Effect of tooth type and ferrule on the survival of pulpless teeth restored with fiber posts: A 3-year clinical study

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ABSTRACT: **Purpose:** To determine, in a 3-year clinical trial, whether tooth type and ferrule significantly affect the survival of pulpless teeth restored with fiber posts. **Methods:** A sample of 87 teeth in 87 patients (32 men and 55 women, age ranged from 23 to 78) were restored using Snowpost: 34 incisors, 12 canines, 25 premolars and 16 molars. The posts were cemented with RelyXUnicem and the core was made with a resin composite (Dentocore Automix). Every tooth was covered with a metal-ceramic or all ceramic crown. Two experimental groups, according to the presence or absence of ferrule, were defined: A) 45 teeth with ferrule (>2 mm height); and B) 42 teeth without ferrule (<2 mm height). Patients were reevaluated every 6 months. **Results:** 14 of the total restorations failed (16.1%). The failure modes were caries (n= 4), post fracture (n= 4), root fracture (n= 2), and marginal gap, post cement failure, crown cement failure, and periapical lesion (n= 1 respectively). In Group A the failure observed was 6.67% and in Group B it was 26.20%. The log-rank test showed statistically significant differences between both groups. According to the type of tooth, the incisors were the teeth with the highest failure rate (73.52%), but Chi-square test showed no statistically significant differences among the four tooth types, perhaps because of the low number of the sample. (*Am J Dent* 2010;23:351-356).

CLINICAL SIGNIFICANCE: In endodontically treated teeth restored with adhesive techniques and fiber posts, the presence of ferrule results in better clinical survival after 3 years of clinical service.

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Introduction

The changes in endodontically treated teeth can be attributed to the modifications that occur at different levels: tissue composition, dentin micro and macro-structure and tooth structure. It has been suggested that endodontically treated teeth are more brittle and may fracture more easily than vital teeth.[1-3] However, the literature does not support the widely held belief that attributes particular weakness or brittleness to non-vital dentin. It is believed that it is the loss of tooth structure due to caries, trauma or endodontic therapy that makes endodontically treated teeth more susceptible to fracture.[4-11] Some clinical studies show a relationship between the prognosis of postendodontic restorations and factors such as type of occlusion,[12] tooth type and position in the dental arch,[13-16] type of final restoration,[17-19] type of abutment,[15] existence of proximal contacts,[20] and degree of hard tissue loss at the coronal level.[13,16,21-29] In addition, the importance of preserving a circumferential dentin collar of at least 2 mm height (ferrule effect) to increase tooth resistance to fracture has been emphasized.[30-36] The preparation of a post space and the placement of a post can also weaken the root and may lead to root fracture.[13,37-39] These studies suggest that a post should be used only when there is not enough tooth substance remaining to support the final restoration,[40-42] according to tooth type and its occlusal function.

It's worth pointing out two factors, ferrule effect and tooth type. According to Sorensen & Engelman[35] ferrule effect is defined as "a 360° metal (or ceramic) collar of the crown surrounding the parallel walls of the dentin extending coronal to the shoulder of the preparation". The concept was proposed in 1961 by Rosen,[43] who thought that this extension of the restored crown, by its hugging action, prevents shattering of the root. Many studies *in vitro* indicate that ferrule effect reduces the incidence of root fracture and makes it occur in a more favorable way.[34,44-47] The fracture resistance increases with the ferrule length. The minimum effective ferrule length should be 1.5 mm of coronal dentin extending beyond the preparation margin,[35,36,48] or 2 mm.[32,49,50] And teeth with a uniform ferrule were more fracture resistant compared to teeth with nonuniform ferrule heights.[33] According to Stankiewicz & Wilson,[30] a suitable classification would be "less than" or "at least" 2 mm-ferrule length. Two prospective clinical trials include the ferrule effect investigation. Both Ferrari *et al*[29] and Cagidiaco *et al*[51] observed that failure risk was significantly higher for teeth that had lost all coronal walls. However, similar failure risks existed for teeth missing all the coronal walls, regardless of the presence or absence of a ferrule effect.[51] The influence of the ferrule effect on multirooted teeth needs further research. In *in vitro* studies only single rooted teeth have been investigated.

As for the type of tooth, the need for a post varies greatly between the anterior and posterior teeth.[40,52] Anterior teeth and premolars are more likely to be subjected to lateral forces during mastication than molars, so they more often need a post. However, many studies do not agree about the survival functions of the different tooth types. Piovesan *et al*[53] observed that there were no differences between anterior and posterior teeth. In other retrospective reports[54,55] premolars were found to be the most frequently fractured teeth. Glazer's prospective study[56] observed that premolars have a higher risk to fail than anterior teeth. It is in contrast with Schmitter[57] and Naumann *et al*[13] who reported failures more frequent in anterior teeth.

Criteria to select the ideal post should include strength, modulus of elasticity, retention, biocompatibility, esthetics and retrievability. Recently, new treatment approaches using more flexible, fiber reinforced materials combined with the advantages of the adhesive technique have been introduced. It is believed that the creation of a mono-block dentin-post-core system through the dentin bonding would allow better distribution of forces along the root. Therefore if excessive

loads are applied to the tooth, the post will be able to absorb stresses, reducing the possibility of root fracture. The mechanical behavior and related mechanisms of failure of fiber posts and metallic posts have been compared. The major disadvantage associated with metallic post is non-retrievable root fracture.[58-69]

Only a few retrospective[70-76] and prospective [13,16,18,29,56,77-80] clinical trials have been conducted to assess the survival of endodontically treated teeth by using fiber posts *in vivo*. According to differences in study design, follow-up periods, inclusion criteria and number of subjects, different rates and modes of failure have been recorded. Maximal failure registered ranged between 8% in a retrospective investigation[70] and 12.8% in a prospective study.[16]

The present study evaluated the survival of fiber posts in teeth in the presence or absence of ferrule effect, and the influence of tooth position in dental arch, age and sex. The research hypothesis was that, using fiber posts in pulpless teeth, these different baseline factors would give equivalent failure rates and failure modes.

Materials and Methods

A total of 87 subjects were included in the trials, 32 men and 55 women, who visited a private dental office between February 2004 and June 2008 and needed restoration of endodontically treated teeth. The follow-up period ranged between a minimum of 377 and a maximum of 1585 days. The average was 1027 days (about 2.8 years). We excluded from the study patients with periodontal disease or caries high risk. Only one tooth per subject was considered for the study. Written informed consent was obtained from the individuals after they had received a clear explanation of the purpose of the trial, according to a protocol approved by the School of Dentistry at the University of Seville, Spain. The individuals' ages ranged from 23 to 78, with an average of 53. The selected teeth needed to be in occlusal function with a natural tooth, and in interproximal contact with at least one adjacent natural tooth. Teeth were not used as abutments for fixed or removable partial dentures. If the teeth had already been endodontically treated, the inclusion criteria (symptom-free root canal filling and a minimum apical seal of 4 mm, without any periapical lesion on the radiograph) had to be met. All the clinical procedures were performed by the same operator, who had more than 15 years experience.

Two experimental groups were defined as follows, based on the amount of dentin left at the coronal level up to the shoulder of the preparation, before the abutment was built-up: 1) ferrule present (a dentin collar of at least 2 mm height and minimal 1 mm thickness, as measured with a periodontal probe, was preserved circumferentially), 45 teeth (51.7%); 2) ferrule absent (less than 2 mm of dentin was present circumferentially), 42 teeth (48.3%). Distribution of 87 treated teeth according to type is shown in Table 1.

Only one post was placed in each tooth. We selected the distal root for mandibular molars, and the palatal root for maxillary molars and premolars with two canals. The selected teeth must have lost more than 50% of coronal structure in volume.[56,81]

The following data were collected at the baseline examination: patient age and sex, follow-up period, tooth type, presence or absence of ferrule. The restorations of 87 teeth were metal-ceramic and all-ceramic crowns.

Table 1. Distribution of teeth and presence or absence of ferrule.

Jaw	Incisors	Canines	Premolars	Molars
Maxilla	34	12	14	5
Ferrule present/absent	17/17	7/5	7/7	4/1
Mandible	0	0	11	11
Ferrule present/absent	0/0	0/0	4/7	6/5
Both	34	12	25	26

Clinical procedures - Snowpost[a] posts were used. These posts are made of zircon-rich glass fiber embedded in an epoxy resin matrix, and are silanated during fabrication. The posts are tapered, 19 mm long and are available in four sizes (1.0, 1.2, 1.4, 1.6 mm diameter).

After at least 7 days of endodontic treatment, used as an evaluation period, the gutta-percha was removed with Largo-Peeso drills numbers 1-6[b] and excavators (LM 612-622 XSi[c]), leaving at least 4 mm of intact apical seal.[82-85] The drill working length was controlled with silicone stops. Prior to cavity preparation, a rubber dam was placed if it was possible. The walls of the root canals were enlarged with low-speed burs provided by the manufacturer, following the criteria of maximum conservation of the residual dental tissue. The post was chosen according to the canal diameter, not to the root one. Then the post was reduced to the proper length outside of mouth using a diamond disk. The root canal was treated with 5% sodium hypochlorite to make cement more efficient and coronal dentin was etched with 37% phosphoric acid for 15 seconds, rinsed with a water spray and dried with air and paper points. The cementation procedure was performed according to the manufacturers' instructions. RelyXUnicem[d] was the cement used. This automixed cement was applied inside the canal and on the post surface. The post was seated immediately, and the excess cement was removed. Light-curing was performed on the post for 90 seconds with a high-power LED curing light (Demetron II[e]). Core build-up was then performed using an all-in-one light-curing adhesive for enamel and dentin (Excite[f]) and a flowable resin composite (Dentocore Automix[g]). Then, the abutment was prepared with diamonds burs and a chamfer finish. It was covered with a metal-ceramic or all-ceramic crown, cemented also with RelyXUnicem. The period between the core build-up and crown placement was about 7 days. A provisional composite crown was always used.

Evaluation parameters - All the individuals were evaluated every 6 months. The rate of success was assessed by the same operator through clinical and intraoral radiographic examinations. Clinical evaluation includes visual inspection conducted with magnifying loupes (x3 magnification) with fiberoptic coaxial illumination (Zeon Illuminator[h]), examination of the continuity of the margins of the restoration by use of an explorer (EXTU17/236[i]), and photographic examination (Canon EOS 350D digital[j]). The triple examination was performed immediately before restoration, after restoration and in every revision. Radiographs were taken with a parallel technique (Super-Bite[e]) using a digital radiography system (Digora Optime[k]).

The following events were considered as failures:

- Root fracture was noted when, after extraction, a fracture line was evident at inspection.

Table 2. Causes of failure.

Failure	Total	Incisors	Canines	Premolars	Molars
Caries	4	3	0	1	0
Crown decementation	1	0	0	1	0
Post decementation	1	1	0	0	0
Root fracture	2	2	0	0	0
Post fracture	4	3	0	0	1
Periapical	1	0	0	0	1
Marginal gap	1	0	0	0	1
Total	14	9	0	2	3

Table 3. Contingency table and Chi-square test for type of tooth.

Contingency table type of tooth/survival

			Survival	Failure	Total
Type of tooth	Incisor	At recall	25	9	34
		Survival %	34.2%	64.3%	39.1%
		Tooth type %	73.5%	26.5%	100.0%
	Canine	At recall	12	0	12
		Survival %	16.4%	.0%	13.8%
		Tooth type %	100%	.0%	100.0%
	Premolar	At recall	23	2	25
		Survival %	31.5%	14.3%	28.7%
		Tooth type %	92%	8%	100.0%
	Molar	At recall	13	3	16
		Survival %	17.8%	21.4%	18.4%
		Tooth type %	81.2%	18.8%	100.0%
Total		At recall	73	14	87
		Survival %	100.0%	100.0%	100.0%
		Tooth type %	83.9%	16.1%	100.0%

Chi-square test type of tooth

	Value	gl	Exact sig. (bilateral)	Exact sig. (unilateral)
Pearson's chi-square test	6.310	3	.093	
Likelihood ratio	8.088	3	.060	
Fisher's exact test	5.796		.105	
Linear-by-linear association	1.384	1	.264	.148
Valid cases	87			

- Post fracture was defined as a separation of two post parts at inspection.
- Post cement failure was defined as a separation of the post-core restoration from tooth structure.
- Crown cement failure was defined as a separation of the crown from post-core.
- Marginal gap formation between tooth and restoration was defined as a radiographic visible opening between tooth structure and restoration and reachable by the explorer.
- Clinical evidence of secondary caries contiguous with the restoration margin was reported when the presence of caries close to the restoration margin was clinically or radiographically observed.
- Periapical lesion was defined as the presence of radiolucent periapical lesion on radiograph.

Evaluation of success or failure was performed by one previously trained examiner. "Repairable" and "non-repairable" failures were differentiated.

Statistical analysis - Calculations were performed using SPSS 14.0 software.[1] Additionally, Pearson's chi-square test was applied to compare frequencies of failure and to investigate the baseline factors' influence on survival rate (patient age and gender, follow-up period and tooth type). The Kaplan-Meier plots were constructed; the Mantel-Cox regression analysis (log-rank test) was applied to compare the survival distribution of two samples. It assesses the influence on failure rate of the presence or absence of ferrule. The level of significance was set at $P< 0.05$.

Table 4. Contingency table and Chi-square test for present/absent ferrule.

Contingency table ferrule/survival

			Survival	Failure	Total
Ferrule	Absent	At recall	31	11	42
		Survival %	42.5%	78.6%	48.3%
		Ferrule %	73.8%	26.2%	100.0%
	Present	At recall	42	3	45
		Survival %	57.5%	21.4%	51.7%
		Ferrule %	93.3%	6.7%	100.0%
Total		At recall	73	14	87
		Survival %	100.0%	100.0%	100.0%
		Ferrule %	83.9%	16.1%	100.0%

Chi-square test ferrule/survival

	Value	gl	Exact sig. (bilateral)	Exact sig. (unilateral)
Pearson's chi-square test	6.133	1	.019	.013
Continuity Correction	4.772	1		
Likelihood ratio	6.420	1	.019	.013
Fisher's exact test			.019	.013
Valid cases	87			

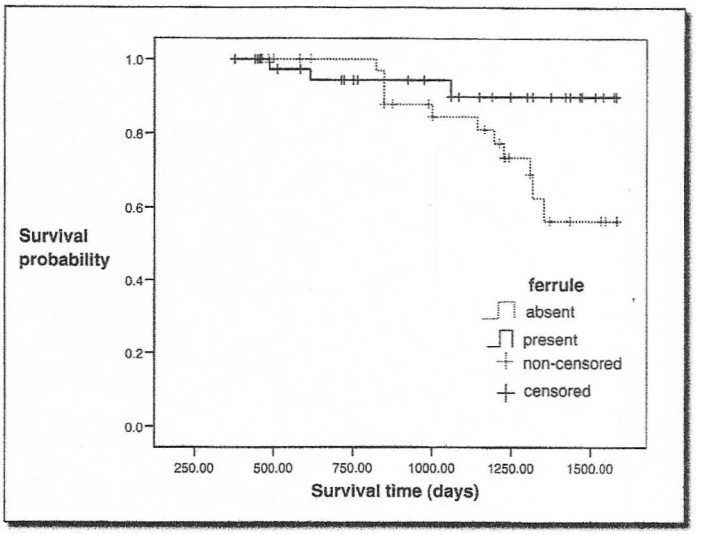

Fig. 1. Kaplan-Meier survival curves according to present/absent ferrule.

Results

Data were not affected by any loss to follow-up. Of the 87 teeth, 73 survived, and 14 failed. The overall 3-year survival rate of crowned endodontically treated teeth was 83.9%. The causes of failure are shown in Table 2. All failures except "root fractures" were repaired.

According to patients' sex, success occurred in 81.25% males and 85.45% females. On applying Chi-square test, no statistically significant differences were found. The patients' age has no statistically significant difference when using Chi-square test. According to the type of tooth, incisors were the teeth which were mostly used (34), 9 of which failed. This is the most important failure range (73.52%), although no significant differences were found with Chi-square test (Table 3). The presence or absence of ferrule showed statistically significant differences ($P< 0.05$). Of a total of 45 treated teeth

with ferrule, 42 succeeded (mean 93.33%) and of 42 without ferrule, 31 succeeded (mean 73.80%) (Table 4). The Kaplan-Meier survival curves were constructed for both groups (presence or absence of ferrule) and the survival was compared with a log-rank test (Fig.1).

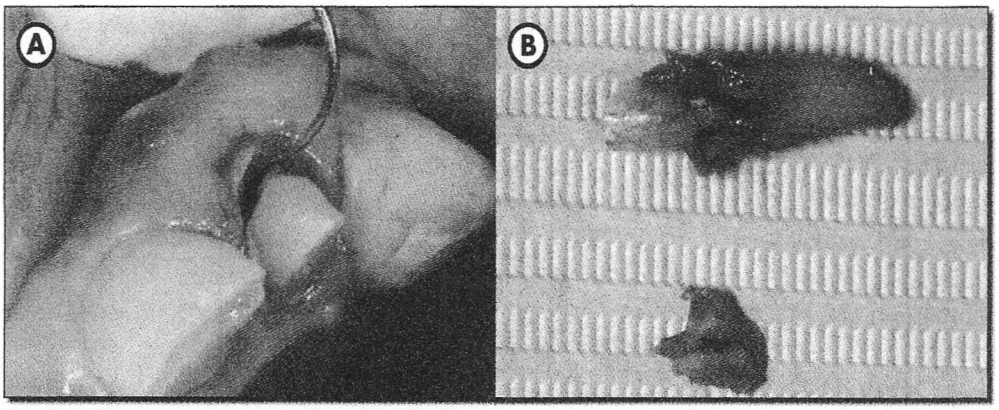

Fig. 2**A.** The explorer assesses the separation between the root fragment and the post in a maxillary left lateral incisor. The crown appeared debonded. **B.** The same case after extraction.

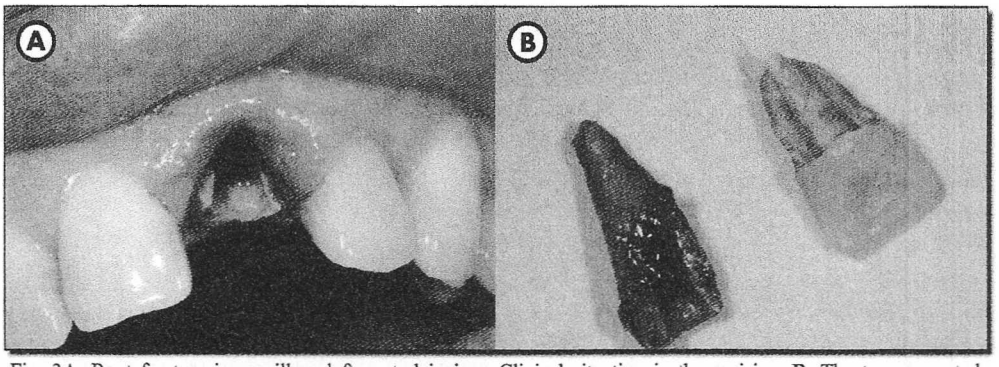

Fig. 3**A.** Root fracture in maxillary left central incisor. Clinical situation in the revision. **B.** The two separated fragments after extraction

Discussion

The present study was designed specifically to assess whether the presence or absence of ferrule and tooth type in arch, and the placement of a fiber post had any influence on survival functions. This way, other variables such as post type, core material, cement material, and presence of antagonist and adjacent teeth were standardized to homogenize the sample.

The first relevant finding in our investigation was that the global clinical survival range, 83.9% in 3 years, is not an outstanding value, compared to other trials. It would not be a recommended treatment with such a high failure risk (16.1%). However, when teeth have a dentin collar of more than 2 mm height, the survival rate improved up to 93.33%. This lower risk of failure agreed with the previous clinical reports. A ferrule has been defined as a 1.5 to 2 mm high vertical band of tooth structure which helps to retention and provides a resistance form, increasing fracture resistance and enhancing the longevity of the restoration.[86] Forces concentrate at the crest of the bone during mastication.[87] This protective effect could occur because the ferrule resists stresses such as functional lever forces, the wedging effect of tapered posts and the lateral forces exerted during the post insertion.[35] Besides, the cement area between core and dentin could be the most fragile both in response to occlusal loads and in possibilities of microleakage. The presence of ferrule would avoid the direct exposure of this area and would reduce the risk of lesions. Ferrari *et al*[29] and Cagidiaco *et al*[51] observed that failure risk was significantly higher for teeth that had lost all coronal walls. However, similar failure risks existed for teeth missing all the coronal walls regardless of the presence or absence of a ferrule effect.[51] In this trial, after 3 years of clinical service, failure risk of fiber posts increased significantly for teeth without ferrule effect. With independence of the rest of variables, it seems that the more tooth structure remains the more success is possible.

In the present study, age and gender had no influence on survival range. It seems endodontically treated teeth are not different considering the variables of time and sex.

In this trial, the incisors were the teeth with the highest failure rate, but not statistically significant (P= .093). This agreed with the Schmitter[57] and Naumann *et al*[13] studies that considered failure more frequent in anterior teeth. This could be position in arch, the vertical overlap level and the frequent loss of posterior teeth. We would need to include other variables and a greater number of samples to obtain definitive conclusions. In this study, incisors (39%) and premolars (28%) were the most used pulpless teeth, *versus* molars (18%) and canines (13%). Molars resist vertical forces and the loss of structure from caries or trauma is not as important. Canines do not usually suffer a significant loss of structure. This corroborates that it is the loss of structure and the functional requirements which recommend the use of a post.

In the present trial, caries was the most frequent failure (four cases). This agreed with several studies[88-92] which assessed that caries was the most frequent clinical complication in fixed prosthodontics. Caries could not be a consequence of using fiber post or baseline factors, but of the patient's hygiene. All the cases could be solved. Post fracture was also the most common failure observed in this study (four cases). This agreed with Naumann *et al*[16] and it may be related to the rather low fatigue resistance of the post used.[93] Three out of four cases occurred in maxillary incisors with absent ferrule. All the cases took place at the end of the follow-up period. Only one case of post debonding occurred. It happened at the beginning of the study. Post dislodgment is usually the result of an adhesive failure from a marginal gap formation which exists between the tooth and the restoration, or a consequence of an incorrect root canal cleaning and preparation for adhesion. The failure could be solved, and the same post was bonded again. The periapical lesion required endodontic retreatment. Crown cement failure and marginal gap formation could be solved and the teeth were maintained in clinical service.

In disagreement with other fiber post studies, two cases of root fractures were observed. None of them could be recovered,

(Fig. 2) occurred in a patient with a complete mandibular arch and a very reduced maxillary arch, with bruxing habits, in a maxillary left lateral incisor without ferrule. It took place 6 months after the beginning of the study. The occlusal imbalance and the absence of ferrule might be the reasons for its failure. The second one (Fig. 3) occurred in a maxillary left central incisor, with a previous cast post treatment, in a completely dentate patient. It happened after 1 year of being placed. This tooth had an at least 2 mm high ferrule. Its failure might be a consequence of non-observed microfractures by the retreatment. Besides, flared canals could be more susceptible to fracture because of the thin walls remaining. The Ferrari *et al*[71] study showed a significant difference in failure rate between teeth restored with cast posts and cores and fiber post-retained restorations. Nine percent of the cast posts had root fracture.

The incapacity of the applied statistical test to identify any significant outcome may be primarily related to the relatively rare occurrence of failures and the short follow-up period. A study with a larger sample and a longer follow-up period could permit identification of the real reasons for failure and plan for future treatments.

Further studies should evaluate some essential baseline factors regarding occlusion determinants (type of occlusion, canine or group guidance, horizontal and vertical overlap, absent/present teeth, and absent/present parafunction).

a. Carbotech, Ganges, France.
b. Dentsply Maillefer, Ballaigues, Switzerland.
c. LM Dental, Parainen, Finland.
d. 3M Espe, St. Paul, MN, USA.
e. Kerrhawe, Bioggio, Switzerland.
f. Ivoclar-Vivadent, Schaan, Liechtenstein.
g. Itena, Paris, France.
h. Orascopic Research, Madison, WI, USA.
i. Hu-Friedy, Leiman, Germany.
j. Canon, Tokyo, Japan.
k. Soredex, Tuusula, Finland.
l. SPSS Inc., Chicago, IL, USA.

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References

1. Baraban DJ. The restoration of pulpless teeth. *Dent Clin North Am* 1967; 633-653.
2. Carter JM, Sorensen SE, Johnson RR, Teitelbaum RL, Levine MS. Punch shear testing of extracted vital and endodontically treated teeth. *J Biomech* 1983;16:841-848.
3. Sokol DJ. Effective use of current core and post concepts. *J Prosthet Dent* 1984;52:231-234.
4. Fernandes AS, Dessai GS. Factors affecting the fracture resistance of post-core reconstructed teeth: A review. *Int J Prosthodont* 2001;14:355-363.
5. Panitvisai P, Messer HH. Cuspal deflection in molars in relation to endodontic and restorative procedures. *J Endod* 1995;21:57-61.
6. Howe CA, McKendry DJ. Effect of endodontic access preparation on resistance to crown-root fracture. *J Am Dent Assoc* 1990;121:712-715.
7. Trope M, Maltz DO, Tronstad L. Resistance to fracture of restored endodontically treated teeth. *Endod Dent Traumatol* 1985;1:108-111.
8. Trope M, Ray HL Jr. Resistance to fracture of endodontically treated roots. *Oral Surg Oral Med Oral Pathol* 1992;73:99-102.
9. Reeh ES, Douglas WH, Messer HH. Stiffness of endodontically-treated teeth related to restoration technique. *J Dent Res* 1989;68:1540-1544.
10. Oliveira Fde C, Denehy GE, Boyer DB. Fracture resistance of endodontically prepared teeth using various restorative materials. *J Am Dent Assoc* 1987;115:57-60.
11. Strub JR, Pontius O, Koutayas S. Survival rate and fracture strength of incisors restored with different post and core systems after exposure in the artificial mouth. *J Oral Rehabil* 2001;28:120-124.
12. Bergman B, Lundquist P, Sjögren U, Sundquist G. Restorative and endodontic results after treatment with cast posts and cores. *J Prosthet Dent* 1989;61:10-15.
13. Naumann M, Blankenstein F, Kiessling S, Dietrich T. Risk factors for failure of glass fiber-reinforced composite post restorations: A prospective observational clinical study. *Eur J Oral Sci* 2005;113:519-524.
14. Sorensen JA, Martinoff JT. Intracoronal reinforcement and coronal coverage: A study of endodontically treated teeth. *J Prosthet Dent* 1984;51:780-784.
15. Hatzikyriakos AH, Reisis GI, Tsingos N. A 3-year postoperative clinical evaluation of posts and cores beneath existing crowns. *J Prosthet Dent* 1992;67:454-458.
16. Naumann M, Blankenstein F, Dietrich T. Survival of glass fibre reinforced composite post restorations after 2 years. An observational clinical study. *J Dent* 2005;33:305-312.
17. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. *J Prosthet Dent* 2002;87:256-263.
18. Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. *J Prosthet Dent* 2002;88:297-301.
19. Dammaschke T, Steven D, Kaup M, Ott KH. Long-term survival of root-canal-treated teeth: A retrospective study over 10 years. *J Endod* 2003;29:638-643.
20. Caplan DJ, Kolker J, Rivera EM, Walton RE. Relationship between number of proximal contacts and survival of root canal treated teeth. *Int Endod J* 2002;35:193-199.
21. Bolhuis HPB, De Gee AJ, Feilzer AJ, Davidson CL. Fracture strength of different core build-up designs. *Am J Dent* 2001;14:286-290.
22. Torbjörner A, Fransson B. A literature review on the prosthetic treatment of structurally compromised teeth. *Int J Prosthodont* 2004;17:369-376.
23. Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: A retrospective cohort study. *J Prosthet Dent* 2005;93:164-170.
24. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NHJ. Up to 17-year controlled clinical study on post-and-cores and covering crowns. *J Dent* 2007;35:778-786.
25. Creugers NHJ, Mentink AGB, Fokkinga WA, Kreulen CM. 5-year follow-up of a prospective clinical study on various types of core restorations. *Int J Prosthodont* 2005; 18:34-39.
26. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. *J Endod* 1989;15:512-516.
27. Larson TD, Douglas WH, Geistfeld RE. Effect of prepared cavities on the strength of teeth. *Oper Dent* 1981;6:2-5.
28. Linn J, Messer HH. Effect of restorative procedures on the strength of endodontically treated molars. *J Endod* 1994;20:479-485.
29. Ferrari M, Cagidiaco MC, Grandini S, De Sanctis M, Goracci C. Post placement affects survival of endodontically treated premolars. *J Dent Res* 2007;86:729-734.
30. Stankiewicz NR, Wilson PR. The ferrule effect: A literature review. *Int Endod J* 2002;35:575-581.
31. Zhi-Yue L, Yu-Xing Z. Effects of post-core design and ferrule on fracture resistance of endodontically treated maxillary central incisors. *J Prosthet Dent* 2003;89:368-373.
32. 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;92:155-162.
33. Tan PL, Aquilino SA, Gratton DG, Stanford CM, Tan SC, Johnson WT, Dawson D. *In vitro* fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. *J Prosthet Dent* 2005;93:331-336.
34. Pereira JR, de Ornelas F, Conti PC, do Valle AL. Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. *J Prosthet Dent* 2006;95:50-54.
35. Sorensen JA, Engelman MJ. Ferrule design and fracture resistance of endodontically treated teeth. *J Prosthet Dent* 1990;63:529-536.
36. Libman WJ, Nicholls JI. Load fatigue of teeth restored with cast posts and cores and complete crowns *Int J Prosthodont* 1995;8:155-161.
37. Guzy GE, Nicholls JI. *In vitro* comparison of intact endodontically treated teeth with and without endo-post reinforcement. *J Prosthet Dent* 1979;42:39-44.
38. Morgano SM. Restoration of pulpless teeth: Application of traditional

principles in present and future contexts. *J Prosthet Dent* 1996;75:375-380.
39. Heydecke G, Butz F, Strub JR. 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;29:427-433.
40. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: A literature review. *J Endod* 2004; 30:289-301.
41. Robbins JW. Guidelines for the restoration of endodontically treated teeth. *J Am Dent Assoc* 1990;120:558,560,562.
42. Goodacre CJ, Spolnik KJ. The prosthodontic management of endodontically treated teeth: A literature review. Part I. Success and failure data, treatment concepts. *J Prosthodont* 1994;3:243-250.
43. Rosen H. Operative procedures on mutilated endodontically treated teeth. *J Prosthet Dent* 1961;11:973-986.
44. Rosen H, Partida-Rivera M. Iatrogenic fracture of roots reinforced with a cervical collar. *Oper Dent* 1986;11:46-50.
45. Barkhordar RA, Radke R, Abbasi J. Effect of metal collars on resistance of endodontically treated teeth to root fracture. *J Prosthet Dent* 1989; 61:676-678.
46. Joseph J, Ramachandran G. Fracture resistance of dowel channel preparations with various dentin thickness. *Fed Oper Dent* 1990;1:32-35.
47. Hemmings KW, King PA, Setchell DJ. Resistance to torsional forces of various post and core designs. *J Prosthet Dent* 1991;66:325-329.
48. Isidor F, Brøndum K, Ravnholt G. The influence of post length and crown ferrule length on the resistance to cyclic loading of bovine teeth with prefabricated titanium posts. *Int J Prosthodont* 1999;12:78-82.
49. McLean A. Predictably restoring endodontically treated teeth. *J Can Dent Assoc* 1998;64:782-787.
50. Freeman MA, Nicholls JI, Kydd WL, Harrington GW. Leakage associated with load fatigue-induced preliminary failure of full crowns placed over three different post and core systems. *J Endod* 1998;24:26-32.
51. Cagidiaco MC, García-Godoy F, Vichi A, Grandini S, Goracci C, Ferrari M. Placement of fiber prefabricated or custom made posts affects the 3-year survival of endodontically treated premolars. *Am J Dent* 2008;21:179-184.
52. Cheung W. A review of the management of endodontically treated teeth. Post, core and the final restoration. *J Am Dent Assoc* 2005; 136:611-619.
53. Piovesan EM, Demarco FF, Cenci MS, Pereira-Cenci T. Survival rates of endodontically treated teeth restored with fiber-reinforced custom posts and cores: A 97-month study. *Int J Prosthodont* 2007;20:633-639.
54. Rud J, Omnell KA. Root fractures due to corrosion. Diagnostic aspects. *Scand J Dent Res* 1970;78:397-403.
55. Tamse A, Fuss Z, Lustig J, Kaplavi J. An evaluation of endodontically treated vertically fractured teeth. *J Endod* 1999;25:506-508.
56. Glazer B. Restoration of endodontically treated teeth with carbon fibre posts. A prospective study. *J Can Dent Assoc* 2000;66:613-618.
57. Schmitter M, Rammelsberg P, Gabbert O, Ohlmann B. Influence of clinical baseline findings on the survival of 2 post systems: A randomized clinical trial. *Int J Prosthodont* 2007;20:173-178.
58. Isidor F, Odman P, Brondum K. Intermittent loading of teeth restored using prefabricated carbon fiber posts. *Int J Prosthodont* 1996; 9:131-136.
59. Cormier CJ, Burns DR, Moon P. *In vitro* comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post systems at various stages of restoration. *J Prosthodont* 2001;10:26-36.
60. Fokkinga WA, Kreulen CM, Vallittu PK, Creugers NH. A structured analysis of in vitro failure loads and failure modes of fiber, metal, and ceramic post-and-core systems. *Int J Prosthodont* 2004;17:476-482.
61. King PA, Setchell DJ. An *in vitro* evaluation of a prototype CFRC prefabricated post developed for the restoration of pulpless teeth. *J Oral Rehabil* 1990; 17:599-609.
62. Akkayan B, Gulmez T. Resistance to fracture of endodontically treated teeth restored with different post systems. *J Prosthet Dent* 2002;87:431-437.
63. Dean JP, Jeansonne BG, Sarkar N. *In vitro* evaluation of a carbon fiber post. *J Endod* 1998;24:807-810.
64. Martinez-Insua A da Silva L, Rio B, Santana U. Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core. *J Prosthet Dent* 1998; 80:527–532.
65. Mannocci F, Ferrari M, Watson TF. Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber, and zirconium dioxide ceramic root canal posts. *J Adhes Dent* 1999;1:153-158.
66. Ukon S, Moroi H, Okimoto K, Fujita M, Ishikawa M, Terada Y, Satoh H. Influence of different elastic moduli of dowel and core on stress distribution in root. *Dent Mater J* 2000;19:50-64.
67. Newman MP, Yaman P, Dennison J, Rafter M, Billy E. Fracture resistance of endodontically treated teeth restored with composite posts. *J Prosthet Dent* 2003;89:360-367.
68. Sidoli GE, King PA, Setchell DJ. An *in vitro* evaluation of a carbon fiber-based post and core system. *J Prosthet Dent* 1997;78:5-9.
69. Ottl P, Hahn L, Lauer HCH, Fay M. Fracture characteristics of carbon fibre, ceramic and non-palladium endodontic post systems at monotonously increasing loads. *J Oral Rehabil* 2002;29:175-183.
70. Ferrari M, Cagidiaco MC, Goracci C, Vichi A, Mason PN, Tay FR. Long term retrospective study of the clinical performance of the fiber posts. *Am J Dent* 2007;20:287-291.
71. Ferrari M, Vichi A, García-Godoy F. Clinical evaluation of fiber-reinforced epoxy resin posts and cast post and cores. *Am J Dent* 2000; (Sp Is B)13:15B-18B.
72. Fredriksson M, Astbäck J, Pamenius M, Arvidson K. A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts. *J Prosthet Dent* 1998;80:151-157.
73. Ferrari M, Vichi A, Mannocci F, Mason PN. Retrospective study of the clinical performance of fiber posts. *Am J Dent* 2000;13:9B-13B.
74. Hedlund SO, Johansson NG, Sjögren G. A retrospective study of prefabricated carbon fibre root canal posts. *J Oral Rehabil* 2003;30:1036-1040.
75. Segerström S, Astbäck J, Ekstrand KD. A retrospective long term study of teeth restored with prefabricated carbon fiber reinforced epoxy resin posts. *Swed Dent J* 2006;30:1-8.
76. Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. *J Dent* 2009;37:115-121.
77. Malferrari S, Monaco C, Scotti R. Clinical evaluation of teeth restored with quartz fiber-reinforced epoxy resin posts. *Int J Prosthodont* 2003;16:39-44.
78. Monticelli F, Grandini S, Goracci C, Ferrari M. Clinical behavior of translucent-fiber posts: A 2-year prospective study. *Int J Prosthodont* 2003;16:593-596.
79. Cagidiaco MC, Radovic I, Simonetti M, Tay F, Ferrari M. Clinical performance of fiber post restorations in endodontically treated teeth: 2-year results. *Int J Prosthodont* 2007;20:293-298.
80. Grandini S, Goracci C, Tay FR, Grandini R, Ferrari M. Clinical evaluation of the use of fiber posts and direct resin restorations for endodontically treated teeth. *Int J Prosthodont* 2005;18:399-404.
81. Christensen GJ. Posts: Necessary or unnecessary? *J Am Dent Assoc* 1996;127:1522-1524, 1526.
82. Mattison GD, Delivanis PD, Thacker RW Jr, Hassell KJ. Effect of post preparation on the apical seal. *J Prosthet Dent* 1984;51:785-789.
83. Goodacre CJ, Spolnik KJ. The prosthodontic management of endodontically treated teeth: A literature review. Part II. Maintaining the apical seal. *J Prosthodont* 1995;4:51-53.
84. Madison S, Zakariasen KL. Linear and volumetric analysis of apical leakage in teeth prepared for posts. *J Endod* 1984;10:422-427.
85. Abramovitz L, Lev R, Fuss Z, Metzger Z. The unpredictability of seal after post space preparation: A fluid transport study. *J Endod* 2001;27:292-295.
86. Sorrentino R, Monticelli F, Goracci C, Zarone F, Tay FR, García-Godoy F, Ferrari M. Effect of post-retained composite restorations and amount of coronal residual structure on the fracture resistance of endodontically-treated teeth. *Am J Dent* 2007;20:269-274.
87. Hunter AJ, Feiglin B, Williams JF. Effects of post placement on endodontically treated teeth. *J Prosthet Dent* 1989;62:166-172.
88. Walton JN, Gardner FM, Agar JR. A survey of crown and fixed partial denture failures: Length of service and reasons for replacement. *J Prosthet Dent* 1986;56:416-421.
89. De Backer H, Van Maele G, De Moor N, Van den Berghe L, De Boever J. A 20-year retrospective survival study of fixed partial dentures. *Int J Prosthodont* 2006;19:143-153.
90. Fayyad MA, al-Rafee MA. Failure of dental bridges. II. Prevalence of failure and its relation to place of construction. *J Oral Rehabil* 1996;23:438-440.
91. Libby G, Arcuri MR, LaVelle WE, Hebl L. Longevity of fixed partial dentures. *J Prosthet Dent* 1997;78:127-131.
92. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications in fixed prosthodontics. *J Prosthet Dent* 2003;90:31-41.
93. Grandini S, Goracci C, Monticelli F, Tay FR, Ferrari M. Fatigue resistance and structural characteristics of fiber posts: Three-point bending test and SEM evaluation. *Dent Mater* 2005;21:75-82.
94. Dietschi D, Duc O, Krejci I, Sadan A. 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.