



Royal College of
Dental Surgeons of Ontario

Ensuring Continued Trust

Restoration of the Endodontically Treated Tooth

Dr. Dorothy McComb, BDS, MScD, FRCD(C)



This PEAK article is a special membership service from RCDSO. The goal of PEAK (Practice Enhancement and Knowledge) is to provide Ontario dentists with key articles on a wide range of clinical and non-clinical topics from dental literature around the world.

PLEASE KEEP FOR FUTURE REFERENCE.

Supplement to Dispatch February/March 2008

Restoration of the Endodontically Treated Tooth



Dr. Dorothy McComb, BDS, MScD, FRCD(C)

*Professor and Head, Restorative Dentistry
Director of Comprehensive Care Program
Faculty of Dentistry, University of Toronto*

Endodontic treatment is largely performed on teeth significantly affected by caries, multiple repeat restorations and/or fracture. Already structurally weakened, such teeth are often further weakened by the endodontic procedures designed to provide optimal access and by the restorative procedures necessary to rebuild the tooth. Loss of inherent dentinal fluid may also effect an alteration in tooth properties. It is therefore accepted that endodontically treated teeth are weaker and tend to have a lower lifetime prognosis. They require special considerations for the final restoration, particularly where there has been extensive loss of tooth structure. The special needs involve ensuring both adequate retention for the final restoration and maximum resistance to tooth fracture. Together, and both equally important, retention and resistance features for the final restoration are sometimes collectively termed anchorage. Ensuring optimal anchorage while maintaining adequate root strength for the particular clinical situation can be challenging and the problems encountered have resulted in the development of many different materials and techniques.

Despite the abundance of literature on this topic, much controversy and empiricism remains, particularly in the area of post usage. Also, new concepts are being rapidly introduced that require further analysis before widespread acceptance can be recommended. Although definitive clinical research – particularly randomized controlled clinical trials – is lacking in this area of dentistry, some significant retrospective analyses of both failure and survival of endodontically treated teeth, as well as some key laboratory studies, have identified the major factors that affect overall prognosis. Although the vast majority of in vitro studies have compared different types of posts, core materials and luting cements, these are considered of far less importance than the amount and quality of the remaining circumferential coronal tooth structure.^{1,2} In a recent review, Morgano et al. have stated: “Although there are many new materials available for the restoration of pulpless teeth, the prognosis of these teeth relies primarily on the application of sound biomechanical principles rather than on the materials used for restorations.”³

It is the purpose of this article to review current principles for restoration of the endodontically treated tooth, based on the best evidence available.

Endodontically treated teeth are weakened due to decreased or altered tooth structure attributed to:

- ◆ caries and/or previous restorations
- ◆ fracture or trauma
- ◆ endodontic access and instrumentation
- ◆ decreased moisture

The weakness is directly correlated to the quantity of lost dentine.

MAINTAINING TOOTH VITALITY

One of the major objectives of operative dentistry is maintenance of tooth vitality. The concept of minimally invasive dentistry and the provision of well-sealed, quality restorations are necessary to reduce the negative effect of multiple repeat restorations leading to more and more teeth receiving endodontic therapy. Recognition of the increased failure rate, susceptibility to fracture and reduced prognosis for the endodontically

treated tooth leads to increased appreciation for the value of maintaining tooth vitality wherever possible. Localised pulp and tooth preservation techniques, as well as overall slowing down of the re-restoration cycle, cover a broad range of factors designed to maintain tooth vitality over a lifetime and include the following:

- Importance of caries risk assessment and management of caries by patient-specific prevention.⁴
- Significance of the initial operative intervention, now reserved for active dentinal caries where no other more conservative management is possible.⁵
- Importance of operative and restoration quality for maximum longevity and reduction in re-restoration frequency.⁶
- Use of 2-stage deep caries management in appropriate cases to retain pulp vitality.⁷
- Acceptance of effective repair techniques for isolated areas of disease, leakage or fracture in an otherwise sound restoration.⁸

The high incidence of teeth currently receiving endodontic therapy has been recently noted in a provocative article by Christenson⁹ entitled “How to kill a tooth.” While acknowledging that more patients are living longer with heavily restored teeth, it was suggested that some of the newer techniques and materials commonly used today are a factor. Included were posterior composites, resin bonded indirect restorations, and aggressively cut veneers or all-ceramic crowns. Optimal bonding procedures are critical for such restorations to prevent leakage leading to pulpal pathology and the technique-sensitivity of bonding materials and resin luting cements was also discussed. For practitioners experiencing patient post-operative sensitivity with total-etch bonding, the author recommended changing to the use of a 2-step self-etching primer and adhesive. Similarly, the use of self-etching resin cements was recommended for pulpal problems associated with resin cements. A major priority is prevention of post-operative problems and maintenance of pulpal health.

Restoration of the Endodontically Treated Tooth

CUSP FRACTURE OF ENDODONTICALLY TREATED TEETH

Cusp fracture is a common occurrence in the heavily restored dentition, but endodontically treated teeth with intra-coronal restorations are at higher risk and the occurrence of unrestorable sub-gingival cusp fractures is more common.¹⁰⁻¹² Using data from over 46,000 patients from 28 dental practices, Fennis et al. found only 20.5 cusp fractures per 1000 person years of risk.¹³ However, there was a positive correlation between endodontically treated teeth and subgingival fracture location. Whereas restoration of a fractured cusp on a posterior vital tooth is relatively straightforward, cusp fracture of a non-vital tooth is likely to be more catastrophic. Loss of strategic internal architecture of the tooth leads to increased cusp deflection during occlusal function. This is most pronounced in endodontically treated bicuspid with MOD cavities and doubling the cavity depth increases the deflection by a factor of 8.¹⁴ Cuspal deflection in molars increases with increasing cavity size and is greatest following endodontic access.¹⁵ An endodontically treated posterior tooth may have a cavity depth 3-4 times greater than a vital tooth – hence the significantly greater risk of fracture. (Figure 1)



Figure 1

Vertical tooth fracture of an endodontically treated maxillary molar restored with a bonded composite restoration.

Both sound and restored teeth may fracture but endodontically-treated teeth are at greater risk and require special considerations.

In a 20-year retrospective analysis of 1638 endodontically treated posterior teeth restored with amalgam without cusp coverage, fracture was a significant problem.¹¹ Maxillary bicuspid with MOD restorations showed the lowest survival rate overall (28% fractured within 3 years, 57% after 10 years and 73% after 20 years). The most serious fractures were found for the maxillary second molar and accounted for the majority of the extractions due to vertical fracture. It was concluded that silver amalgam without cusp coverage was unsuitable for restoration of multiple surfaces of the endodontically treated tooth.

Enamel-bonded MOD composite restorations in bicuspid have shown greater resistance to fracture than amalgam restorations – but only up to 3 years¹⁰. After this time period, the failure of resin-restored and amalgam-restored endodontically treated teeth was similar. The long-term effect of current-day bonded intra-coronal restorations is largely unknown due to a lack of clinical studies on non-vital teeth. It is accepted that effective composite bonding can restore some of the strength lost through cavity preparation, but the prognosis is guarded for the endodontically treated tooth due to the higher stresses and expected progressive fatigue of the bonding mechanism. Short-term use of direct posterior composites may be justified in selected situations. Bonded CAD/CAM ceramic inlays for endodontically treated teeth performed poorly in vitro, with a high number of severe tooth fractures, and should be avoided.¹⁶

It is evident therefore that endodontically treated posterior teeth with intra-coronal restorations show a high risk of unrestorable cusp fracture. The use of crowns can significantly improve the success for posterior teeth.¹²

FAILURE OF ENDODONTICALLY TREATED TEETH

Analysis of the reason for all extractions of endodontically treated teeth over a period of 1 year in a busy military clinic revealed that almost 60% of these were unrestorable tooth fractures, 32% involved periodontal problems and only 7% were endodontic failures.¹⁷ Failure can be due to less than optimal endodontic therapy but inadequate or unsuccessful restorative treatment is the major issue. Close to half of

all failures were due to fracture of the natural coronal tooth structure and appeared to involve either uncrowned teeth or crowned teeth without definitive anchorage. They were deemed unrestorable due to the extent of lost tooth structure. Teeth with crowns showed longer clinical life than non-crowned teeth.

Approximately 10% of failures were due to root fracture and all root fractures pivoted from the apical end of a post and were most common in bicuspid or other teeth with narrow roots. (Figure 2) Endodontic failures were less frequent but tended to occur more quickly. The most common endodontic failures were seen in mandibular molars.

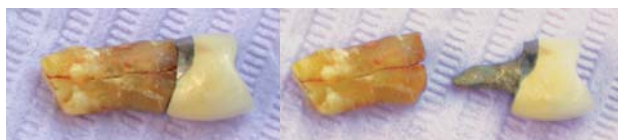


Figure 2

Crowned maxillary bicuspid with extra wide, tapered cast post and minimal ferrule showing typical vertical root fracture.

A potential cause of endodontic failure is bacterial recontamination of the root canal from the oral cavity, due to loss of temporary restorations or leakage of an inadequate final restoration. Prompt and effective definitive restoration is recommended upon completion of endodontic therapy to prevent recontamination.¹⁸ If timely restoration is not possible, a thicker layer of temporary material should be used, almost filling the whole pulp chamber for adequate bulk strength.¹⁹ Resin-modified glass ionomer, zinc oxide and eugenol and zinc oxide/calcium sulphate cements can all be effective. Although zinc oxide and eugenol cements show more dye leakage in vitro, they are effective because they possess antimicrobial properties and are resistant to bacterial penetration.¹⁹ Resin-modified glass ionomer cements have greater strength for more long term temporization.

The majority of studies on failure of endodontically treated teeth involve post-restored teeth. Torbjørner et al²⁰ reported a failure rate of 2.1% per year and Mentink et al²¹ similarly reported 18% failure after 10 years. An

analysis of 12 clinical studies revealed a 10% complication rate over an average of six years.²² This information on typical failure rates (approximately 2% per year) is useful in treatment planning and discussions with patients.

ENDODONTICALLY TREATED TEETH AS ABUTMENTS

Loss of retention and fractures of both teeth and reconstructions in fixed²³ and removable²⁴ prosthodontics have been shown to be more frequent when the distal abutments are non-vital. Higher frequency of fractures for non-vital abutment teeth is in accordance with other studies,²⁵⁻²⁷ one of which²⁵ noted that 75% of the abutment teeth that fractured were endodontically treated, had posts and were terminal abutments. In a widely quoted retrospective clinical investigation²⁶ comparing 1273 endodontically treated teeth as abutments or crowns, it was found that the success rate was higher for single crowns (94.8%) than FPD (89.2%) and RPD abutments (77.4%). This is related to the greater lateral functional stresses. Additional important observations were:

- the greatest failure rate was seen for pulpless teeth without crowns (24.2%);
- the presence of intra-coronal reinforcement did not appreciably alter success of teeth without coronal coverage;
- post placement had limited influence on the success rate of FPD abutments but, parenthetically, provided significant improvement for RPD abutments;
- parapost and amalgam or resin composite cores had considerably greater success than tapered cast post-cores.

The increased leverage and non-axial stresses associated with the abutment tooth, and the lowered prognosis for the endodontically treated abutment tooth need to be recognized. The amount of remaining tooth structure and presence of appropriate coronal-radicular anchorage are even more critical for endodontically treated teeth that are to function as abutments.

Restoration of the Endodontically Treated Tooth

THE NEED FOR EXTRA-CORONAL SUPPORT

The clinical longevity of endodontically treated *posterior teeth* (molars and bicuspid) is significantly improved with coronal coverage.^{12,28,29} The evidence strongly supports that placement of a crown to encircle the tooth can increase the resistance of posterior teeth to fracture and a high incidence of failure for posterior endodontically treated teeth without cusp coverage has been reported.¹² In a retrospective study of uncrowned endodontically treated teeth, the overall survival rates of molars without crowns at 1, 2, and 5 years were 96%, 88% and 36% respectively.²⁹ The amount of remaining tooth structure was a significant factor in tooth survival. Aqualina et al²⁸ found that endodontically treated teeth without crowns failed at a 6 times greater rate than uncrowned teeth. The presence of a crown was more important than the type of foundation restoration, although it was noted that teeth with posts demonstrated better survival. It is therefore current teaching in most dental schools to give serious consideration to the provision of full coverage crowns for endodontically treated posterior teeth, particularly molars and maxillary bicuspid. Other forms of cusp coverage such as gold, ceramic, composite onlays or cusp coverage amalgam can also be considered in appropriate clinical situations.

- ◆ The prognosis for posterior endodontically treated teeth is significantly improved with coronal coverage.
- ◆ The prognosis for anterior endodontically treated teeth is not necessarily improved with coronal coverage.

The clinical longevity of endodontically treated maxillary and mandibular *anterior teeth* does not appear to be dependant on coronal coverage.¹² Separation forces are generally lower in the anterior dentition and catastrophic vertical tooth fracture is less common, provided adequate coronal dentin remains. Placement of a crown is not necessary just because an anterior tooth is endodontically treated. It becomes a matter of clinical judgment depending on whether the tooth can be adequately restored to form and function with direct



Figure 3

Anterior tooth (canine) required endodontic therapy after successful major orthodontic repositioning. This tooth solely requires a bonded composite restoration for the access cavity. If the discoloration concerns the patient, bleaching is indicated.

restorative materials. (Figure 3) The presence of moderate class 3, or class 4, bonded composite restorations can frequently provide excellent longevity, provided that the endodontic access is not excessive. Full crown consideration is only required when 1) substantial loss of external coronal tooth structure has occurred or 2) the tooth is unaesthetic, does not respond to bleaching and is an unsatisfactory candidate for more conservative veneering.

THE IMPORTANCE OF THE REMAINING TOOTH STRUCTURE (FERRULE)

The predominant cause of failure of endodontically treated teeth is fracture and the fracture resistance of endodontically treated teeth to horizontal and vertical forces is related to the amount of healthy dentin remaining. Maximum conservation of internal dentine

should therefore be a major objective during *both* endodontic therapy and subsequent restorative procedures. Minimal tooth cutting is the most effective measure for preventing vertical root fractures.³⁰

All endodontically treated teeth that require extra-coronal coverage also require a coronal-radicular core restoration – with *consideration* for the need for a post. The purpose of the core restoration, with or without a post, is to replace lost dentine, provide internal support and retention for the crown and ensure resistance against cervical tooth fracture. The presence of adequate circuitous tooth structure (ferrule) at the crown-root interface is critical for the long-term success of the crowned endodontically treated tooth.^{31,32-35}

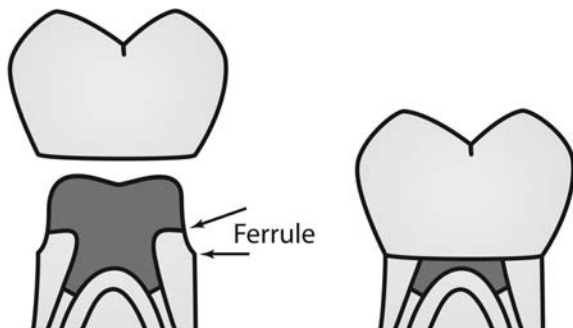


Figure 4a

Diagrammatic representation of the necessary circumferential ferrule between the core margin and the crown margin that is enveloped by the crown.



Figure 4b

Clinical example of an optimal ferrule on a crown preparation for an endodontically treated canine with a post-core that will be an abutment for a removable partial denture.

The ferrule is the circumferential ring of sound tooth structure that is enveloped by the cervical portion of the crown restoration. A minimum sound dentine height of 1.5-2 mm is required between the core and crown margins. (Figures 4a and 4b) The final restoration provides a bracing, casing or hugging action to improve the integrity of the endodontically treated tooth.³⁶

The Importance of the Ferrule

- ◆ Of paramount importance to the longevity of the restored endodontically treated tooth is the presence of adequate height (1.5-2 mm) of sound tooth structure, or ferrule, between the core and the crown margin.
- ◆ The ferrule provides bracing or casing action to protect the integrity of the root.

When a crown is placed on a tooth with optimal ferrule, the crown and root function as one integrated unit and occlusal forces are transmitted in normal physiological fashion to the periodontium. Where inadequate ferrule exists, occlusal stresses are transferred directly to the core and/or post with high likelihood of tooth, root or post fracture or post dislodgement. (Figure 5)

It is for this reason that the practice of elective endodontic treatment for teeth with inadequate ferrule, in an attempt to gain retention from the root, is doomed to failure. In such cases adequate circumferential tooth structure for the vital tooth can best be gained by a) surgical crown lengthening, b) forced orthodontic eruption or, in selected cases, c) sub-gingival preparation and prolonged temporization to allow re-establishment of the biological width.



Figure 5

Radiograph of a central incisor with a dislodged post and crown. Although a parallel sided direct post had been utilized, the prognosis was compromised due to the absence of a ferrule and the length restrictions of the short root.

Restoration of the Endodontically Treated Tooth

The practice of elective endodontic treatment for vital teeth with inadequate ferrule in an attempt to gain retention from the root is doomed to failure.

The fracture resistance of post-cores increases with the presence of retained coronal dentine and the longer the ferrule the higher the fracture resistance.³⁷ Ferrule length greater than or equal to 1.5 mm provides highly significant increased resistance to cyclic loading than shorter ferrule length.³³ This long-taught ferrule guideline has recently been confirmed in a 5-year clinical study.¹ Teeth with substantial dentin height performed significantly better than teeth with less tooth structure remaining. Remaining dentine height was found to be of greater importance than the type of core restoration.

A ferrule effect is considered essential and extraction of the tooth is advised if an adequate ferrule cannot be obtained.³

CRITERIA FOR POST PLACEMENT

Previously considered to provide reinforcement of the root, it is now recognized that posts may help reinforce the remaining coronal tooth structure but post preparation can significantly weaken the root. Unrealistic expectations using large, wide posts in severely compromised teeth with little or no residual crown structure will fail for a variety of reasons but typically by catastrophic root fracture. (Figure 2) This can be a major source of patient dissatisfaction, particularly if used as the foundation for expensive crowns, bridges or other costly rehabilitation. Without adequate circumferential tooth structure, occlusal forces are directed internally down the root creating a wedge effect and the high likelihood of root fracture. Other consequences of lack of ferrule are cement fatigue and post loosening.

Consequences of Inadequate Ferrule

- ◆ Catastrophic root fracture
- ◆ Cement failure and post loosening
- ◆ Post fracture

Because posts are frequently associated with root fracture, their use is currently undergoing significant current debate and there is a definite trend to reduced post usage. Without clear guidelines from definitive research, specific factors for the individual tooth and clinical situation require careful consideration. The decision regarding the need for a post will depend on a) the size and position of the tooth in the arch, b) the amount of coronal tooth structure remaining, c) the functional requirements of the tooth, and d) the canal configuration.³⁸ While recognizing the inherent tendency of posts to weaken the root, they are still indicated for the majority of single or double-rooted bicuspid and anterior teeth that are to receive a crown.³ They provide retention for the core restoration and can contribute to the reinforcement of endodontically-treated teeth by supporting remaining coronal tooth structure.³⁹

I. Anterior Teeth

If a crown is not required for esthetic or functional reasons, then it is generally considered unnecessary to place a post. The potential for root weakening from post preparation tends to outweigh any possible benefits. Uncrowned anterior teeth with access restoration and no post provided greater resistance to fracture under cyclic loading in vitro than even crowned teeth with post-core restorations.⁴⁰⁻⁴² Optimally bonded composite restorations are appropriate. Intra-coronal and/or extra-coronal bleaching can be considered for the relatively sound, but discoloured, anterior tooth to avoid the need for extra-coronal tooth preparation. The risk of resorption due to use of intra-coronal bleach can be prevented by placing a resin modified glass ionomer restoration at the base of the pulp chamber to prevent leakage to the periodontal ligament.

If a crown is necessary, due to the loss of external tooth structure, then a post is usually required for anterior teeth, due to the predominantly shearing forces present and the narrow tooth dimensions. Extra-coronal crown preparation combined with endodontic access preparation significantly weakens the cervical area of anterior teeth. The amount of tooth structure remaining and the particular functional demands will determine the absolute need. Large, bulky anterior teeth with minimal access preparation may not require a post. If

the situation is in doubt, it is better to complete the crown preparation first to allow complete assessment of the remaining tooth structure. Where the strength of the remaining tooth structure is borderline, then a post is indicated.³⁸

II. Posterior Teeth

Crowns, or some type of cusp coverage, are recommended for posterior teeth due to the high risk of catastrophic tooth fracture. The coronal-radicular restorative requirements however differ between molars and bicuspid.

(1) MOLARS

Molar teeth rarely require a post unless there has been significant loss of tooth structure. A coronal-radicular core buildup with silver amalgam utilizing the pulp chamber, and possible 2 mm canal extensions, has proved very effective in vitro and in vivo.^{43,44} (Figure 6) The anchorage provided by a well-placed core utilizing the pulp chamber is considerable and posts should be avoided. Bonded composite is considered to be equally



Figure 6

Direct coronal-radicular buildup, without a post, is recommended for molar teeth with an adequate pulp chamber. 1-2 mm canal extensions can be considered for increased anchorage.

effective provided optimal polymerization is assured in deeper layers by use of either incremental insertion of a photo-polymerized composite or an auto-cured composite core material. Adequate mechanical retention continues to be necessary with current adhesives. Both amalgam and bonded composite cores require the presence of a minimum of 1.5-2 mm height of ferrule after crown preparation. For single crowns, some relaxation of the ferrule rule can be applied interproximally where previous proximal restorations extend

gingivally, provided the core restoration has optimal anchorage, the proximal crown margin is placed on sound tooth structure, and the facial and lingual tooth structure provides optimal ferrule.³⁴ The coronal-radicular core buildup, without a post, has been standard teaching in North America for molar teeth for many years and has been extremely successful. It is not recommended for maxillary bicuspid due to the more limited dimensions of the pulp chamber and root canals which does not allow adequate bulk of material to prevent fracture.

The placement of pins in endodontically treated teeth is not advised due to the increased risk of stress cracks during placement. Existing sound pinned restorations can often usefully be incorporated into a core restoration. In the absence of a pulp chamber, a post may occasionally be required; however, this situation usually suggests that there is minimal tooth structure remaining and that the prognosis for the tooth is lowered. An optimal circumferential ferrule becomes essential. Generally the largest, straightest canal is utilized for the post. The palatal of maxillary molars and the distal of mandibular molars are preferred. Post space preparations are contraindicated in the curved, narrow mesial canals of mandibular molars and the mesio-buccal canals of maxillary molars.⁴⁵

(2) BICUSPIDS

Posts are generally considered necessary for bicuspid teeth because of their smaller diameter and the presence of high shear stresses, particularly for steep-cusped maxillary teeth.^{28,46} A common site of endodontically treated tooth failure, maxillary bicuspid represent a unique sub-group with a high occurrence of failure. Without extra-coronal support these teeth are prone to serious cusp or root fractures. As with anterior teeth, the slender cervical circumference and concave mesial anatomy is greatly weakened through the combination of extra-coronal tooth preparation and endodontic access preparation. Placement of a post with the core is often necessary for adequate anchorage. Minimal enlargement and shaping of the canal is advised during post preparation due to anatomical considerations including thin mesio-distal dimensions and proximal root invaginations.⁴⁷

Restoration of the Endodontically Treated Tooth

Mandibular bicuspid frequently function more as small molars with short crowns and less steeply inclined cusps. They receive more vertical and less shearing forces. The need for extra-coronal support will be based on the amount of lost tooth structure and the anticipated functional forces. If a crown is required, the need for a post will be based on the quantity of sound peripheral dentine remaining after crown preparation. Those with a large pulp chamber may be adequately restored with a coronal-radicular core without a post. Steep-cusped teeth with high function and teeth that will be abutments will require a post.²⁶

General Guidelines for Post Placement

ANTERIOR TEETH

- ◆ If no crown is required, a post is generally unnecessary.
- ◆ If a crown is necessary, a post is generally required.

POSTERIOR TEETH (crowns generally required)

- ◆ Molar teeth with an adequate pulp chamber do not require a post.
- ◆ Molar teeth with inadequate pulp chamber may require a post.
- ◆ Maxillary bicuspid generally require a post.
- ◆ Mandibular bicuspid require independent consideration.

POST SELECTION

A 10% complication rate resulted from a meta-analysis of 12 clinical studies involving a total of 2784 teeth treated with posts and cores over an average of six years (range 1-25 years).²² Post loosening was the major cause of failure at 5% (range 0-10%), root fracture incidence was 3% (range 0-11%) and caries incidence was 2% (range 1-9%). A similar analysis of durability confirmed that loss of retention was the most frequent type of post failure and that root fracture had the most serious consequences, always resulting in extraction.²⁰ Lowest survival rates were reported for active, threaded posts. No other significant differences in failure rates for

different post systems available at that time could be ascertained and it was concluded that additional factors, such as the amount of remaining tooth structure, ferrule effect of the crown and magnitude and direction of functional loads, have a greater influence on survival rate than does the type of post used.

In conjunction with the need for adequate ferrule, post requirements include high strength to prevent cervical fracture, high elastic limit to prevent distortion, and adequate radiopacity to allow future radiographic assessment. Traditionally, posts were always metallic – either cast gold alloy or prefabricated stainless steel or titanium alloy. In recent years, non-metallic posts have been introduced including carbon fibre posts (black) and more recently, composite posts (white) and zirconium posts (white). Differences of opinion currently exist regarding the optimal material, design and fixation of posts.

I. Metallic Posts

The custom cast post has been used for many years and can provide excellent clinical service, however, a recent major systematic review of the available literature (6 in vivo and 10 in vitro studies) was unable to demonstrate any superiority of cast posts over direct post-core restorations.⁴⁸ With evidence of relatively equal performance, direct post and core restorations can reduce both cost and time factors for the patient. A further advantage is the lack of necessity to remove additional dentine in order to remove undercuts, which further weakens the tooth. Clinical studies support the effectiveness of prefabricated posts.^{12,20,38,49} Greater tooth structure is removed for cast posts, two appointments are necessary and the cost is high. Even clinical situations with considerable loss of internal dentine, traditionally restored with a custom cast post and core, have been shown more successful in vitro when restored with bonded resin composite reinforced by a central metal post.⁴⁹

Prefabricated metal posts of many different designs are available in stainless steel and titanium alloy. There is no consensus on superiority of one over another. Post retention and core retention are similar between the two materials. However, a commonly used parallel titanium post was found to be significantly less rigid than an

equivalent stainless steel post and was not recommended for clinical application where heavy loads are anticipated.⁵⁰ The majority of metal posts involve tapered or parallel design of which parallel provides greatest retention, particularly if the surface is grooved or roughened. Although tapered post shape requires less dentine removal and is more consistent with root anatomy, a growing body of evidence suggests that tapered, unbonded posts exert a wedge effect that puts the root at risk of fracture and predisposes to loss of retention.⁵¹ (Figures 7a and b)

Optimal ferrule and residual root strength are essential to prevent vertical root fracture caused by concentration of occlusal stresses down a tapered post. Passive post placement for any post design provides least amount of stress on the root.



Figure 7a

A tapered post without a ferrule predisposes the tooth to root fracture, due to occlusal forces being directed internally down the canal.

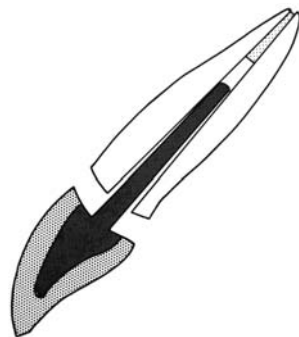


Figure 7b

A tapered post without a ferrule also predisposes the post to dislodgement, due to occlusal forces directed down the canal causing fatigue failure of cement.

II. Non-Metallic Posts

The addition of non-metallic posts composed of various different fibre-reinforced polymer or composite materials from many different manufacturers, with differing designs, sizes and composition has introduced considerable variability and debate into the subject of post-core restorations. Newer concepts, including possible advantages from use of less rigid posts and the

potential for adhesive luting cements, are somewhat controversial and comparisons and conclusions from the limited available research are difficult to make at this time.

(1) CARBON FIBRE POSTS

The carbon fibre prefabricated post, introduced in the early 1990s, is comprised of longitudinally aligned carbon fibres embedded in an epoxy resin matrix (approx 36%). This type of post has no radiopacity and is black in colour – both significant clinical disadvantages. Although it has been claimed that the carbon fibre post has a modulus of elasticity close to that of dentine, there have been several studies refuting this.²⁷ The carbon fibre post is “quite stiff and strong, to a degree comparable to several posts made of metal”⁵² and to have a modulus about ten times higher than dentine.²⁷ Water immersion has been found to reduce the strength and stiffness considerably, due to epoxy degradation. Clinical success with carbon fibre posts cannot therefore be used as evidence for the desirability of more flexible posts and may well be associated with the use of tougher resin luting cements used to retain the post within the root canal. Effective bonding between the industrially processed and highly polymerized epoxy resin post and composite cores can be problematic. Retention of composite core to carbon-fibre posts is lower than that to metal posts and retentive failure at the post-cement interface has been documented.^{53,54}

Clinical results are few and somewhat variable. In a Cochrane systematic review⁵⁵ designed to compare the clinical failure rates of metal versus non-metal posts, only one study comparing Compositopost carbon fibre posts with cast posts⁵⁶ met the review objectives. There were fewer failures (0/97) associated with the carbon fibre post than with the conventional cast posts (9/98) after 4 years of clinical service. However, the review authors identified potential for a high risk of bias in the methodology and felt that the results should be interpreted cautiously for clinical practice. Two other retrospective clinical studies have reported success with carbon fibre posts. Fredericksson et al⁵⁷ reported no failures in 236 teeth over 32 months and Ferrari et al⁵⁸ reported a low failure rate of 3.2% over a period of 1-6 years in 1304 teeth.

Restoration of the Endodontically Treated Tooth

Contradictory results have been reported more recently. In a prospective clinical trial more failures were seen in the carbon-fibre-posted teeth than those with conventional prefabricated posts.⁵⁹ Also, a longer term follow up of the 236 teeth in the favourable Fredericksen report concluded that the carbon-fibre restored teeth had shorter survival times than those previously documented for cast posts. Only 65% of teeth restored with the carbon-fibre post system were successful after a mean time of 6.7 years.⁶⁰ Tooth fracture and apical infection were the major cause of failure and the authors recommended caution in the use of fibre posts, particularly when extensive fixed prosthodontics is planned. These later studies emphasize the value of longer-term clinical research.

The concept of endodontically treated bicusps restored with bonded carbon-fibre posts and no crown is being studied in a clinical trial. The clinical success rates of such post-composite restorations at 3 years were equivalent to similar treatment with the addition of PFM crowns.⁶¹ However, caution is advised due to the short time period, the post problems observed, and the fact that fractures in endodontically treated teeth without crowns tend to accelerate after 3 years.^{10,29}

(2) TOOTH-COLOURED POSTS

With the development of all-ceramic crowns and the high interest in esthetic restorations, many different esthetic white or translucent prefabricated posts have been introduced. These include zirconium-coated carbon fibre, glass fibre-reinforced epoxy, fibre-reinforced composite and zirconia posts. The multiplicity of designs and materials makes comparisons and recommendations difficult, particularly given the paucity of clinical studies.

(i) Zirconia Ceramic Posts

Zirconia ceramic posts are white, radiopaque, strong and very rigid. They have a modulus of elasticity higher than stainless steel and any modification to the post may affect the strength and must be carried out with a diamond disc. The high rigidity of zirconia ceramic posts produces higher stresses at the entrance to the canal when minimal tooth structure remains and more catastrophic root fractures in vitro compared to metal

and carbon fibre posts.⁶² Bonding of composite resin cores to the post has proved unpredictable and has been shown to be problematic for composite core integrity.⁶³

Use of zirconia posts with heat-pressed ceramic cores has provided good results in vitro⁶⁴ and in a small pilot clinical study over 29 months.⁶⁵ However, poorer results have been seen in vivo over 4 years.⁶⁶ This indirect technique also involves added expense and a second appointment. It is probable that zirconia posts with heat-pressed ceramic core essentially provide an esthetic version of the cast post core. In a relatively recent review, Morgano has stated that "little is known about the long-term survival of these all-ceramic posts and they seem to have limited applicability."³

(ii) Fibre-reinforced and Composite Posts

Introduced in recent years, many different types of reinforced polymeric posts are available in a variety of shapes and sizes from different manufacturers. Largely used for highly esthetic restorations, these posts typically are bonded with resin luting cements and utilize composite cores. In vitro studies have indicated that these posts are not as strong as conventional posts³ and manufacturers caution that they should not be used where remaining tooth structure is less than ideal or where high occlusal forces are present. The instructions for one state the post should not be used if there is less than 2-3 mm of supra-gingival tooth structure present, if there is parafunction or a deep overbite. The mechanical and physical properties of these commercial posts vary considerably and caution is advised in using research results for a particular product as a generalization for all fibre-reinforced posts. Several in vitro studies have determined the resistance to fracture of teeth with post-core restorations under static loading and the conflicting results demonstrate the difficulties involved in standardizing this type of experiment.⁵¹

Glass-fibre reinforced posts have less stiff fibres than carbon fibre posts. They are therefore more flexible than both metal and carbon-fibre posts²⁷ and this has been both cited as an advantage in some reports and a disadvantage in others. The two sides of the current debate pit the possibility of flexure producing micro-movement of the core, cement breakdown, leakage and

failure versus the possibility of reduced catastrophic root fracture.⁶⁷ Much of the laboratory research utilizes post-restored teeth that are loaded directly on the core or crown without the presence of any ferrule. In these situations it is customary to find that the load to failure is significantly higher for the stronger metallic posts than any of the fibre-reinforced posts, but results in more significant root fracture.⁶⁷⁻⁶⁹ In other words, the failure occurs at lower loads, but is less catastrophic with fibre-reinforced posts. It is frequently stated that such teeth remain re-restorable as fibre posts will be more readily retrievable from the canal.^{69,70} How useful this would be in the clinical situation is unclear. In the absence of an adequate ferrule, failure will occur and the debate centres on whether it is better to have re-restorable failures in the short term or unrestorable failures after a long time in function or at high stress levels.²⁷ An unacceptably high 12.8% clinical failure rate has been documented over 2 years for glass-fibre posts and no difference was noted between parallel or tapered design.⁷¹ The main type of failure was post fracture and this high failure rate was linked to lack of remaining vertical tooth structure.

With the presence of an optimal ferrule and normal function for a single anterior esthetic crown, glass-fibre posts may provide adequate results. However, clinical studies are currently unavailable and in-vitro results are equivocal, suggesting caution in more universal application.

POST SPACE PREPARATION

Where posts are required, the provision of a longer post that preserves maximum root dentine and 4-5 mm of gutta percha apical seal, combined with extra-coronal support to provide a ferrule effect on sound tooth structure, offers the best prognosis.³ Short posts lead to greater stress at the coronal aspect of the canal and are more susceptible to dislodgement or root fracture. Very short posts, those ending in the cervical third of the canal, are associated with a high number of vertical root fractures.^{12,72} The length of the post ideally should be at least as long as the clinical crown, provided that 4-5 mm of gutta percha remains. A post length of 7.0-8.0 mm is frequently stated as a typical guideline. The diameter of the post should be kept to a minimum, consistent with

the rigidity required and the width of the endodontic obliteration.² (Figure 8)

Preservation of natural root structure will maintain maximum tooth strength. It is also essential to maintain the integrity of the endodontic obliteration.



Figure 8

Optimal conservative post placement, with appropriate length, width and fit, for a maxillary canine that required a crown due to the amount of lost tooth structure.

The ubiquitous use of posts has been questioned and the lack of clearly defined criteria decried from the point of view of the iatrogenic problems that post preparation can cause.⁴⁵ The major concern is the production and impact of root perforations during the preparation of the post space which can cause the demise of the tooth. Minimal canal enlargement is necessary to reduce the known weakening effect of post preparation³¹ and will reduce the technical dangers. Current guidelines promote adjusting the post to fit the canal if drill-matched post dimensions do not seat to the intended depth. This can easily be achieved by custom tapering of the post tip which has the added benefit of removing sharp edged potential stress concentrations.

Safe post space preparation can be achieved with non-end-cutting slow speed rotary instruments, but extreme care is required. Initial removal of excess gutta percha using a heat and touch technique is recommended. Iatrogenic perforations generally arise from use of end-cutting burs, failure to appreciate root anatomy or pulp chamber depth, and use of incorrect bur angulation.⁴⁵ A Gates Glidden instrument, no wider than the canal width, used to post-length followed by careful use of a Peeso Bur are the instruments of choice for least-invasive preparation. A minimum 1.5 mm remaining root wall is recommended. It is advisable to perform this procedure without local anaesthetic as patient sensitivity

Restoration of the Endodontically Treated Tooth

may herald and prevent overt perforation. Root perforation can lead to persistent biting sensitivity, chronic periodontal inflammation or furcation involvement, chronic exudate from the site, and eventual loss of the tooth.⁴⁵

Optimal Post Preparation

- ◆ Use of non-end-cutting rotary instruments
- ◆ Minimal canal enlargement
- ◆ Diameter one-third root width or less
- ◆ Length at least equivalent to crown height (short and extra long posts increase root fracture)
- ◆ Minimum 4-5 mm gutta percha remaining
- ◆ Post modification to fit canal
- ◆ Passive post design and placement
- ◆ Adequate ferrule (1.5-2 mm) between core and crown margins



Figure 9

The coronal-radicular buildup for this two-rooted maxillary bicuspid involved a narrow diameter direct post in one canal, and a composite core utilizing the remaining pulp chamber, to provide adequate anchorage for the crown restoration.

In the typical figure-eight shaped bicuspid canal, use of the most convenient access single canal shape provides adequate retention and resistance. The remaining pulp chamber is used for the direct core material which may be extended 1-2 mm into the opening of the remainder of the canal. (Figure 9) Sound tooth structure should never be removed to convert the oval shape to a circular outline form, as it will significantly weaken the tooth and may cause root perforation. A safer objective would be to achieve post fit on opposing walls for a major part of the post length.

Posts are often associated with both iatrogenic damage and root weakening. They should be used judiciously and carefully.

CEMENTATION

As with the cementation of any indirect restoration, the purpose of the cement is to secure the retention inherent in the design and to ensure a seal against micro-leakage. Cements are best introduced into the canal with a lentulo-spiral and the post also coated with cement. Current resin-modified glass ionomer luting cements provide adequate properties and are widely used for routine cementation.^{2,73} Zinc phosphate cement cannot be discounted as it provides high modulus, ease of use, and has withstood the test of time. For post situations with less than optimal retention, resin cements can provide a significant increase in retentive strength.^{74,75}

The concept of adhesive fixation of a post and core in order to stabilize the tooth is an emerging concept⁷⁶ and several in-vitro studies suggest adhesive cementation of posts can both increase post retention and reinforce the tooth.^{31,77-79} Effective bonding of the post can also reduce dentine stresses.⁵¹ Bonded resin luting cements may be advantageous with any type of post, but are definitely indicated with fibre-reinforced epoxy posts to increase internal retention and decrease water-sorption which can decrease their strength.⁸⁰ Bonding, however, can be impaired by the presence of remnants of endodontic sealers and it has been suggested that the canal surface be cleaned with alcohol or detergent prior to bonding.¹⁹ Caution is required with resin cements that set very rapidly, as seating problems have been encountered. Adherence to manufacturers' directions is required. Recently introduced self-etching resin cements that

require no tooth conditioning or priming reduce technique sensitivity and are particularly advantageous for this purpose. Flexural strength and modulus properties are similar or better than regular resin cements.⁸¹ The cements are dual-cured, providing command set for stabilization of the post and allowing immediate core buildup with composite resin.

The success of any type of post is highly dependent on the presence of an adequate ferrule for the overlying crown. All post parameters such as length, width, design and cement are far less important than vertical tooth structure between the crown and core margins. Where there is minimal vertical tooth structure, all other parameters become far more critical and the long-term prognosis is reduced.

TREATMENT PLANNING

Comprehensive treatment planning often involves decisions concerning the need for, and advisability of, endodontic treatment (initial or retreatment) within the overall clinical picture for the patient. Endodontic treatment is a significant investment, particularly for a tooth that will require a core and crown. Therefore the overall situation must be assessed to ensure a good long-term prognosis. Treatment planning will include the restorative implications and the restorability of the tooth will require careful analysis. If previous endodontic treatment is present, the quality of the endodontic obturation is an important pre-operative consideration. The costs and prognosis should be discussed with the patient. Knowledge of the factors most likely to affect the long term prognosis of the restored tooth provide significant guidance as whether endodontic therapy is advisable or whether alternate treatments should be recommended. The current level of success and predictability of osseointegrated implants now needs to be incorporated into such decisions, particularly when little coronal tooth structure remains and restorability is in question.

The specific type of restoration required will depend on the position of the tooth in the arch, the amount of tooth structure remaining, the functional demands anticipated and the overall condition of the dentition. Posterior teeth, particularly molars and maxillary bicuspid, and some anterior teeth will benefit from the placement of a

crown. Anterior teeth can function well without extra-coronal support provided the tooth structure can be restored with composite. The presence, or possible creation, of a sound dentine ferrule is a major factor in the long-term prognosis for a tooth to be crowned. If crown-lengthening will be necessary to achieve a ferrule, the resulting crown-root ratio and the possible deleterious effect of bone removal on adjacent teeth must be assessed, and the patient informed of the need for surgery prior to endodontic therapy. If extensive caries is present this must be removed to enable adequate pre-operative assessment. Other treatment planning considerations include a) periodontal condition and bone support, b) root length, c) anticipated functional demands, and d) completeness of the remaining dentition.

The prognosis for an endodontically treated tooth is better in a complete dental arch because of the stabilizing effect of mesial and distal proximal contacts.²⁸ Teeth with two proximal contacts have better survival and are three times less likely to be lost than those with one or no proximal contact.⁸² Teeth without adjacent teeth, teeth that are mobile due to periodontal bone loss, and those that will function as abutments receive increased non-axial lateral forces and are far more susceptible to fatigue failure and fracture. Favourable prosthesis design combined with optimal restorative factors become paramount for teeth that will function as abutments.²⁷

A synergistic approach between endodontic and restorative treatment is considered particularly beneficial to the integrity of the tooth.⁸³ Both endodontist and restorative dentist need to be aware of the objectives of each others treatment and the effect on the overall prognosis. Both need to be aware of the importance of preservation of tooth structure to ensure postoperative root strength and prevent vertical root fracture. When high-quality endodontic and restorative treatment is achieved, successful long-term outcomes are possible.

Restoration of the Endodontically Treated Tooth

Conclusions

- ◆ A major objective in dentistry is maintenance of tooth vitality.
- ◆ Pulpless teeth are weaker and have a lower prognosis.
- ◆ Pulpless teeth require restorations that both conserve and protect remaining tooth structure.
- ◆ Non-axial forces (abutments, teeth without adjacent teeth and those with reduced bone support) are most deleterious.
- ◆ Remaining vertical coronal tooth structure (ferrule) is paramount to resist fracture and is more important than post design, material or luting cement.
- ◆ Clinical success depends on application of sound biomechanical principles for the specific tooth and clinical situation.

REFERENCES

- Creugers, N.N., et al., *5-year follow-up of a prospective clinical study on various types of core restorations*. Int J Pros, 2005. **18**: p. 34-39.
- Robbins, J.W., *Restoration of the endodontically treated tooth*. Dent Clin N Am, 2002. **46**: p. 367-384.
- Morgano, S.M., A.H.C. Rodrigues, and C.E. Sabrosa, *Restoration of endodontically treated teeth*. Dent Clin N Am, 2004. **48**: p. 397-416.
- Featherstone, J.D., S.M. Adair et al., *Caries management by risk assessment: Consensus Statement*. Cal Dent Assoc J, 2003. **31**: p. 257-269.
- McComb, D., *Conservative operative management strategies*. Dent Clin N Am, 2005. **49**: p. 847-865.
- Tyas, M.J., K.J. Anasavice et al., *Minimal intervention dentistry - a review. F.D.I. Commission Project I-97*. Int Dent J, 2000. **50**: p. 1-12.
- Bjorndahl, L., *Dentin caries: Progression and clinical management*. Oper Dent, 2002. **27**: p. 211-217.
- Mjor, I.A., *Minimally invasive dentistry - concepts and techniques in cariology. Part 5. Repair of restorations*. Oral Health Prev Dent, 2003. **1**: p. 70-72.
- Christensen, G.J., *How to kill a tooth*. J Am Dent Assoc, 2005. **136**: p. 1711-1713.
- Hansen, E.K., *In vivo cusp fracture of endodontically treated premolars restored with MOD amalgam or MOD resin fillings*. Dent Mater, 1988. **4**: p. 169-173.
- Hansen, E.K., E. Asmussen, and N.C. Christiansen, *In vivo fractures of endodontically treated posterior teeth restored with amalgam*. Endod Dent Traumatol, 1990. **6**: p. 49-55.
- Sorenson, J.A. and J.T. Martinoff, *Intracoronary reinforcement and coronal coverage: a study of endodontically treated teeth*. J Prosthet Dent, 1984. **51**: p. 780-784.
- Fennis, W.M.M., R.H. Kuijs, and Kreulen, C.M., et al. *A survey of cusp fractures in a population of general dental practices*. Int J Prosthodont, 2002. **15**: p. 559-563.
- Hood, J.A.A., *Methods to improve fracture resistance of teeth., in Posterior composite resin dental restorative materials., G. Vanherle and D.C. Smith, Editors. 1985, Peter Szule Publishing: Netherlands. p. 443-450.*
- Panitvisai, P. and H.H. Messer, *Cuspal deflection in molars in relation to endodontic and restorative procedures*. J Endod, 1995. **21**: p. 57-61.
- Hannig, C., et al., *Fracture resistance of endodontically treated maxillary premolars restored with CAD/CAM ceramic inlays*. J Prosthet Dent, 2005. **94**: p. 342-349.
- Vire, D.E., *Failure of endodontically treated teeth: Classification and evaluation*. J Endod, 1991. **17**: p. 338-342.
- Heling, I., et al., *Endodontic failure caused by inadequate restorative procedures: review and treatment recommendations*. J Prosthet Dent, 2002. **87**: p. 674-678.
- Schwartz, R.S. and R. Fransman, *Adhesive dentistry and endodontics: materials, clinical strategies and procedures for restoration of access cavities: A review*. J Endod, 2005. **31**: p. 151-165.
- Torbjorner, A., S. Karlsson, and P. Odman, *Survival rate and failure characteristics for two post designs*. J Prosthet Dent, 1995. **73**: p. 439-444.
- Mentink, A.G.B., et al., *Survival rate and failure characteristics of the all metal post and core restoration*. J Oral Rehab, 1993. **20**: p. 455-461.
- Goodacre, C.J., et al., *Clinical complications in fixed prosthodontics*. J Prosthet Dent, 2003. **90**: p. 31-41.
- Randow K, P.-O. Glantz, and B. Zoger, *Technical failures and some related clinical complications in extensive fixed prosthodontics*. Acta Odont Scand, 1986. **44**: p. 241-255.
- Wegner, P.K., S. Freitag, and M. Kern, *Survival rate of endodontically treated teeth with posts after prosthetic restoration*. J Endodont, 2006. **32**: p. 928-931.
- Nyman, S. and J. Lindhe, *A longitudinal study of combined periodontal and prosthetic treatment of patients with advanced periodontal disease*. J Periodont, 1979. **50**: p. 163.
- Sorenson, J.A. and J.T. Martinoff, *Endodontically treated teeth as abutments*. J Prosthet Dent, 1985. **53**: p. 631-636.
- Torbjorner, A. and B. Fransson, *A literature review on the prosthetic treatment of structurally compromised teeth*. Int J Prosthodont, 2004. **17**: p. 369-376.
- Aqualina, S.A. and D.J. Caplan, *Relationship between crown placement and the survival of endodontically treated teeth*. J Prosthet Dent, 2002. **87**: p. 256-263.
- Nagasari, R. and S. Chitmongkolsuk, *Long-term survival of endodontically treated molars without crown coverage: a retrospective cohort study*. J Prosthet Dent, 2005. **93**: p. 164-170.
- Reeh, E.S., H.H. Messer, and W.H. Douglas, *Reduction in tooth stiffness as a result of endodontic and restorative procedures*. J Endod, 1989. **15**: p. 512-516.
- Sornkul, E. and J.G. Stannard, *Strength of roots before and after endodontic treatment and restoration*. J Endod, 1992. **18**: p. 440-443.
- Isidor, F., K. Brondum, and G. Ravnholt, *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**: p. 78-82.
- Libman, W.J. and J.I. Nicholls, *Load fatigue of teeth restored with cast posts and cores and complete crowns*. Int J Prosthodont, 1995. **8**: p. 529-536.
- Ng, C.C.H., et al., *Influence of remaining coronal tooth structure location on the fracture resistance of restored endodontically treated anterior teeth*. J Prosthet Dent, 2006. **95**: p. 290-296.
- Sorenson, J.A. and M.J. Engleman, *Ferrule design and fracture resistance of endodontically treated teeth*. J Prosthet Dent, 1990. **63**: p. 529-536.
- Fernandes, A.S. and G.S. Dessai, *Factors affecting the fracture resistance of post-core reconstructed teeth: A review*. Int J Prosthodont, 2001. **14**: p. 355-363.
- Al-Omiri, M.K. and A.M. Wahadni, *An ex-vivo study of the effects of retained coronal dentine on the strength of teeth restored with composite core and different post and core systems*. Int Endod J, 2006. **39**: p. 890-899.
- Robbins, J.W., *Restoration of endodontically treated teeth, in Fundamentals of Operative Dentistry. A contemporary approach, J.B. Summitt, et al., Editors. 2006, Quint Pub Co Inc. p. 570-590.*
- Hyashi, M., et al., *Fracture resistance of pulpless teeth restored with post-cores and crowns*. Dent Mater, 2006. **22**: p. 477-485.
- Heydecke, G., F. Butz, and J.R. Strub, *Fracture strength and survival of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an in-vitro study*. J Dent, 2001. **29**: p. 427-433.
- Pontius, O. and J.W. Hutter, *Survival rate and fracture strength of incisors restored with different post and core systems and endodontically treated incisors without coronoradicular reinforcement*. J Endod, 2002. **28**: p. 710-715.
- Trope, M., D.O. Maltz, and L. Tronstad, *Resistance to fracture of restored endodontically treated teeth*. Endod Dent Traumatol, 1985. **1**: p. 108-111.
- Nayyar, A., *An amalgam coronal-radicular dowel and core technique for endodontically treated posterior teeth*. J Prosthet Dent, 1980. **43**: p. 511.

Restoration of the Endodontically Treated Tooth

44. Plasmans, P.J.J.M., et al., *In vitro comparison of dowel and core techniques for endodontically treated molars.* J Endod, 1986. **12**: p. 382-387.
45. Stockton, L., C.L.B. Lavelle, and M. Suzuki, *Are posts mandatory for the restoration of endodontically treated teeth?* Endod Dent Traumatol, 1998. **14**: p. 59-63.
46. Cheung, W., *A review of the management of endodontically treated teeth: Post, core and the final restoration.* J Am Dent Assoc, 2005. **136**: p. 611-619.
47. Manning, K.E., et al., *Factors to consider for predictable post and core build-ups of endodontically treated teeth. Part 1: Basic theoretical concepts.* Can Dent Assoc J, 1995. **61**: p. 685-695.
48. Heydecke, G. and M.C. Peters, *The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores: A systematic review.* J Prosthet Dent, 2002. **87**: p. 380-386.
49. Saupe, D.J. and J.A. Weintraub, *A comparative study of fracture resistance between morphologic dowel and cores and a resin-reinforced dowel system in the intraradicular restoration of structurally compromised roots.* Quint Int, 1996. **27**: p. 483-491.
50. Hew, Y.S., D.G. Purton, and R.M. Love, *Evaluation of pre-fabricated root canal posts.* J Oral Rehab, 2001. **28**: p. 207-211.
51. Asmussen, E., A. Peutzfeldt, and A. Sahafi, *Finite element analysis of stresses in endodontically treated, dowel-restored teeth.* J Prosthet Dent, 2005. **94**: p. 321-329.
52. Asmussen, E., A. Peutzfeldt, and T. Heitmann, *Stiffness, elastic limit and strength of newer types of endodontic posts.* J Dent, 1999. **27**: p. 275-278.
53. Drummond, J.L., *In vitro evaluation of endodontic posts.* Am J Dent, 2000. **13**: p. 5B-8B.
54. Purton, D.G. and J.A. Payne, *Comparison of carbon fiber and stainless steel root canal posts.* Quint Int, 1996. **27**: p. 93-97.
55. Bolla, M., et al., *Root canal posts for the restoration of root filled teeth.* Cochrane Database of Systematic Reviews, 2007. **Issue 1, Art No.CD004623.**
56. Ferrari, M., A. Vichi, and F. Garcia-Godoy, *Clinical evaluation of fiber-reinforced epoxy resin posts and cast post and cores.* Am J Dent, 2000. **13(Spec No)**: p. 15B-18B.
57. Fredriksson, M., et al., *A retrospective study on 236 subjects with teeth restored by carbon fiber-reinforced epoxy resin posts.* J Prosthet Dent, 1998. **80**: p. 151-157.
58. Ferrari, M., et al., *Retrospective study of the clinical performance of fiber posts.* Am J Dent, 2000. **13(Spec No)**: p. 9B-13B.
59. King, P.A., D.J. Setchell, and J.S. Rees, *Clinical evaluation of a carbon fibre reinforced endodontic post.* J Oral Rehab, 2003. **30**: p. 785-789.
60. Segerstrom, S., J. Astback, and K. Ekstrand, *A retrospective long term study of teeth restored with prefabricated carbon fiber reinforced epoxy resin posts.* Swed Dent J, 2006. **30**: p. 1-8.
61. Mannocci, F., et al., *Three-year comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration.* J Prosthet Dent, 2002. **88**: p. 297-301.
62. Hu, Y.H., et al., *Fracture resistance of endodontically treated anterior teeth restored with four post-and-core systems.* Quint Int, 2003. **34**: p. 349-353.
63. Cohen, B.I., et al., *Retention of a core material supported by three post head designs.* J Prosthet Dent, 2000. **83**: p. 624-628.
64. Heydecke, G., et al., *Fracture strength after dynamic loading of endodontically treated teeth restored with different post-and-core systems.* J Prosthet Dent, 2002. **87**: p. 438-445.
65. Nothdurft, F.P. and P.R. Pospiech, *Clinical evaluation of pulpless teeth restored with conventionally cemented zirconia posts: a pilot study.* J Prosthet Dent, 2006. **95**: p. 311-314.
66. Paul, S.J. and P. Werder, *Clinical success of zirconium oxide posts with resin composite or glass ceramic cores in endodontically treated teeth: a 4-year retrospective study.* Int J Prosthodont, 2004. **17**: p. 524-528.
67. Newman, M.P., et al., *Fracture resistance of endodontically treated teeth restored with composite posts.* J Prosthet Dent, 2003. **89**: p. 360-367.
68. Bonifante, G., et al., *Fracture strength of teeth with flared root canals restored with glass fibre posts.* Int Dent J, 2007. **57**: p. 153-160.
69. Cormier, C.J., D.R. Burns, and P. Moon, *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**: p. 26-36.
70. Akkayan, B. and T. Gulmez, *Resistance to fracture of endodontically treated teeth restored with different post systems.* J Prosthet Dent, 2002. **87**: p. 431-437.
71. Naumann, M., F. Blankenstein, and T. Dietrich, *Survival of glass fibre reinforced composite post restorations after 2 years - an observational clinical study.* J Dent, 2005. **33**: p. 305-312.
72. Fuss, Z., et al., *An evaluation of endodontically treated vertical root fractured teeth: impact of operative procedures.* J Endod, 2001. **27**: p. 46-48.
73. Duncan, J.P. and C.H. Pameijer, *Retention of parallel-sided titanium posts cemented with six luting agents: an in vitro study.* J Prosthet Dent, 1998. **80**: p. 423-428.
74. Leary, J.M., D.C. Holmes, and W.T. Johnson, *Post and core retention with different cements.* Gen Dent, 1995. **43**: p. 416-419.
75. Standlee, J.P. and A.A. Caputo, *Endodontic dowel retention with resinous cements.* J Prosthet Dent, 1992. **68**: p. 913-917.
76. Peroz, I., et al., *Restoring endodontically treated teeth with posts and cores - A review.* Quint Int, 2005. **36**: p. 737-746.
77. Mendoza, D.B., et al., *Root reinforcement with a resin-bonded reformed post.* J Prosthet Dent, 1997. **78**: p. 10-14.
78. Sahafi, A., et al., *Resistance to cyclic loading of teeth restored with posts.* Clin Oral Investig, 2005. **9**: p. 84-90.
79. Utter, J.D., B.H. Wong, and B.H. Miller, *The effect of cementing procedures on retention of prefabricated metal posts.* J Am Dent Assoc, 1997. **128**: p. 1123-1127.
80. Mannocci, F., M. Sherrif, and T.F. Watson, *Three-point bending test of fiber posts.* J Endod, 2001. **27**: p. 758-761.
81. Sakalauskaite, E., L. Tam, and D. McComb, *Flexural strength, elastic modulus and pH profile of self-etching resin luting cements.* J Prosthet Dent, 2007. In Press.
82. Caplan, D.J. and J.A. Weintraub, *Factors related to loss of root canal filled teeth.* J Public Health Dent, 1997. **57**: p. 31-39.
83. Lopez, L., *Endodontic and esthetic/restorative treatment of the same tooth: a synergistic approach for successful outcomes.* Comp Cont Educ Dent, 2005. **26(Suppl 2)**: p. 19-23.



Royal College of
Dental Surgeons of Ontario

Ensuring Continued Trust

6 Crescent Road
Toronto ON Canada M4W 1T1
T: 416.961.6555 F: 416.961.5814
Toll Free: 800.565.4591 www.rcdso.org