A Literature Review on the Prosthetic Treatment of Structurally Compromised Teeth

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Purpose: This article presents a review of the literature on biomechanical factors affecting the treatment outcome of prosthetic treatment of structurally compromised dentitions, with the main emphasis on often-compromised endodontically treated teeth. ***Materials and Methods:*** Articles cited in a MEDLINE/PubMed search were reviewed with a focus on factors influencing the risk for fatigue failures. ***Results:*** Technical failures in connection with fixed prosthodontics are often caused by fatigue fractures. The abutments, cement, and reconstruction are all subjected to stress caused by occlusal forces, and fatigue fracture may occur at the weakest point or where the maximum stress occurs. The weakest point is frequently in connection with endodontically treated teeth restored with posts and cores. ***Conclusion:*** The literature points to nonaxial forces as a risk for fatigue fracture of teeth, cement, and restorative material. Favorable occlusal prosthesis design is probably more important for survival of structurally compromised endodontically treated teeth than is the type of post used.
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In studies on fixed prosthodontics, reported technical failures are frequently associated with endodontically treated teeth restored by means of posts and cores; failure rates between 7% and 15% after 3 years have been reported.[1–8] The main factors that make endodontically treated teeth more disposed to technical failure are: *(1)* thin-walled, weakened roots unable to withstand high stress until fatigue-caused root fractures occur; and *(2)* reduced retentive surfaces resulting in high stress levels in the cement. General principles for avoiding technical failures on endodontically treated teeth do not differ from conventional restorative principles described previously.[9] Treatment could in many respects be considered analogous with prosthetic treatment of structurally severely damaged teeth.

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The strength of a tooth is directly related to the amount of remaining tooth structure. Hence, preservation of tooth structure is important in successful treatment of structurally compromised endodontically treated teeth.[10–16] Using modern principles for tooth preparation, enough coronal dentin is often preserved to retain a fixed prosthesis without retention from the root canal. New restorative materials and adhesive techniques have also contributed to a reduced need for posts and cores.

The aim of this literature review was to evaluate biomechanical factors affecting the outcome of prosthetic treatment of structurally compromised teeth and dentitions, with the main emphasis on often-compromised endodontically treated teeth. A literature search was conducted using MEDLINE/PubMed for the years 1970 to 2003. MeSH terms used were “dental prosthesis failure,” “biomechanics,” “post and core technique,” “occlusal force,” and “dental occlusion.”

Clinical Studies

Many investigators have studied the long-term quality of tooth-retained fixed dental restorations. The complex biologic and technical variables, such as the structural status of the dentition, interocclusal relationships, occlusal

Table 1 Clinical Studies on Post Treatment Containing Durability Data

Study	Post type(s)	Follow-up (y)	Sample size	Operators	Clear definition of post failure	No. of failures
Bergman et al[5]	Custom cast	6	96	Many students	Yes	9
Ellner et al[23]	Custom cast	10	14	6	Yes	–
	Prefabricated passive	10	26			1
	Prefabricated active	10	10			2
Ferrari et al[24]	Carbon fiber	4	95	?	No	0
	Custom cast		100			9
Ferrari et al[25]	Carbon fiber	3.8	850	3	No	25 total for both post types
	Glass fiber	1.2	539			
Fredriksson et al[26]	Carbon fiber	2.7	236	7	Yes	0
Glazer[27]	Carbon fiber	2.3	52	1	Yes	4
Hatzikyriakos et al[28]	Custom cast	3	44	?	Yes	4
	Prefabricated passive		47		No	7
	Prefabricated active		63		No	6
Lindé[29]	Prefabricated active	5.7	49	1	Yes	8
Malferrari et al[30]	Glass fiber	5	180	13	Yes	3
Mannocci et al[31]	Carbon fiber	3	117	1	Yes	7
Mentink et al[32]	Custom cast	4.8	516	Many students	No	39
Mentink et al[33]	Prefabricated passive	7.8	44	2	Yes	1
	Prefabricated active	11.2	68			13
Roberts[34]	Custom cast	5.2	49	Many students and clinicians	Yes	11
Sorensen and Martinoff[8]	Custom cast	1–25	245	9	Yes	31
	Prefabricated passive		170			3
	Prefabricated active		5			2
Torbjörner et al[6]	Custom cast	3	456	69	Yes	47
	Prefabricated passive	3.4	175			25
Valderhaug et al[35]	Custom cast	25	106	Many students	Yes	40
Weine et al[36]	Tapered smooth prefabricated	10	138	3	No	5

designs, and magnitude and direction of functional forces, are difficult to evaluate clinically; studies on the influence of these factors on treatment outcome are therefore scarce.

Some articles based on longitudinal clinical trials or case reports dealing with the problems inherent in the reconstructive treatment of the mutilated dentition have had a great impact on general treatments of the structurally compromised dentition.[17–20] With follow-up times up to 18 years, treatment concepts that are useful in both everyday treatment and extreme borderline cases have been presented. The one principle given in the clinical guidelines of these papers is to reduce the horizontal stress acting on the reconstruction. This concept has been supported in theory.[21,22]

On the subject "restoration of the endodontically treated tooth," 17 clinical studies published since 1970 and containing durability data were found (Table 1).[5–8,23–36] None of these studies include information concerning the occlusal force pattern. Four are prospective studies.[23,27,28,31] In two retrospective studies, follow-up is limited to data from dental records,[6,8] one study is based on a combination of dental records and clinical examinations,[25] and the others are clinical follow-up studies.

The data reported in the clinical follow-up studies show substantial variations in patient selection, clinical procedures, and dental materials used. For instance, within the same study, different cements were used for different post types.[24] The parameters studied and the criteria for success or failure have varied between studies. An analysis of durability data concluded that, as "the characteristics of the selected studies were too heterogeneous, they could not be combined for an overall survival assessment."[37] This statement is still valid today, which means that we lack long-term clinical results at a high level of evidence from studies containing survival data for various post systems.

The following inclusion criteria for selection to a meta-analysis have been suggested[37]:

1. Mean follow-up time of at least 5 years
2. Relevant information about patients and selection procedure
3. Sufficient information about the post-and-core system
4. Clear definition of the term "failure"
5. Survival data (including censored information) or appropriate information to calculate or assess survival data, including confidence intervals (life tables)

Only four studies fulfill these criteria,[5,23,29,32] illustrating both the difficulties in performing clinical studies and the need for scientific guidelines concerning evaluation criteria in studies on prosthetic restorations.

Loss of retention is generally reported as the most frequent post failure, whereas root fracture has the most serious consequences, almost always resulting in extraction.[6–8,25,33] A third mode of failure, post fracture, is less common and often regarded as a restorable failure (Table 2).

The lowest survival rates in follow-up studies on post treatments have been reported for active, threaded posts.[29,33] However, a substantial number of the teeth included in the two major studies on active posts had a dubious prognosis, and the alternative treatment would in many cases have been extraction. With this fact and the long follow-up times in mind, the reported failure rates of 13% to 30% in 6 to 8 years would be regarded as acceptable.

For studies on passive, serrated metal posts, study designs, failure rates, and follow-up times show great variation.[6,8,28,33] In a frequently quoted study, two post systems were compared: parallel serrated posts (ParaPost, Coltène/Whaledent) and individually cast posts and cores.[8] A failure rate of only 2% for ParaPost was reported. The conclusions drawn from that study have been subjected to critical review. The follow-up times for the two post systems were not presented separately and varied between 1 and 25 years. As the ParaPost technique was fairly new at that time, one might assume that the prefabricated posts had a considerably shorter follow-up time than the cast posts and cores, which may partly explain the higher reported success rates for the ParaPost posts. In contrast, a 25-year follow-up study showed similar success rates for vital and root-filled crowned teeth with cast posts and cores.[36] The authors concluded that when high-quality endodontic and prosthetic treatment is performed, successful results may also be achieved for structurally damaged and endodontically treated teeth.

A majority of the posts presented in the 17 studies above were cemented with zinc phosphate cement. For fiber-reinforced posts, resin-based cements have been used; failure rates between 0% and 10% have been reported, with follow-up times of 1 to 4 years.[25–27,30,31] The results are promising, but patient selection methods are not fully clarified in all studies, and some conclusions show lack of scientific objectivity. One study states that carbon-fiber posts "are the most predictable system available today," without having compared the carbon-fiber posts with any other post system.[27] Another concludes that "no technical failures due to the fiber posts were recorded," although several failures involved loss of retention of the posts.[25]

Altogether, great differences in failure rates for different post systems are not obvious. Other factors, such as the amount of remaining tooth structure, ferrule effect of the crown, and magnitude and direction of functional loads, probably have a greater influence on survival rate than does the type of post used. However, these factors have not been evaluated in the cited studies.

Table 2 Distribution of 72 Technical Post Failures in a Follow-up Study*

Post failures	Loss of retention	Root fracture	Post fracture	Total
Restorable	38	—	5	43
Nonrestorable	7	21	1	29

*Modified from Torbjörner et al.[6]

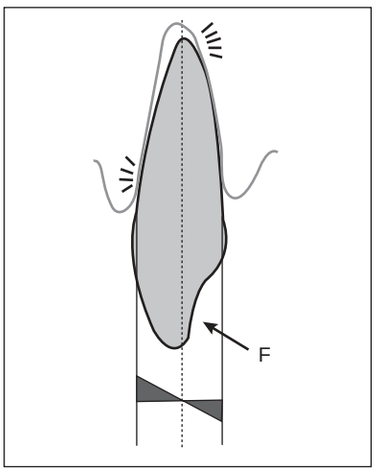

Fig 1 Stress in radicular dentin during function is concentrated to circumference of tooth; stress is lowest within root canal.

In Vitro Studies

Findings from in vitro studies on post-and-core treatments can provide some guidelines, but at a lower level of evidence, as the complex intraoral conditions (eg, stress patterns and influence of moisture), are impossible to simulate in vitro. Three techniques have been used to study stress distribution for various post designs: mechanical studies, photoelastic techniques, and finite element analysis. Various resistances to root fracture for different post designs have been obtained depending on the technique used, and the conclusions drawn from these studies should be interpreted with care. Several of the in vitro studies were conducted on the post only, a questionable choice because the core, under clinical conditions, is generally covered by a complete crown with its margins on healthy tooth structures, providing a ferrule effect. Only minor variations in fracture resistance for different post designs after cementation of a complete crown have been noted.[16,38,39]

Root Fractures

As described by several authors, stress in the radicular dentin during function is concentrated to the circumference of the tooth, whereas the stress level is lowest within the root canal (Fig 1).[14,40–42] The center of the root is a neutral

Table 3 Contents and Mechanical Properties of Some Fiber-Reinforced Root Canal Posts*

Post	Contents	Flexural modulus (GPa)	Flexural strength (MPa)
Composipost, RTD	Carbon fiber 64%, epoxy	145	1,500
Light-Post, RTD	Quartz fiber 60%, epoxy	46	1,400
Luscent, Dentatus	Quartz fiber 70%, polyester	40	890
ParaPost Fiber White, Coltène/Whaledent	Glass fiber 42%, filler 29%, methacrylate resin 29%	29	990
Postec, Ivoclar Vivadent	Glass fiber 61.6%, urethane dimethacrylate 18.3%, triethylene glycol dimethacrylate 7.6%	45	1,390

*According to manufacturers.

Table 4 Elastic Moduli of Some Dental Materials[56–58]

Material	Elastic modulus (GPa)
Enamel	50
Dentin	15
Type III gold alloy	85
Titanium	110
Zirconium dioxide	210
Composite filling material	16
Cobalt chromium	220
Carbon-fiber epoxy	75–215
Glass-fiber epoxy	40
Epoxy resin	4

area with regard to stress concentration, and thus no reinforcement is needed in this area. If reinforcement is desired, incorporating a ferrule into the design of the crown, embracing the circumference of the root, protects the root where the maximum forces occur. The ferrule effect is a key factor in failure threshold for post-treated teeth.[16,38,42–47]

Can Alternative Post Materials Reduce Risk of Root Fracture?

In fiber-reinforced root canal posts, the fibers contribute stiffness and strength to the usually elastic matrix; the mechanical properties of fiber-reinforced composite materials depend on the type of fibers, fiber content, and direction of the fibers. The stiffness (flexural modulus) of carbon-fiber posts is about three times as high as for glass-fiber posts (Table 3).

Many fiber-reinforced posts are advertised as having mechanical properties corresponding to those of dentin, and a chemical bond between post and cement has been claimed. Research on fiber-reinforced post systems has accordingly focused on two major questions:

1. Is it possible to achieve a long-term chemical bond between the matrices of any of these posts and polymer cements?
2. Will any of these posts reduce the risk of root fracture?

The retention of Composipost to polymer cement has been investigated, but significantly higher retention values have been recorded for passive, serrated metal posts than for carbon-fiber posts.[48–50] Retention values for the posts to composite cores are twice as high for metal compared to carbon-fiber posts.[50] However, when serrations are added to the fiber posts, similar retention values for the two types of post are registered.[51] A conclusion from these studies is that the bond between the epoxy-based matrix and polymer cement seems to be mainly mechanical. This conclusion is supported by several retention studies in which retentive failure in Composipost was noted to occur at the post-cement interface.[49,50,52] The epoxy matrix in the industrially processed post is highly polymerized, and further chemical reactions between matrix and cement should not be expected.

The manufacturers of several carbon fiber–reinforced posts claim their stiffness to be similar to that of dentin. Thus, on loading, the deflection of the post and root would be of the same magnitude and the risk of a root fracture should thereby be minimized. Published studies on the mechanical properties of Composipost, however, report flexural moduli about 10 times as high as for dentin; some studies even report a modulus higher than that of stainless steel (Table 4).[50,53–55]

A fiber-reinforced post is fairly easy to remove. With the research available to date showing no tendency to a chemical bond between post and cement, and stiffness far from corresponding to that of dentin, this is one of the few advantages of using carbon-fiber posts instead of metal root canal posts.

Today several glass fiber–reinforced root canal posts are also on the market. Because they have less-stiff fibers, they have a lower modulus than do carbon-fiber posts (Table 3). Most, but not all, fiber-reinforced posts use epoxy as the matrix. Whether a chemical bond between any of the other matrices and polymer cement is achievable is not yet elucidated. This would, however, be of interest, and more research in this field is desirable.

Should Posts Have Stiffness?

A root canal post should have strength; on that point there is no controversy. A post material of high strength can withstand high loads without risk of fracture. Two opposing views of stiffness have been expressed. Some authors advocate posts with mechanical properties similar to those of dentin, whereas others emphasize the necessity of rigid posts. The matter has been discussed, but there is not yet a consensus.[53,59]

Whether high or low stiffness of the root canal post is advantageous can be visualized by considering a post-treated maxillary incisor in the extreme but not unusual situation of minimal remaining coronal tooth structure (Fig 2). With elastic posts, the tooth, cement, and post will all deform during function. Failure will appear at the weakest point, which seems to be the adhesive joints at the core-dentin and post-cement-dentin interfaces. Hence, the mode of failure will be loss of marginal seal, core fracture, post fracture, or loss of retention.[30,59–61] The less remaining coronal tooth structure, the greater will be the stress on the adhesive joint. In vitro studies have shown elastic posts to have a lower tendency to cause root fractures than posts of higher stiffness.[62,63] The reinforcement effect after cementation of a complete crown with a ferrule effect makes the difference between stiff and elastic posts less obvious.

A stiff post in a case with minimal coronal dentin distributes the forces along the post into the root. Fatigue-caused failure would occur at higher stress levels and after a considerably longer time compared to a low-modulus post, but the risk of an irreparable root fracture would be increased.[62–64] This biomechanical approach is supported by a number of studies[11,61,65–69] and can be summarized as follows: either a post with low modulus and an early but hopefully reparable technical failure, or a post with high modulus, technical failure after a long time in function and/or at high stress levels, and more frequently irreparable failures.

Can Alternative Cements Reduce Risk of Root Fracture?

Zinc phosphate cement has been selected for cementation of posts for many years and is well-documented. It is still the method of choice for most conventional fixed prostheses because of its easy handling characteristics and adequate long-term clinical results.[70] Zinc phosphate cement adheres by mechanical interlocking to irregularities in the dentin and prosthetic reconstruction. Resin-based cements adhere both mechanically and chemically to tooth structure, and a number of studies report significantly higher retention and resistance to fatigue for resin cements than for zinc phosphate cements.[71–74]

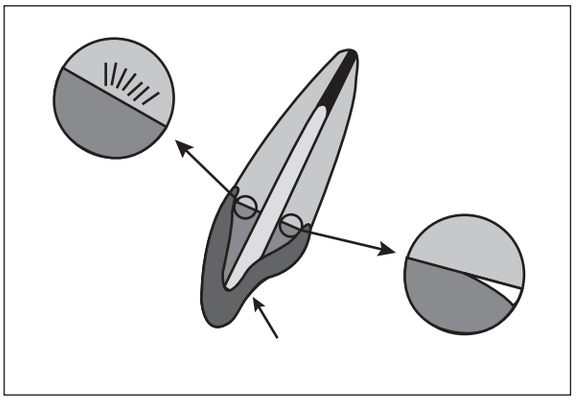

Fig 2 Consideration of post-treated maxillary incisor in the extreme but not unusual situation of minimal remaining coronal tooth structure allows visualization of whether high or low post stiffness is advantageous.[59]

The advantages of using resin cements for post cementation are supported by data reporting the modulus of elasticity of resin-based cements as approaching that of dentin (Table 4). A cement layer elastically compatible with dentin, forming an inner tube bonded to the intraradicular tooth structure, would have the potential to clinically reinforce thin-walled roots.[75,76] Many clinicians claim excellent results with fiber-reinforced posts. Their positive experience might be a result of the resin-based cement instead of the post material per se.

Resin cements are, however, technically far more difficult to manipulate than zinc phosphate cement. Luting root canal posts with resin-based cements is a technique-sensitive procedure. The technique sensitivity is illustrated in studies reporting significant differences in bond strength between operators performing the same bonding procedure.[54,77] The long-term clinical result of bonding root canal posts is not elucidated, and several questions remain unanswered: Will microleakage through apical foramina or lateral canals affect the bond over time? Will polymerization shrinkage in thick cement layers cause stresses in the dentin? Resin-based cements will not miraculously improve the prognosis of a structurally compromised tooth and cannot be universally recommended. There are, however, clinical situations in which all efforts are needed to avoid root fracture, or in which maximum retention is required, and the use of resin cements may be prudent.

Retention

Many studies on post retention focus on factors increasing the retention of a post without increasing the risk of root fracture, ie, the surface texture of the post and root canal and type of cement used. Roughening the post space increases the retention for zinc phosphate,

glass-ionomer, and resin-based cements without compromising the remaining tooth structure.[78–80]

Retention in vitro is measured by a tension test, and the forces in vivo are far more complex. Comparison of posts with various surface roughnesses still gives an indication of preferable surface design. Depending on the configuration of the root canal, amount of remaining tooth structure, and retentive needs, different post types are suitable for different clinical situations.

Prefabricated Posts

More than 100 prefabricated post systems are available. The posts show variations in type of material, taper, and surface texture and have different designs for retaining the core material. Compared to custom-cast posts, many prefabricated posts have superior retentive abilities, involve less time-consuming chairside and laboratory procedures, and, when a direct technique is used, require only one visit to complete the foundation. Prefabricated posts also have some disadvantages, such as the fact that the root canal is designed to receive the post rather than the post being designed to fit within the root.

Active, threaded posts have the greatest retention. However, inserting threaded posts may easily induce stress in the root because of the threads indenting into dentin.[81–85] This could lead to crack initiation and might induce root fracture at a later time. Threaded posts should be reserved for situations with severe retention problems and should be handled with great care.

Serrated or roughened passive posts significantly increase retention compared to smooth posts, irrespective of post material.[80,81,85,86] An increase in retention potential for serrated posts has been recorded for zinc phosphate, glass-ionomer, and resinous cements.[80,86,87] Clinical studies also indicate higher survival rates for serrated posts than for individually cast posts and cores[6,8]; passive serrated or rough prefabricated posts may therefore be recommended as the first choice as long as the root canal shape is suitable.

Stabilized zirconium ceramic (ZrO_2) has been introduced for the fabrication of posts and cores.[88] Zirconium dioxide ceramic has higher strength and fracture toughness than other ceramics and may therefore be more suitable for posts.[89] Ceramic posts offer potential advantages with respect to esthetics and biocompatibility, but they also have some disadvantages. They show lower retention values compared to serrated metal posts,[86,90] and they are not yet available in small diameters.

Core Materials

Dental casting alloys, amalgam, resin composites, and ceramic materials may be used as core materials.[91,92] Glass-ionomer materials, with or without silver alloy, should be avoided as core materials because of their weak tensile strength and lower resistance to fracture.[93–95] In vitro studies report a higher frequency of core failures for composite cores than for metal cores. However, the force distribution is altered once a crown embracing the root is placed; the more remaining dentin, the less significant are the mechanical properties of the core materials.[38,66,92] One proposed guideline is that a direct technique with a composite buildup may be an alternative when more than one third of the coronal dentin remains.

Endodontic Considerations

Post-treated teeth show periapical infections more frequently than do other endodontically treated teeth; care to avoid microleakage during post canal preparation, provisional restoration, and post cementation has a positive effect on the life of both the post-treated tooth and prosthetic reconstruction.[96]

Bacteria and endotoxins from the saliva can penetrate unsealed full-sized root canal fillings. The longer the exposure time to saliva, the greater is the risk of microleakage.[97–99] The shorter the root filling, the greater also is the risk of microleakage. The seal is thus markedly compromised by a post preparation, after which only a small volume of obturating material remains as a barrier against penetration of microorganisms and toxins.[100] This causes a dilemma for the operator, who often needs a long retentive post. An absolute minimum of 3 mm remaining gutta percha has been suggested, but the less remaining obliterating material, the more the post space should be regarded as an unsealed root canal.[101–103]

Microleakage can be minimized when the post preparation is performed immediately after root canal obturation.[103] This approach also has practical advantages, as the rubber dam can easily be left in place and the morphology, length, and direction of the canal are still fresh in the operator's memory. Concerning microleakage, the use of prefabricated posts in a direct technique has several advantages. The exposure time of the remaining root canal filling to the oral cavity is minimized, and the risk of massive bacterial contamination because of a loosened provisional post-crown is eliminated.

Conclusion

Technical failures on fixed prosthodontics are often caused by fatigue fractures. The abutments, cement, and reconstruction are all subject to fluctuating stress/strain caused by occlusal loads. Cyclic deformation during function may cause formation and propagation of a crack at the weakest point or where the maximum stress occurs. Horizontal occlusal forces accelerate the process, and occlusal design of the prosthesis is a decisive factor in avoiding technical failures on abutments and reconstructions. Favorable occlusal prosthesis design is probably far more important

for survival of structurally compromised endodontically treated teeth than is the type of post used.

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