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Published in:
Brazilian oral research

DOI:
[10.1590/1807-3107bor-2018.vol32.0074](https://doi.org/10.1590/1807-3107bor-2018.vol32.0074)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2018

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

de Carvalho, M. A., Lazari, P. C., Gresnigt, M., Del Bel Cury, A. A., & Magne, P. (2018). Current options concerning the endodontically-treated teeth restoration with the adhesive approach. *Brazilian oral research*, 32, 147-158. <https://doi.org/10.1590/1807-3107bor-2018.vol32.0074>

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Current options concerning the endodontically-treated teeth restoration with the adhesive approach

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Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

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<https://doi.org/10.1590/1807-3107bor-2018.vol32.0074>

Submitted: May 10, 2018
Accepted for publication: May 29, 2018
Last revision: June 12, 2018

Abstract: Adhesive procedures have changed the way to restore endodontically treated teeth (ETT). It started with the shift from cast post-and-core to fiber post. The original focus on strength also shifted towards failure modes, revealing that catastrophic failures are still a concern when restoring endodontically-treated teeth even with fiber posts. As an alternative, postless approaches have been proposed in order to improve the chances of repair. The goal of this critical review is to present a survey of the current knowledge on adhesive approaches to restore endodontically treated teeth with and without extensive coronal tissue loss. The preservation of tooth structure of endodontically treated teeth is paramount. Partial versus full coverage of ETT, the role of the ferrule, the post type effect on catastrophic failures and postless alternatives as endocrowns and postless build-ups are reviewed. There is a consensus that the remaining tooth structure plays an important role in ETT survival, although the current literature still is contradictory on the influence of post type on root fractures as well as the benefits of avoiding a post or partially restoring a tooth. More clinical studies should be carried out with the modern postless adhesive alternatives to conventional approaches.

Keywords: Tooth, Nonvital; Dental Materials; Crowns; Dental Restoration Failure; Dental Bonding.

Introduction

The optimal way to restore teeth after endodontic treatment continues to remain a controversial topic of heated debate to this day. Endodontically treated teeth (ETT) present with significantly different mechanical properties compared to vital teeth.^{1,2} The modifications in the biomechanical properties and structural integrity of the teeth are most-likely attributed to the volumetric loss of the hard tissues, extent of carious lesion, fracture propagation, final cavity preparation in addition to the access cavity prior to endodontic therapy.^{3,4,5,6,7}

There is still a debate regarding which technique would be ideal for ETT restoration, since those teeth are considered to have a higher risk of fracture than vital teeth.^{4,7,8,9,10} From a biomimetic perspective, the preservation and conservation of tooth structure is paramount in maintaining the balance between biological, mechanical, adhesive, functional, and esthetic



parameters. It is beneficial to preserve coronal tissues and avoid invasive endodontic procedures, because these approaches violate the biomechanical balance and compromise the long-term performance of restored teeth.¹¹ As quantified by Dietschi et al,⁴ the cavity depth, isthmus width, and configuration are highly critical factors in determining the reduction in tooth stiffness and risk of fracture. The remaining vertical coronal tooth structure named “ferrule” is clearly considered the crucial factor for the optimal biomechanical behavior of endodontically treated teeth.^{12,13,14,15,16} However, sufficient coronal structure is sometimes deficient in clinical situations and the teeth do not offer enough sound structure to generate a ferrule effect.

The restorative approach regarding ETT has changed in recent years. The availability of proven and reliable adhesive dental techniques has expanded the restorative options for the clinician. Amalgam cores and cast metal posts are being replaced by direct composite and glass-fiber posts, in addition to all ceramic and composite resin crowns being often chosen because of their superior aesthetic outcome.^{17,18} Furthermore, restorations techniques without the use of post-and-core build-ups are gaining in popularity due to their minimal invasiveness and simplification of clinical steps.^{19,20} Clinicians still face the same dilemma when restoring ETT: should this tooth be restored with or without a post?

The aim of this critical review is to assess the literature on the recent trends in adhesive dentistry to restore the endodontically treated teeth.

Preserving the coronal structure

The restoration replacement can result in a restorative cycle of death and was first described by Elderton²¹ in 1988 and Simonsen²² in 1991. The defective restorations are eventually replaced by larger restorations that will someday fail again, which will lead to even larger restorations or possible post-and-core approach, increasing the risk for complications, and eventually loss of the tooth.²³ The concept of minimal intervention in dentistry to preserve and conserve tooth structure is gaining popularity equally when restoring endodontically treated teeth.^{15,20,24}

Tooth structure preservation and conservation is directly correlated with fracture resistance,^{4,25} whilst reducing the occurrence of catastrophic failures and enhancing the longevity of the restored tooth.^{12,15}

The first point to be discussed is the interruption/enlargement of the restorative cycle of teeth by preserving and conserving sound tooth structure with modern adhesive partial restorations (preservation of extension) instead of tooth volumetric reduction for full contoured crowns (extension for prevention). Nevertheless, once the coronal structure has been reduced for full crown placement, the preservation of the reminiscent ferrule should be of most importance, as it may improve dramatically the survival of ETT.^{12,15} Another factor is precision and minimally invasiveness when replacing restorations on ETT with the aid of magnification, electric driven hand pieces and applying adhesive dental modalities.

Partial restorations versus full crowns on ETT

In the modern practice, a direct composite is often preferred over full crowns since additive adhesive restorations may prevent root fracture.^{17,26} The traditional approach in ETT is to place a post, core and a crown after the endodontic treatment. The need to place a crown on an ETT has been investigated in *in vitro* studies and clinical trials,²⁷⁻²⁹ however a recent Cochrane review was inconclusive because of a lack of suitable studies.²⁸ It was concluded that there is no literature evidence to support placement of a crown over a direct restoration on severely broken down ETT.

Adhesive dentistry for tooth restorations should be taken in consideration when restoring ETT in current days, as post-and-core are associated with a full crown approach which was developed using non-adhesive luting, but rather a cementable restoration (porcelain fused to metal crown and cast post-and-core). Without the need of macro mechanical retention that is mandatory to retain a cementable restoration, most of sound dental tissue now can be preserved and conserved and partial restorations can be adhesively bonded to the remaining coronal structure, particularly to the enamel substrate, directly or indirectly.

A recent randomized clinical trial²⁷ compared the survival of composite resin restorations and porcelain fused to metal (PFM) crowns on ETT that received a glass-fiber post. The overall annual failure rate was 0.92% after 50 months of success of the restorations without difference for survival between the types of restoration. This was the first randomized clinical trial (RCT) including all tooth types and severely broken-down teeth comparing PFM crowns vs composite restorations. Although the study only assessed direct resin composite restorations, adhesive indirect partial restorations could possibly have provided a better outcome in terms of material aspects.

In a recent systematic review, Suksaphar et al.³⁰ investigated the survival rate of posterior ETT restored with crowns or resin composite restorations. Three clinical studies were included: a RCT,³¹ a prospective³² and a retrospective cohort study.³³ Pooled survival rates ranged from 94%–100% and 91.9%–100% for crowns and resin composite, respectively. The authors were not able to do a meta-analysis due to the heterogeneity of the studies. The authors concluded that survival rates of endodontically treated posterior teeth restored with crowns or resin composites were not significantly different to teeth with minimum to moderate loss of tooth structure. Therefore, preparing sound tooth structure in order to place a full contour crown may not be suitable anymore in a contemporary dental practice aided by adhesive dentistry.

Partial restorations like indirect onlays have been suggested as an alternative to full crowns as it preserves more sound tooth structure while providing cuspal coverage to protect weakened cusps.²⁹ As cavity size increases, predominately after the endodontic access and the marginal ridges are lost, structural integrity decreases and flexibility increases.⁴ The use of alternative partial bonded restorations should be considered for certain clinical situations, due to their ability to preserve enamel. Direct or indirect bonded restorations for cuspal coverage have been advocated in order to eliminate the need for axial wall destruction.³⁴ The use of composites has also allowed clinicians to adhesively restore teeth that would otherwise require extensive mechanical retention. The use of partial restorations is becoming increasingly popular and this also helps prevent tooth structure loss. There is

no study that compares direct composite restorations with adhesive indirect restorations (ceramic partial restorations or ceramic crowns) and therefore more studies could be carried out in order to assess the real need of preparing sound tooth structure for a full crown restoration.

The role of the ferrule on the survival of full coverage crowns in ETT

Endodontically treated teeth often suffer from extensive structural defects because of access cavity preparation, caries, replacement of restoration and trauma. The lack of coronal structure is associated with a lower survival rate of ETT.³⁵ *In vitro* and *in vivo* studies support the ferrule as the principal factor to increase the fracture resistance of the ETT.^{12,13,14,15,16,35} A prospective clinical study concluded that PFM crowns with less than 50% of remaining coronal structure have twice the risk of failing compared to teeth with more than 50% of remaining coronal structure.³⁶ A systematic review¹² included laboratory studies, computer simulations, and clinical trials for the evaluation of the ferrule effect on ETT. Considering the sixty-two articles included, the authors concluded that the presence of a 1.5- to 2-mm ferrule had a positive effect on the fracture resistance of ETT and that providing an adequate ferrule lowers the impact of the post-and-core system, luting agents, and the final restoration on tooth performance. On the other hand, a recent meta-analysis of clinical studies provided no significant difference between the failure risk of glass-fiber post-and-core restored teeth with ferrule and that of teeth without ferrule³⁷ due to lack of clinical data – only two studies could be included in the analysis.

With the improvement of adhesive dentistry, a paradigm shift to postless approaches in restoring endodontically treated teeth with ferrule is in progress.^{8,15,16,20,38,39,40} Teeth with a minimum of 2 mm of ferrule have been restored without posts in combination of a resin composite core build-up.^{15,16,35} This technique seems to mimic more closely the structure and biomechanical behavior of a natural tooth, in contrast to the concept of post-and-core build-ups.¹⁵ Other techniques could be used to improve bond strength and tooth resistance, such as IDS⁴¹ and indirect

composite resin.⁴⁰ All aspects of the restoration (crown, adhesive interface, build-up, and tooth) seem to form a cohesive assembly which ideally mimics the properties of the dentin-enamel junction. Modern approaches for posterior and anterior ETT with ferrule have been investigated and proved to be efficient even without the use of a post, as the retention of the crown is granted by the bonding to the ferrule-retained core build-up.^{12,15,20,35} The effect of the ferrule in the survival of ETT has already been proven, therefore sound tooth structure preservation is of paramount importance. Precision in minimally-invasive approaches aids delaying the restorative cycle of death, maintaining ferrule and thus increasing the survival of ETT.

Preserving tooth structure by precision with minimally invasive treatment on ETT

Precision plays an important role in minimally invasive dentistry. Magnification and precise rotary instrumentation grant the operator the visual accuracy and the fine preparation skills needed in order to maintain healthy dental tissue by only removing solely decayed tissue.⁴²

Air driven turbines at high speed do not offer proper tactile sensitivity as can be obtained via low-speed/high-torque electric handpieces, which is necessary for precise caries removal. Thus, healthy coronal tissue in ETT are mistakenly removed due to the lack of fine tactile skills during caries removal and/or tooth preparation. Many studies have shown that there is a direct correlation between residual coronal structure and tooth survival,^{4,43} therefore, the less coronal dentin and enamel is removed, the higher the survival of ETT. With the aid of an electric handpiece, dentists are more likely to be precise for preparations and caries removal. Especially in compromised teeth, such as ETT, these instruments improve the preservation of underlying tooth structure. Regardless of the extent or severity of the carious lesion, it is now recognized that the outline of the final restoration should follow the three-dimensional shape of the individual lesion in order to preserve and conserve as much tooth structure as possible.⁴⁴ Cavity width and size correlate inversely with fracture strength and positively with

the incidence of tooth fracture, respectively.⁴³ The modern biomimetic principles rely on the adhesion of materials to safeguard the underlying tooth structure via bonded partial restorations.^{39,44,45,46}

Visual accuracy is another factor that influences precision in dentistry. Magnification has a well-documented history in dentistry.⁴⁷ The benefits of enhanced illumination and magnification on endodontic and restorative procedures has been described.^{42,48} These advantages include a more detailed view of carious and healthy structures. The operator is able to examine more efficiently, detect imperfections and clean the tooth structure without removing healthy tissue.⁴⁸ In addition, superior resolution improves fit accuracy during bonding procedures and restoration delivery.⁴² Combined with caries detecting solutions and light and filters aids, such as fluorescence illumination and cross-polarization filters, magnification enables to detect changes in dentin color and texture, allowing for intelligent and strategic caries removal. The minimally-invasive approach during caries removal and replacement of restorations is of paramount importance to the preservation and survival of ETT.

Adhesive micro-mechanical retention versus macro-mechanical retention and catastrophic failure of ETT

ETT often require post-and-core restorations for retention of the crown because of extensive structure loss, according to traditional approaches.⁴⁹ The decision of how to restore ETT without ferrule has become increasingly difficult because of the large number of restorative materials and treatment options.⁵⁰ Traditionally, when the remaining tooth structure is not sufficient to retain a crown (height less than 2 mm), a cast post-and-core was indicated to provide retention of the restoration. Generally, they were recommended when minimal or no coronal tooth structure was available for anti-rotational features or bonding.¹⁸ However, the traditional cast post-and-core technique is more time-consuming and frequently involves higher laboratory and material costs.⁴⁹ In addition, this approach is associated with catastrophic types of failure since posts present higher elastic modulus compared to dentin.⁵¹

The success of a restored ETT has to be considered not only in view of restoration survival rates but also and most importantly in view of tooth survival rate and re-restorability following failure (failure modes). The most common failure types described in *in vitro* studies and also observed clinically are either repairable or catastrophic failures. Repairable failures are: cohesive, cohesive/adhesive fracture, minor damage, chipping or cracking of underlying tooth structure. The catastrophic failures, however, involve the tooth/root fracture requiring tooth extraction.^{13,15,20,25,52}

Catastrophic root fractures are the most problematic complications of ETT.⁵³ A general consensus is that despite the high fracture resistance of the metal posts, stresses concentrate in the root, and are transmitted internally towards the apical level increasing the incidence of root fractures.^{54,55} Opposite results were reported when using glass-fiber posts, presenting similar elastic modulus to that of dentin.⁵⁶ This could improve the stress distribution along the root^{57,58} and reduce the risk of vertical root fractures.¹⁴ Fracture strength studies reported tooth fractures to be more “favorable” using glass-fiber posts. Failures with fiber posts happened at lower loads but with higher chances of leaving an intact root.^{59,60,61}

Nowadays, enhanced adhesive procedures are possible through the use of adhesive luting systems in combinations with prefabricated posts and direct core build-ups.²⁰ The glass-fiber posts have been widely used, maybe due to the enhanced esthetics and time-efficiency. However, the effect of the post-and-core materials on the fracture strength of ETT have conflicting results.^{25,53,62,63,64,65} Prefabricated glass-fiber posts seem to demonstrate less resistance than cast post-and-core, but present a more favorable failure pattern, providing more reparability.^{4,49} In a 4-year clinical evaluation, the success rate of cast posts-and-cores (cemented approach) was 84% compared to 95% when using glass-fiber posts and composite resin cores (adhesive approach); root fractures and crown dislodgements were observed only in the cast post-and-core group.⁶⁶ The literature also confirmed that inserting pre-fabricated posts using an adhesive luting system could result in greater retention, less microleakage, and higher resistance against root fracture.⁶⁷

Studies have demonstrated conflicting results regarding glass-fiber posts. The elastic behavior of this

type of post allows a cyclic bending between the crown and core build-up inducing micro-gaps in crown/root interface.^{64,68,69} This gap has been assumed to be the initial failure of the restoration^{16,69,70} and is clinically undetectable allowing leakage between the restoration and tooth. The infiltration may extend into the prepared post space leading to the failure of the restoration.⁷⁰

A meta-analysis on thirteen *in vitro* studies⁵⁵ evaluated the fracture resistance on ETT treated with cast posts versus glass-fiber posts, and concluded that the cast post group displayed significantly higher fracture resistance than the glass-fiber post group. A recent meta-analysis⁵³ indicated the overall incidence rate of root fractures (catastrophic failures) was similar between metal and glass-fiber posts when evaluating seven randomized clinical trials and seven cohort studies. Cloet et al.⁷¹ in 2017 presented a 5-year follow-up RCT comparing cast post-and-core and fiber-reinforced composite post-and-core systems on ETT with ferrule without statistical difference on survival and success rates. A systematic review in 2017 on ETT failure modes revealed that metal posts are associated with higher risks of root fracture, while glass-fiber posts are associated with higher risks of post/crown/core loss of retention.⁷²

In conclusion, recent studies do not agree on the clinical benefit of using pre-fabricated glass-fiber posts rather than cast post-and-core. More clinical studies should be carried out in order to provide more data for a meta-analysis.

No-post approaches

Due to the significant improvements in adhesive dentistry, principles for the restoration of ETT, particularly those with limited tissue loss, may require revision. The focus of attention should not be on the type of post to be used but rather on the benefit of the post itself.¹⁵

The original purpose of a post is to retain the core¹⁸ and not to increase the intrinsic resistance of the root.⁷³ Recent *in vitro* studies demonstrated that the use of posts did not influence the fatigue resistance of posterior teeth^{20,74} and neither did in anterior teeth with ferrule.⁷⁵ In fact, for anterior teeth with ferrule, more favorable failure modes were associated with no-post approaches, as the placement of a post was

always associated with catastrophic failure of the root.¹⁵ On the other hand, randomized clinical trials have suggested better survival rates of ETT with PFM crowns restored with posts than without posts.^{76,77} The lack of consistency in the literature on the influence of posts in ETT led to some recent investigations of no-post approaches as more biomimetic alternatives: endocrowns versus postless build-ups-and-crowns.⁷⁸

Endocrowns

It is previously established that the use of a post may cause a catastrophic failure of the tooth, no matter the type of material.⁵³ As they are associated with additional removal of sound tissue for post preparation, some studies have been focus on the alternative postless treatment of ETT.^{38,78,79} A postless alternative to treat ETT includes the use of the pulp chamber as an extension of crown itself, the so-called endocrown. This technique consists in combining the crown and core build-up in a single element or “monobloc”.¹⁹ The endocrown requires a simpler and less invasive preparation compared to the multi-step approach of the post-and-core build-up with crown preparation, resulting in decreased treatment time and costs.^{8,74,80,81} Nowadays, endocrowns are even obtained in a single appointment using chairside computer-aided design/computer-aided manufacturing (CAD/CAM) technology.

As they gained popularity, many researchers and clinicians have published highly successful cases describing the clinical steps for the fabrication of endocrowns.^{78,80,82,83} A finite element study concluded the endocrown to be a conservative, predictable and clinically feasible restorative approach for endodontically treated maxillary premolars.⁸⁴ According to short-term clinical reports, the survival rate of the endocrowns was 90-95% in posterior teeth.^{85,86} A recent meta-analysis evaluated studies on endocrowns and concluded they perform similarly or better than conventional treatments using intraradicular posts, direct composite resin or inlay/onlay restorations.³⁸ This technique represents a promising and conservative alternative to full crowns for the treatment of posterior nonvital teeth that require long-term protection and stability.^{80,87}

There are few studies using endocrowns for the anterior dentition, including a few finite

element analyses^{88,89} and one *in vitro* study. Ramírez-Sebastià et al.⁹⁰ found that the use of endocrowns with adhesive material is sufficient for the restoration of endodontically treated incisors with 2 mm of ferrule. Anterior endocrowns have not yet been tested in clinical trials. For posterior teeth, a recent clinical study conducted by Belleflamme et al.⁷⁸ evaluated 99 endocrowns made of lithium disilicate or polymer-infiltrated ceramic with a success rate of 99.0% and 89.9% respectively for a mean period of 44.7 months. The authors concluded that, when the adhesive technique is properly applied, endocrowns constitute a reliable approach to restore severely damaged molars and premolars, even in the presence of extensive coronal tissue loss or occlusal risk factors, such as bruxism or unfavorable occlusal relationships.

No-post approaches such as endocrowns or postless build-ups-and-crowns are only possible with the application of optimal and reliable adhesion. A very important factor to consider when relying mainly on the adhesive approach is the quality of the adhesion between the restoration and the underlying tooth structure. The adhesion to dentin is considered weaker than adhesion to enamel^{91,92} and when restoring ETT, most of the interface is in dentin. A proven strategy to increase the dentin bond strength of indirect restorations is by using the immediate dentin sealing (IDS) technique.^{41,93,94} The studies on postless approaches showing high success rates and outcomes discussed in this review all used IDS in their protocol to optimize bond strength to dentin.^{15,16,20,78,87} Other studies revealed lower success rates using postless build-ups.^{76,77,95} Those results may be explained by the fact that neither IDS technique or bonded restorations were used, but rather cemented PFM crowns to build-ups with different adhesive approaches.

Postless build-ups with crowns

In recent studies on posterior crowns, the internal walls of the pulp chamber were used to bond the core build-ups, without the use of extra intracanal retention.^{20,87} It was concluded that the post did not increase the fatigue resistance of the endodontically treated molars, but caused more root fractures.^{20,40} Hence, the use of a post can be questioned due to the higher number of catastrophic failures.^{13,20}

In vitro studies, in spite of being less relevant than clinical trials, have the ability to isolate and investigate a particular variable of interest under strictly standardized conditions. This level of standardization is a significant limitation of clinical trials. Hence, post placement appeared to have no influence in the mechanical performance of endodontically treated incisors, premolars and molars with and without ferrule restored with a bonded crown or endocrown in *in vitro* studies.^{13,15,16,87} In fact, the placement of a post was associated with more catastrophic failure than the postless approaches in all those studies. Randomized clinical trials (RCT) would be necessary to confirm these *in vitro* findings with the same adhesive approach. To date, there is no RCT with bonded ceramic crowns as simulated in the aforementioned *in vitro* studies, but only RCT with PFM crowns over postless build-ups.

Clinical studies evaluated the effect of post placement in teeth restored with PFM crowns.^{76,77,95,96} In these studies, crown dislodgments were very common in teeth restored without post and thus were responsible for the low success rates in postless build-ups. Up to 50% of postless teeth failures were crown dislodgments. Here again, this finding could be explained by the non-adhesive approach used by the authors when restoring a postless core build-up with a cemented PFM crown.⁷⁷ Such conditions were never studied or suggested by any other *in vitro* studies on postless approaches,^{13,15,16,87} but instead all of them used bonded all-ceramic crowns or endocrowns.

Hence, a recent meta-analysis⁹⁷ and systematic review⁹⁸ concluded that post placement would be beneficial for the success rate and failure mode of ETT. This conclusion was based exclusively on the same clinical studies in which PFM crowns were used to restore teeth with postless build-ups.^{77,96} Therefore, the scientific evidence (RCT, systematic review and meta-analysis) tends to indicate that post placement increases the success rate of ETT when using PFM crowns, which is a different approach compared to the *in vitro* studies restoring ETT with all-ceramic bonded crowns and presenting results in favor of the postless approaches. The stress distribution throughout the restoration and restored tooth assembly proved to be different when PFM crowns are used, instead of bonded all-ceramic restorations.⁹⁹ More stress concentration and magnitude

were found at the underlying core build-up and tooth structure with PFM. The restoration type may have influenced on the outcome.

Naumann et al.¹⁰⁰ also evaluated the effect of post placement on the clinical performance of restored ETT in a systematic review. The majority (10 out of 14) of the clinical studies included in this analysis did not show a positive effect of post placement, however a post was advocated when no cavity wall was present. The authors concluded there was no unequivocal clinical evidence to support or reject the use of posts even in no-ferrule situations, either in direct or indirect restorations. Therefore, to date, the literature is not conclusive regarding the need of posts when restoring ETT. More RCT are needed to gain scientific evidence on the clinical performance of ETT restored with and without posts¹⁰⁰. Another literature review³⁵ concurs after analyzing 8 clinical studies: ferrule effect and residual cavity walls are predominant factors with regard to tooth and restoration survival of endodontically treated teeth. Most studies do not confirm a positive effect of post placement for indirect restoration. Therefore, considering the available *in vitro* studies, clinical trials and systematic reviews, current literature does not provide enough evidence to support the use of a post to restore ETT.¹⁰¹

Final considerations

The survival of ETT is contingent on the residual sound tooth structure that remains after the endodontic access and caries removal are performed, consequently the most important factors upon restoring ETT become the maximum preservation and conservation of enamel, dentin and the dentinoenamel junction. Hence, bonded partial restorations are always preferred over full coverage cementable crowns.²¹ The current goal is to switch approaches from extension for prevention to prevention of extension.¹⁰² Precision in dentistry obtained by the aid of magnification and electric handpieces as well as bonding optimization provided by proper forms of isolation and IDS are essential steps to protect the remaining tooth structure in a minimally invasive adhesive approach.^{41,42,93}

Since the success of restored ETT relies on residual tooth structure, extension for prevention concepts

should be avoided. In the presence of a ferrule, *in vitro* and *in vivo* studies strongly support the fact that posts are not needed to restore ETT.^{13,15,103} Those studies provide further evidence that posts are not needed in order to retain crowns/endocrowns, and are even associated with increased rates of catastrophic failures.^{20,78} On the other hand, posts are associated with higher survival of ETT when restored with PFM.^{76,77,95} More clinical studies comparing adhesive crowns bonded to postless build-ups or

post-and -core build-ups are needed for a better understanding of postless approaches in biomimetic restorative dentistry.

Acknowledgements

The authors deny any conflict of interest related to this study. This study was supported in part by grants from the National Council for Scientific and Technological Development (CNPq grants 150054/2018-1 to M.A.C).

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