Original Article

Restorative Strategies for Posterior Teeth Following Endodontic Treatment

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Abstract

Objective: This paper aims to describe the approaches to reinstating posterior teeth following endodontic therapy; structural and biomechanical shifts, biological considerations, and various restoration modalities. **Methods:** A detailed analysis is performed by synthesizing the latest scientific research and clinical practices. Direct fillings, onlays, complete crowns, and new treatments like endo-crowns are among the restoration approaches investigated. Recommendations are made based on material qualities and application procedures to improve the lifetime and function of repaired teeth. **Results:** The review emphasizes the need of retaining structural integrity using appropriate restoration procedures. The ferrule effect and proper use of posts are highlighted as critical aspects in guaranteeing the stability and endurance of recovered teeth. Advancement in materials and techniques, for instance the use of endo-crowns, provide new avenues for successful repair. **Conclusion:** By integrating current research and clinical insights, dental practitioners can make informed decisions that ensure the long-term health and functionality of endodontically treated posterior teeth.

Keywords: Endodontically Treated Teeth, Ferrule Effect, Restorative Dentistry, Posterior Teeth Restoration, Dental Biomaterials.

Introduction

Endodontic treatment presents a number of key procedures that are essential in the retention of dentition, especially where cases of deep caries or significant trauma exist. Some of these techniques include endodontic procedures such as root canal treatments, which involves the removal of infected material and sealing of the root canal to prevent further infection; pulp conservation techniques, which are used to maintain the vitality of the teeth; and apical surgeries like the apicoectomy that involves removal of the tip of the tooth root and any infected tissue present therein.[1] Furthermore, one can identify the development of regenerative endodontics as another ability that can potentially reverse the damage inflicted on tissues.[1] Endodontic treatments generally achieve high success rates, with statistics demonstrating that root canal therapy effectively maintains natural teeth, displaying success percentages ranging from 75% to 85%[2]. Numerous studies confirm that endodontic treatment is a reliable choice for patients needing dental care.[2,3] It is also important to recognize that the majority of failures in teeth treated endodontically are often linked to factors unrelated to endodontic procedures. Prosthetic issues contribute to almost 60% of these failures, periodontal problems account for 32%, and pure endodontic failures are less than 10%, making them relatively scarce.[4] The long-term function of posterior teeth after endodontic

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treatment depends on accurate restorative interventions. These restorations are not just about rebuilding the lost structures; they are about attempting to reconstruct a tooth that can endure the forces of mastication and serve the role in the oral cavity as it used to. It entails incorporating restorative materials and procedures that possess mechanical properties that are comparable to the natural tooth as well as having the right shade. The range of restorative treatments includes direct restorations such as fillings, inlay/onlay, crowns and post-and-core systems. All these options have their benefits and uses, and choosing between them requires consideration by clinicians and is not always straightforward.[5]

Currently there is controversy and confusion on which is the most effective, scientifically proven restorative technique for posterior teeth after endodontic treatment. This review is intended to fill this gap by providing a comprehensive review of the restorative measures employed after endodontic treatment. It examines the mechanical and biological properties that undergo alterations in posterior teeth after endodontic treatment and evaluates how these alterations affect the utility and longevity of various restorative approaches. Through the synthesis of the recent studies and clinical practices, this review aims at providing practitioners with the required information to make appropriate decisions that ensure posterior teeth function and esthetics post-treatment.

Changes in Posterior Teeth Following Endodontic Treatment

It has also been established that posterior teeth are subjected to a lot of structural, mechanical and biological alteration following endodontic treatment hence affecting their long-term stability and function. Pulpally, when infected or inflamed pulp tissue is taken out and the root canals are then filled, the tooth becomes weaker and more prone to fractures, compared to its preoperative status. This increased brittleness is because the essential elasticity and the capacity to absorb shock once offered by the pulp tissue are lacking, and this makes the tooth more susceptible to cracks and breaks when subjected to normal chewing forces.

Changes in Structural Mechanics

Mechanically, after endodontic treatment, posterior teeth often undergo substantial changes that affect their durability and functionality. The process of removing pulp tissue, followed by cleaning and filling the root canals, generally leads to a reduction in the tooth's toughness and elasticity. This loss of biomechanical properties makes the tooth more brittle and prone to fractures. Studies have demonstrated that post-treatment teeth are more likely to develop small cracks, which can expand and cause major structural failures if not appropriately managed with restorative techniques. A significant decrease in both the hardness and elastic modulus of dentin has been observed in many studies following root canal therapy.[6,7] These changes drastically alter the tooth's ability to endure masticatory stress, potentially leading to a higher incidence of structural complications.[8,9] For instance, minimally invasive procedures that preserve the integrity of the marginal ridges have been shown to reduce the resistance of tooth structure by only 5%. In contrast, teeth that have lost one marginal ridge post-treatment exhibit a 35% decrease in resistance, and those with both marginal ridges compromised can see a reduction in resistance by up to 55%.[10]

This vulnerability is particularly evident in the changes observed in the root dentin's mechanical properties, as highlighted by Marhab *et al*.[11]. The reduction in hardness and elastic modulus implies that the root becomes more and more brittle and thus compromised in its ability to withstand regular forces during chewing. Since biomechanical properties are critical determinants of the overall health and functionality of the tooth, dental care professionals need to consider these factors when planning for any operative interventions.

Biological Changes

Endodontic treatment alters not just the mechanical structure of a tooth but also induces significant biological changes. This routine procedure involves removing the dental pulp, which eliminates the tooth's internal blood and nutrient supply and fundamentally changes the microenvironment of the tooth's hard tissue. Such alterations can severely affect the tooth's ability to repair itself and reduce its resistance to microbial invasion, making it more prone to future complications.[12]

Additionally, the structural integrity of dentin, which significantly contributes to a tooth's durability, is compromised due to changes in the cross-linking of collagen fibers within the dentin. These biochemical changes can increase brittleness which is a feature evident in teeth that have been subjected to root canal treatment. This increased brittleness not only renders the teeth more prone to fractures but also the functional effectiveness of the teeth, which shows that biological and mechanical alterations are interrelated following endodontic treatments. Tomson *et al*.'s[13] systematic review and meta-analysis on the treatment of spontaneous non-traumatic pulpitis using vital pulp therapy and RCT revealed a one-year success rate of 98% for both forms of pulp therapy. The five-year success rates were 78.1% for vital pulp therapy and 75.3% for RCT.[13]

In various studies evaluating treatment options for pulpitis and periapical periodontitis, root canal therapy has been consistently demonstrated as an effective approach for addressing pulpal diseases. This method is known for its ability to preserve teeth and restore their functionality.[4,14] However, it may also have long-term effects on the structural integrity and biomechanical properties of teeth. The primary reasons include reductions in dentin hardness and thickness, as well as decreased fracture resistance due to further removal of tooth structure during the canal preparation process. Therefore, dentists must consider comprehensive protective measures post-treatment to lessen potential structural weaknesses and ensure the long-term health and functionality of the teeth. Research indicates that restorative measures following root canal treatment can aid in restoring the shape, function, and aesthetics of teeth while enhancing their durability and fracture resistance.[13] These restoration methods typically involve covering the treated tooth with a crown to restore its original shape and strength, using resin-based filling materials, full crowns, inlays/onlays, or, when necessary, employing a post and crown method to further stabilize the tooth structure.[5]

Restorative Approaches for Endodontically Treated Posterior Teeth

In the restoration of posterior teeth following endodontic treatment, it is imperative to select an appropriate restoration method to ensure the long-term functionality, durability, and overall oral health of the patient. Failing to replace temporary restorations with permanent solutions can significantly compromise tooth survival; Tang *et al.*[15] reported that over 65% of such teeth were lost within three years without permanent restoration.[15] Equally critical is the integrity of the restoration seal post-treatment. *In vitro,* tests indicate that root canal systems can become recontaminated with microbes if the endodontic sealers are exposed to oral fluids within 24 to 30 days after application.[16] Therefore, ensuring a robust coronal seal is essential to prevent infection and ensure the success of the restoration.

Choosing an appropriate restoration technique must consider the structural integrity of the remaining tooth, the level of occlusal forces, and the tooth's specific functional purpose, such as its role in supporting fixed bridges or removable partial dentures. Restoration methods for these teeth generally fall into two categories: direct and indirect restorations. This classification facilitates the customization of treatment according to the unique requirements and conditions of each individual tooth, enhancing the effectiveness of the restoration process.

Following this overview, the discussion will focus on specific restorative methods, starting with Direct Restorative Approaches, to further explore how these strategies can be applied effectively to endodontically treated posterior teeth.

Factors Influencing Restoration Methods for Endodontically Treated Posterior Teeth

Despite extensive research on endodontically treated teeth, there remains ongoing debate regarding the optimal treatment plans and materials for their restoration. Controversies persist over the most effective methods for restoring such teeth, including the choice between direct and indirect restorations, the use of posts, and the selection of the most suitable materials.[17]

In devising restoration strategies for teeth treated with root canal therapy, it is critical to evaluate several key factors: the volume of remaining dental structure, the tooth's anatomical placement, its functional demands, and the aesthetic expectations.[18]

The Amount of Remaining Tooth Structure

A critical factor that enhances the predictability of successfully restoring endodontically treated teeth is known as the 'ferrule effect'.[19] Research confirms that a ferrule's presence significantly boosts the resistance of such teeth to fractures. The Ferrule Effect is essential for strengthening teeth following endodontic treatment, where the height of the dental structure in the cervical region under a crown plays a vital role in supporting extra-coronal restorations and averting fractures. Having a ferrule enhances the fracture resistance of these teeth and helps support indirect restorations, as shown in many studies. While the use of posts is essential for retaining core materials in dental restorations, their insertion or lateral movement within the root may increase the likelihood of root fractures due to the exerted pressure. This underscores the importance of meticulously designing the ferrule in restorations involving post-and-core techniques. For optimal protection, termed the "ferrule effect," it is crucial to ensure a minimum of 1.5 to 2 mm of the tooth's vertical structure remains above the commencement of the dental procedure. The greater the extent of the tooth's natural structure preserved above this threshold, the more effectively it can withstand fractures. Studies suggest that the effectiveness of this ferrule effect relies heavily on the thickness of the remaining tooth wall; if this wall is thinner than 1 mm, it's generally considered too weak. Although having a complete ring (a full 360° ferrule) around the tooth provides the best protection against fractures, even partial coverage can be beneficial.[20] For instance, possessing at least 3 mm of natural tooth structure on the anterior aspect of a tooth, even if no other sides are encompassed, can markedly enhance the tooth's resilience against fractures, almost to the degree provided by a complete ferrule.

Beyond the amount and integrity of the remaining coronal tooth structure, the state of the residual roots plays a crucial role as well. Maintaining periodontal health and ensuring controlled occlusion are essential, with a minimum recommended ratio of 1:1 deemed necessary to handle lateral forces effectively.

This diagram (Figure 1) provides a visual explanation of the ferrule effect, which is crucial for the structural integrity of a tooth after endodontic treatment. It shows a cross-sectional view of a tooth with a crown restoration. The ferrule effect is created by the remaining tooth structure above the core build-up, ensuring a minimum thickness of 1mm and a height of 2mm. The retention and stability of the crown are crucial as they resist forces during mastication. The core build-up strengthens the tooth internally, while the post offers additional support. The remaining gutta-percha marks the area filled within the root post-endodontic treatment.

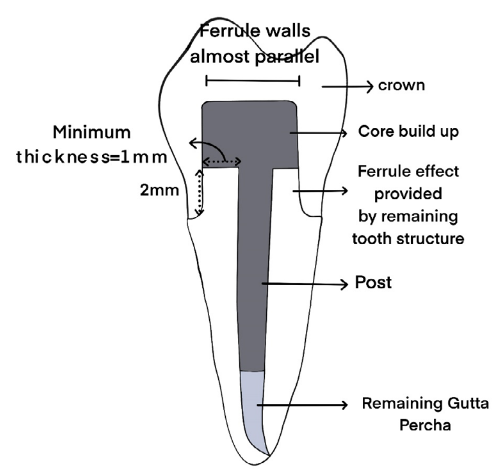

Figure 1: Schematic Diagram Illustrating the Ferrule Effect.

This illustration highlights the critical design elements of the ferrule effect in dental restorations. The ferrule effect is crucial in dentistry, describing how a vertical "collar" of a dental crown surrounds the underlying tooth structure to enhance fracture resistance following treatments like root canal therapy.

Table 1: Key Components of the Ferrule Design.

Component	Description
Ferrule Walls	These parts of the tooth structure are encircled by the crown. For adequate support, these walls should be at least 1 mm thick and parallel to provide a uniform encircling of the core and post structure.
Crown	This external restoration sits on top of the core buildup and post, providing the final shape and aesthetic of the tooth.
Core Buildup	Material is added to build up the tooth structure after root canal therapy, supporting the crown and ensuring a suitable surface for the ferrule effect.
Post	Placed inside the root canal, this component helps retain the core buildup in teeth with extensive structural loss.
Remaining Gutta Percha	The material left inside the root canal after treatment, remains beneath the post and core buildup.

The Anatomical Position of the Tooth

Posterior teeth often bear significant masticatory forces, so it's crucial to reinforce them during restoration to prevent fractures. Studies have shown that the failure risk for molars increases sixfold if they are not covered with a cuspal coverage cast restoration, supporting the use of crowns to encircle the tooth and enhance its fracture resistance.[18] In posterior teeth, the use of posts is generally discouraged as these teeth often have narrow or curved roots and preparing space for a post can compromise the tooth's integrity, such as causing strip fractures or lateral perforations.[18] The Nayyar core technique, which utilizes the spacious pulp chamber for direct composite restoration, offers an effective alternative to using posts.[21]

Premolars present a distinct scenario; they typically possess less dental material and smaller pulp chambers, which complicates the retention of sufficient core structure following root canal therapy. Additionally, premolars are particularly vulnerable to lateral forces exerted during mastication. Considering the anatomical features and functional load of premolars, opting for conservative restoration methods like direct composite restoration or using smaller posts to minimize further damage to the tooth is a practical option.[22] When fewer than two cavity walls remain intact, the integration of glass fiber posts substantially bolsters the fracture resistance of the tooth. Conversely, when two or three walls are intact, the impact of glass fiber posts on enhancing the tooth's fracture resistance becomes relatively minimal. As illustrated in Figure 2, the premolar, after undergoing root canal treatment and being restored with two glass fiber posts, clearly demonstrates the considerations taken during the restoration process. Ultimately, a full crown restoration was chosen to enhance the tooth's structural stability and fracture resistance. This case exemplifies the detailed steps of the restoration and the personalized treatment strategies for the specific type of tooth, the premolar.

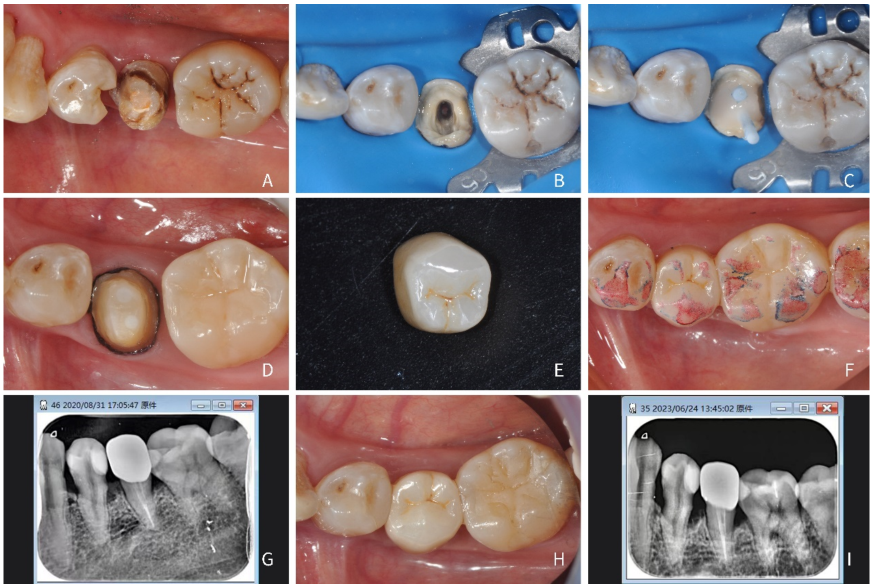

Figure 2: Illustrates a Case where Tooth #35, Following Endodontic Treatment, is Restored Using a Glass Fiber Post-implantation.

A, Extensive crown fracture in tooth #35 and distal caries in tooth #34. B, Resin filling of the asymptomatic tooth #34, and endodontic treatment of tooth #35. C, Placement of a glass fiber post in tooth #35 after endodontic treatment. D, Tooth preparation of #35 following glass fiber post placement. E, Fabrication of a full crown for tooth #35. F, Intraoral placement of the full crown on tooth #35. G, Post-placement radiograph of the full crown on tooth #35. H, Follow-up photo at 34 months after restoration of tooth #35. I, Follow-up radiograph at 34 months after restoration of tooth #35.

Function Load on the Tooth

Occlusal load significantly influences the treatment planning for teeth that have undergone root canal filling, and understanding this factor can help mitigate the risk of future failures. Reviews of the literature have determined that the design of the occlusal prosthesis plays a crucial role in the longevity of structurally compromised, endodontically treated teeth, potentially more so than the type of post implemented. In instances where a compromised root-filled tooth plays a critical role in occlusion, not only should the placement of the post be strategically planned, but also the design of the occlusal surface must be carefully considered.

The Aesthetic Requirements of the Tooth

Aesthetic considerations for posterior teeth, while often secondary to functionality, are crucial for patient satisfaction and can influence the choice of restorative materials and techniques.

Research indicates that pulpal necrosis and subsequent bleeding from damaged blood vessels can result in substantial dentin staining, leading to tooth discoloration. An article in the Journal of Esthetic and Restorative Dentistry has demonstrated the effectiveness of using sodium hypochlorite irrigation during root canal procedures to mitigate such discoloration. Teeth treated with thorough sodium hypochlorite irrigation showed significantly less discoloration compared to those treated with other solutions.[23]

In the context of posterior dental treatments that do not necessitate complete crowns, the aesthetic appearance can be significantly enhanced through the careful handling of gutta-percha. Studies indicate that the aesthetic outcomes are markedly improved when gutta-percha is meticulously trimmed away from the pulp chamber down to the level of the amelodentinal junction and effectively sealed using a resin-modified glass-ionomer. This technique not only enhances the visual result but also crucially blocks coronal leakage, which is a common cause of discoloration. A study published in Quintessence International found that teeth restored using this technique exhibited better color stability and less discoloration over time compared to traditional methods.[24]

Non-Vital Bleaching: In cases of severe discoloration, non-vital bleaching can be an effective solution. According to a study in the *Journal of Dental Research*, non-vital bleaching using a combination of sodium perborate and hydrogen peroxide significantly improved the color of discolored posterior teeth. The study reported an average improvement of 2-3 shades on the Vita shade guide, with results maintained over a 12-month follow-up period.[25]

Selecting an appropriate dental restoration post-root canal therapy involves assessing multiple critical elements: the integrity of the remaining tooth structure, its positional context within the mouth, the forces exerted during occlusion, and the aesthetic demands of the patient. The concept of the ferrule effect is particularly significant; it bolsters the tooth's resilience against fractures and underpins the success of indirect restorative procedures. Ensuring a balance between functional integrity and aesthetic appeal is pivotal for the sustained health and effectiveness of the restored tooth.

Direct Restorative Approaches

Commonly, direct restoration methods are applied to rehabilitate posterior teeth following procedures such as endodontic treatments, including root canals. This approach involves directly placing restorative materials into the affected areas to restore the tooth's shape, function, and aesthetics. Advances in materials and techniques for direct restorations have significantly improved outcomes for these treated teeth. Evaluating specific materials used in these procedures, including Dental Amalgam and Composite Resin, is crucial for understanding their effectiveness and benefits in restoring endodontically treated posterior teeth.

Dental Amalgam

One of the earliest materials used for direct fillings, dental amalgam has been widely applied in the restoration of posterior teeth following endodontic treatment since the 19th century. Its durability, high strength, and cost-effectiveness have made it a popular choice for long-lasting restorations in treated posterior teeth. Evidence from multiple clinical studies supports the reliable performance of high-copper amalgams over periods that exceed 12 years. An evaluation on the durability of multisurface restorations revealed that the broad use of amalgam did not compromise their longevity. Correspondingly, a retrospective analysis by Robins and Summitt reported a survival rate of 50% over a span of 11.5 years.[26]

However, due to its mercury content, there are potential risks to health and the environment, along with poor aesthetics. Additionally, the implementation of the Minamata Convention on Mercury by the United Nations Environment Programme, which took effect in August 2017, has led to restricted use of dental amalgam in recent years. In recent research by Guy Tobias and colleagues, a retrospective analysis was conducted on amalgam and composite resin restorations performed from 2014 to 2021, utilizing a large database from 58 dental clinics, 440 dental units, and over 650,000 patients. The study included 260,905 treated patients and found that out of 113,281 amalgam restorations, 19,692 (17.49%) failed, while out of 555,671 composite restorations, 65,943 (11.98%) failed. These findings indicate the superior performance of composite materials compared to dental amalgam, supporting the decision to phase out mercury-containing amalgam restorative materials.[27]

Composite Resin

Since the 1960s, the introduction of composite resin materials has revolutionized the field of direct restorative dentistry. Known for their mechanical strength and wear resistance, composite resins also offer superior aesthetic qualities and the ability to closely match natural tooth color, making them a favored alternative to traditional dental amalgam for filling materials. Significant improvements in bonding technology have enhanced the adhesion and durability of composite resins, optimizing the restoration process and outcomes.[28]

In a study conducted by Ernesto Borgia and colleagues, entitled "Composite Resin Restorations in Posterior Teeth: A 5- to 20-Year Retrospective Longitudinal Study," 61 patients underwent treatment with 105 direct-light-activated composite resin restorations in posterior teeth. These restorations demonstrated an average functional survival period of 11 years and 7 months.[29] A different study retrospectively assessing the efficacy of direct composite resin fillings in endodontically treated posterior teeth for up to 13 years recorded an average monitoring period of 8.6 ± 2.3 years, with a success rate of 76.8% for these restorations. The development of light-curing technology in the 1980s advanced the precision and efficiency of composite resin applications, enabling dental professionals to control the curing time with specific light wavelengths.[30] Evaluations by the American Dental Association in 1998 and studies on resin bonding in 2003 have supported the use of composite resins for a wide range of cavity restorations, based on sufficient bonding surface and effective moisture isolation.[31] By 2014, the European Society of Conservative Dentistry and the Professional Committee on Operative Dentistry and Endodontics of the Chinese Stomatological Association recognized composite resins as the preferred material for posterior tooth restorations, highlighting their utility in various dental repair and cosmetic applications without restrictions on cavity size.[25]

In cases where there is a mild to moderate reduction in tooth structure, the utilization of composite resins emerges as a viable restoration option. Recent studies have revealed that posterior teeth, when restored endodontically with these materials, exhibit a fracture survival rate that is on par with those teeth restored using conventional crowns. This evidence suggests that extensive tooth preparation might not be imperative in every scenario.[32]

Despite the advantages, potential challenges such as polymerization shrinkage might affect the long-term stability of the restoration.[33] Studies have shown that composite resin can achieve a survival rate similar to crowns in endodontically treated teeth with minimal structural loss Resin composite-State of the art. Nevertheless, the overall success rate for such treatments appears slightly lower compared to vital teeth.[33,34]

For optimal results, a conservative approach involving glass ionomer cement as a base is recommended to minimize tooth strain and prevent microleakage.[33.34] The selection of composite resin, especially considering the filler content and the use of a rubber dam for isolation, is crucial for enhancing the longevity and effectiveness of the restoration.

In conditions with normal occlusal forces and minimal structural damage, composite resin restorations can preserve more tooth structure while also reducing clinical visits and associated costs. However, for teeth with limited remaining walls or those subjected to high occlusal stress such as bruxism, covering the cusps with restorations provides better protection against fractures.[32]

Overall, composite resins offer a reliable and aesthetically pleasing option for restoring endodontically treated posterior teeth, especially when structural loss is minimal and occlusal conditions are favorable. The detailed procedural requirements underscore the need for careful planning and execution by dental professionals to maximize the therapeutic benefits of this restorative material.

Figure 3 illustrates the complete process of direct composite resin filling in tooth #16 following endodontic treatment, including follow-up records at 1- and 5-years post-operation.

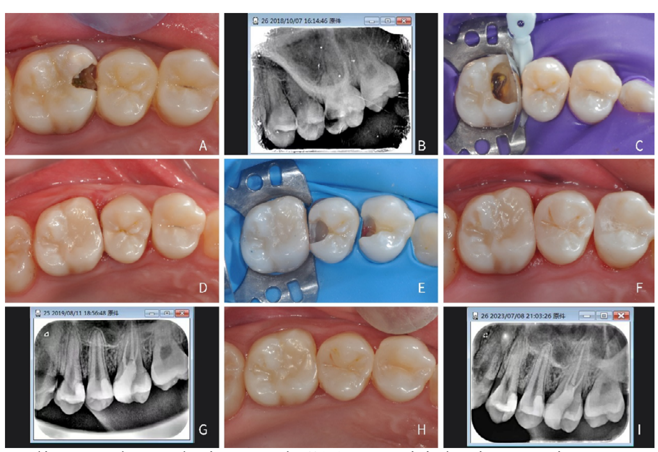

Figure 3: A, Caries Extending to the Pulp in Tooth #16. B, Initial Diagnostic X-ray. C, Tooth #16 Following Complete root canal treatment, showing filled root canals. D, Direct composite resin filling in tooth #16 after pulp therapy. E, One-year Follow-up Showing Caries in Teeth #14 and #15, Subsequent Caries Removal and Resin Filling Performed. F, Completion of Resin Filling in Teeth #14 and #15. G, Post-filling X-ray. H, 57-month Follow-up of Tooth #16 After Direct Resin Filling Post Pulp Therapy. I, X-ray at 57-month Follow-up of Tooth #16 Showing the Direct Resin Filling Post Pulp Therapy.

Indirect Restorations

Indirect restorations for posterior teeth following endodontic treatment typically involve fabricating and fitting restorations such as inlays, onlays, full crowns, or post-and-core crowns to restore the tooth's shape, function, and aesthetics. This type of restoration is suitable for cases where there is significant loss of tooth structure, particularly when direct filling methods cannot provide adequate support and strength. Indirect restorations are initially created in a dental laboratory or via CAD/CAM technology before being bonded to the affected tooth.

Advantages of indirect restorations include superior material properties, higher precision of the restoration, and excellent durability and fracture resistance. They also allow for finer margin adaptation and anatomical form reconstruction, contributing to the restoration of the tooth's natural appearance.

However, this method may necessitate multiple dental visits, is more expensive, and requires more precise tooth preparation.

It is therefore important to consider the most appropriate restorative approach to employ when restoring posterior teeth after endodontic treatment to ensure they are functional and long-lasting. It is a fact that if temporary restorations are not replaced with permanent restorations as soon as possible, more than 65% of patients end up losing their teeth within 3 years1. Hence, there is need for the clinician to consider the remaining tooth tissue, the position of the tooth, the amount of occlusal forces and aesthetic demands when choosing the approach to restorative procedure.

Direct restorative techniques as composite resins are suitable for teeth with little structural damage and allows for more of the healthy tooth structure to be saved. The results revealed that the survival rate of restored posterior teeth by using composite resins was 76. 8% after 13 years. However, in cases where the tooth structure is compromised, it is advisable to use indirect restorations such as inlays, onlays and crowns since they offer more support and are resistant.

For instance, research shows that inlays have a five-year survival rate of 86%, while ceramic inlays/onlays boast a survival rate exceeding 90% within the same period.[2] When dealing with severe tooth structure loss, full crowns are generally the preferred option due to their extensive coverage and protective benefits. Ensuring a ferrule effect with at least 1.5 to 2 mm of remaining tooth structure is critical for enhancing fracture resistance.[3] The following table (Table 2) summarizes the different restorative options, their indications, advantages, disadvantages, and special considerations, providing a comprehensive reference for clinical decision-making.

Table 2: Summary for Restoring Endodontically Treated Posterior Teeth.

Restoration Options	Indications	Advantages	Disadvantages	Special Considerations
Direct Filling	Mild tooth structure loss, ≥3 remaining tooth walls, thickness ≥1mm	Simple, cost-effective	Limited applicability	Suitable for teeth not under heavy load
Post and Core	Extensive tooth structure loss, <2 remaining tooth walls, thickness <1mm	Enhanced retention for restoration	May increase the risk of root fracture	Careful assessment of root conditions, avoid over-preparation
Full Crown	Severe tooth structure loss, requiring ferrule effect support of ≥1.5-2mm, intact remaining margins	Comprehensive protection and aesthetics	Requires significant tooth preparation	The ferrule effect is crucial
Inlay	Moderate tooth structure loss, ≥3 remaining tooth walls, thickness ≥1mm	Conserves more healthy tooth structure	Requires precise preparation	Retain at least 1.5-2mm of tooth structure
Onlay	Extensive tooth structure loss, ≤2 remaining tooth walls, cusp coverage needed for ≥1 cusp	Cusp coverage for enhanced strength	More conservative than full crowns but complex preparation	Consider cusp coverage for fracture resistance
Occlusal Veneer	Posterior teeth with occlusal wear, good remaining tooth structure, intact margins	Minimally invasive, more tooth conservation	Primarily for mild wear	Evaluate the extent and degree of occlusal wear
Endocrowns	Extensive tooth structure loss, post-endodontic treatment, ferrule effect support of ≥1.5-2mm	Monolithic restoration, no post required	Technically demanding, requires sufficient tooth depth	Ensure adequate ferrule height and tooth thickness

This table provides a clear comparison of various restorative methods and their practical applications, offering valuable guidance for the restoration of posterior teeth following endodontic treatment.

Inlay/Onlay

The materials used for fabricating inlays are primarily divided into metals, composite resins, and ceramic materials. Metal inlay materials include precious metals such as gold-platinum alloys and non-precious metals such as cobalt-chromium alloys. Gold-platinum alloys offer good ductility and low expansion rates, making them high-quality but expensive restoration materials; whereas cobalt-chromium alloys have high strength, good corrosion resistance, and are cost-effective, but they have poorer ductility and may cause sensitivities. Due to the bonding outcomes, aesthetic limitations, and the stringent requirements for cavity preparation, the use of metal inlays has relatively decreased.[35] Composite resin inlays, which have an elasticity similar to that of dentin, possess high adhesive strength, are easy to adjust, and have good physical and mechanical properties. As material technologies advance, the filler content in these resins has increased. However, their wear resistance is relatively low, making them prone to marginal leakage or fracture under high occlusal forces, hence they are more suitable for small-area defects or non-load-bearing restorations. Additionally, the aging of the resin may impact the aesthetic appeal.[36]

Ceramic inlays are increasingly used in clinical settings due to their high hardness, excellent wear resistance, and aesthetic qualities. However, due to their high modulus of elasticity, ceramic inlays struggle to withstand elastic deformation.[37] All-ceramic materials include traditional feldspathic ceramics and heat-pressed ceramics, among which heat-pressed ceramics like the IPS E.max system are widely favored due to their dense intrinsic crystal structure and high fracture resistance. CAD/CAM technology has advanced the use of machinable ceramics, such as lithium disilicate glass ceramics. Studies indicate that IPS E.max CAD exhibits high fracture strength and microhardness. Despite full zirconia materials enhancing the fracture strength of teeth, their limited use in inlay restorations is due to poor acid-etching results. New ceramic-reinforced resin materials, such as Vita Enamic, which combine good physical properties and higher toughness, represent a promising material for inlay fabrication.[38,39]

Some systematic reviews and meta-analyses have indicated that resin inlays have a 5-year survival rate of 86% and a 10-year survival rate of 75%. In contrast, ceramic inlays/onlays and resin-matrix ceramics have a similar survival rate exceeding 90% over five years, which is superior to resin inlays. Inlay and onlay restorations involve less tooth preparation, substantially preserving healthy tooth structure and reducing tooth damage. Additionally, they effectively prevent food impaction and secondary caries in adjacent teeth.[39,40]

In a systematic review by Georgia I. Vagropoulou and colleagues on inlays and onlays versus complete coverage restorations, nine in vivo and in vitro studies were included. It was found that inlays, onlays, and complete coverage restorations had a fracture incidence rate of 11.34% within five years.[41] Because dental hard tissue is more resistant to compressive forces than to tensile forces, studies have shown that inlay restorations, particularly when the isthmus is wide, can act like a wedge. When subjected to occlusal forces, they can exert significant stress on the surrounding tooth structure, leading to cusp splitting. Several scholars have demonstrated the stress effects caused by inlays through finite element analysis.[40] Therefore, inlays can only replace the missing tooth tissue in the defect area and do not protect the remaining part of the tooth tissue, making them suitable only for small defects. Conversely, onlays can convert tensile stress into compressive stress and disperse it, reducing the possibility of tooth fracture, and are more appropriate for extensive defect restorations. The prerequisite for onlay restoration is that the tooth has intact buccal and lingual walls; if there is extensive damage to the enamel, full crown restoration should be considered.[41]

When the remaining healthy crown height of a tooth is below 2-3 mm due to considerable loss of coronal structure, opting for a post-and-core restoration becomes a suitable alternative. Some scholars believe that posts can improve the stress distribution in teeth after root canal treatment, enhancing their fracture resistance, especially in anterior teeth and premolars.[6] Although posts are commonly used to retain cores and restorations, it is argued that they do not enhance the structural integrity of the tooth root; rather, preparing the post space could heighten the risk of root fractures.[42] Posts are generally recommended only when the existing tooth structure is insufficient to support the restoration independently. A meta-analysis revealed no significant statistical differences in the survival and failure rates between endodontically treated teeth that were restored using either glass fiber-reinforced or metal posts. The survival rates were reported at 92.8% for glass fiber posts and 78.1% for metal posts, indicating that both materials perform effectively when there is a significant loss of coronal tooth structure and post-treatment becomes essential.[43] For molars, due to their thin and curved roots, it is recommended to avoid using posts when there is sufficient remaining tooth structure; for premolars, due to their small pulp chambers and multidirectional forces, using a post for restoration may be more necessary. Endocrowns are suitable for situations where there is insufficient space for restoration, the dental crown is too short, or it is difficult to perform post-and-core restorations, as they can be secured through the friction and adhesive forces between the tooth and the restoration. For posterior teeth with occlusal surface wear, occlusal veneers provide a minimally invasive restoration option.

In summary, for small area defects, resin fillings or inlay restorations can be utilized; for extensive defects, onlays or full crowns are more appropriate, but efforts should be made to preserve as much tooth structure as possible. In specific cases, such as when the buccal and lingual walls are incomplete or there is significant coronal damage, consideration should be given to post-and-core or endocrowns restorations. For posterior teeth with occlusal surface wear, occlusal veneers provide an effective minimally invasive restoration option. Figure 4 illustrates a case depicting the complete process of an inlay restoration for tooth #15 following endodontic treatment.

Figure 4: A, Tooth #15 Exhibiting Caries and Pulpal Symptoms. B, Radiograph Revealing Low-density Radiolucency in Tooth #15, Extending Into the Pulp Chamber. C, Endodontic Treatment Performed on Tooth #15. D, Tooth #15 Following Endodontic Therapy, Showing Completed Filling And Preparation for Restoration. E, Fabrication of the Porcelain Inlay. F, Final Placement of the Porcelain Inlay on Tooth #15. G, Post-restoration Radiograph of Tooth #15 with the Inlay in Place. H, Three-year Follow-up Photo of Tooth #15 After Inlay Placement. I, Three-year Follow-up Radiograph of Tooth #15 Showing the Inlay in Situ.

Figure 5 illustrates a case of tooth #36 undergoing an onlay restoration following endodontic treatment.

Figure 5: A, Tooth #36 After Tooth Preparation Following Endodontic Treatment. B, Fabrication of the Onlay for Tooth #36. C, Completion of Onlay Placement on Tooth #36. D, Occlusal Adjustment Finalized for the Onlay on Tooth #36. E, Post-restoration Radiograph of Tooth #36 with the Onlay. F, Two-year Follow-up Photograph of Tooth #36 After Onlay Restoration.

Full Crown

Full crown restorations are among the most common restorative procedures in prosthodontics, used to restore the shape, function, and aesthetics of damaged teeth. They are versatile, serving not only as restoratives but also as abutments for fixed dental prostheses, and can be fabricated from various materials.

Metal Crowns: Among the earliest materials used for full crowns, these include precious metals (such as gold and platinum) and non-precious metals (such as cobalt-chromium alloys). Metal crowns are widely used due to their excellent durability and biocompatibility, but they lack aesthetic appeal.

Porcelain Fused to Metal Restorations (PFM): Emerging in the mid-20th century to enhance aesthetics, PFMs combine the strength of metal with the beauty and low complication rate of porcelain. They have become a long-term mainstream choice, with research reporting an average survival rate of 75.5% over 20 years.[44]

All-Ceramic Crowns: With the advancement of ceramic materials, all-ceramic crowns have become increasingly popular due to their superior aesthetics and good biocompatibility, exhibiting excellent clinical performance with a survival rate of 74% over 104 months, thus becoming an alternative to PFMs.[45,46] Initially, all-ceramic crowns had lower strength, but with the introduction of high-strength ceramic materials like zirconia, their application has expanded. The advent of computer-aided design-computer-aided manufacturing (CAD-CAM) technologies, along with 3-D printing and digital techniques, has significantly improved the accuracy of restorations and expanded the opportunities to use new materials, including various ceramics with improved properties, pre-polymerized resin composite blocks, hybrid ceramics, and different alloys. Resin materials, due to their excellent restorative properties and lower cost, are used for temporary crowns or some permanent restorations. However, their wear resistance and long-term stability are relatively poor, limiting their use in posterior teeth after endodontic treatment.[32]

Figure 6 illustrates a case of tooth #46 restored with a full ceramic crown following endodontic treatment.

Figure 6: A, Tooth #46, Previously Filled and Now Presenting Symptoms of Pulpitis. B, Endodontic Treatment Initiated for Tooth #46. C, Completion of Endodontic Therapy and Filling for Tooth #46. D, Preparation of Tooth #46 for Restoration. E, Fabrication of a Full Ceramic Crown for Tooth #46. F, Final Placement of the Full Ceramic Crown on Tooth #46. G, Post-restoration Radiograph of Tooth #46 with the Ceramic Crown in Place. H, Follow-up Photograph at 33 Months Post-restoration for Tooth #46. I, Follow-up Radiograph at 33 Months for tooth #46.

Endocrowns are particularly advantageous for teeth that have experienced substantial coronal damage, making traditional post-and-core restorations impractical. These restorations, which are monolithic in nature, depend on adhesive bonding and the macro-mechanical retention provided by the pulp chamber. Research indicates that endocrowns are a reliable and durable option for teeth with significant structural loss. A detailed case study of tooth #46, which underwent endodontic treatment, demonstrates the steps involved in fabricating and placing an endocrown, showcasing its effectiveness over a two-year follow-up period (Figure 7).

Figure 7: A, Tooth #46 Following Endodontic Treatment with Extensive Tooth Structure Loss. B, Fabrication of Endocrowns for Tooth #46. C, Placement of the Endocrowns on Tooth #46. D, Post-placement Radiograph of the Endocrowns on Tooth #46. E, Two-year Post-restoration Follow-up Photo of Tooth #46. F, Two-year Post-restoration Follow-up Radiograph of Tooth #46.

After discussing the various specific restorative methods, such as inlays, onlays, and full crowns, it is essential to provide a comprehensive comparison of the materials and techniques used in these restorations. This comparison outlines the mechanics and requirements for each technique, and as such provides clinicians with the tools to make a decision based on the specifics of the particular patient case. In particular, inlays and onlays are particularly useful since they can strengthen the tooth while minimizing the amount of material that has to be removed from the tooth. According to research conducted on the longevity of ceramic inlays and onlays, the five-year success rate is more than ninety percent. Full coverage crowns on the other hand are advised for teeth that have a lot of structure loss because of the full coverage they provide and the protective nature of the restoration. Scientific evidence points to the fact that full ceramic crowns have a durability of approximately 74% after a decade.[45]

The following table (Table 2) provides a comprehensive summary of the available restorative procedures for posterior teeth that have been treated using endodontic therapy. It contains details on the kind of materials to use, the need for posts and what should be the right height of the ferrule. This table is beneficial for clinicians as it presents the factors that should be taken into consideration when choosing the restorative methods.

Table 3: Restoration Options for Posterior Endodontically-Treated Teeth.

Restoration Options	Materials	Use of Post	Ferrule Height	Notes
All-Ceramic Crown	Lithium Disilicate, Zirconia	Not recommended in wide, curved roots	At least 1.5-2mm	High aesthetics, suitable for the anterior region
Porcelain Fused to Metal Crown, PFM	Metal base, Porcelain	Applicable	At least 1.5-2mm	A classic choice, the balance of aesthetics and strength
Direct Composite Restoration	Composite Resin	Usually not needed	Not applicable	Mild defects, minimally invasive option
Inlay	Metal, Ceramic, Composite Resin	Usually not needed	At least 1.5-2mm	Suitable for moderate tooth defects, conserves more healthy tooth structure
Onlay	Metal, Ceramic, Composite Resin	Usually not needed	At least 1.5-2mm	Covers one or more cusps, suitable for extensive defects
Occlusal Veneer	Ceramic, Composite Resin	Usually not needed	Not applicable	Suitable for posterior teeth with occlusal wear, a minimally invasive option
Endocrowns	Ceramic, Composite Resin	Not applicable	At least 1.5-2mm	Monolithic restoration, suitable for extensive tooth defects

This table offers a concise and clear summary of the restorative options available, aiding clinicians in selecting the most appropriate method based on specific clinical situations and patient needs. It provides a detailed overview of the restorative options for endodontically treated posterior teeth, including the materials used, the necessity of posts, and the recommended ferrule height. This table serves as a reference for clinicians, summarizing the critical factors that influence the choice of restorative methods.

Conclusion

Thus, when restoring posterior teeth after endodontic treatment, clinicians need to consider several factors and find a proper balance between conserving tooth tissue and achieving the expected prognosis for the restored teeth. The decision as to which technique should be employed to restore a specific tooth should be influenced by the extent of structural involvement, the position of the tooth in the dental arch, the forces of occlusion, and aesthetic demands. This review provides an overview of the direct and indirect restorative approaches, focusing on the strengths and weaknesses of each.

Direct restorations especially the composite resin fillings are ideal for teeth with little structural damage, giving long-term high survival rates. However, where there is considerable structural damage, less invasiveness cannot be relied on to restore the tooth adequately, and inlays, onlays and full crowns offer better support and protection, increasing the ability of the tooth to withstand forces that cause fracture.

The main factor that plays a vital role in increasing the chances of withstanding fractures in teeth that have been treated through endodontic is the ferrule effect especially where there is more than average loss of tooth structure. The height of the ferrule should range from 1. 5 to 2 mm in order to support the principles of indirect restorations. Further studies should also be conducted to compare various types of restorative materials and methods in terms of their long-term effectiveness in clinical practice. Continuous advancements in materials and techniques will undoubtedly enhance the success rates of restorations and improve patient outcomes.

Overall, this review underscores the need for individualized treatment planning based on a thorough assessment of each patient's clinical situation. By integrating current research and clinical insights, dental practitioners can make informed decisions that ensure the long-term health and functionality of endodontically treated posterior teeth.

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