


Diagram-4

Flow chart for axial wall preparation



The axial wall dimensions were standardized by periodontal probe (GDC-AC-002-W) and digital vernier caliper. All teeth samples were prepared free hand under 2x magnifications by the same operator.

6) MOUNTING OF TEETH ON ACRYLIC BLOCKS.

The root surface of the tooth was marked 2 mm below the CEJ and covered with 0.12 mm thick Aluminium foil. FRC post was placed into the post space of the tooth to be mounted by friction fit. The post and the tooth were suspended from the surveying arm of Ney's surveyor. Glass slab was oriented perpendicular to surveying rod. Stainless steel cylindrical mold(1inch x 1 inch) filled with autopolymerising resin was placed on glass slab such that the tooth sample held by the surveying arm was centered in stainless steel ring(Fig 17,18,19).

The surveying arm was lowered into resin. The entire root was embedded into the resin except for 2mm below CEJ. This simulated the bone level [85]. The tooth sample was placed in cool water bath during polymerization of resin (Fig-20, 21).

After the first signs of polymerization, tooth sample was removed from the resin block. Aluminium foil spacers were removed from the root surface. Light body polyvinyl siloxane (PVS) impression material was injected in to the acrylic resin blocks and teeth were reinserted into the resin blocks (Diagram-8 and Fig 22).

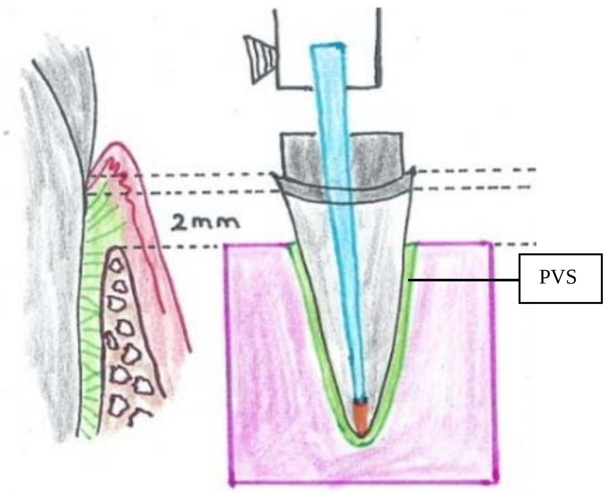


Diagram-8

A standardized silicone layer was formed over root surface to simulate periodontal ligament. In this manner mounting for the remaining samples was completed [1, 52, 66] .

7) BONDING FRC POST AND CORE BUILDUP.

FRC post was bonded to post space by direct method under following steps.

a) Try-in and conditioning of FRC Postec Plus.

Proper fit of the post was checked. After determining the coronal length the post was shortened using rotary diamond grinders. Then post was etched with phosphoric acid etching gel (Total Etch) for 60 seconds. FRC Postec Plus post was thoroughly rinsed with water and dried. After silanateing the post (Monobond-S) for 60 seconds, it was carefully dried with an air syringe. Care was taken so as not to touch the surface with fingers after that (Fig-23).

b) Conditioning of post space.

Phosphoric acid gel (Total Etch) was applied to the prepared post space and axial walls of tooth. The etchant should be left to react for 10-15 seconds. Following this, the etchant was thoroughly removed with a vigorous water spray for at least 5 seconds. Excess moisture was removed leaving the surface with a glossy wet appearance (wet bonding). This can be done with paper points. Care was taken so as to not over dry the dentine.

c) Adhesive cementation of post with a dual curing composite.

- ExciTE F DSC (contains HEMA, dimethacrylate, phosphonic acid acrylate, dispersed silicone dioxide, initiators, stabilizers and potassium fluoride in an alcohol solution) was applied to the enamel and dentin and agitated for 10 sec making sure that all prepared walls are completely covered.

- The components of MultiCore Flow was mixed and applied to the post. The post was seated into the root canal and held in place using slight pressure.

– Light-curing for 60 seconds from the occlusal aspect using a curing unit with a light intensity more than 400 mW/cm^2 was done. The light emission window was positioned as close to the post as possible (Fig 24).

d) Core build-up using MultiCore Flow.

Multicore Flow was applied directly on top of post and axial walls and core built up was done to achieve an axial wall height of 4mm. That is 2mm of axial wall and 2mm of Multi flow core [76, 81] (Fig 25). The material was light-cured; and ground immediately after completing the curing cycle. The distance between the light emission window and the occlusal surface was kept at a minimum. Further curing was done for 40 seconds. Radiographs were taken to ensure correct placement of post [59, 71] (4mm above apex) (Fig26).

RECAP-

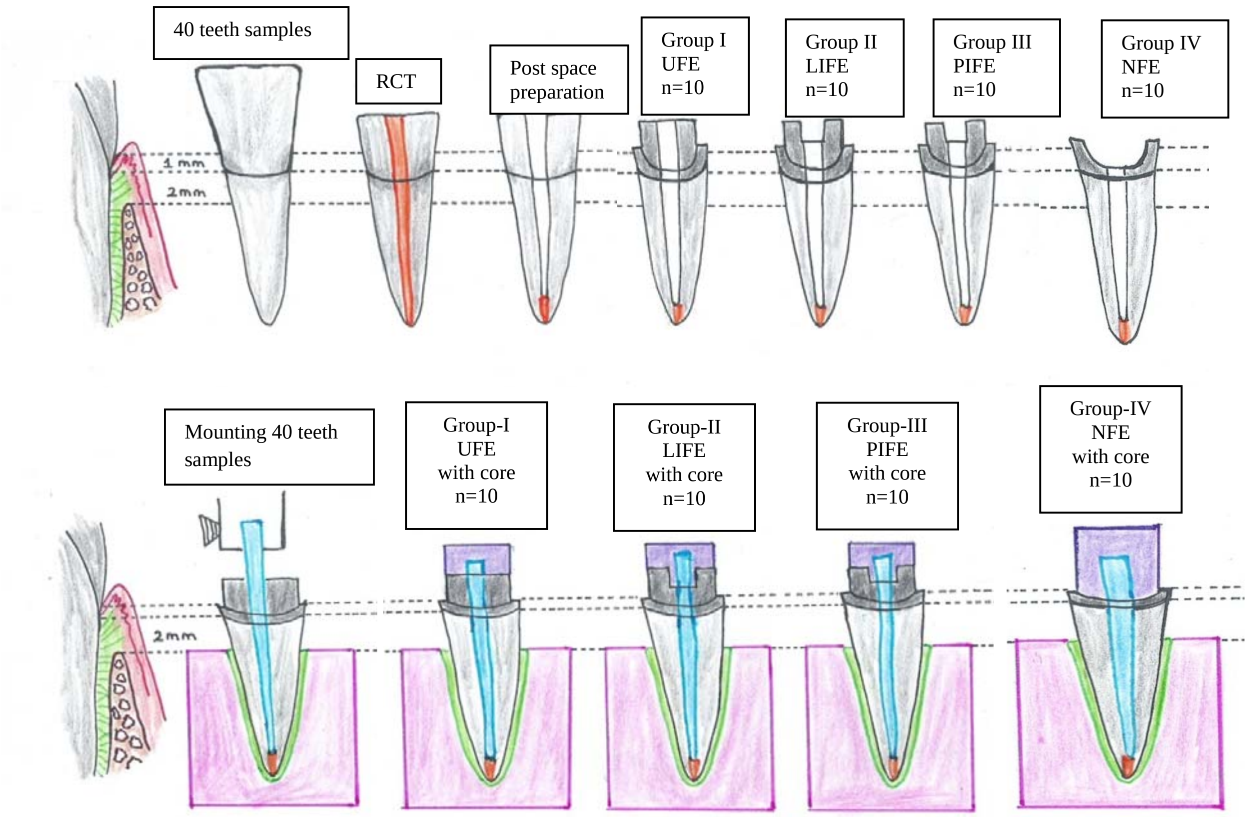


Diagram-9

8) REFINING AXIAL CONVERGENCE.

A jig was fabricated to hold airotor to Ney's surveyor so that long axis of bur parallels to the long axis of surveyor arm (Diagram-10).

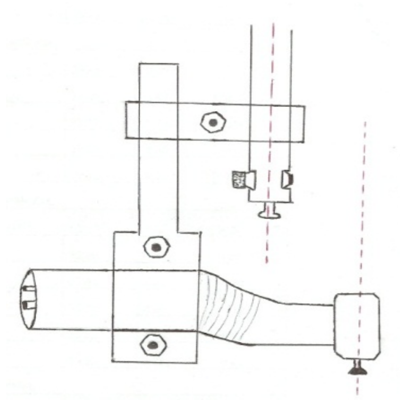


Diagram-10

Mounted specimen was refined to provide uniform axial convergence. A bur (Mani SF11) was fitted to airotor and specimen was refined so as to provide parallel walls (Fig 27, 28). 40 specimens were refined in this manner (Fig 29).

9) WAX PATTERN FABRICATION.

Wax patterns for the crowns were formed directly on tooth specimens coated with die spacer (Pico fit, Renfert) 12 to 15 micron thickness and a lubricant (Iso-Stift,Renfert) was applied(Figure-30). Wax patterns (Geo classic, Renfert) were formed using a vinyl polysiloxane impression material (Putty 3M) mold made from one natural tooth (Fig 31, 32, 33).This mold was used in fabricating all wax crown patterns. A standardized notch was placed across the palatal surface of each crown 3 mm from the incisal edge. This notch was carved into the wax patterns to accommodate the loading device of the universal testing machine, which has a blade-shaped configuration with a straight flat surface shaped to simulate the incisal edge of a mandibular incisor [63,80].

10) INVESTING AND CASTING

The wax patterns were sprued, debubblizer applied and invested in high expansion phosphate-bonded investment material (Bellavest SH,Bego ,Germany) and cast using non-precious metal alloy free of nickel and beryllium (Wirobond 280, Bego,Germany). Casting was sand blasted and sprues sectioned with carborundum disc. Cast crowns were adjusted with fit checker until they were fully passively seated [63] (Fig 34, 35).

11) CEMENTATION

The cast crowns were cemented with glass ionomer luting cement (Meron, Voco, Germany) under 20 newton's of load for 10 min [63,81] (Fig36, 37). Excess cement was removed and 40 samples (Fig 38) were stored in 100% humidity at room temperature for 30 days before testing [80].

12) TESTING OF SPECIMENS.

Each sample was placed in a testing Jig which angulates the samples to 135° for testing fracture resistance (Fig 39, 40). A universal testing machine with load cell having maximum capacity of 1000N(Instron 3382, London, UK) was used to apply a compressive load to tooth specimens with a cross head speed of 1mm/min at an angle of 135° using angulated testing jig to the long axis of teeth,until fracture occurred (Fig 41,42) [2, 80, 63].

Labially inclined compressive force was applied to the notch on the palatal surface of the crowns simulating the load applied by mandibular incisor. Force data applied over time was recorded . The fracture of the specimen was determined when the force versus time graph showed abrupt change in load,indicating a sudden decrease in the specimens resistance to compressive loading.Specimens were visually examined for the type , location and direction of fracture.

FIGURES

SELECTION OF TEETH

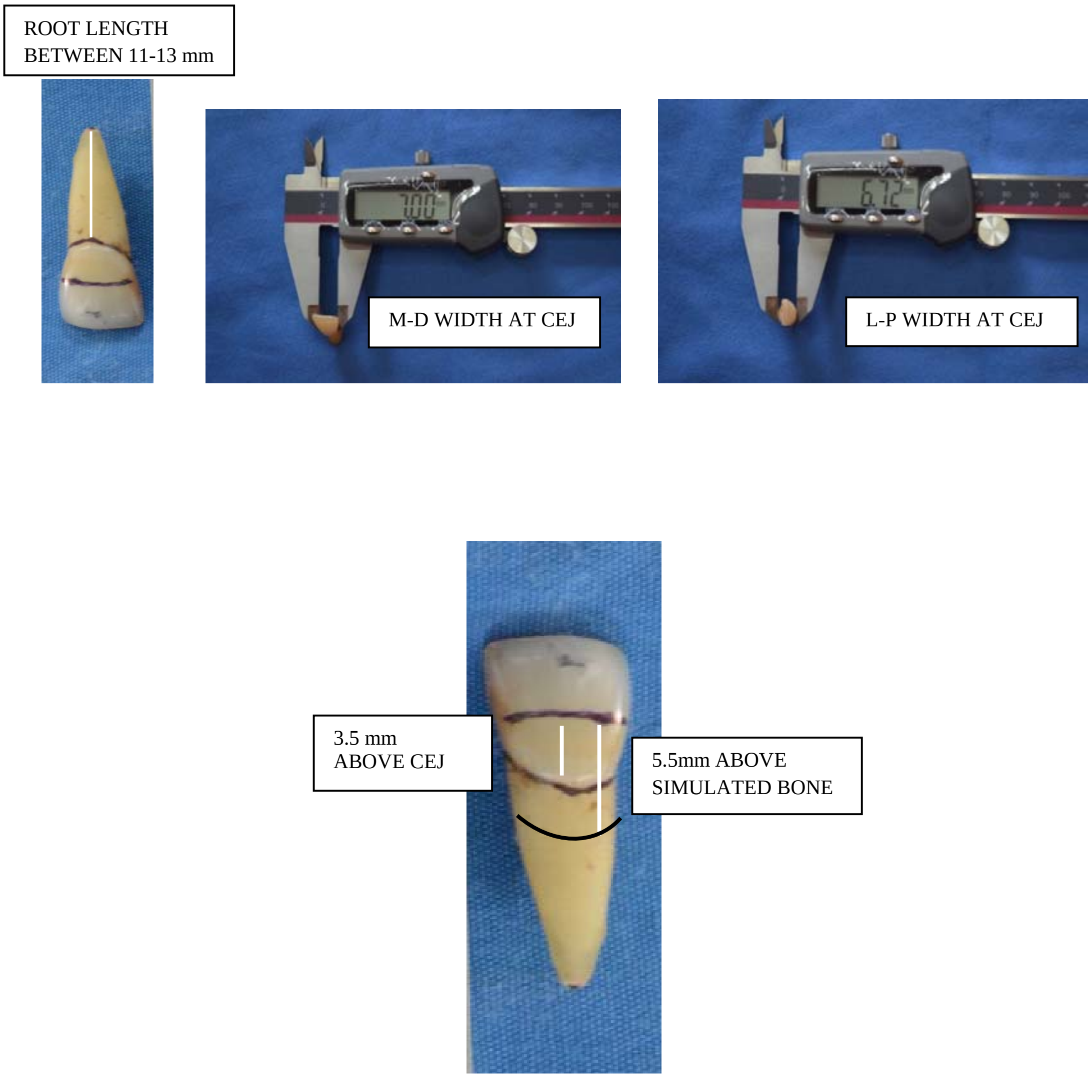


Fig-1

ARMAMENTARIUM FOR ROOT CANAL PREPARATION AND OBTURATION

Fig-2

POST SPACE PREPARATION

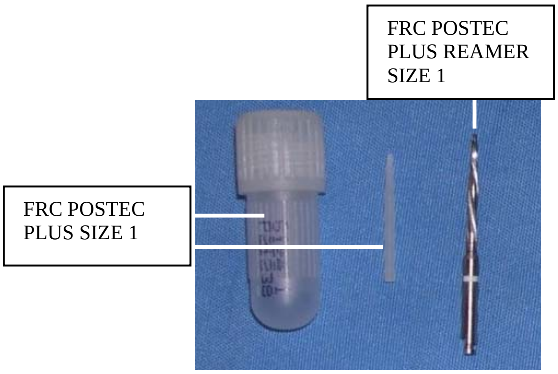


Fig-3

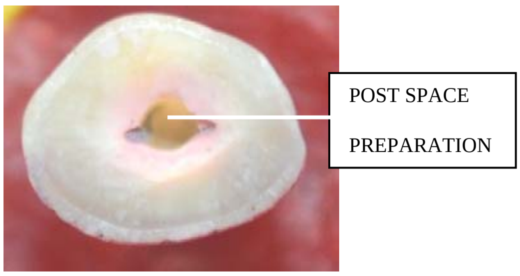


Fig-4

AXIAL WALL PREPARATION FOR GROUPS

Group I (Control Group) - Uniform ferrule effect (UFE).

Fig-5

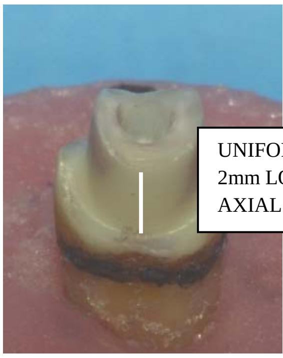


Fig-6

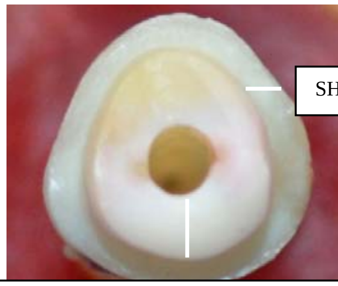


Fig-7

Group II-Labially irregular ferrule effect (LIFE).

Fig-8

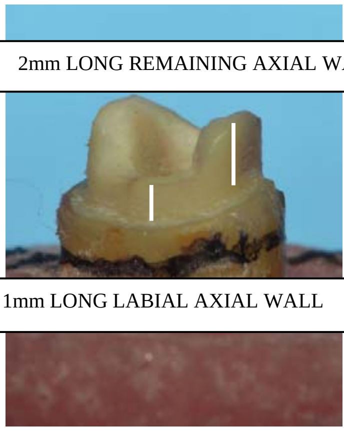


Fig-9

Fig-10

Group III-Palatal irregular ferrule effect (PIFE).

Fig-11

Fig-12

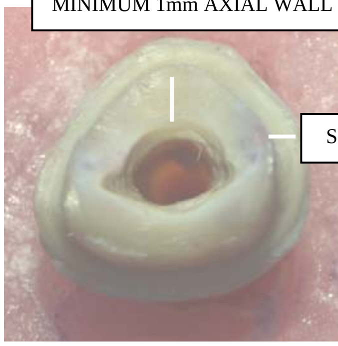


Fig-13

Group IV- No ferrule effect (NFE).

Fig-14

Fig-15

Fig-16

MOUNTING OF TEETH ON ACRYLIC BLOCKS.

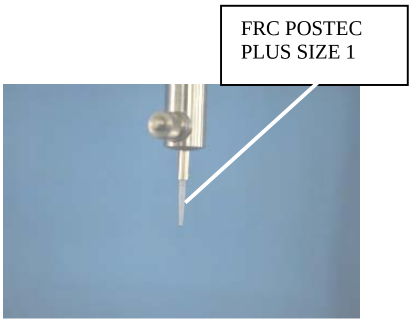


Fig-17

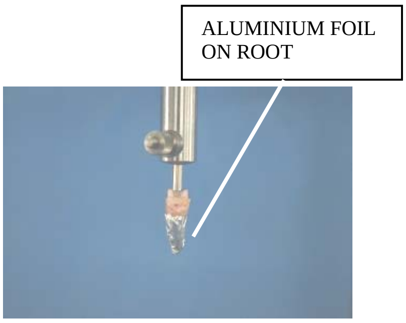


Fig-18

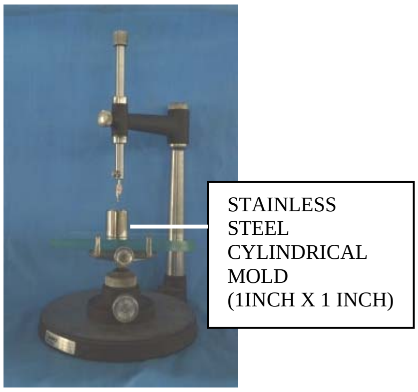


Fig-19

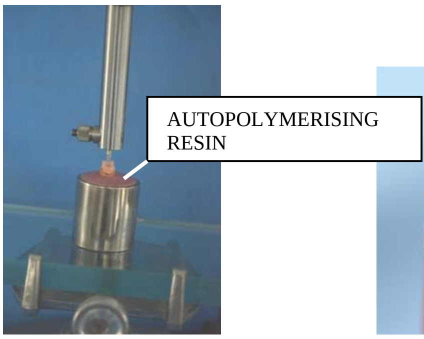


Fig-20

Fig-21

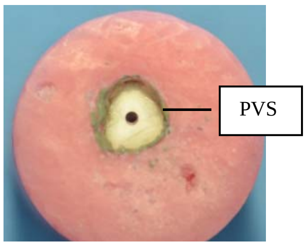


Fig-22

BONDING FRC POST AND CORE BUILDUP.

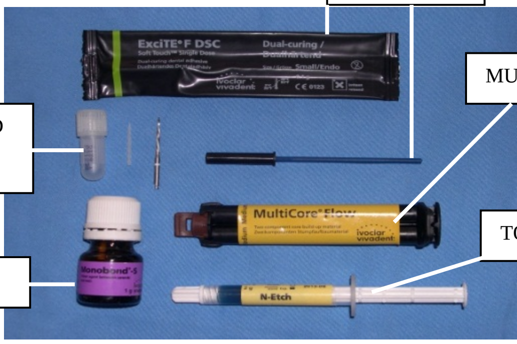


Fig-23

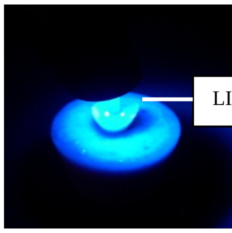


Fig-24

BUILT UP OF 4mm AXIAL WALL

(2mm dentinal wall +2mm Multiflow core wall for Group I, II, III and Group IV had 4 mm Multiflow core axial wall).

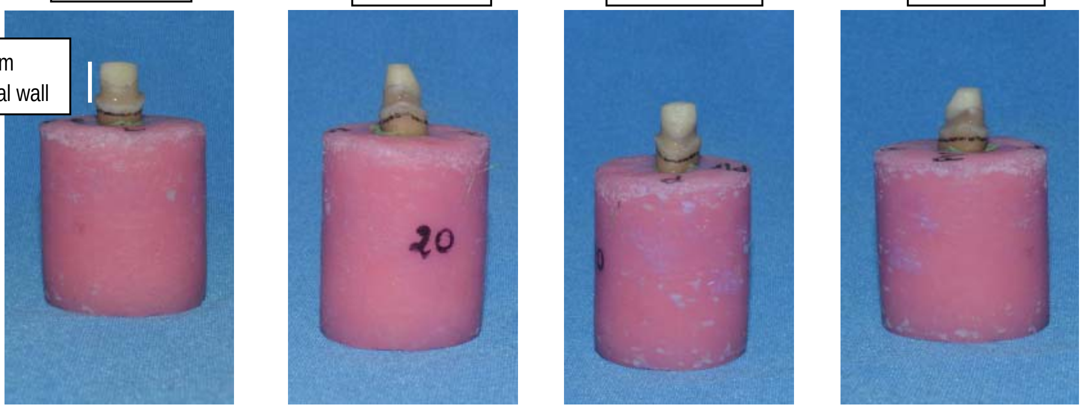


Fig-25

RADIOGRAPH.

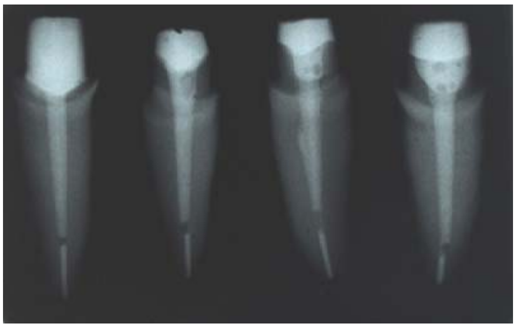


Fig-26

REFINING AXIAL CONVERGENCE.

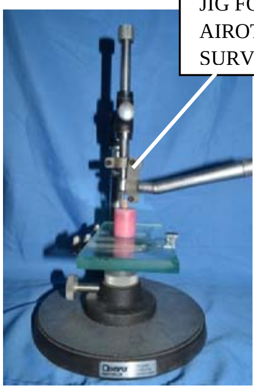


Fig-27

Fig-28

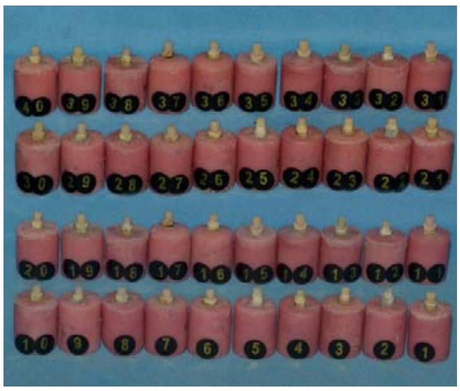


Fig-29

WAX PATTERN FABRICATION.

DIE SPACER

Fig-30

PUTTY INDEX

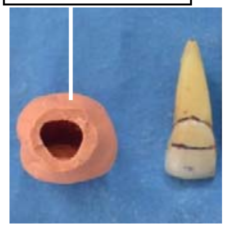


Fig-31

WAX PATTERN
LABIAL SURFACE

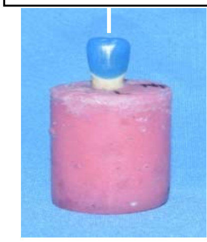


Fig-32

WAX PATTERN
PALATAL SURFACE

NOTCH

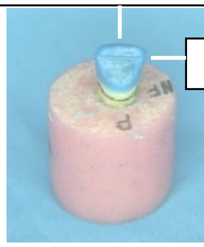


Fig-33

INVESTING AND CASTING

LABIAL

Fig-34

PALATAL

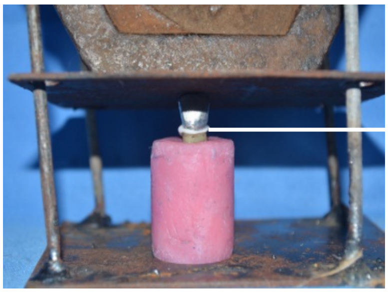
NOTCH

Fig-35

CEMENTATION

JIG FOR CEMENTATION WITH 2Kg WEIGHT

Fig-36



EXCESS CEMENT

Fig-37

40 TEETH SAMPLES

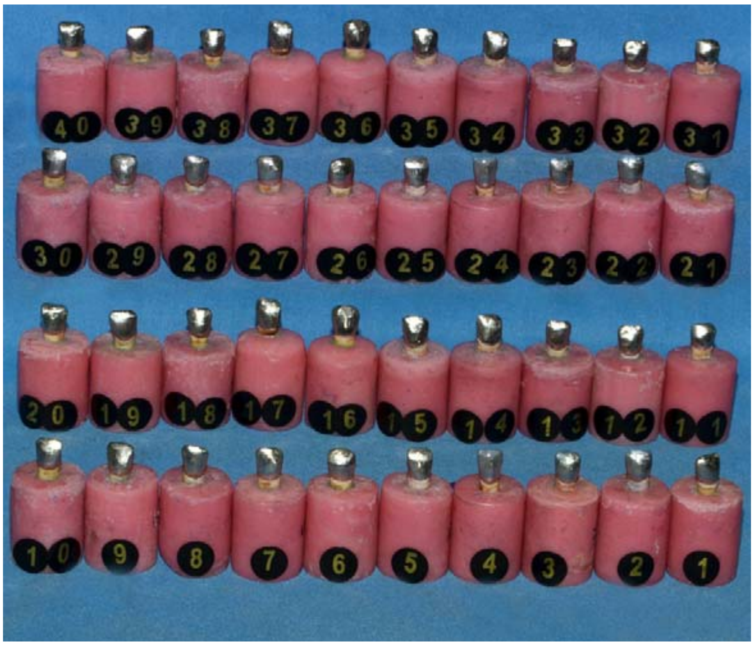


Fig-38

TESTING OF SPECIMENS

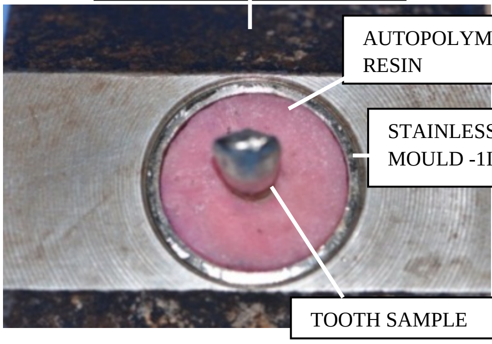


Fig-39

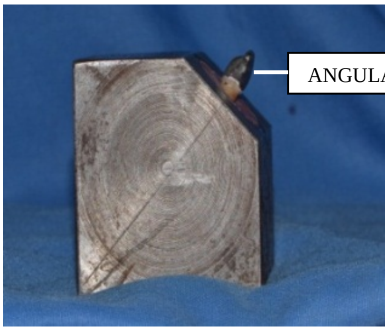


Fig-40

Fig-41

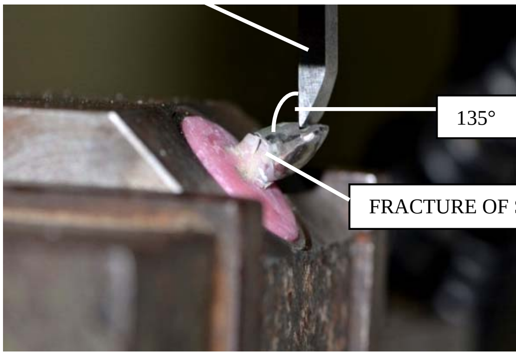


Fig-42

RESULT

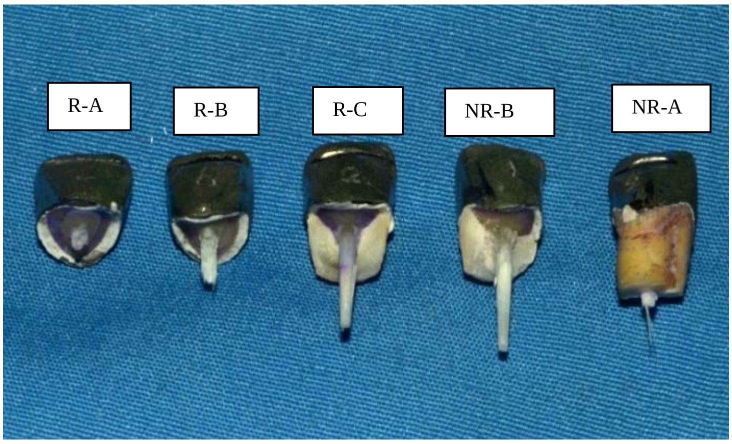


Fig-43

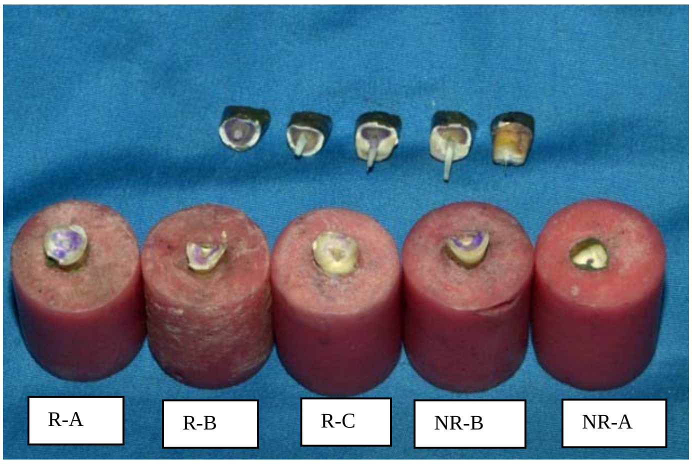


Fig-44

RESULT

RESULT

This study was conducted

1} To compare fracture resistance of endodontically treated teeth, with and without ferrule effect.

2} To compare fracture resistance of endodontically treated teeth having uniform 2mm ferrule effect with non-uniform ferrule effect.

3} To compare fracture resistance of endodontically treated teeth having nonuniform palatal and nonuniform labial ferrule effect.

All the 40 samples were tested with universal testing machine at a cross-head speed of 1 mm/min with the load applied at 135°using the specimen holder. The stainless-steel stylus was shaped to mimic mandibular incisor and was used to test failure resistance and failure load was recorded in Newton’s (N).

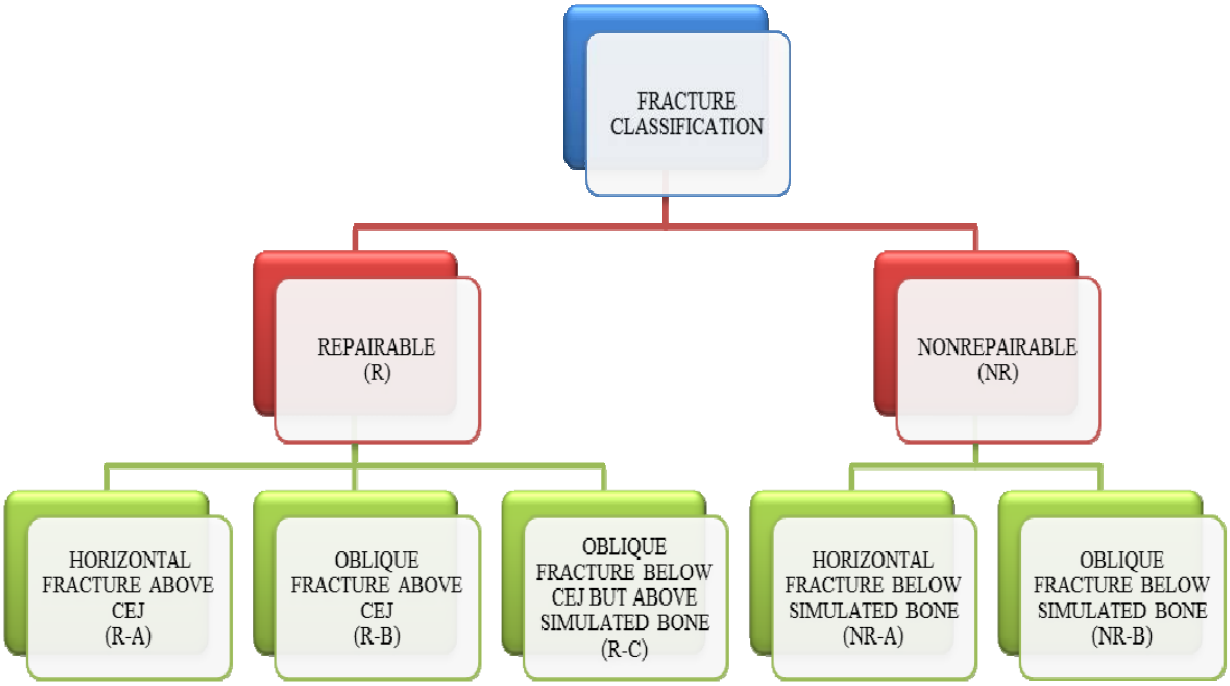
Failures that occurred under fracture testing were classified into repairable and non-repairable in relation to simulated bone. When fracture occurs below simulated bone the remaining apical fragment cannot be used for prosthetic reconstruction and considered non-repairable. In fracture occurring above simulated bone the remaining apical fragment could be used for reconstruction after orthodontic extrusion or by crown lengthening, hence considered repairable.

I - Repairable (including tooth fractures and adhesive failures of the core) when the fracture line was above the simulated bone level (Fig 43 and 44).

- Repairable horizontal fracture above CEJ (R-A).
- Repairable oblique fracture above CEJ (R-B).
- Repairable oblique fracture below CEJ but above simulated bone(R-C).

II - Nonrepairable (including root fracture) when the fracture line was below the simulated bone level (Fig 43 and 44).

- Nonrepairable horizontal fracture below simulated bone (NR-A).
- Nonrepairable oblique fracture below simulated bone (NR-B).



Group II (LIFE) showed consistent R-C fracture with maximum mean compressive load of 657.34 N. The treatment modality of R-C fracture would be on the basis of length of apical fragment. Removal of crown fragment followed by orthodontic extrusion of apical fragment could be done [11]. The data from the results of this study is shown in table 5 to 9.

TABLE 5-FRACTURE RESISTANCE OF ENDODONTICALLY TREATED CENTRAL INCISOR WITH UNIFORM FERRULE EFFECT (UFE) GROUP-I.										
TOOTH NUMBER	**MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)**	**COMPRESSIVE STRENGTH Mpa**	**F-L WIDTH mm**	**M-D WIDTH mm**	**ROOT SIZE mm^2**	**ROOT LENGTH**	**FRACTURE – IN RELATION TO CEJ AND SIMULATED BONE**			
							LABIAL	**PALATAL**	**CLASSIFICATION**	**POST**
1	568.81	12.46	6.83	6.51	44.46	12.85	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
2	480.47	13.10	6.20	6.58	40.80	12.82	4mm BELOW CEJ	4mm BELOW CEJ	NR-B	BREAKAGE
3	561.12	12.05	6.84	6.81	46.58	12.70	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
4	621.98	15.46	6.45	6.24	40.25	11.54	3mm BELOW CEJ	4mm BELOW CEJ	NR-A	BREAKAGE
5	511.17	11.70	6.89	6.34	43.68	12.84	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
6	520.49	13.39	6.35	6.45	40.96	12.43	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	BREAKAGE
7	557.64	12.86	6.65	6.52	43.36	12.14	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
8	490.47	13.27	5.95	6.81	40.52	12.12	1.5 mm ABOVE CEJ	1 mm ABOVE CEJ	R-A	BREAKAGE
9	530.64	13.48	6.23	6.32	39.37	11.64	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
10	510.15	11.74	6.76	6.43	43.47	12.21	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-B	DEBONDING AND BREAKAGE
AVERAGE	**535.29**	**12.95**	**6.52**	**6.50**	**42.35**	**12.33**				

Tooth samples of UFE (Group-I) showed average maximum compressive load of 535.29 N and tooth fractures were mostly repairable 80 %(R). Non-repairable fracture (NR) was 20%.

TABLE 6 - FRACTURE RESISTANCE OF ENDODONTICALLY TREATED CENTRAL INCISOR WITH LABIAL IRREGULAR FERRULE EFFECT (LIFE) GROUP-II.										
TOOTH NUMBER	**MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)**	**COMPRESSIVE STRENGTH Mpa**	**F-L WIDTH mm**	**M-D WIDTH mm**	**ROOT SIZE mm^2**	**ROOT LENGTH**	**FRACTURE – IN RELATION TO CEJ AND SIMULATED BONE**			
							LABIAL	**PALATAL**	**CLASSIFICATION**	**POST**
11	584.82	12.63	6.70	6.91	46.30	12.57	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
12	731.38	16.80	6.21	7.01	43.53	12.67	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
13	708.14	16.53	7.32	5.85	42.82	11.62	2mm BELOW CEJ	1.5mm BELOW CEJ	R-C	DEBONDING AND BREAKAGE
14	638.59	15.83	6.12	6.59	40.33	12.46	2mm BELOW CEJ	1.5mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
15	573.24	14.21	6.13	6.58	40.34	12.72	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
16	690.44	16.60	6.32	6.58	41.59	12.51	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
17	625.29	14.74	6.23	6.81	42.43	12.80	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
18	720.56	15.34	6.73	6.98	46.98	12.43	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
19	710.54	14.28	6.98	7.13	49.77	12.45	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
20	590.49	13.03	6.53	6.94	45.32	12.85	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
AVERAGE	**657.34**	**15**	**6.53**	**6.74**	**43.94**	**12.51**				

Tooth samples of LIFE (Group-II) showed average maximum compressive load 657.34 N and all fractures were repairable (R) 100%.

TABLE 7 - FRACTURE RESISTANCE OF ENDODONTICALLY TREATED CENTRAL INCISOR WITH PALATAL IRREGULAR FERRULE EFFECT (PIFE) GROUP-III.										
TOOTH NUMBER	**MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)**	**COMPRESSIVE STRENGTH Mpa**	**F-L WIDTH mm**	**M-D WIDTH mm**	**ROOT SIZE mm^2**	**ROOT LENGTH**	**FRACTURE – IN RELATION TO CEJ AND SIMULATED BONE**			
							LABIAL	**PALATAL**	**CLASSIFICATION**	**POST**
21	300.36	5.91	7.39	6.88	50.84	12.19	3mm BELOW CEJ	3mm BELOW CEJ	NR-B	BREAKAGE
22	365.21	9.00	6.88	5.90	40.59	12.19	3mm BELOW CEJ	4mm BELOW CEJ	NR-A	BREAKAGE
23	473.11	10.05	6.66	7.07	47.09	12.53	4mm BELOW CEJ	1mm ABOVE CEJ	NR-B	DEBONDING AND BREAKAGE
24	486.04	1O.74	6.56	6.90	45.26	12.75	3mm BELOW CEJ	5mm BELOW CEJ	NR-B	BREAKAGE
25	684.77	15.80	6.77	6.40	43.33	12.06	3mm BELOW CEJ	4mm BELOW CEJ	NR-A	DEBONDING AND BREAKAGE
26	350.46	7.56	6.73	6.89	46.37	11.98	3mm BELOW CEJ	5mm BELOW CEJ	NR-B	BREAKAGE
27	370.44	8.87	6.78	6.16	41.76	12.26	3mm BELOW CEJ	4mm BELOW CEJ	NR-A	BREAKAGE
28	420.54	8.48	6.86	7.23	49.60	12.64	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
29	320.14	8.07	6.32	6.38	40.32	11.89	3mm BELOW CEJ	3mm BELOW CEJ	NR-B	BREAKAGE
30	490.94	10.76	6.87	6.64	45.62	12.36	3mm BELOW CEJ	4mm BELOW CEJ	NR-A	BREAKAGE
AVERAGE	**426.20**	**9.52**	**6.78**	**6.65**	**45.08**	**12.29**				

Tooth samples of PIFE (Group-III) showed average maximum compressive load of 426.20 N and most fractures were nonrepairable (NR) 90%.Repairable fracture (R) was10%.

TABLE 8 - FRACTURE RESISTANCE OF ENDODONTICALLY TREATED CENTRAL INCISOR WITH NO FERRULE EFFECT (NFE) GROUP-IV.										
TOOTH NUMBER	**MAXIMUM COMPRESSIVE LOAD (NEWTONS -N)**	**COMPRESSIVE STRENGTH Mpa**	**F-L WIDTH mm**	**M-D WIDTH mm**	**ROOT SIZE mm^2**	**ROOT LENGTH mm**	**FRACTURE – IN RELATION TO CEJ AND SIMULATED BONE**			
							LABIAL	**PALATAL**	**CLASSIFICATION**	**POST**
31	350.15	5.72	7.32	8.04	58.85	11.99	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
32	446.11	7.58	7.15	8.23	58.84	12.46	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
33	828.04	15.12	7.01	7.81	54.75	12.95	3mm BELOW CEJ	4mm BELOW CEJ	NR-H	BREAKAGE
34	251.15	4.13	7.34	8.06	59.16	11.41	1.5 mm ABOVE CEJ	1.5 mm ABOVE CEJ	R-B	BREAKAGE
35	297.92	6.44	6.60	7.01	46.27	12.45	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
36	270.25	5.14	6.95	7.56	52.54	11.04	1.5 mm ABOVE CEJ	1 mm ABOVE CEJ	R-A	BREAKAGE
37	300.15	4.86	7.23	8.12	58.71	12.36	1.5 mm ABOVE CEJ	1.5 mm ABOVE CEJ	R-B	DEBONDING AND BREAKAGE
38	340.67	5.69	7.35	8.15	59.90	12.05	2mm BELOW CEJ	1.5 mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
39	280.81	5.66	6.84	7.25	49.59	11.13	1mm BELOW CEJ	1.5mm ABOVE CEJ	R-C	DEBONDING AND BREAKAGE
40	260.75	4.21	7.12	8.34	59.38	11.25	1.5 mm ABOVE CEJ	1 mm ABOVE CEJ	R-A	BREAKAGE
AVERAGE	**362.6**	**6.46**	**7.09**	**7.85**	**55.8**	**11.91**				

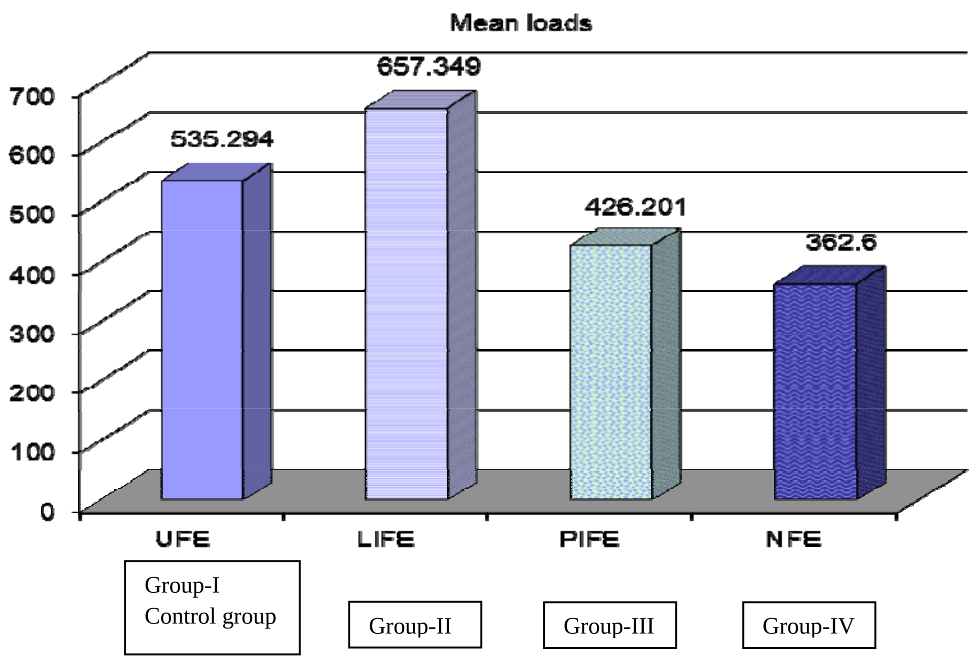
Test samples with NFE (Group-IV) showed average maximum compressive load of 362.6 N and most tooth fracture were repairable (R) 90%.Non repairable fracture (NR) was 10%.

The average maximum compressive load and fracture classification are as follows.

TABLE-9

GROUP I to IV	AVERAGE MAXIMUM COMPRESSIVE LOAD (N)	PREDOMINANT FRACTURE TYPE
GROUP I -UNIFORM FERRULE EFFECT (UFE)	535.29	REPAIRABLE
GROUP II-LABIAL IRREGULAR FERRULE EFFECT (LIFE)	657.34	REPAIRABLE
GROUP III-PALATAL IRREGULAR FERRULE EFFECT (PIFE)	426.20	NON REPAIRABLE
GROUP IV-NO FERRULE EFFECT (NFE)	362.6	REPAIRABLE

GRAPH-2



STATISTICAL ANALYSIS

From the results obtained, the mean values were calculated. These results were subjected to statistical analysis to test the study hypothesis.

NULL HYPOTHESIS-

There is no significant difference in fracture resistance between UFE (Control group), NFE, LIFE, PIFE based on mean compressive loading.

ALTERNATE HYPOTHESIS-

There is significant difference between the four groups based on mean loading

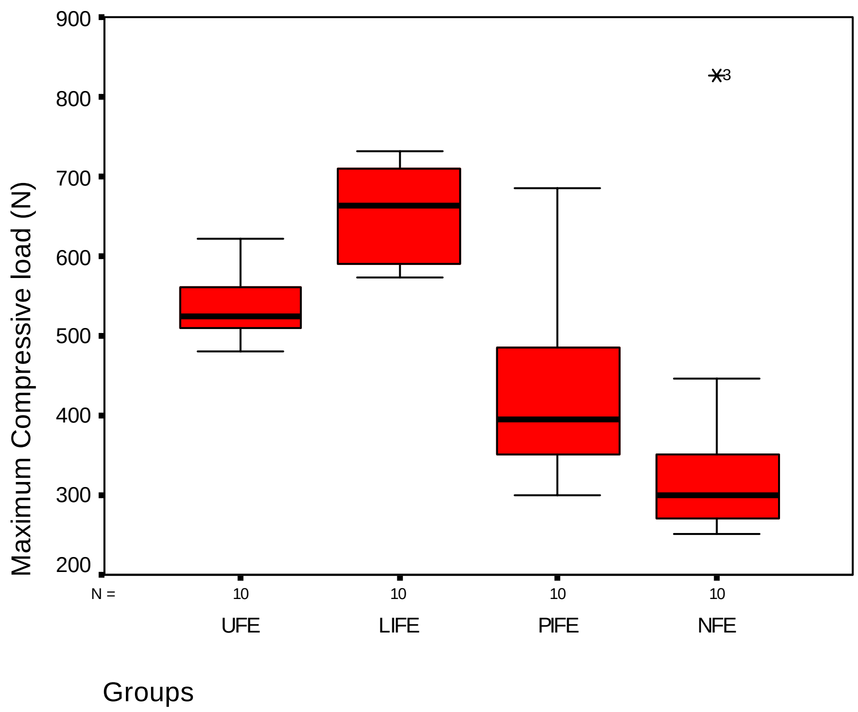
TABLE 10 -DESCRIPTIVE TABLE

TABLE 10-DESCRIPTIVES									
		Mean		95% Confidence Interval for Mean		5% Trimmed Mean	Std. Deviation	Minimum	Maximum
				Lower Bound	Upper Bound				
	TYPE	Statistic	Std. Error	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)	UNIFORM FERRULE EFFECT(UFE) CONTROL GROUP	535.2940	13.44701	504.8748	565.7132	533.5239	42.52317	480.47	621.98
	LABIAL IRREGULAR FERRULE EFFECT(LIFE)	657.3490	19.48356	613.2741	701.4239	657.9089	61.61243	573.24	731.38
	PALATAL IRREGULAR FERRULE EFFECT(PIFE)	426.2010	35.98040	344.8077	507.5943	418.8272	113.78003	300.36	684.77
	NO FERRULE EFFECT(NFE)	362.6000	54.80677	238.6185	486.5815	342.9339	173.31423	251.15	828.04

MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)

Since the standard deviation is lower for UFE (42.52) and LIFE (61.61) and more for NFE (173.31) and PIFE (113.78) the observations may vary in broader interval for NEF and PIFE, but for LIFE and UFE it varies moderately.

GRAPH 3- BOX PLOT COMPARISON OF DISTRIBUTION OF FOUR GROUPS UFE, LIFE, PIFE and NFE



But the trimmed mean value of UFE(533.52), NFE(342.93) , LIFE(657.90) ,PIFE(418.82) is close to their respective estimated mean values, so the experiment is not affected by extreme values within group.

One way Anova and Tukey HSD tests (t-test) were done.

One-way analysis of variance (ANOVA) tests is used to compare more than two groups based on their average scores. The total variations among the observations are split between groups' variations and within group variations, and the comparison is made. If the between group variation is considerably larger than within group variation, then there is a statistical significance for mean differences.

TABLE 11-ANOVA FOR

MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)

TABLE 11-ANOVA MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)					
	Sum of Squares	df	Mean Square	F	Sig. p
Between Groups	502433.454	3	167477.818	13.788	.000
Within Groups	437292.260	36	12147.007		
Total	939725.714	39			

Statistical inference (From Table 11) -

Since p value is less than 0.01 (1% level of significance), the null hypothesis is proven wrong and the test favors alternative hypothesis that there is significant difference between the four groups based on mean loading.

In ANOVA when the null hypothesis is rejected, conclusion is that all group means are not equal. But the test does not indicate the comparative equality of pairs of means. Therefore Post Hoc tests are applied.

Tukey's Honesty Significant Difference (HSD) is one among the post –hoc test methods to do multiple pairwise comparisons. If the difference between two group's means is considerably bigger than the general variation, then it is inferred that there is a significant difference.

Since there is a significant difference among groups, Tukey's HSD (Post-hoc) test is employed to compare the groups pairwise based on mean values. The t statistic values and p values are given in Table 12.

TABLE 12-TUKEY HSD TESTS

Table 12-Multiple Comparisons
Dependent Variable: MAXIMUM COMPRESSIVE LOAD (NEWTONS-N)
Tukey HSD

(I) TYPE	(J) TYPE	Mean Difference (I-J)	Std. Error	p
UNIFORM FERRULE EFFECT (UFE / GROUP-I)	NFE	172.6940**(*)**	49.28896	.007
	LIFE	-122.0550(#)	49.28896	.081
	PIFE	109.0930	49.28896	.139
LABIAL IRREGULAR FERRULE EFFECT (LIFE /GROUP-II)	NFE	294.7490**(*)**	49.28896	.000
	UFE	122.0550(#)	49.28896	.081
	PIFE	231.1480**(*)**	49.28896	.000
PALATAL IRREGULAR FERRULE EFFECT (PIFE / GROUP III)	NFE	63.6010	49.28896	.575
	UFE	-109.0930	49.28896	.139
	LIFE	-231.1480**(*)**	49.28896	.000
NO FERRULE EFFECT (NFE / GROUP IV)	UFE	-172.6940**(*)**	49.28896	.007
	LIFE	-294.7490**(*)**	49.28896	.000
	PIFE	-63.6010	49.28896	.575

* The mean difference is significant at the 0 .05 level (5%).

#The mean difference is significant at 0.10 level (10%).

Since most of the p value in Table 12 is less than 10% and 5%, the null hypothesis is proven wrong. The results favour alternative hypothesis.

This infers that with regard to fracture resistance

1) UFE is statistically significant from NFE by 5% (p0.007) and LIFE by10 %(p 0.081)

2) LIFE is statistically significant from NFE by 1 %(p 0.000), PIFE by1 %(p 0.000) and UFE by10% (p 0.081).

3) PIFE is statistically significant from LIFE by 1% (p0.000).

4) NFE is statistically significant from UFE by 5% (p 0.007) and LIFE by 1 %(p 0.000).

DISCUSSION

DISCUSSION

Restoring endodontically treated maxillary central incisor is a complex procedure because of multifactorial ramifications. The condition of the tooth and occlusal forces acting on it along with a wide array of materials available to restore usually puzzles the treatment modality. Preservation of tooth tissue, presence of a ferrule effect, and adhesion are regarded as the most effective conditions for long-term success of post-endodontic restorations [32].

This study aims at comparing uniform ferrule effect (2mm axial wall) with irregular ferrule effect (1mm labial axial wall or 1mm palatal axial wall) and no ferrule effect (absence of axial wall).

In order to prosthodontically restore endodontically treated maxillary central incisors, 2 parameters should be considered;

Parameter 1 - Minimum tooth structure required to go ahead with restoration.

Parameter 2 - Ideal restorative materials.

Parameter 1- Minimum tooth structure required to go ahead with restoration.

Mc Lean [53] stated that for a tooth to be successfully restored there must be a minimum of 4.5 mm of solid tooth structure above the bone crest; given that a minimum of 2.5 mm is required for biologic width and 2 mm for an effective ferrule.

Sivers JE [83] defined biologic width as the dimension of the Junctional epithelial and connective tissue attachment to the root above the alveolar crest. This distance has been established as approximately 1 mm for the Junctional epithelium and 1 mm for the connective tissue attachment. An additional millimeter within the gingival crevice is necessary to allow for the establishment of the restorative margin. Therefore, when a subgingival defect is restored, a minimum of 3 mm of sound tooth structure coronal to the alveolar crest is necessary.

DeSort [24] defined ferrule effects, as a metal ring or cap put around the end of a tool, cane, etc., to give added strength. This effect is used in endodontically treated teeth to reinforce the coronal aspect of the dowel preparation by aiding in effective occlusal seat [34].

The term ferrule is often misinterpreted. It is used as an expression of the amount of remaining sound dentine above the finish line. It is infact not the remaining tooth structure that is the 'ferrule' but rather the actual bracing of the complete crown over the tooth structure that constitutes the ferrule effect, i.e. the protection of the remaining tooth structure against fracture[63].

360° coverage of crown, on tooth / root structure is required for ferrule effect [44, 45, 89, 90.] This constitutes to 360° coverage by ferrule in restorative crown + presence of 360° 2mm long axial wall on tooth or root = ferrule effect (Diagram-11). In this study teeth samples of control group are made to simulate 360° ferrule effect.

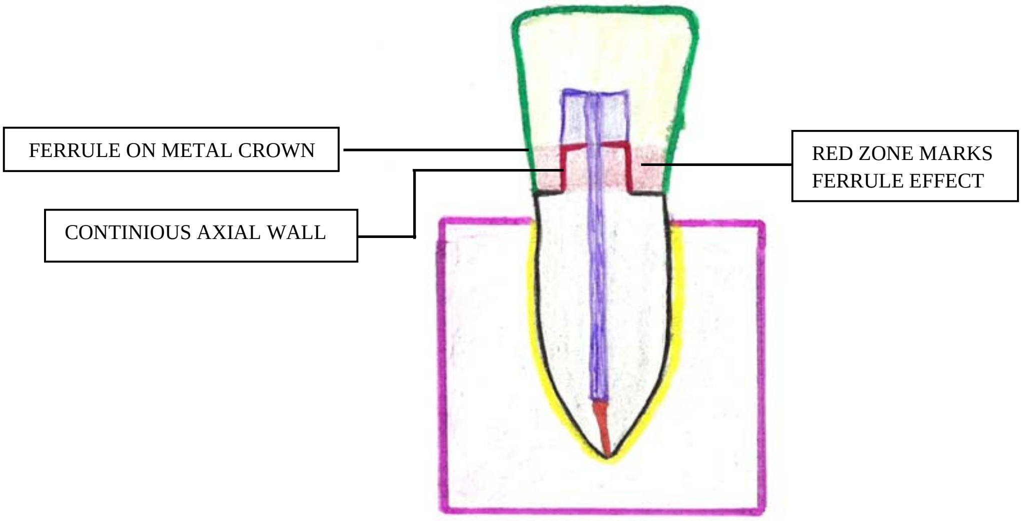


Diagram-11

In clinical situations, the location of remaining coronal tooth structure is not a controllable factor, as it is dictated by the condition of the tooth after trauma, endodontic treatment and caries removal. Due to this there is irregularity of circumferential coronal tooth structure, and difficulty in obtaining uniform 360° ferrule effect. Available literature favours uniform 2mm axial wall for ferrule effect. Clinical experience shows that when a tooth fractured due to trauma it often follows a pattern. Occlusal overload may cause facial sub-gingival tooth damage and leave palatal hard tissue intact. Perpendicular loading to the facial surface commonly results in a palatal sub-gingival level fracture. Under these circumstances obtaining uniform 2mm axial wall is difficult [60, 74, 96, 103].

Ideally, a fractured tooth should be classified before preparation, with the desired finished preparation in mind. This assists the practitioner to make adjustments to preserve maximum thickness and height of the remaining tooth structure during preparation. Peroz et al [68] has classified clinical crown loss and restorations required, on the basis of remaining axial cavity walls. He stated that a dentine thickness greater than 1mm provides an amount of hard tissue sufficient to stabilize the core material even after crown preparation. Jotkowitz and Samet [44] had classified the amount of remaining tooth structure that can be incorporated into the ferrule effect, so that the risk of mechanical failure can be judged and appropriate treatment options can be selected. In the present study, dentin of minimum 1mm thickness and 2mm axial wall (cavity wall) length has been maintained for uniform ferrule effect group.

Various different ferrule designs have been suggested but currently there is little research supporting one design over the other [87]. Most publications discuss the required height of ferrule, however, other design characteristics like dentine thickness, location of the remaining dentine walls, and the load the restoration has to withstand, were not considered.

Parameter 2- Ideal restorative materials.

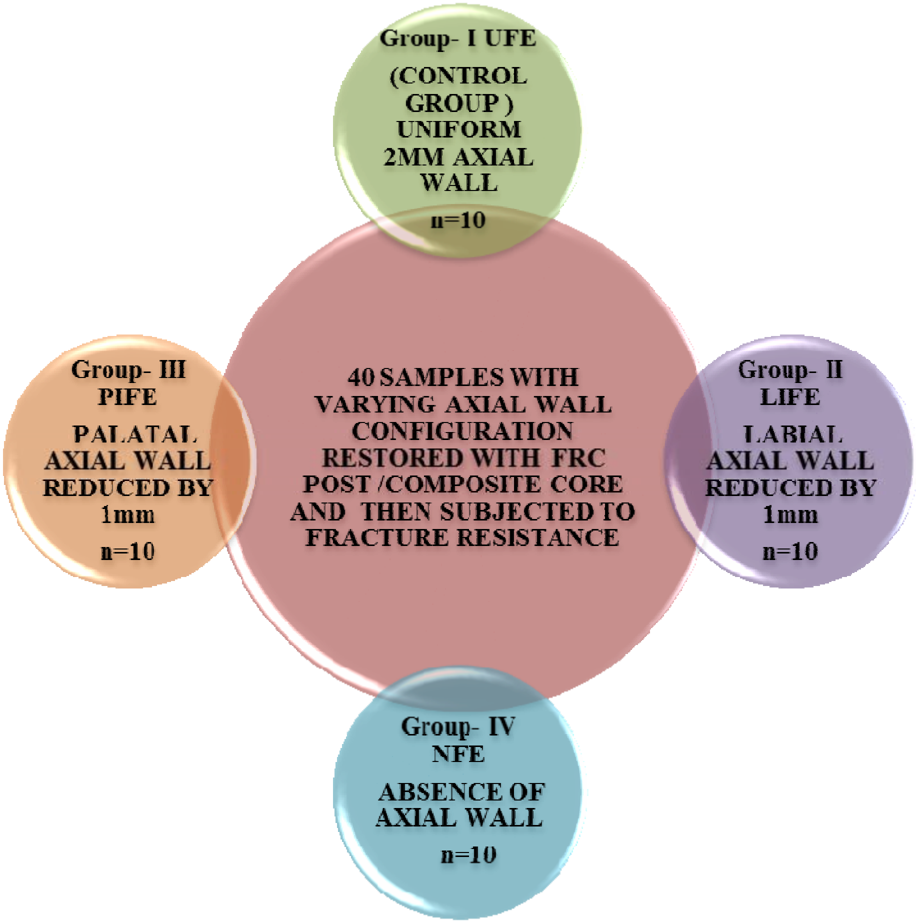
Didier Dietschi [25, 26] stated that since no finding suggest that the natural dentin is an inappropriate core material, the use of materials with dentin like properties currently appears to be the most suitable approach. Resin-fiber posts currently are preferred option because they have physical properties closer to dentin than do metals or ceramics. Adhesively luted fiber-reinforced composite post restorations have demonstrated satisfactory survival rates over long follow-up periods. The clinical effectiveness of such restorations had been mainly ascribed to the more biomimetic behavior of fiber reinforced composite posts that reduces the risk of vertical root fractures [16, 83]. Owing to a greater similarity in elastic properties with dentine, FRC posts allow for a relatively uniform stress distribution to the tooth and the surrounding tissues, thus yielding a protective effect against root fracture [23, 32, 37,60].

Posts can be bonded to tooth structure with resin luting agents. It has been postulated that this allows the formation of a cohesive unit between tooth, post, and core [63]. This concept of the monobloc configuration further increases fracture resistance.

Posts are frequently used for the retention of a core material in teeth that have had extensive loss of coronal tooth structure [18]. Their use, however, may increase root fracture due to excessive pressures during insertion or because of lateral movement of the post within the root, thus ironically increases the risk of root fracture [35, 98] and failure [86].Therefore, the use of a correct ferrule design is of utmost importance for teeth restored with post and cores. Since placing crown margins significantly subgingivally is not advisable because of the violation of biologic width, the quest for the perfect ferrule may lead to the incorporation of treatments like crown lengthening and/or an orthodontic extrusion[45, 86] .Clearly, this presents a dilemma as crown lengthening surgery may result in a poorer crown to root ratio and also compromised the aesthetics with loss of the inter-dental papilla and a potential loss of the support of the adjacent teeth. Orthodontic intervention may resolve some of these risks, however, the crown to root ratio may still be compromised and it is time consuming with an additional fee to the whole procedure, making it non-feasible in many cases [12]. For this reason it becomes necessary to explore the existing parameters of the ferrule effect as it stands in the literature.

In this study, specimens represent restored maxillary anterior teeth. The fracture resistance of the specimens is a function of bond strength (between post/core/crown and remaining tooth structure) and direction of the force applied. The specimens of this study were subjected to force applied from the palatal direction mimicking mandibular incisors.

Study design-



In this study 3.5mm + 2mm (5.5 mm tooth structure from simulated bone) tooth structure was maintained for ferrule effect in groups I, II, III. Group I (control group) had uniform 2mm axial wall representing ideal requirement and Group IV had no axial wall and no ferrule effect. This study evaluated fracture resistance to static loading. The load was applied at 135° which was 5° more than the normal average 130° contact between maxillary and mandibular central incisor. This angulation appeared to be one of the worst case scenarios with regard to the fracture resistance of endodontically treated teeth and was considered suitable for evaluating the biomechanical behavior of fiber-post restorations in Group IV samples [43, 87].

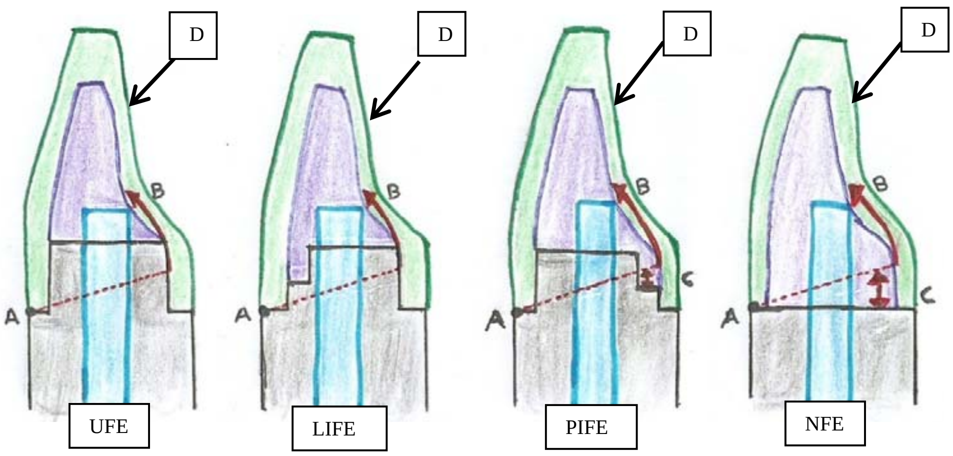
The results of this investigation confirms the general consensus that a uniform 2-mm ferrule is superior to the lack of a ferrule in the prevention of tooth fracture under a static load [91] The average maximum compressive load in newton's (N) for Group I-UFE (Control group) is 532.29N, Group II – LIFE is 657.34 N, Group III -PIFE is 426.20N and Group IV-NFE is 362.6N.

The reported maximal occluding force for males exerted by a maxillary incisor tooth is 146 + or - 44 N [91] Even though forces in this study were above 146 N, teeth in Group IV without a ferrule effect (362.6 N) are at risk of fracture when compared with Group I uniform 2 mm ferrule effect (532.29N). This observation leads to the conclusion that there is substantial benefit in providing a ferrule whenever possible.

To the question –Which ferrule effect configuration would resist fracture more? The answer seems to favor Labial irregular ferrule effect (LIFE) with 657.34N. This Group II (LIFE) sample has shown maximum fracture resistance with an average of 122.05N more than Control Group I (UFE). The Group III (PIFE) with 426.20N shows more fracture resistance than Group IV (NFE) but significantly less than Group I (UFE) and Group II (LIFE). Group IV (NFE) with 362.6N showed the least fracture resistance.

In this study LIFE is highly significant from NFE and PIFE (mean differences 294.7490 and 231.1480) with p value (0.000) less than 5%. In-between UFE and LIFE since p value (0.081) is less than 10%, it may be inferred that there is a moderate level significance (mean difference of 122.0550). There is no significant difference between the pairs NFE and PIFE; and UFE and PIFE.

Ng et al [63] had stated that when the remaining axial wall is at the location where the load is applied, the arc of displacement of complete crown places the remaining tooth structure under tension. In contrast if the remaining axial wall is on the labial aspect, with no palatal wall the arc of displacement affects the bond between the post and core first, followed by the strength of remaining tooth structure. With no coronal tooth structure remaining, the resistance to displacement is primarily a function of the bond between the post/core and the remaining tooth. To study this arc of displacement Group I (UFE) to Group IV (NFE) samples were used. Results obtained from this study are consistent with the above stated study (Diagram-12).



Arc of displacement of crown. (A) fulcrum (B) arc of crown displacement(C) bond strength of post /core to root (D) direction of force.

Diagram-12

Further analysis was done on fracture line. They were classified into repairable and non-repairable with relation to bone level [35] (Table 13).

TABLE-13			
GROUP AND SAMPLE NUMBERS	MEAN FAILURE LOAD (N)	REPAIRABLE FRACTURE AND %	NON REPAIRABLE FRACTURE AND %
GROUP-I(UFE) Number-10	535.29	8(80%)	2(20%)
GROUP-II(LIFE) Number-10	657.34	10(100%)	0(0%)
GROUP-III(PIFE) Number-10	426.20	1(10%)	9(90%)
GROUP-IV (NFE) Number-10	362.6	9 (90%)	1(10%)

Diagram13-shows the direction of fracture

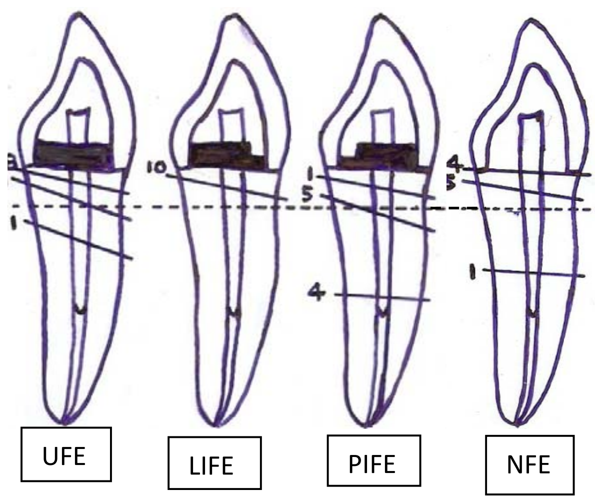


Diagram-13

In this study Group III (PIFE) shows maximum non-repairable fracture and Group II (LIFE) showed maximum repairable fracture. Group II is the most favourable in terms of fracture resistance this could be because the labial irregularity increases the bonding surface area and also due to the presence of intact 2mm palatal axial wall buttressing the arc of displacement. It could be postulated that specimens restored with fiber reinforced post systems offered more homogenous stress distribution due to their modulus of elasticity close to that of dentin resulting in a better stress distribution that occurs at the post-dentin interface [32] .Conversely, titanium, stainless steel and zirconia have elastic moduli (110 GPa, 200 GPa, 300 GPa, respectively) well above that of dentine (18 GPa). In the presence of rigid posts, stress is transmitted internally and concentrates towards the apical level, thus increasing the risk for vertical root fracture that represents a catastrophic failure [25, 26, 62, 32].This could explain why in this study all favourable fractures were limited to the cervical portion of the root including the core-dentin interface, since the stresses were concentrated in the cervical area and the outer root surface.

Group II showed consistent R-C type of fracture .There is a feasibility of treating them again, depending on the available length of apical fragment. The coronal fragment is removed and crown lengthening could be done [12, 84].

The mean fracture resistance was more than 400 Newton in all groups except for NFE, which was more than the force that causes fracture clinically [52, 61, 101]. As the fracture loads in all groups in the present study were found to be greater than the ordinary chewing force, and maximum biting force, their mechanical strength could be considered satisfactory from a clinical point of view due to the choice of post material [81].The results also indicated that LIFE is more effective at resisting fracture than a tooth with NFE and UFE. If a maxillary central incisor initially does not have sufficient axial wall, an attempt should be made to allow for at least 2 mm palatal axial wall.

In a similar study carried out by Ng et al [63] in 2006, the impact of five types of ferrule preparation was examined on the mean fracture resistance. The result is consistent with the result of this study (i.e.) palatal axial wall is important in fracture resistance in endodontically treated maxillary central incisor.

In a study carried out by Naumann et al [61] they concluded that the absence of portions of a crown ferrule (missing facial or palatal aspects, proximal interrupted) is associated with greater variation of failure load and strength values might be reduced to below a clinically acceptable load bearing. This result was in contrast to the present study. In the present study continuous axial wall was preserved and strength values were more in LIFE.

Based on a report by Torbjorner and colleagues, anterior teeth will sustain fracture as a result of tension and not compression [96] .A palatal loading on maxillary anterior teeth may cause stress in the form of tension in the palatal margin and may also cause stress in the form of compression in the facial margin [10, 52]. Therefore, the first marginal and cervical opening will be visible in the palatal area [10] which can explain the different types of fracture in this study.

Bone support and the periodontal ligament are important for the mechanisms of stress distribution over teeth. In this study PDL simulation was done with Light bodied PVS material and bone simulation was done with acrylic resin. Soares [85] stated that greater influence of periodontal ligament simulation is noted on the fracture mode rather than on the fracture load values. In his study the teeth embedded in acrylic resin or polystyrene resin without periodontal ligament simulation tended to fracture on the top of the resin cylinders, while the teeth with periodontal ligament simulation tended to fracture in different locations with a greater prevalence towards root portion. Fracture locations found in this study correlate with Soares study, fracture with partial invasion below CEJ and above simulated bone (R-C type fracture).

The primary mode of failure for NFE, UFE, LIFE, and PIFE groups was coronal root fracture. This suggested that a cohesive relationship existed between the tooth, post, core, and crown. The resin bond between the different restorative components in these 4 groups appears to have been sufficient to resist fracture of the post or debonding from the root, which is the most common mechanism of clinical failure for endodontically treated teeth [86, 87, 100] .

It is important to note that the type of testing used that is, a single cycle to failure does not represent the intraoral condition. Intraorally, teeth are subject to loading through mastication and are in a wet environment that is subject to chemical and thermal changes. This study design examined angle and force from a single direction, and this design is not necessarily representative of clinical conditions. The study also simulated maxillary central incisors, and therefore, the results can be applied only to that group of teeth. The results of this in vitro study, however, show that in the absence of 360° of circumferential coronal tooth structure, the location of remaining axial tooth structure incisal to the preparation finish line may be an important factor for determining the fracture resistance of restored endodontically treated teeth.

Future research with cyclical loading to closely simulate clinical conditions can be explored. Cast posts and cores could also be compared with prefabricated posts and cores to determine differences under simulated clinical conditions. Future research can also be done with varying thickness of axial wall.

SUMMARY AND CONCLUSION

SUMMARY

Literature on endodontically treated teeth state that 2mm uniform ferrule effect, is ideal for fracture resistance. In clinical situations it is rare to have uniform 2mm ferrule effect.

This in-vitro study was conducted to evaluate varied ferrule effect geometry on the fracture resistance of endodontically treated maxillary central incisors. A total number of forty extracted maxillary central incisors were selected for this study. Teeth samples were divided into 4 groups of 10 teeth each. Group I (Control group) was compared with Group II (LIFE), Group III (PIFE) and Group IV (NFE).

These teeth samples were mounted on acrylic blocks.FRC posts were bonded and composite core built up was done. Metal crowns were cemented with type I glass ionomer cement. The restored teeth samples were loaded on a universal testing machine at an angulation of 135° by using custom made jig for fracture testing. The results were subjected to one way ANOVA and HSD TUKEY test to analyze the statistical significance.

The results of this study revealed that uniform 2mm ferrule increased fracture resistance. Due importance must be given to preserve the palatal axial wall (i.e.) in the absence of uniform 2mm axial wall at least 1mm labial axial wall and 2mm of remaining axial walls should be preserved when treating endodontically treated maxillary central incisor.

CONCLUSION

Within the limitations of this study, the following conclusions can be drawn.

1. Uniform ferrule effect and Labial irregular ferrule effect increased the failure threshold.
2. Palatal axial wall had profound effect on fracture resistance and in the absence of uniform 2mm axial wall, maximum 2mm palatal axial wall with minimum 1mm labial axial wall increased the fracture resistance.
3. Insertion of a fiber post could reduce the percentage of catastrophic failure.

BIBLIOGRAPHY

BIBLIOGRAPHY

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

2. Akkayan B. An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically treated teeth restored with fiber-reinforced and zirconia dowel systems. J Prosthet Dent 2004; 92(2):155-62.

3. 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 care restoration. Int endod J 2001; 34(1): 40-6.

4. Al-Omiri MK, Al-Wahadni AM. An ex vivo study of the effects of retained coronal dentine on the strength of teeth restored with composite core and different post and core systems. Int Endod J 2006; 39:890–9.

5. Al-Omiri MK, Mahmoud AA. Fracture resistance of teeth restored with post-retained restorations: an overview. J Endod 2010; 36(9):1439-49.

6. Al-Wahadni A, Gutteridge D L. An in vitro investigation into the effects of retained coronal dentine on the strength of a tooth restored with a cemented post and partial core restoration. Int Endod J 2002; 35: 913-918.

7. Arunpraditkul S, Saengsanon S. Fracture resistance of endodontically treated teeth: three walls versus four walls of remaining coronal tooth structure. J Prosthodont 2009; 18: 49-53.

8. Assif D. et al. Photoelastic analysis of stress transfer by endodontically treated teeth to the supporting structure using different restorative techniques J Prosthet Dent 1989; 61(5):535-43.

9. Assif D. et al. Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993; 69(1):36-40.

10. Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. J Prosthet Dent 1994; 71(6):565-7.

11. Barkhordar RA, Radke R, Abbasi J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. J Prosthet Dent1989; 61(6):676-8.

12. Berman LH, Blanco L, Cohen S.A clinical guide to dental traumatology.2007 Mosby-Elseveer. Chapter 4, Pg-51-69.

13. Buttel L, Krastl G. Influence of post fit and post length on fracture resistance. Int Endod J 2009; 42(1):47-53.

14. Butz F, Lennon AM, Heydecke G, Strub JR. Survival rate and fracture strength of endodontically treated maxillary incisors with moderate defects restored with different post-and-core systems: an in vitro study. Int J Prosthodont 2001; 14(1):58-64.

15. Cagidiaco MC, Radovic I. Clinical performance of fiber post restorations in endodontically treated teeth: 2-year results. Int J Prosthodont 2007; 20(3):293-8.

16. Cathro PR, Chandler N P, Hood J A. Impact resistance of crowned endodontically treated central incisors with internal composite cores. Endod Dent Traumatol 1996; 12(3):124-8.

17. Cho H, Michalakis K X. Impact of interproximal groove placement and remaining coronal tooth structure on the fracture resistance of endodontically treated maxillary anterior teeth. J Prosthodont 2009; 18: 43–48.

18. Christensen GJ. When to use fillers, build-ups or posts and cores. J Am Dent Assoc 1996; 127(9):1397-8.

19. Christensen GJ. Posts: necessary or unnecessary? J Am Dent Assoc 1996; 127(10):1522-4.

20. Creugers NHJ, Kreulen CM.A 5-year prospective clinical study on core restorations without covering crowns. Int J Prosthodont 2005a; 18:40-41.

21. Creugers NHJ, Kreulen CM. 5-year follow-up of a prospective clinical study on various types of core restorations. Int J Prosthodont 2005b; 18:34-39.

22. Da Silva NR et al. The effect of post, core, crown type, and ferrule presence on the biomechanical behavior of endodontically treated bovine anterior teeth. J Prosthet Dent 2010; 104:306-317.

23. de Castro Albuquerque R, Polleto LT. Stress analysis of an upper central incisor restored with different posts. J Oral Rehabil. 2003; 30(9):936-43.

24. DeSort KD. The prosthodontic use of endodontically treated teeth: theory and biomechanics of post preparation. J Prosthet Dent. 1983; 49(2):203-6.

25. Didier Dietschi et al. Biomechanical considerations for the restoration of endodontically treated teeth: A systematic review of the literature-Part 1. Composition and micro- and macrostructure alterations. Quintessence Int 2007; 38:733–743.

26. Didier Dietschi et al. Biomechanical considerations for the restoration of endodontically treated teeth: A systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). Quintessence Int 2008; 39:117–129.

27. Erslan O, Aykent F. The finite element analysis of the effect of ferrule height on stress distribution at post and core restored all ceramic anterior crowns. Clin Oral Invest 2009 13:223–227.

28. Ferrari M, Vichi A, Mannocci F. Retrospective study of the clinical performance of fiber posts. Am J Dent. 2000; 13:9B-13B.

29. Ferrari M, Cagidiaco MC. Post placement affects survival of endodontically treated premolar. J Dent Res 2007; 86(8):729-734.

30. Gegauff A. G. Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns. J Prosthet Dent 2000; 84(2):169-79.

31. Goldberg IS, Slutzky H. Restoration of endodontically treated teeth review and treatment recommendations. Int J Dent2009; 2009:150251.

32. Goracci C, Ferrari M. Current perspectives on post systems: a literature review. Aust Dent J. 2011; 56(1):77-83.

33. Gutmann JL. The dentin-root complex: anatomic and biologic considerations in restoring endodontically treated teeth. J Prosthet Dent 1992; 67(4):458-67.

34. Hemmings KW, King PA, Setchell DJ. Resistance to torsional forces of various post and core designs.J Prosthet Dent 1991; 66(3):325-9.

35. Heydecke G,Butz F.Fracture Strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in vitro study. J Dent. 2001; 29(6):427-33.

36. Heydecke G, Peters, M. C. The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores: a systematic review. J Prosthet Dent 2002; 87(4):380-6.

37. Hinckfuss S. et al. Effect of core material and restoration design on strength of endodontically treated bovine teeth: a laboratory study. J Prosthodont 2008; 17: 456-461.

38. Hoag EP, Dwyer TG. A comparative evaluation of three post and core techniques. J Prosthet Dent. 1982; 47(2):177-81.

39. Hu S, Osada T et al. Resistance to cyclic fatigue and fracture of structurally compromised root restored with different post and core restorations. Dent Mater J 2005; 24:225–31.

40. Ichim I, Kuzmanovic DV. A finite element analysis of ferrule design on restoration resistance and distribution of stress within a root. Int Endod J 2006; 39(6) 443-452.

41. Idil Dikabas, Tanalp J. Evaluation of different ferrule designs on the fracture resistance of endodontically treated maxillary central incisor incorporating fiber posts, composite cores and crown restorations. J Contemp Dent Pract 2007; 1; 8(7):62-9.

42. Iqbal MK, Kim S. A review of factors influencing treatment planning decisions of single-tooth implants versus preserving natural teeth with nonsurgical endodontic therapy. J Endod 2008; 34(5):519-29.

43. Isidor F, Brondum K, Ravnholt G. The influence of post length and crown ferrule on the resistance to cyclic loading of bovine teeth prefabricated titanium post. Int J Prosthodont1999; 12(1):78-82.

44. Jotkowitz A, Samet N. Rethinking ferrule –a new approach to an old dilemma. Br Dent J 2010; 10; 209(1):25-33.

45. Juloski J et al. Ferrule Effect: A Literature Review. J Endod 2012; 38(1):11-9.

46. Kantor ME, Pines MS. A. Comparative study of restorative techniques for pulpless teeth. J Prosthet Dent 1977; 38(4):405-12.

47. Kutesa-Mutebi A, Osman YL. Effect of the ferrule on fracture resistance of teeth restored with prefabricated posts and composite cores. Afr Health Sci 2004; 4(2):131-5.

48. Libman WJ, Nicholls JI. Load fatigue of teeth restored with case posts and cores and complete crowns. Int J Prosthodont 1995; 8: 155-61.

49. Lima AF, Spazzin AO. Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth. J Appl Oral Sci 2010;18(4):360-3.

50. Loney RW,Kotowics WE, Mc Dowell G. C. Three-dimension photoelastic stress analysis of the ferrule effect in cast post and cores. J Prosthet Dent 1990; 63(5):506-12.

51. Ma P S, Nicholls JI. Load fatigue of teeth with different ferrule lengths, restored with fiber posts, composite resin cores, and all ceramic crowns. J Prosthet Dent 2009; 102:229-234.

52. Mahdavi Izadi Z, Jalalian E. Evaluation of the effect of different ferrule designs on fracture resistance of maxillary incisors restored with bonded posts and cores. J Dent Tehran 2010; 7(3):146-55.

53. McLean A. Criteria for predictably restorable endodontically treated tooth. J Can Dent Assoc 1998; 64(9):652-6.

54. McLean, A. Predictability of restoring endodontically treated teeth. J Can Dent Assoc 1998; 64(11): 782-7.

55. Melo MP et al. Evaluation of fracture resistance of endodontically treated teeth restored with prefabricated posts and composites under varying quantities of remaining coronal tooth structure. J Appl Oral Sci 2005; 13(2):141-6.

56. Meng QF, Chen YM. Effect of ferrule and increased crown length on the in vitro fracture resistance of premolars restored using two dowel and core systems. Oper Dent 2007; 32(6):595-601.

57. Mezzomo E, Massa F. Fracture resistance of teeth restored with two different post-and-core designs cemented with two different cements: an in vitro study. Part I. Quintessence Int 2003; 34(4):301-6.

58. Monticelli F, Goracci C, Ferrari M. Micromorphology of the fiber post-resin core unit: a scanning electron microscopy evaluation. Dent Mater 2004; 20(2):176-83.

59. Morgano SM, Brackett SE. Foundation restorations in fixed prosthodontics: current knowledge and future needs. J Prosthet Dent 1999; 82(6):643-57.

60. Morgano SM, Rodrigues AHC, Sabrosa CE. Restoration of endodontically treated teeth. Dent Clin North Am. 2004; 48(2): 397-416.

61. Naumann M, Preuss A, Rosentritt M. Effect of incomplete crown ferrules on load capacity of endodontically treated maxillary central incisors restored with fiber posts, composite build-ups, and all-ceramic crowns: An in vitro evaluation after chewing stimulation. Acta Odontol Scand 2006; 64(1) 31-36.

62. Newman MP, Yaman P. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003; 89(4):360-7.

63. Ng CC, Dumbrigue HB. Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth. J Prosthet Dent 2006; 95(4): 290-296.

64. Nissan J et al. Effect of reduced post length on the resistance to fracture of crowned, endodontically treated teeth. Quintessence Int 2008; 39(630):179–182.

65. Pereira J. R. et al. Influence of the remaining coronal structure on the resistance of teeth with intraradicular retainer. Braz Dent J 2005; 16(3):197-201.

66. Pereira JR. et al. Effect of a crown ferrule on the resistance of endodontically treated teeth restored with prefabricated posts. J Prosthet Dent 2006; 95(1):50-4.

67. Perel ML, Muroff FI. Clinical criteria for posts and cores. J Prosthet Dent 1972; 28(4):405-11.

68. Peroz I, Blankenstein F, Lange K, et al. Restoring endodontically treated teeth with posts and cores: a review. Quintessence Int 2005; 36:737–46.

69. Peters MC, Poort HW. Stress analysis of a tooth restored with a post and core. J Dent Res 1983; 62(6):760-3.

70. Pierrisnard L. et al. Corono-radicular reconstruction of pulpless teeth. A mechanical study using finite element analysis. J Prosthet Dent 2002; 88(4):442-8.

71. Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995; 28(1):12-8.

72. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989; 15(11):512-6.

73. Richards DW, Kao RT. Strategic extraction: comparison of traditional and implant therapies. J Calif Dent Assoc 2008; 36(3):181-6.

74. Robbins JW, Earnest L A, Schumann SD. Fracture resistance of endodontically treated cuspids. Am J Dent1993; 6(3):159-61.

75. Rosen H. Operative procedures on mutilated endodontically treated teeth. J Prosthet Dent 1961; 11(5): 973-986.

76. Salameh Z, Sorrentino R .The effect of different full-coverage crown systems on fracture resistance and failure pattern of endodontically treated maxillary incisors restored with and without glass fiber posts. J Endod 2008; 34(7):842-6.

77. Saupe WA, Gluskin AH, Radke RA. A comparative study of fracture resistance between morphologic dowel and cores and a resin-reinforced dowel system in the intraradicular restoration of structurally compromised roots. Quintessence int 1996; 27(7): 483-491.

78. Schmitter M, Rammelsberg P. Teeth restored using fiber-reinforced posts: In vitro fracture tests and finite element analysis. Acta Biomater. 2010; 6(9):3747-54.

79. Sedgley CM, Messer HH. Are Endodontically Treated Teeth more Brittle? J Endod 1992 Jul; 18(7):332-5.

80. Sendhilnathan D, Nayar S. The effect of post-core and ferrule on the fracture resistance of endodontically treated maxillary central incisors. Indian J Dent Res 2008; 19(1):17-21.

81. Sherfudhin H, Hobeich J. Effect of different ferrule designs on the fracture resistance and failure pattern of endodontically treated teeth restored with fiber posts and all-ceramic crowns. J Appl Oral Sci 2011; 19(1):28-33.

82. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE. Preparations for extensively damaged teeth. In: Fundamentals of fixed prosthodontics. Chicago: Quintessence; 1997: 181-209.

83. Sirimai S, Riis DN, Morgano SM. An in vitro study of the fracture resistance and the incidence of vertical root fracture of pulpless teeth restored with six post-and-core systems. J Prosthet Dent 1999; 81(3):262-9.

84. Sivers JE, Johnson GK. Periodontal and restorative considerations for crown lengthening. Quintessence Int 1985; 16(12):833-6.

85. Soares CJ, Pizi EC.Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. Braz Oral Res. 2005;19(1):11-6.

86. Sorensen JA, Martinoff JT. Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth. J Prosthet Dent 1984; 51(6):780-4.

87. Sorensen JA, Martinoff JT. Endodontically treated teeth as abutments. J Prosthet Dent 1985; 53(5):631-6.

88. Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. J Prosthet Dent 1990; 63(5):529-36.

89. Sorensen JA, Engelman MJ. Effect of post adaptation on fracture resistance of endodontically treated teeth. J Prosthet Dent 1990; 64(4):419-24.

90. Stankiewicz N, Wilson P. The ferrule effect. Dent Update. 2008; 35(4):222-4, 227-8.

91. Stankiewicz NR, Wilson PR. The ferrule effect: A Literature review. Int Endod J 2002; 35(7):575-81.

92. Tan PLB et al.In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. J Prosthet Dent 2005; 93(4): 331 -336.

93. The glossary of prosthodontic terms. J Prosthet Dent. 2005; 94(1):10-92.

94. Tjan AH, Whang SB. Resistance to root fracture of dowel channels with various thicknesses of buccal dentin walls. J Prosthet Dent 1985; 53: 496-500.

95. Toksavul S, Zor M. Analysis of dentinal stress distribution of maxillary central incisors subjected to various post-and-core applications. Oper Dent 2006; 31(1):89-96.

96. Torabinejad M, Goodacre CJ. Endodontic or dental implant therapy: the factors affecting treatment planning. J Am Dent Assoc 2006; 137(7):973-7.

97. Torbjöner A, Fransson B. A literature review on the prosthetic treatment of structurally compromised teeth. Int J Prosthodont 2004; 17(3):369-76.

98. Trabert KC, Caput AA, Abou-Rass M. Tooth fracture-a comparison of endodontic and restorative treatments. J Endod 1978; 4(11):341-5.

99. Trope M, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated teeth. Endod Dent Traumatol 1985; 1(3):108-11.

100. Turner CH. The utilization of roots to carry post-retained crowns. J Oral Rehabil 1982; 9(3):193-202.

101. Valle AL et al. Comparison of the fracture resistance of endodontically-treated teeth restored with prefabricated post and composite resin core with different post lengths. J Appl Oral Sci 2007 Feb; 15(1):29-32.

102. Varvara G, Perinetti G.In vitro evaluation of fracture resistance and failure mode of internally restored endodontically treated maxillary incisors with different height of residual dentin. J Prosthet Dent 2007; 98(5): 365-72.

103. Wagnild GW, Mueller KL. Restoration of the endodontically treated tooth. In: Cohen S, Burns R C, (Ed.) Pathways of the pulp. 8th ed. St. Louis: Elvevier, 2001: 765-95.

104. Xible AA, de Jesus Tavarez RR. Effect of cyclic loading on fracture strength of endodontically treated teeth restored with conventional and esthetic posts. J Appl Oral Sci 2006; 14(4):297-303.

105.Zerman N, Cavalleri G. Traumatic injuries to permanent incisors. Endod Dent Traumatol 1993;9:61-4.

106. Zhang Yu-Xing, Zhang Wei-Hong. Fracture strength of custom-fabricated Celay all-ceramic post and core restored endodontically treated teeth. Chin Med J (Engl) 2006 Nov 5; 119(21):1815-20.

107. Zhi-Yue L, Yu-Xing Z. Effects of port-core design and ferule on fracture resistance of endodontically treated maxillary central incisors. J Prosthet Dent 2003; 89(4):368-73.