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Restorative Modalities for Structurally Compromised Teeth with Thin-walled Roots: A Literature Review

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Abstract

Proper restoration and maintenance of endodontically treated teeth with thin-walled roots and immature apices is of a great concern due to the high prevalence of such cases. The aim of this study was to review the efficiency of different materials used for post–core systems in order to restore endodontically treated teeth. A literature review was conducted using electronic databases including PubMed, Scopus, Web of Science, and Google Scholar to find relevant articles. Randomized controlled trials that were related to different post–core techniques for restoring endodontically treated teeth and were in the English language were included from 2000 until 2022. Most articles concluded that cast posts have higher fracture resistance than fiber posts. All articles comparing stainless steel posts with other materials found that it had higher fracture strength. No particular difference between various types of fiber posts was identified, and all can reinforce the immature roots with thin dentinal walls.

Keywords

- dental dowels
- endodontically treated teeth
- flexural strength
- post and core technique
- thin-walled teeth

Introduction

Thin-walled teeth can be a result of overinstrumentation and endodontic treatment, large dental caries, or immature root development.[1] Fracture resistance of filled thin-walled roots appears to be lower than vital teeth. The remaining dentin thickness and the selection of restorative materials and post–core systems influence the tooth resistance.[2] Also in childhood, dental caries and traumatic accidents can cause severe coronal structure damage in permanent immature teeth. This can lead to necrosis of pulps; therefore, treating these immature teeth with thin walls and wide apices have always been a difficult challenge. Several techniques for healing immature apices are practiced; however, for preserving the roots walls and cervical region, reinforcement and the choice of restorative materials are essential.[3,4] Several studies report different treatments for endodontically treated teeth (ETT) and the endurance of post systems. In some of them, optimal treatments with suitable techniques have been proposed; however, the long-term success of those treatments is not determined yet.[5,6] In ETT, posts are placed to improve fracture resistance and the maintenance of coronal restorative treatments.[7] In current restorative approaches, post and core systems are gradually developing toward being more corrosion resistant and stronger, and less invasive techniques that do not weaken the remaining root structure are recommended due to the likeliness of flared canals to fracture.[8] Therefore, the remaining dentin should be retained as much as possible when preparing the root canal for post fabrication.[9]

Generally, two main types of post systems are advocated to restore root canal; cast posts and fiber-reinforced composite (FRC) posts. Cast posts include prefabricated and

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custom-made posts. They are used clinically to reinforce and rehabilitate ETT by distributing forces through the root structure. Prefabricated post systems are less pricey and may be less invasive in certain conditions.[8] Several drawbacks are associated with cast posts including unsatisfactory aesthetics, lengthy treatment and laboratory procedures, highly reductive effects on teeth, and insufficient retention. Fiber posts are utilized as an alternative with some improved features and they are as well, used as prefabricated and custom-made. Different materials are used for fiber reinforcement including glass, carbon, and quartz fibers for the prefabricated FRC posts and polyethylene fibers (Ribbond) for customized fiber post systems. Their main proposed benefit was that they are more adaptable than metal posts and more adjustable to the root shape. They have nearly the same modulus of elasticity (stiffness) as dentin and when bonded in canal with resin cement, it is assumed that forces would be distributed more evenly through the root walls, resulting in fewer root fractures.[10]

Since restoring teeth with insufficient and weakened canal wall is a clinical challenge, the aim of this paper is to review various studies that utilized different materials and techniques for restoration of ETT.

Materials and Methods

An electronic search of PubMed, Scopus, Web of Science, and Google Scholar, limited to articles published from 2000 to 2022 was conducted. The following query keywords were included: Thin-walled teeth, Thin-walled roots, Weakened roots, Post and Core Techniques, "Dowels, Dental," Fracture resistance, Endodontically-treated teeth, Immature teeth, Structurally compromised teeth. Studies that were relevant to this study, written in English, and were conducted as a randomized controlled trial were chosen. For the initial article searching, titles and keywords were considered and 566 articles were found (PubMed: 247, Scopus: 234, Web of Science: 10, Google Scholar: 75). In the first study selection based on screening abstracts and titles and removing duplicate articles, 87 studies remained. In the second study selection based on full-text analysis, the studies were chosen if related to different post and cores application and methods for thin-walled and structurally compromised teeth, and the evaluation of post and dentin thickness and length. Eventually, 36 studies were chosen. Twenty studies compared different post–core materials. Eight studies compared weakened and nonweakened roots, five studies compared using composite resin or glass ionomer cement (GIC) or neither as restorative materials for reinforcing thin-walled roots, and three studies compared stainless steel posts with fiber posts and cast posts.

Results

Effect of Post Material on Fracture Resistance of Thin-Walled Teeth

Among studies that compared cast posts with fiber posts, most of them came to the same conclusion that thin-walled teeth with cast post–cores had the highest fracture resistance (►Table 1). Kivanç et al and Maccari et al[11,12] reported that cast posts had higher strength and there was no significant difference among various fiber post types. Also, Balkaya and Birdal[1] showed that parallel-sided cast posts have the highest fracture resistance among all, and cast posts with less diameter show higher resistance, whereas fiber posts with larger diameters are slightly more resistant. In Marchi et al[13] study, the fracture resistance was shown to decrease for custom cast posts, prefabricated metallic posts, and prefabricated carbon fiber posts. In contrast, Goncalves et al[14] stated that among the weakened roots, groups with metal CuAl cast post had the lowest resistance and there was no significant difference between roots filled with light-transmitting polymerization post and prefabricated titanium post with different resin types in each group. Also, Li et al[15] reported that groups with fiber posts showed more resistance compared with metal posts. Considering stress values, Khadar et al[5] observed higher stress concentration for teeth restored with cast metal posts, whereas it is more even for fiber post and composite posts. This may be due to the possible monoblock unit formation in the tooth structure.

Regarding the mode of fracture Vidya et al[16] found that groups with cast posts showed more catastrophic fractures leading to extraction compared with glass fiber and titanium posts.

Considering fiber posts with different materials, Ayad et al and Akkayan and Gülmez[17,18] concluded that quartz fiber posts required a higher mean load to fracture than titanium posts. Akkayan and Gülmez[18] reached the result that the fracture resistance from high to low was found for quartz fiber posts, glass fiber posts, zirconia posts, and titanium posts, respectively. While in Sharafeddin et al, Maccari et al, and Dikbas et al[12,19,20] studies, there was no statistical difference found between quartz and glass fiber posts. Dikbas et al[20] stated that using either glass fiber, quartz fiber, or zirconia posts can reinforce the root in immature teeth. Furthermore, application of multiple unidirectional FRC posts as an individual post leads to a higher fracture resistance comparing with one single FRC post.[21]

According to Newman et al,[8] stainless steel para post had the highest fracture resistance comparing with glass fiber posts and Ribbond woven polyethylene fibers. Also in Makade et al[22] study, it was found that the mean fracture resistance was lessened for the group with stainless steel posts and composite core, glass fiber post with composite resin, and cast posts, respectively. Amarnath et al[23] came to the same result that groups with stainless steel posts had higher mean failure load. Additionally, Zogheib et al[24] found that no statistical difference was seen in roots filled with glass fiber posts used with different techniques such as using composite resin with incremental technique, accessory fiber posts, and anatomic glass fiber posts.

In the articles studied, all reported that bonding of a thick layer of composite in the root canal and tag formation along the dentin tubules significantly increased the fracture resistance.[17,25,26] Wu et al[26] found that using a layer of resin-

Table 1 Effect of post material on fracture resistance of thin-walled teeth

Authors/year	Tooth	Groups	Results
Khadar et al[5]/2022	Single rooted maxillary central incisors	4 groups ($N = 80$): Group A: No posts (control) Group B: Cast metal post (CMP) Group C: Customized Composite Post (CCP) Group D: Fiber post (FP)	Cast metal post groups exhibited the highest fracture resistance followed by customized composite posts, the fiber posts, and the control group. Higher stress concentration in the radicular region was observed for the cast metallic posts
Iemsaengchairat and Aksornmuang[6]/2022	Mandibular single-root canal premolars	4 groups ($N = 48$): Direct resin composite post and core (CP) Multiple fiber posts and resin composite core (FP) CAD/CAM anatomical post and core (AP) Metal cast post and core (MP)	Metal cast post and core demonstrated the highest fracture resistance for restoring a thin-walled endodontically treated tooth, followed by multiple fiber posts with resin composite core
Fráter et al[21]/2021	Maxillary central Incisors	4 groups ($N = 60$): Control group: multiple unidirectional FRC-post + dual-cured composite-core PFC: multiple unidirectional FRC-post + packable short fiber-reinforced composite (SFRC) BPFC: Bioblock technique with only packable SFRC BFFC: Bioblock technique with only flowable SFRC	PFC and control group had significantly better survival rates, indicating that multiple unidirectional FRC posts seem to be a good choice for treating severely damaged anterior teeth
Santos et al[56]/2021	Bovine incisors	8 groups ($N = 80$): Without simulating weakness ($n = 40$) Simulating weakness ($n = 40$) Subgroups of each group ($n = 10$): without intraradicular reinforcement glass fiber–reinforced composite posts (GT) Rebilda conventional glass fiber posts (RP) GT + RP	The groups with GT + RP showed the highest resistance with a significant difference with other groups except nonweakened RP group. This indicates that a combination of GT and RP glass fiber posts is more resistant for immature teeth
Fráter et al[57]/2020	Bovine incisors	6 groups ($N = 180$): Group 1: Bioblock technique with short fiber-reinforced composite (SFRC) Group 2: Bioblock technique with flowable SFRC Group 3: Individually-made FRC post Group 4: Conventional FRC post Group 5: Dual-cured core build-up composite Group 6: intact (control)	Use of Flowable SFRC resulted in a favorable survival and fracture strength. Group 4 results displayed a high number of microgaps
Veeraganta et al[9]/2020	Mandibular first premolars	Two main groups ($N = 64$) based on one or two residual walls ($n = 32$): Each groups has two subgroups based on post material (Glass fiber post of Titanium post) ($n = 16$) Each subgroup divides into two subsubgroups ($n = 8$): 70 or 90 ISO size diameter	A significantly higher fracture strength was found for titanium groups compared to glass fiber posts
Lassila et al[27]/2020	Bovine incisors	5 groups ($n = 40$): Group A: fiber-post and Dual-cured core	The highest fracture resistance was found for Group B. Moreover, fiber post

(*Continued*)

Table 1 (*Continued*)

Authors/year	Tooth	Groups	Results
		build-up composite (Gradia Core) + PFC crown Group B: fiber-post and Flowable fiber reinforced composite (everX Flow) core + PFC crown Group C: everX Flow as post–core + PFC crown Group D: post–core indirectly made from CERASMART Group E: Gradia Core as post–core + PFC crown	plus everX Flow as core increased the teeth durability
Josic et al[58]/2020	Mandibular premolars	2 groups ($N=20$): Group1: Sealed with Acroseal (Septodont, France) and gutta-percha, Group 2: Fiber posts (FRC Postec Plus, Ivoclar Vivadent) were luted using self-adhesive composite cement (SpeedCEM Plus, Ivoclar Vivadent)	No statistically significant difference was found between groups therefore, fiber post has no considerable influence on the preservation of immature edodontically treated teeth
Öztürk et al[59]/2018	Maxillary canines	4 groups ($N=80$): Group 1: No post–core, composite resin Group 2: Cast post–core Group 3: Glass fiber-reinforced epoxy post system (Radix fiber post), composite resin core Group 4: Glass fiber-reinforced epoxy post system (I-TFC ipost), composite resin core	The highest fracture resistance was observed for the group 2, group 3, group 4, and control group, respectively. With the highest rate of nonrestorable fractures for group 2. In the Groups 3,4 fracture mode would allow restoring the tooth
Amarnath et al[23]/2015	Mandibular premolars	6 groups ($N=60$): Group 1,2,3: Stainless-steel (SS) Group 4,5,6: Glass fiber post (FP)	The highest mean strength was obtained for stainless-steel posts, and the lowest was obtained for glass fiber posts
Cauwel et al[60]/2014	Weakened bovine incisors	4 groups ($N=75$), Group 1: (n = 20), control group, Unfilled teeth Group 2: (n = 17), filled with mineral trioxide aggregate (MTA) Group 3: (n = 18), filled with calcium phosphate bone cement (CPBC) Group 4: (n = 20), filled with fiber reinforced composite (FRC) posts	The results denoted the highest mean initial fracture load for the FRC group and the lowest for the control group. The control group (95%), The FRC (90%), and CPBC (89%) groups showed most favorable fractures, respectively. All fractures were at the cervical area of the palatal part of the root
Sharafeddin et al[19]/2014	Mandibular premolar roots	4 groups ($N=40$), $n=10$ Group EX: Exacto glass fiber post Group EXR: Exacto glass fiber post + 2 Reforpin accessories Group DT: D.T. Light quartz fiber post Group DTF: D.T. Light quartz fiber post + 2 Fibercone accessories	There were no statistically significant differences in fracture resistance among teeth. The fracture resistance order was as follows: EX > DT > EXR > DTF
Wandscher et al[61]/2014	–	2 groups ($N=80$): Weakened teeth ($n=50$): 5 subgroups $n=10$: CPC-gold (cast post and core made of gold alloy) CPC-Ni (cast post and core made of Ni-Cr alloy) FP (glass fiber posts) FP-W (glass fiber posts with a wider coronal diameter)	In the survival analysis, group FP-W demonstrated the highest survival rate. Cast post groups had higher fracture loads than fiber post groups. No differences were observed among groups with nonweakened roots

Table 1 (*Continued*)

Authors/year	Tooth	Groups	Results
		FP-CR (fiber posts relined with composite resin). Nonweakened roots ($n = 30$) 3 subgroups $n = 10$: CPC-gold CPC-Ni FP	
Balkaya and Birdal[1]/2013	Maxillary incisors	9 groups ($N = 90$), 4 groups without root canal enlargement: C1.3: tapered end cast posts of 1.3 mm C1.7: tapered end cast posts of 1.7 mm F1.3: tapered end fiber posts of 1.3 mm F1.7: tapered end fiber posts of 1.7 mm 5 groups with root canal enlargement: LF1.3: low viscosity composite resin + 1.3-mm fiber post LF1.7: low viscosity composite resin + 1.7-mm fiber post SF1.3: self-adhesive resin cement + 1.3-mm fiber post SF1.7: self-adhesive resin cement + 1.7-mm fiber post C4: parallel cast posts of 4 mm	The fracture resistance of the teeth with cast posts (C1.3 group) was significantly higher than those with fiber posts (F1.3 group). The teeth restored with composite resin and fiber posts demonstrated higher fracture resistance than those with fiber posts alone (F1.3, F1.7). The parallel-sided cast posts (C4 group) had the highest fracture resistance
Amin et al[55] /2013	Endodontically treated teeth	3 groups ($n = 60$): Group 1 (control): Nonweakened roots + glass fiber–reinforced dowels Group 2: weakened roots + glass fiber–reinforced dowels relined with composite resin Group 3: weakened roots + glass fiber–reinforced dowels and a thick layer of luting cement each group has two subgroups (n = 10): subgroup a: custom-made core subgroup b: prefabricated glass fiber–reinforced core	The highest fracture bearing capacity was for the nonweakened group and the composite relined group. The prefabricated core indicated higher fracture resistance than the custom-made core
Pinho et al[62]/2013	Bovine lower central incisors	2 groups ($N = 30$) CMP-Cr: composite resin and cast metal post GFP-Cr: composite resin and glass fiber post	Group with composite resin and cast metal post showed higher fracture strength
da Rosa et al[30]/2013	Mandibular incisors	5 groups ($N = 50$), Group 1: healthy roots with a glass fiber post Group 2: partially weakened teeth with a glass fiber post Group 3: partially weakened teeth with a glass fiber post and 2 accessory glass fiber posts Group 4: extensively weakened teeth with a glass fiber post Group 5: extensively weakened	No significant differences among the groups. Most fractures were cervical. Favorable fractures (fractures at the simulated bone level or above, failures in the coronal part of the post, or displacement of the crown or post) mainly occurred in group 2

(*Continued*)

Table 1 (*Continued*)

Authors/year	Tooth	Groups	Results
		teeth with a glass fiber post and 5 accessory glass fiber posts	
Dikbas et al[20]/2012	Axillary anterior teeth	4 groups ($N = 48$): Control group: AH Plus sealer + Gutta-percha Group 2: Glass fiber posts + self-adhesive resin cement Group 3: Quartz fiber posts + self-adhesive resin cement Group 4: Zirconia posts	No significant difference was found between the experimental groups
Makade et al[22]/2011	Maxillary incisors	4 groups ($N = 40$), each $n = 10$ Control group (A): intact coronal structure without post core Group B: cast post–core Group C: stainless steel post with composite core Group D: glass fiber post with composite core using adhesive resin cement	Group C had the highest fracture resistance among all four groups and the control group had the lowest
Zogheib et al[24]/2011	Anterior teeth	4 groups: ($N = 40$) Group I (control): nonweakened, glass fiber posts Group II: weakened roots, glass fiber post and composite resin by incremental technique Group III: weakened roots, glass fiber post and accessory glass fiber posts Group IV: weakened roots, anatomic glass fiber post technique	The control group was significantly higher in resistance. No statistically notable difference was observed between the three experimental groups. Most of the fracture modes with incremental technique were repairable in contrast with other group techniques
Li et al[15]/2011	Maxillary anterior teeth	2 groups ($N = 48$) Group A: minor diameter open apex Group B: major diameter open apex Each has 3 subgroups: Subgroup 1: fiber-post Subgroup 2: metal post Subgroup 3: non-post	No significant difference was found overally between two groups and between post types in group B, whereas in group A the mean value of fracture resistance for fiber post was higher than metal or non-post
Vidya et al[16]/2011	Anterior teeth	3 groups ($N = 36$): Group A: cast post & core Group B: composite + Luminex titanium post Group C: composite + Luscent Anchor glass fiber post	No significant difference between post types. Mode of fracture was more favorable in groups with resin reinforcement whereas in cast posts group, fractures were non-restorable
Solomon and Osman[2]/2011	Maxillary incisors	4 groups ($N = 100$): Group MC: cast post and core Group GF: glass-fiber post and composite resin core Group CF: carbon fiber post with composite resin core Group Ti: prefabricated parallel-sided titanium post and composite resin core	It was concluded that cast post and cores have remarkably higher fracture resistance compared to fiber post groups. No considerable difference was found among other groups
Ayad et al[17]/2010	Maxillary central incisors	7 main groups: ($N = 140$), Control: no irrigant 20% lactic acid 10% lactic acid 15% EDTA[a]	The highest mean values were observed for the group with 20% lactic acid and reinforced with composite resin with values about 100.7% higher than the group with lowest resistance (5% sodium

Table 1 (*Continued*)

Authors/year	Tooth	Groups	Results
		5% Hydrogen peroxide 5% Sodium hypochlorite Combination (5% hydrogen peroxide and sodium hypochlorite) Each group was divided into 2 subgroups according to restorative materials and each sub group was divided into 2 sub subgroups according to dowel type: Subgroup 1: $n = 10$, composite resin cement Subgroup2: $n = 10$, Glass ionomer Subsubgroup 1: Titanium alloy dowel (control) Subsubgroup 2: Quartz fiber-reinforced dowel	hypochlorite-treated group reinforced with glass ionomer). Application of composite resin increased the fracture resistance in comparison to glass ionomer. Groups filled with quartz fiber-reinforced dowels showed the highest mean fracture resistance
Kivanç et al[11]/2009	Maxillary central incisors	3 groups ($n = 165$): Group 1: $n = 55$, 1.0-mm circumferential dentin Subgroup R: $n = 11$, Polyethylene woven fiber post Subgroup L: $n = 11$, Composite resin cured by light-transmitting post + Glass fiber post Subgroup E: $n = 11$, Electrical glass fiber post Subgroup C: $n = 11$, composite coronoradicular restoration Subgroup M: n-11, cast metal post Group 2: $n = 55$, 2.0-mm circumferential dentin Subgroups R, L, E, C and M Group 3: $n = 55$, 1.5-mm circumferential dentin Subgroups R, L, E, C and M	For each group, fracture resistance ranges from low for the composite coronoradicular restoration group to high for the cast metal post group. Fracture strength was higher for teeth restored with cast metal posts than for fiber posts and all composite coronoradicular restoration groups. Moreover, no notable difference in fracture strength between the different fiber post materials and between composite coronoradicular restorations was seen
Marchi et al[13]/2008	Bovine incisor roots	24 groups ($N = 288$), each $n = 12$ 2 main groups: submitted or not to thermomechanical aging, each have 4 subgroups: custom cast core composite resin core prefabricated metallic post prefabricated carbon fiber post, each subgroups has 3 subsubgroups: intact, semi-weakened, weakened	The greatest and lowest fracture resistance was observed for roots filled with custom cast cores and carbon fiber posts, respectively
Liang et al[25]/2007	Maxillary central incisors	2 groups ($n = 12$) Control group: Ni-Cr post–core Group 2: 1.0-mm thick layer of dual-cured RBC[b] encircling a Ni-Cr post–core	Group 2 fractured under a significantly higher mean force
Maccari et al[12]/2007	Anterior teeth	3 groups ($N = 30$), Group A: Quartz Fiber- Reinforced Resin post Group B: Glass Fiber- Reinforced Resin Post Group C: Cast Metal post	The mean load value was significantly higher for cast metal post group. No difference in fracture strength amount between groups A and B was observed. All fractures in fiber-reinforced resin posts restorations were repairable. 7/10 teeth restored with cast posts had irreparable fractures
Wu et al[26]/2007	Maxillary central incisors	3 groups ($N = 21$), Group 1(control): cast post–core Group 2: dual-cured RBC[b] + cast	A remarkable higher mean force was required to fracture the roots reinforced with RBC than for the control group and

(*Continued*)

Table 1 (*Continued*)

Authors/year	Tooth	Groups	Results
		post–core Group 3: ChemFil Superior GIC[c] + cast post–core	group3. A significantly higher micro tensile bond strength is observed for RBC than GIC. All of the roots in Group 1 and five of Group3 fractured in the cervical region and four of the roots in Group 2 fractured at the apices of the posts
Goncalves et al[14]/2006	Maxillary incisors	6 groups (*N* = 48), Control group (C): cast CuAl posts CP group: Weakened roots and CuAl posts LT group: light-transmitting polymerization post (Luminex) + Tetric Ceram resin + prefabricated titanium post (PTP) LF group: Luminex posts + Filtek Supreme resin + PTP LZ group: Luminex posts + Z100 resin + PTP LR group: Luminex posts + Renew resin + PTP	There is a statistical difference ($P < .01$) between the control group and the CP group that had the lowest fracture resistance. No notable difference was reported among control group specimens and LT group, LF group, LZ group, and LR group
Newman et al[8]/2003	Maxillary central incisors	3 main groups: (*N* = 90) Group 1,4 (Control): (*n* = 10), Parapost XH 1.5-mm stainless steel Narrow group: (*n* = 40), 4 subgroups (*n* = 10), Group 1,1: FibreKor 1.5-mm Glass fiber Group 1,2: Dentatus Luscent anchors 1.6-mm Glass fiber Group1,3: Ribbond standard 1.6-mm Woven polyethylene fiber Group1,5: Ribbond Nonstandardized 1.6-mm Woven polyethylene fiber Flared Group (with thin-walled canals): (*n* = 40), 4 subgroups (*n* = 10), Group 2,1: FibreKor 1.5-mm Glass fiber Group 2,2: Dentatus Luscent anchors 1.6-mm Glass fiber Group 2,3: Ribbond standard 1.6-mm Woven polyethylene fiber Group 2,5: Ribbond Nonstandardized 2.0-mm Woven polyethylene fiber	The ParaPost control group had the highest load value. The mean load value for narrow canal groups varies from low for the Ribbond standard to high for the Luscent anchors, while for flared canal groups it ranges from low for FibreKor to high for both Luscent anchors and Ribbond standard groups. The statistical difference among narrow groups was notable while it was not significant for flared groups. The Ribbond standard groups were highly weaker than the nonstandardized Ribbond
Akkayan and Gülmez[18]/2002	Maxillary canines	4 groups (*N* = 40), Group 1: Titanium posts 1.60 mm Group 2: Quartz fiber posts 1.70 mm tapered form Group 3: Glass fiber posts 1.50 mm Group 4: Zirconia posts 1.70 mm	The highest mean failure load was measured for quartz fiber posts (group 2). Glass fiber and zirconia posts (groups 3 and 4) restorations were statistically similar. Fracture in groups 1 and 4 were unrestorable while repairable fractures were seen in group 2 and 3

[a]Ethylenediaminotetraacetic acid.
[b]Resin-based composite.
[c]Glass–ionomer cement.

based composite (RBC) or GIC both lead to a better function than a cast post alone. Also, short FRCs have been found to be promising as a core for structurally compromised teeth compared with dual-cured core build-up composite.[27]

Effect of the Thickness of Dentin and Post Length on the Fracture Resistance of Endodontically Treated Teeth

Regarding the remaining dentin thickness, generally, weakened roots have a lower fracture resistance than nonweakened roots.[24,28,29] Kivanç et al[11] found that fracture resistance was highly influenced by the remaining dentin thickness in fiber post groups, although not significant. In contrast, in groups with cast metal posts, load failure was affected by axioproximal dimension of dentin walls and the cast metal posts with dentin thickness of 2.0 mm showed fewer values than that of 1.0 and 1.5 mm.

Da Rosa et al[30] reported that favorable failures were most predominant in partially weakened teeth with a glass fiber post, followed by the groups with healthy roots and a glass fiber post, and groups with extensively weakened teeth and glass fiber post plus five accessory glass fiber posts.

In a study by Junqueira et al,[31] glass fiber posts with different lengths were utilized in nonweakened, medium weakened, and highly weakened roots and no significant alteration in fracture resistance due to neither post length nor root dentin thickness was observed, although the relation between length and dentin thickness were remarkably related. However, Amarnath et al[23] reported that as the post length increased, the fracture resistance was higher to an extent of two-thirds of the root length and core debonding occurred in short-length posts. In contrast, Seto et al[32] study demonstrated that the 3-mm post length had higher fracture resistance than 7 mm.

According to Newman et al,[8] there was no significant difference between flared or narrow canals and mean load fractures of the post systems used, except for the Ribbond standard groups. For the narrow canal roots, the highest mean load value required for fracture was for the glass fiber posts, and in the flared canal groups it was for both glass fiber posts and woven polyethylene fibers, respectively (►**Table 2**).

Discussion

The main purpose of post and cores is to contribute to retaining endodontically treated and thin-walled teeth. Numerous materials and techniques have been recommended for using posts for ETT due to the high demand for appropriate treatment. Metallic cast posts, zirconia posts, titanium and stainless steel posts, and nonmetallic dowels such as carbon, glass, quartz, or polyethylene fiber-reinforced post systems are utilized. Also, in case of immature teeth with open apices, large caries or trauma lead to thin and weak dentinal walls, thereby intraradicular reinforcement of immature teeth after apexification is a concept that has been found to improve the tooth's function and maintenance.[33]

The aim of this review was to compare and evaluate studies that examined at least two different post materials, in order to select materials that may improve the retention in root canals.

According to the findings in this study, cast posts and cores are more rigid than fiber posts and are able to resist higher loads. An explanation might be that custom cast cores comprise homogenous structures with a high modulus of elasticity

Table 2 Effect of the thickness of dentin and post length on the fracture resistance of endodontically treated teeth

Authors/year	Tooth	Groups	Results
Veeraganta et al[9]/2020	Mandibular first premolars	Two main groups ($N=64$) based on one or two residual walls ($n=32$): Each groups has two sub groups based on post material (Glass fiber post of Titanium post) ($n=16$) Each subgroup divides into two subsubgroups ($n=8$): 70 or 90 ISO size diameter	Regarding post diameter, groups with increased diameter exhibited more resistance. Also, there was no statistically significant result between 1 or 2 residual walls
Junqueira et al[31]/2016	Bovine roots	9 groups ($N=90$), each $n=10$, with glass fiber posts NW: Nonweakened, MW: Medium weakened, HW: Highly weakened Post length: 7, 9, and 12 mm	Although no change in fracture resistance due to either post length ($P=0.784$) or root dentin thickness was observed, interaction between length and dentin thickness are remarkably related
Amarnath et al[23]/2015	Mandibular premolars	6 groups ($N=60$): Group 1: Stainless-steel post(SS), 4-mm post length Group 2: SS, 7-mm post length Group 3: SS, 10-mm post length Group 4: Glass fiber post (FP), 4-mm post length Group 5: FP, 7-mm post length Group 6: FP, 10-mm post length	Post length of 7 mm in SS groups and 10 mm in FP groups showed the highest mean resistance. 4-mm length had the lowest rate for both post types

(*Continued*)

Table 2 (*Continued*)

Authors/year	Tooth	Groups	Results
Balkaya and Birdal[1]/2013	Maxillary incisors	9 groups (*N* = 90), 4 groups without root canal enlargement: C1.3: tapered end cast posts of 1.3 mm C1.7: tapered end cast posts of 1.7 mm F1.3: tapered end fiber posts of 1.3 mm F1.7: tapered end fiber posts of 1.7 mm 5 groups with root canal enlargement: LF1.3: restored with low viscosity composite resin with fiber posts of 1.3 mm LF1.7: restored with low viscosity composite resin with fiber posts of 1.7 mm SF1.3: self-adhesive resin cement with fiber posts of 1.3 mm SF1.7: self-adhesive resin cement with fiber posts of 1.7 mm C4: parallel cast posts of 4 mm	For the cast posts it was higher with 1.3 mm diameter than for 1.7-mm posts whereas, for the fiber posts it increased as the diameter also increased. The teeth restored with composite resin and fiber posts demonstrated higher fracture resistance than those with fiber posts alone (F1.3, F1.7). Also, no significant difference was found between roots with and without space enlargement and their interaction with post diameters. The parallel-sided cast posts (C4 group) had the highest fracture resistance
Seto et al[32]/2012	Maxillary anterior teeth	7 groups (*N* = 75): Group 1 (Negative control): intact (n = 5) Group 2 (Positive control): 3 mm drilled below CEJ, no restoration (n = 5) Group 3 (Positive control): 7 mm, no restoration (*n* = 5) Group 4: 3-mm composite (n = 15) Group 5: 3-mm quartz fiber post (n = 15) Group 6: 7-mm composite (n = 15) Group 7: 7-mm quartz fiber post (n = 15)	Groups with 3-mm depth preparation composite and quartz fiber post (group 4, 5) had the highest strength for teeth with thin dentinal walls
Kivanç et al[63]/2009	Maxillary central incisors	3 groups (*n* = 165): Group 1: *n* = 55, 1.0-mm circumferential dentin Group 2: *n* = 55, 2.0-mm circumferential dentin Group 3: *n* = 55, 1.5-mm circumferential dentin	In fiber posts fracture resistance was under influence of the dentin diameter, while for cast metal post groups axioproximal dimension of dentin walls affected the load failure
Zogheib et al[28]/2008	Maxillary canines	3 groups (*N* = 30), control: teeth without weakened roots PWR: partially weakened roots LWR: largely weakened roots	Since the mean load value for groups were significantly different, it was concluded that thinner dentin thickness significantly decreases the fracture resistance of teeth
Marchi et al[13]/2008	Bovine incisor roots	24 groups (*N* = 288), each *n* = 12 2 main groups: submitted or not to thermomechanical aging, each have 4 subgroups: custom cast core composite resin core prefabricated metallic post prefabricated carbon fiber post, each subgroup has three subsubgroups: intact-semiweakened-weakened	Roots with custom cast cores and weakened dentin walls, showed a lower fracture resistance

that imitates the contour of the inner root wall; therefore, they have higher load-bearing capacity.[9] Somehow, in some cases they have been linked to root/crown fractures and also endodontic failures due to their elastic modulus mismatch.[7] Overall, in a retrospective study it was found that after an average of 4-year follow-up, postendodontic treatments with Kurer anchor system metal posts had high survival rates.[34]

Fiber posts have increased the operation of adhesive dentistry due to their benefits such as better bonding to canal surface, simpler placement, and removal during a single office visit, having the same elastic modulus as dentin, and better aesthetic appearance.[29] As stated in the monoblock concept, in order to increase the rigidity of weakened roots after endodontic instrumentation and immature teeth with open apices, a mechanically homogenous unit is required. Therefore, a strong bond between the reinforcement material and root canal as well as a similar modulus of elasticity of the material with the bonding surface will reduce the stress concentration.[35] It has been suggested that post materials with similar elastic modulus to dentin and carbon fiber posts accomplish this aim.[36]

Regarding composite cores, some authors have asserted that restorations with fiber posts and composite resin cores result in a higher fracture resistance in comparison to cast metal post cores due to their elasticity and their applied luting cement.[37,38] It was explained in a study that in contrast to cast posts, between the fiber-reinforced resin posts and the dentin walls, a gap is present. This gap is filled with resin cement that can balance the stress instead of directly transferring it to the root.[12] On the contrary, another study have stated that a fiber post in a wide and flared canal such as immature teeth will fit improperly and the thick layer of resin cement might cause air bubbles entrapment, leading to debonding.[5] Generally, the most frequent failures are due to adhesion when adhesively luted posts are used, which can be related to problems in using techniques. Other causes might be root structure fractures or defects and lack of the ferrule effect. Additionally, root cracks and fractures are by themselves associated with the elastic modulus of posts according to some studies.[39]

Considering the mode of fracture, based on the articles included in this study and a systematic review, in comparison to metal posts, fiber posts have considerably demonstrated less severe root fractures.[10]

Among different post materials, in a systematic review, it has been stated that carbon fiber posts with resin matrix show significantly fewer failure outcomes than cast posts with precious alloys.[40] The fracture resistance of carbon fiber posts may depend on appropriate mechanical retention, and hence a proper bond of adhesive materials to the root canal.[13]

Among different alloys used in posts, titanium alloys have the most corrosion resistance and high fracture resistance, whereas alloys including brass show less strength corrosion resistance.[9,41] In comparison with fiber posts, a systematic review concluded that titanium and fiber posts show similar fracture resistance.[10]

Glass fiber resin post systems that are formed from unidirectional glass fibers embedded in a resin matrix are reported to lower the risk of fractures of restored roots.[42] Elasticity of dentin is 20 Gpa, and glass fiber posts with a 40 Gpa modulus of elasticity would be an ideal post material.[16] Schmitter et al[43] found that glass fiber posts are significantly better than metal screw posts. On the contrary, in a study after performing a 3-year follow-up it was concluded that the survival rate of glass fiber and cast metal posts was similar.[39] Polyethylene woven fibers are materials with woven network that permit wetting of the fibers and resin infusion into the fibers. Therefore, the network effectively transfers the stress through the interface of enamel and adhesive materials to increase the fracture strength of restorative materials.[44] Ribbond materials can be used as individually shaped dowels by placing the pieces into the canal with a technique described by Erkut et al.[45] They are a kind of polyethylene woven fibers that seem to show better maintenance and continuity at the adhesion interface compared with glass fiber or quartz fiber reinforced dowels.[45] They are composed of Leno-woven, which is a special triaxial pattern of cross-linked threads. This lace-like structure improves its durability and adaption to teeth contours. It also increases mechanical interlocking of composite resins to surfaces.[46] Plastic light-transmitting posts were developed aiming to transmit light to the surrounding composite resin as a matrix around metallic posts and reinforcing the remaining flared root canals.[47] Frater et al[21] compared the use of multiple long unidirectional FRC posts and short fiber-reinforced composite (SFRC) post applied with bioblock technique. In the bioblock technique, SFRC post, either packable or flowable, is luted directly as a bulk into the canal, eliminating the use of luting cement. They came to the result that multiple long unidirectional FRC posts have better fracture behavior than SFRC posts. Also, multiple fiber post technique in comparison to a single FRC posts has shown better results.[6,21]

Post diameter has a great influence on post stiffness, but its effect on fracture resistance is yet to be researched. According to some studies, posts with larger diameters are recommended since they have demonstrated higher resistance than less diameter posts, but this is not as important as saving the tooth structure.[9] Also, in some studies evaluating post lengths, no significant difference in fracture resistance between glass fiber posts of different lengths was found.[31,48] Dentin thickness is as well an effective factor. As much tooth tissue as possible should be preserved while restorative procedures since it has been reported that 1 mm of dentin thickness has less fracture resistance under horizontal pressure than 2 to 3 mm dentin walls.[26,49] Another approach with regard to post diameter is the proportional approach where post width should not be larger than one-third of the canal width.[41] Therefore, the dentin tissue around the post impacts fracture strength, mostly when cast metal posts are used.[30] Although during the preparation of root canal for cast posts, more dentin is removed and root walls may be weakened, there is no consensus whether this fact is solely a weak point for cast posts compared with fibers posts. Several other factors such as post material and its modulus of elasticity, diameter, type of cement and post adaptation must be considered.[50]

Considering the intensity of the failure, in most studies, nonrepairable fracture patterns have been seen in teeth filled with cast metal posts, whereas repairable fractures are mostly observed in roots filled with fiber posts. A reason can be that cast posts apply stress directly on the root.[7,31]

In many studies, the ferrule effect is suggested to enhance the fracture resistance against functional forces and wedge effect of posts and also reduces possible microleakage of cement area in teeth with enough remaining supragingival structure.[51,52] However, in a recent systematic review it was assumed that no conclusive evidence suggesting that ferrule effect significantly reduce fractures is available.[53] In many clinical conditions, the teeth might be obliquely broken or have lost the coronal walls. Methods such as crown lengthening and orthodontic forced eruption methods are performed to provide more tooth structure in this cases. However, it is unclear whether it is also useful in case of oblique fractures. Meng et al found that these methods decreased the fracture resistance of teeth with oblique fractures.[54] Further clinical studies comparing teeth with or without ferrule is needed.

RBCs increase the thickness of the dentin walls. Also, it is assumed that having the same elastic modulus as dentin for these reinforcing materials as well as posts can help the tooth withstand functional forces.[26] In composite resin restorations, a bond is formed with the dentin tubules, resulting in production of a hybrid layer and resin tags, which can improve micromechanical retention.[17] Amin et al[55] found that relining the post with composite resin increases the resistance compared with using a bulk of luting cement. GICs also can improve fracture resistance of root canaled teeth with thin-walled roots.[26] Failure in resistance might be ascribed to inconvenient application or fracture of the composite resin layer.[12]

The studies that we reviewed has some limitations such as not studying full crowns or the absence of the periodontal ligament that may affect the failure modes and further investigations are needed to clarify the effects of these conditions. Another limitation concerns the fact that in most studies tests were performed on single-rooted and different anterior teeth. Specific post preparations and similar methods of compressive pressure were used but in various angles. This might differ from the natural occlusion forces on teeth.

Conclusion

Within the limitations of this study, the following can be concluded:

- It seems that cast posts, despite their need for more root canal dentin removal, show higher fracture strength when used for ETT treatment.
- Quartz fiber posts, glass fiber posts, and Ribbond customized posts can preferably be used as an alternative to zirconia and titanium posts due to their advantages.
- Stainless steel posts show the highest fracture resistance in studies that compared them to other materials including fiber posts and cast posts.
- Applying a layer of composite and resin tag formation through the root canal can increase the fracture resistance.

It is still a matter of controversy over which post length is more effective.

Author's Contribution
R.G. contributed in study design, data analysis/interpretation, writing of the manuscript. N. A. contributed in study design, collection of data, data analysis/interpretation, writing of the manuscript. N.A. contributed in collection of data, data analysis/interpretation, writing of the manuscript and M.M.K. contributed in collection of data, data analysis/interpretation, writing of the manuscript.

Conflict of Interest
None declared.

References

1 Balkaya MC, Birdal IS. Effect of resin-based materials on fracture resistance of endodontically treated thin-walled teeth. J Prosthet Dent 2013;109(05):296–303
2 Solomon CS, Osman YI. In vitro comparison of endodontic posts in structurally compromised roots of maxillary incisors. SADJ 2011; 66(05):220–223
3 Bolhari B, Mojazi Amiri E, Kermanshah H, Ghabraei S, Jamei A. Fracture resistance of simulated immature teeth obturated with gutta-percha or Resilon and reinforced by composite or post. J Dent (Tehran) 2015;12(02):125–133
4 Seraj B, Ghadimi S, Estaki Z, Fatemi M. Fracture resistance of three different posts in restoration of severely damaged primary anterior teeth: an in vitro study. Dent Res J (Isfahan) 2015;12(04): 372–378
5 Khadar S, Sapkale K, Patil PG, Abrar S, Ramugade M, Huda F. Fracture resistance and stress distribution pattern of different posts-core systems in immature teeth: an in vitro study and 3D finite element analysis. Int J Dent 2022;2022:2610812
6 Iemsaengchairat R, Aksornmuang J. Fracture resistance of thin wall endodontically treated teeth without ferrules restored with various techniques. J Esthet Restor Dent 2022;34(04): 670–679
7 Wang X, Shu X, Zhang Y, Yang B, Jian Y, Zhao K. Evaluation of fiber posts vs metal posts for restoring severely damaged endodontically treated teeth: a systematic review and meta-analysis. Quintessence Int 2019;50(01):8–20
8 Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent 2003;89(04):360–367
9 Veeraganta SK, Samran A, Wille S, Kern M. Influence of post material, post diameter, and substance loss on the fracture resistance of endodontically treated teeth: a laboratory study. J Prosthet Dent 2020;124(06):739.e1–739.e7
10 Alhajj MN, Qi CH, Sayed ME, Johari Y, Ariffin Z. Fracture resistance of titanium and fiber dental posts: a systematic review and meta-analysis. J Prosthodont 2022;31(05):374–384
11 Kivanç BH, Alaçam T, Ulusoy OI, Genç O, Görgül G. Fracture resistance of thin-walled roots restored with different post systems. Int Endod J 2009;42(11):997–1003
12 Maccari PC, Cosme DC, Oshima HM, Burnett LH Jr, Shinkai RS. Fracture strength of endodontically treated teeth with flared root canals and restored with different post systems. J Esthet Restor Dent 2007;19(01):30–36, discussion 37
13 Marchi GM, Mitsui FH, Cavalcanti AN. Effect of remaining dentine structure and thermal-mechanical aging on the fracture

resistance of bovine roots with different post and core systems. Int Endod J 2008;41(11):969–976
14 Goncalves LA, Vansan LP, Paulino SM, Sousa Neto MD. Fracture resistance of weakened roots restored with a transilluminating post and adhesive restorative materials. J Prosthet Dent 2006;96 (05):339–344
15 Li Q, Yan P, Chen Z. Fracture resistance and failure patterns of open apex root teeth with different posts after endodontic treatment. J Huazhong Univ Sci Technolog Med Sci 2011;31(02):271
16 Vidya V, Deepa CS. A comparative evaluation of the fracture resistance of endodontically treated teeth with compromised intra radicular tooth structure using three different post system. J Adv Prosthodont 2011;3(02):90–95
17 Ayad MF, Bahannan SA, Rosenstiel SF. Morphological characteristics of the interface between resin composite and glass-ionomer cement to thin-walled roots: a microscopic investigation. Am J Dent 2010;23(02):103–107
18 Akkayan B, Gülmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent 2002;87(04):431–437
19 Sharafeddin F, Alavi AA, Zare S. Fracture resistance of structurally compromised premolar roots restored with single and accessory glass or quartz fiber posts. Dent Res J (Isfahan) 2014;11(02): 264–271
20 Dikbas I, Tanalp J, Koksal T, Yalnız A, Güngör T. Investigation of the effect of different prefabricated intracanal posts on fracture resistance of simulated immature teeth. Dent Traumatol 2014; 30(01):49–54
21 Fráter M, Sáry T, Braunitzer G, et al. Fatigue failure of anterior teeth without ferrule restored with individualized fiber-reinforced post-core foundations. J Mech Behav Biomed Mater 2021;118:104440
22 Makade CS, Meshram GK, Warhadpande M, Patil PG. A comparative evaluation of fracture resistance of endodontically treated teeth restored with different post core systems - an in-vitro study. J Adv Prosthodont 2011;3(02):90–95
23 Amarnath GS, Swetha MU, Muddugangadhar BC, Sonika R, Garg A, Rao TR. Effect of post material and length on fracture resistance of endodontically treated premolars: an in-vitro study. J Int Oral Health 2015;7(07):22–28
24 Zogheib LV, Saavedra GdeS, Cardoso PE, Valera MC, Araújo MA. Resistance to compression of weakened roots subjected to different root reconstruction protocols. J Appl Oral Sci 2011;19(06): 648–654
25 Liang BM, Chen Y-M, Wu X, Yip KH, Smales RJ. Fracture resistance of roots with thin walls restored using an intermediate resin composite layer placed between the dentine and a cast metal post. Eur J Prosthodont Restor Dent 2007;15(01):19–22
26 Wu X, Chan AT, Chen Y-M, Yip KH-K, Smales RJ. Effectiveness and dentin bond strengths of two materials for reinforcing thin-walled roots. Dent Mater 2007;23(04):479–485
27 Lassila L, Oksanen V, Fráter M, Vallittu PK, Garoushi S. The influence of resin composite with high fiber aspect ratio on fracture resistance of severely damaged bovine incisors. Dent Mater J 2020;39(03):381–388
28 Zogheib LV, Pereira JR, do Valle AL, de Oliveira JA, Pegoraro LF. Fracture resistance of weakened roots restored with composite resin and glass fiber post. Braz Dent J 2008;19(04): 329–333
29 Manicardi CA, Versiani MA, Saquy PC, Pécora JD, de Sousa-Neto MD. Influence of filling materials on the bonding interface of thin-walled roots reinforced with resin and quartz fiber posts. J Endod 2011;37(04):531–537
30 da Rosa RA, Barreto MS, da Rosa TA, Reis KR, Kaizer OB. Fracture resistance of weakened teeth restored using accessory glass fiber posts. Gen Dent 2013;61(02):45–49
31 Junqueira RB, de Carvalho RF, Marinho CC, Valera MC, Carvalho CAT. Influence of glass fibre post length and remaining dentine thickness on the fracture resistance of root filled teeth. Int Endod J 2017;50(06):569–577
32 Seto B, Chung KH, Johnson J, Paranjpe A. Fracture resistance of simulated immature maxillary anterior teeth restored with fiber posts and composite to varying depths. Dent Traumatol 2013;29 (05):394–398
33 Linsuwanont P, Kulvitit S, Santiwong B. Reinforcement of simulated immature permanent teeth after mineral trioxide aggregate apexification. J Endod 2018;44(01):163–167
34 Tickotsky N, Petel R, Haim Y, Ghrayeb M, Moskovitz M. Post-and-core restoration of severely damaged permanent posterior teeth in young adolescents. Int J Prosthodont 2017;30(05):458–460
35 Tay FR, Pashley DH. Monoblocks in root canals: a hypothetical or a tangible goal. J Endod 2007;33(04):391–398
36 Mortazavi V, Fathi M, Katiraei N, Shahnaseri S, Badrian H, Khalighinejad N. Fracture resistance of structurally compromised and normal endodontically treated teeth restored with different post systems: an in vitro study. Dent Res J (Isfahan) 2012;9(02): 185–191
37 Bateman G, Ricketts DN, Saunders WP. Fibre-based post systems: a review. Br Dent J 2003;195(01):43–48, discussion 37
38 Goracci C, Ferrari M. Current perspectives on post systems: a literature review. Aust Dent J 2011;56(Suppl 1):77–83
39 Sarkis-Onofre R, Jacinto RC, Boscato N, Cenci MS, Pereira-Cenci T. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. J Dent 2014;42(05):582–587
40 Theodosopoulou JN, Chochlidakis KM. A systematic review of dowel (post) and core materials and systems. J Prosthodont 2009; 18(06):464–472
41 Fernandes AS, Shetty S, Coutinho I. Factors determining post selection: a literature review. J Prosthet Dent 2003;90(06): 556–562
42 Souza J, Fernandes V, Correia A, et al. Surface modification of glass fiber-reinforced composite posts to enhance their bond strength to resin-matrix cements: an integrative review. Clin Oral Investig 2022;26(01):95–107
43 Schmitter M, Rammelsberg P, Gabbert O, Ohlmann B, Ohlmann B. Influence of clinical baseline findings on the survival of 2 post systems: a randomized clinical trial. Int J Prosthodont 2007;20 (02):173–178
44 Kemaloglu H, Emin Kaval M, Turkun M, Micoogullari Kurt S. Effect of novel restoration techniques on the fracture resistance of teeth treated endodontically: An in vitro study. Dent Mater J 2015;34 (05):618–622
45 Erkut S, Gulsahi K, Caglar A, Imirzalioglu P, Karbhari VM, Ozmen I. Microleakage in overflared root canals restored with different fiber reinforced dowels. Oper Dent 2008;33(01):96–105
46 Belli S. and G. Eskitascioglu. Biomechanical properties and clinical use of a polyethylene fiber post-core material. Int Dentistry South Afr 2006;8(03):20–26
47 Lui JL. Composite resin reinforcement of flared canals using light-transmitting plastic posts. Quintessence Int 1994;25(05):313–319
48 Franco ÉB, Lins do Valle A, Pompéia Fraga de Almeida AL, Rubo JH, Pereira JR. Fracture resistance of endodontically treated teeth restored with glass fiber posts of different lengths. J Prosthet Dent 2014;111(01):30–34
49 Naumann M, Preuss A, Frankenberger R. Load capability of excessively flared teeth restored with fiber-reinforced composite posts and all-ceramic crowns. Oper Dent 2006;31(06):699–704
50 Martins MD, Junqueira RB, de Carvalho RF, Lacerda MFLS, Faé DS, Lemos CAA. Is a fiber post better than a metal post for the restoration of endodontically treated teeth? A systematic review and meta-analysis. J Dent 2021;112:103750
51 Tan PL, Aquilino SA, Gratton DG, et al. In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. J Prosthet Dent 2005;93(04):331–336
52 Stankiewicz NR, Wilson PR. The ferrule effect: a literature review. Int Endod J 2002;35(07):575–581

53 Batista VES, Bitencourt SB, Bastos NA, Pellizzer EP, Goiato MC, Dos Santos DM. Influence of the ferrule effect on the failure of fiber-reinforced composite post-and-core restorations: a systematic review and meta-analysis. J Prosthet Dent 2020;123(02):239–245
54 Meng Q, Ma Q, Wang T, Chen Y. An in vitro study evaluating the effect of ferrule design on the fracture resistance of endodontically treated mandibular premolars after simulated crown lengthening or forced eruption methods. BMC Oral Health 2018;18(01):83
55 Amin RA, Mandour MH, Abd El-Ghany OS. Fracture strength and nanoleakage of weakened roots reconstructed using relined glass fiber-reinforced dowels combined with a novel prefabricated core system. J Prosthodont 2014;23(06): 484–494
56 Santos TDSA, Abu Hasna A, Abreu RT, et al. Fracture resistance and stress distribution of weakened teeth reinforced with a bundled glass fiber-reinforced resin post. Clin Oral Investig 2022;26(02): 1725–1735
57 Fráter M, Lassila L, Braunitzer G, Vallittu PK, Garoushi S. Fracture resistance and marginal gap formation of post-core restorations: influence of different fiber-reinforced composites. Clin Oral Investig 2020;24(01):265–276
58 Josic U, Radovic I, Juloski J, et al. Can fiber-post placement reinforce structurally compromised roots? J Adhes Dent 2020; 22(04):409–414
59 Öztürk C, Polat S, Tunçdemir M, Gönüldaş F, Şeker E. Evaluation of the fracture resistance of root filled thin walled teeth restored with different post systems. Biomed J 2019;42(01):53–58
60 Cauwels RGEC, Lassila LVJ, Martens LC, Vallittu PK, Verbeeck RMH. Fracture resistance of endodontically restored, weakened incisors. Dent Traumatol 2014;30(05):348–355
61 Wandscher VF, Bergoli CD, Limberger IF, Ardenghi TM, Valandro LF. Preliminary results of the survival and fracture load of roots restored with intracanal posts: weakened vs nonweakened roots. Oper Dent 2014;39(05):541–555
62 Pinho LGND, Vinholi GH, Coelho TK, Neto DJR, Kopplin DC, Silva AL. Evaluation of the fracture resistance of remaining thin-walled roots restored with different post systems. J Res Dent 2013;1(03):184–191
63 Kivanç BH, Alaçam T, Görgül G. Fracture resistance of premolars with one remaining cavity wall restored using different techniques. Dent Mater J 2010;29(03):262–267