

**AN EVALUATION USING FDI CRITERIA TO
COMPARE FULL-CERAMIC CROWNS,
COMPOSITE RESIN FILLINGS, CERAMIC
INLAYS AND ONLAYS IN POSTERIOR TEETH
AFTER ENDODONTIC TREATMENT**

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by

CHE SHIWEI

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LIST OF SYMBOLS

E	Elastic modulus (stiffness of dental materials)
F	Applied force on restorative materials
K_{Ic}	Fracture toughness (resistance of a material to crack propagation)
p	P-value (statistical significance indicator)
s	Standard deviation (variation in dataset)
σ	Stress (force per unit area affecting material strength)
ε	Strain (measure of deformation in materials)
VH	Vickers hardness (measure of material hardness)
W	Wear resistance (ability of material to withstand friction)
$\bar{x}$	Mean value (average in statistical analysis)
CI	Confidence interval (range indicating result reliability)

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance (statistical method)
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CI	Confidence Interval
CR	Composite Resin
FCC	Full-Ceramic Crown
FDI	World Dental Federation
KIC	Fracture Toughness
PCA	Principal Component Analysis
PLS	Partial Least Squares (used in statistical modeling)
Ra	Surface Roughness Parameter
RCT	Root Canal Treatment
SD	Standard Deviation
SEM	Scanning Electron Microscopy
USPHS	United States Public Health Service (clinical evaluation criteria)
VHN	Vickers Hardness Number
ANOVA	Analysis of Variance (statistical method)

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**PENILAIAN MENGGUNAKAN KRITERIA FDI UNTUK
MEMBANDINGKAN KORONA SERAMIK PENUH, TAMPALAN RESIN
KOMPOSIT, INLAI DAN ONLAI SERAMIK PADA GIGI POSTERIOR
SELEPAS RAWATAN ENDODONTIK**

ABSTRAK

Restorasi gigi posterior yang telah menjalani rawatan endodontik adalah satu cabaran kritikal disebabkan oleh kerosakan struktur selepas rawatan saluran akar. Kajian ini menilai prestasi klinikal korona seramik penuh (FCC), tampalan resin komposit (CR), dan inlai/onlai seramik pada gigi posterior menggunakan kriteria Persekutuan Pergigian Dunia (FDI). Satu kajian kohort prospektif telah dijalankan melibatkan 150 pesakit (194 gigi posterior), menilai hasil fungsi seperti ketahanan terhadap patah, penyesuaian marginal, haus, dan kepuasan pesakit selama purata tempoh susulan 58.14 bulan (SD = 2.93). Analisis statistik mendedahkan perbezaan yang signifikan ($p < 0.05$) dalam kadar kejayaan jangka panjang antara tiga kumpulan, dengan FCC menunjukkan daya tahan dan penyesuaian marginal yang lebih baik, manakala tampalan CR menyediakan pilihan yang kurang invasif dan kos efektif dengan haus yang lebih tinggi dan penurunan marginal dari masa ke masa. Inlai/onlai seramik menawarkan keseimbangan antara pemeliharaan struktur dan daya tahan, menjadikannya sesuai untuk kes dengan kehilangan struktur gigi yang sederhana. Skor kepuasan pesakit, seperti yang diukur menggunakan kriteria FDI, adalah tertinggi dalam kumpulan FCC (skor min: 1.2 ± 0.4), diikuti oleh kumpulan inlai/onlai seramik (1.4 ± 0.5) dan kumpulan CR (1.8 ± 0.6), dengan perbezaan yang signifikan secara statistik ($p < 0.05$). Penemuan ini memberikan cadangan

berdasarkan bukti untuk pemilihan bahan restorasi, menekankan keperluan untuk perancangan rawatan yang diperibadikan berdasarkan keadaan klinikal dan keperluan pesakit.

**A PROSPECTIVE EVALUATION USING FDI CRITERIA TO COMPARE
FULL-CERAMIC CROWNS, COMPOSITE RESIN FILLINGS, AND
CERAMIC INLAYS/ONLAYS IN POSTERIOR TEETH AFTER
ENDODONTIC TREATMENT**

ABSTRACT

Restoring endodontically treated posterior teeth is a critical challenge due to structural compromises following root canal treatment. This study evaluates the clinical performance of full-ceramic crowns (FCC), composite resin (CR) fillings, and ceramic inlays/onlays in posterior teeth using the World Dental Federation (FDI) criteria. A prospective cohort study was conducted involving 150 patients (194 posterior teeth), assessing functional outcomes such as fracture resistance, marginal adaptation, wear, and patient satisfaction over a mean follow-up period of 58.14 months (SD = 2.93). Statistical analysis revealed significant differences ($p < 0.05$) in long-term success rates among the three groups, with FCC demonstrating superior durability and marginal adaptation, while CR fillings provided a minimally invasive, cost-effective option with higher wear and marginal deterioration over time. Ceramic inlays/onlays offered a balance between structural conservation and durability, making them suitable for cases with moderate tooth structure loss. Patient satisfaction scores, as measured by the FDI criteria, were highest in the FCC group (mean score: 1.2 ± 0.4), followed by the ceramic inlays/onlays group (1.4 ± 0.5) and the CR fillings group (1.8 ± 0.6), with differences statistically significant ($p < 0.05$). These findings provide evidence-based recommendations for restorative

material selection, emphasizing the need for personalized treatment planning based on clinical conditions and patient needs.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Dental restorations have evolved significantly over the past few decades, with advancements in materials and techniques offering a wider range of options for clinicians and patients. The primary goal of any dental restoration is to restore the function, aesthetics, and longevity of the tooth. Following endodontic treatment, the structural integrity of the tooth may be compromised, especially in posterior teeth. Due to their functional demands and location in the oral cavity, there is a need for durable and reliable restorative materials (de Kuijper et al., 2023). Achieving durability and reliability in restorations involves selecting appropriate materials, utilizing advanced techniques, and considering the specific needs of the patient. Recent advancements have led to the development of restorative materials that enhance the strength, aesthetics, and biocompatibility of dental restorations. Full-ceramic crowns, composite resins, and ceramic inlays/onlays are among the materials that have been engineered to meet these demands (Naik et al., 2022).

Full-ceramic crowns have gained significant popularity due to their superior esthetic properties and biocompatibility, offering a metal-free alternative to traditional crowns. These crowns are particularly valued for their ability to mimic the natural translucency of tooth enamel, providing an aesthetically pleasing result that closely resembles natural teeth (Sharma et al., 2023). Recent advancements in CAD/CAM (Computer-Aided Design/Computer-Aided Manufacturing) technology have further enhanced the precision and fit of full-ceramic crowns, significantly improving their clinical performance and longevity (Vág et al., 2020). This precision is especially crucial in the context of post-endodontic treatment, where the structural

integrity of the tooth may be compromised. By providing a strong and durable seal, full-ceramic crowns help reinforce the tooth, protecting it from future fractures or decay while maintaining the health of surrounding tissues. This combination of aesthetic appeal, biocompatibility, and functional durability makes full-ceramic crowns an ideal choice for restoring both the function and appearance of teeth following endodontic treatment.

Composite resin fillings provide a direct and minimally invasive approach to tooth restoration, making them a preferred choice for many clinicians. Their tooth-colored appearance and strong bonding capability to tooth structure are particularly advantageous in post-endodontic treatment, where preserving the integrity of the remaining tooth is essential (Rodrigues et al., 2020). Over the years, composite resins have seen significant improvements in wear resistance and durability, which has expanded their application to include posterior restorations where higher stress is placed on the material, providing essential reinforcement to teeth that have been structurally compromised by root canal therapy (Fages et al., 2017). These advancements allow composite resins not only to restore the natural appearance of teeth but also to offer the strength needed to withstand masticatory forces, ensuring long-term success in post-endodontic restorations.

Ceramic inlays and onlays represent an intermediate option between full crowns and direct fillings, offering a balance between the conservation of natural tooth structure and the need for durable, aesthetic restorations. Custom-made in a laboratory or crafted using chairside CAD/CAM systems, these restorations are carefully cemented into place, ensuring a precise fit. Ceramic inlays and onlays combine the advantages of both crowns and fillings, providing superior aesthetics

and durability while preserving more of the natural tooth structure compared to full crowns (Mandal et al., 2022). This characteristic is particularly important in post-endodontic treatment, where the preservation of the remaining tooth structure is crucial to maintaining the tooth's long-term viability. Studies have indicated that ceramic inlays/onlays offer superior marginal adaptation and internal fit, both of which contribute to their longevity and effectiveness, making them an excellent choice for teeth that have undergone endodontic therapy (Naik et al., 2022).

The choice of restorative material can influence the clinical performance and longevity of the restoration. A study by (Otto, Dent & Schneider, 2008) highlighted the long-term clinical results of chairside CAD/CAM inlays and onlays, emphasizing their durability and success over time, which is particularly relevant for endodontically treated teeth that require robust restorations. Another study evaluated the clinical performance of partial and full coverage fixed dental restorations fabricated from hybrid polymer and ceramic CAD/CAM materials (Guess et al., 2009). Additionally, the appropriate selection of direct composite resin fillings following endodontic treatment has been a topic of considerable interest, as these materials must offer sufficient strength and durability to withstand the increased demands placed on the tooth. A retrospective clinical study on the longevity of class 2 direct restorations in root-filled teeth provides valuable insights into the performance of these materials in post-endodontic scenarios, further underscoring the importance of material selection in achieving long-term success (Bhuva et al., 2021).

Given the myriad of restorative options available, evaluating and comparing their clinical performance is crucial, especially in posterior teeth following endodontic treatment. Direct restorations, such as composite resin fillings, generally

preserve more tooth structure and are often indicated when sufficient coronal structure remains and occlusal load is moderate. Indirect restorations, including inlays, onlays, and full-coverage crowns, typically offer superior mechanical support, fracture resistance, and marginal seal, which are particularly important in teeth with extensive structural loss or high occlusal demands. Understanding the clinical significance of choosing between direct and indirect restorations is essential, as the decision impacts not only the functional longevity but also the risk of future complications in endodontically treated teeth. This study aims to provide insights into the comparative clinical performance of full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays in this specific clinical scenario.

1.2 Problem Statement

Dental restorations play a pivotal role in restoring the function and aesthetics of teeth, especially those that have undergone endodontic treatment. Posterior teeth, in particular, bear the brunt of masticatory forces and are thus susceptible to wear, fracture, and subsequent failure if not adequately restored. The choice of restorative material and technique can significantly influence the clinical performance, longevity, and patient satisfaction of the restoration.

Full-ceramic crowns, known for their superior esthetic properties and biocompatibility, have emerged as a popular choice for many clinicians and patients seeking a metal-free alternative to traditional crowns (Guess et al., 2009). Composite resin fillings offer a direct, minimally invasive approach and are favored for their tooth-colored appearance and ability to bond directly to the tooth structure (Spitznagel, Boldt & Gierthmuehlen, 2018). Ceramic inlays and onlays, which are custom-made using chairside CAD/CAM systems or in dental laboratories, bridge

the gap between full crowns and direct fillings, providing an intermediate restorative option (Otto, Dent & Schneider, 2008).

However, despite the advancements in dental materials and techniques, there remains a lack of comprehensive studies comparing the clinical performance of these three restorative options in posterior teeth following endodontic treatment. Given the increasing prevalence of endodontically treated teeth and the myriad of restorative options available, there is a pressing need to evaluate and compare the clinical outcomes of these materials to guide clinicians in making informed decisions.

This study aims to address this gap in the literature by prospectively analyzing the clinical performance of full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays in posterior teeth following endodontic treatment, using the World Dental Federation, FDI as the evaluation tool (Hickel et al., 2007).

1.3 Justification of Study

The choice of restorative material for posterior teeth following endodontic treatment is a critical decision that impacts the longevity, functionality, and aesthetic outcome of the treatment. Despite the availability of various restorative options such as full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays, there remains a lack of comprehensive studies that compare their clinical performance specifically within a defined population (Spitznagel, Boldt & Gierthmuehlen, 2018).

1.4 Significance of Study

The significance of this study lies in its potential to advance the fundamental understanding of the clinical performance of various restorative materials, specifically full-ceramic crowns, composite resins, and ceramic inlays/onlays, in the

context of posterior teeth following endodontic treatment. This research addresses the need for evidence-based data to guide clinical decisions in restorative dentistry. By providing comprehensive, mid-to-long-term clinical outcomes, this study aims to contribute insights into material selection and treatment planning, ultimately improving patient care and treatment success rates in dental practice.

a. Need for Comprehensive Evaluation

While numerous studies have explored the efficacy of various dental restorative materials, few have undertaken a direct comparison of full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays in the context of posterior teeth following endodontic treatment. The existing literature often focuses on isolated evaluations, lacking a holistic approach that considers the comparative advantages and limitations of these materials under similar clinical conditions. This study seeks to fill this gap by providing a side-by-side comparison based on real-world clinical data (Fan et al., 2021).

b. Long-Term Follow-Up

The timing and follow-up of this study are crucial. By selecting a patient cohort treated within a specific timeframe and ensuring a follow-up period of four to five years, the study offers insights into the mid-to-long-term performance and durability of the restorations. This period is sufficient to observe significant clinical outcomes, such as the success rate, complication incidence, and patient satisfaction, thereby providing a robust data set for analysis. This approach allows for a comprehensive assessment of the restorative methods over a substantial period, ensuring that the data reflects the true longevity and effectiveness of the treatments. By monitoring these outcomes, the study aims to provide valuable information that

can guide clinical decision-making and improve patient care in dental restorations (Ying et al., 2022).

c. Expertise and Methodological Rigor

The study leverages the expertise of specialist dentists with over five years of professional experience, ensuring that the restorative procedures were performed with high precision. Additionally, the use of the World Dental Federation (FDI) criteria as an evaluation tool enhances the reliability and standardization of the outcome measures. This methodological rigor is essential for producing credible and reproducible results that can inform clinical guidelines and decision-making (Hickel et al., 2023; Mesinger et al., 2023).

d. Contribution to Clinical Practice

The findings from this study will contribute significantly to the existing body of knowledge by offering a detailed evaluation of the three restorative methods in a specific clinical scenario. This contribution is particularly valuable for clinicians seeking to make informed decisions about the most suitable restorative material for their patients. By understanding the comparative performance of full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays, clinicians can tailor their treatment strategies to enhance patient outcomes and satisfaction.

e. Addressing Regional Needs

The study's focus on a population from northern China also addresses a specific regional need, as dental practices and material preferences can vary significantly across different regions. The insights gained from this study can thus be

particularly beneficial for practitioners within this geographical area, providing them with relevant data to guide their clinical practices.

In summary, this study is justified by its potential to provide comprehensive, mid-term or long-term comparative data on the performance of different restorative materials in endodontically treated posterior teeth. The insights gained will aid clinicians in making evidence-based decisions, ultimately enhancing the quality of dental care provided to patients.

1.5 Research Questions

The research questions of the project are listed below:

- a. What are the scores for functional outcomes, including aspects such as fractures and retention, marginal adaptation, contact point/food impact, and patient's view, for full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays in posterior teeth following endodontic treatment over a defined duration, utilizing the FDI Criteria?
- b. What are the success rates of full-ceramic crowns (FCC), composite resin (CR) fillings, and ceramic inlays/onlays in posterior teeth following endodontic treatment, when assessed using the functional properties scoring criteria within the FDI Criteria?
- c. How do the complication rate and background distribution, considering variables such as patient's gender, age, tooth position, root canal treatment, and the presence of a post-and-core, compare among the study groups (full-ceramic crowns [FCC], composite resin [CR], and ceramic inlays/onlays) at a 5-year follow-up?

1.6 Research Hypothesis

The hypotheses of the project are listed below:

- a. H1: There will be observable differences in the scores for functional outcomes and the patient's view among the three distinct restorative methods (full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays) in posterior teeth following endodontic treatment, as assessed using the FDI Criteria.
- b. H2: The success rates of full-ceramic crowns, composite resin fillings, and ceramic inlays/onlays in posterior teeth following endodontic treatment will exhibit significant variations when evaluated using the FDI Criteria.
- c. H3: There will be notable differences in the complication rate and background distribution (patient's gender and age, tooth position, root canal treatment, and the presence of a post-and-core) among the study groups (full-ceramic crowns, composite resin, and ceramic inlays/onlays) at a 5-year follow-up.

1.7 Research Aim and Objectives

The primary aim of this study is to evaluate the clinical outcomes of full-ceramic crowns, direct composite resin fillings, and ceramic inlays/onlays in posterior teeth following endodontic treatment, using the FDI Criteria.

Specific objectives are as follows:

- a. To determine the scores for functional outcomes (such as fractures and retention, marginal adaptation, wear, contact point/food impact), and the patient's view of the three distinct restorative methods in posterior teeth

following endodontic treatment over a defined duration, utilizing the FDI Criteria.

- b. To ascertain the success rates of full-ceramic crowns (FCC), composite resin (CR) fillings, and ceramic inlays/onlays in posterior teeth following endodontic treatment, utilizing the functional properties scoring criteria within the FDI Criteria.
- c. To evaluate complication rate and compare background distribution (patient's gender and age, tooth position, root canal treatment, and the presence of a post-and-core) of study groups (FCC, CR, and inlays/onlays) at 5-year follow-up.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Endodontic treatment presents several 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 involve 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 (Iandolo, 2023). Furthermore, one can identify the development of regenerative endodontics as another ability that can potentially reverse the damage inflicted on tissues (Iandolo, 2023).

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% (Caussin et al., 2024). Numerous studies confirm that endodontic treatment is a reliable choice for patients needing dental care (Ng et al., 2004, 2007; Burns et al., 2022). It is also important to recognise that most 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 (Vire, 1991; Brudvik & Shor, 2004; Mannocci & Cowie, 2014).

The long-term function of posterior teeth after endodontic 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 (Wang et al., 2022).

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 to provide practitioners with the required information to make appropriate decisions that ensure posterior teeth function and esthetics post-treatment.

2.2 Changes in Posterior Teeth Following Endodontic Treatment

Posterior teeth undergo significant structural, mechanical, and biological changes following endodontic treatment, which can impact their long-term stability and function. Endodontic treatment involves the removal of infected or inflamed

pulp tissue, which is then replaced with a filling material. This process, while necessary to eliminate infection and preserve the tooth, inherently weakens the tooth structure.

One of the primary changes is the loss of tooth elasticity. The pulp tissue, which is removed during the procedure, plays a critical role in providing the tooth with elasticity and the ability to absorb occlusal forces (Yan et al., 2019a). Without the cushioning effect of the pulp, the tooth becomes more brittle and prone to fractures under normal chewing forces. This increased brittleness is particularly concerning in posterior teeth, which are subjected to higher masticatory loads compared to anterior teeth.

Additionally, the loss of moisture content within the dentin after endodontic treatment further contributes to the brittleness of the tooth. The dehydrated dentin exhibits reduced toughness, making it more susceptible to crack propagation (Monga, Sharma & Kumar, 2009). Furthermore, the removal of tooth structure during access cavity preparation, combined with the potential for incomplete bonding of restorative materials, can result in weakened teeth that are less able to resist functional forces (Monga, Sharma & Kumar, 2009).

The implications of these changes are profound, emphasizing the need for carefully selected restorative materials and techniques that can address the altered structural mechanics and biological changes in endodontically treated teeth. Modern restorative approaches, including fiber-reinforced composite posts and full-coverage crowns, are designed to mitigate these effects by reinforcing the tooth structure, thereby restoring its mechanical strength and enhancing its ability to withstand functional stresses. These methods not only compensate for the loss of tooth

elasticity and moisture but also contribute to the long-term preservation of tooth integrity and function.

2.2.1 Changes in Structural Mechanics

Mechanically, after endodontic treatment, posterior teeth often undergo substantial changes that affect their durability and functionality (Rajbhoj et al., 2021). 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 (Fransson & Dawson, 2023). This loss of biomechanical properties makes the tooth more brittle and prone to fractures (Bjørndal et al., 2019). 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 (Fransson & Dawson, 2023). A significant decrease in both the hardness and elastic modulus of dentin has been observed in many studies following root canal therapy (Sahebi et al., 2020; Selvaraj et al., 2023). These changes drastically alter the tooth's ability to endure masticatory stress, potentially leading to a higher incidence of structural complications (Zaslansky, 2008). 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% (Michaud & Dort, 2024).

This vulnerability is particularly evident in the changes observed in the root dentin's mechanical properties, as highlighted by Fathy and Hamama (Fathy et al.,

2022). 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 (Soares et al., 2007). Since biomechanical properties are critical determinants of the overall health and functionality of the teeth, dental care professionals need to consider these factors when planning for any operative interventions.

2.2.2 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 (Colombo et al., 2014).

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 (Bjørndal et al., 2010). 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. Phillip et al.'s 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 (Tomson et al., 2023).

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 (Genovese, Lamberti & Pappalettere, 2006; Mannocci & Cowie, 2014; Elias, Jalili & Martin, 2015; Yan et al., 2019b). 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 (Nikolopoulou, Loukidis & Proffesor, 2014; Abduo & Sambrook, 2018). 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 (Tomson et al., 2023). 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 (Wang et al., 2022).

2.3 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. reported that over 65% of such teeth were lost within three years without permanent restoration (Tang, Wu & Smales, 2010). 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 (Carratù et al., 2002; Sah et al., 2024). 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 (Kuijper et al., 2023). This classification facilitates the customization of treatment according to the unique requirements and conditions of each tooth, enhancing the effectiveness of the restoration process.

Marginal integrity refers to the ability of restoration to maintain a continuous, gap-free interface with the surrounding tooth structure, preventing microleakage, bacterial infiltration, and secondary caries. In endodontically treated posterior teeth, marginal adaptation is especially critical because any breakdown at the restoration – tooth interface can lead to periapical inflammation, reinfection of the root canal system, and eventual restoration failure (Pereira et al., 2024). Factors influencing marginal integrity include the restorative material's polymerisation shrinkage, coefficient of thermal expansion, wear resistance, and the quality of the bonding

procedure. Indirect restorations, particularly full-ceramic crowns and well-fitted ceramic inlays and onlays, generally provide superior marginal integrity compared to direct composite resin fillings, due to better control over fabrication precision and occlusal adjustment. However, even with indirect restorations, proper tooth preparation, adhesive cementation, and occlusal harmony are necessary to maintain a marginal seal over time. Evaluating marginal integrity is therefore a key criterion within the FDI system, directly affecting the long-term prognosis of the treated tooth(Fan et al., 2025).

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.

2.3.1 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 (Faria et al., 2011).

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 (Tait Bds et al., 2005).

2.3.1(a) 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'. 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 (Zhang et al., 2015; Naumann et al., 2018). 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 (Al-Wahadni & Gutteridge, 2002; Al-Omiri & Al-Wahadni, 2006). 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.

In anterior teeth, the ferrule effect is particularly critical due to their narrower cross-sectional dimensions, higher susceptibility to lateral forces, and the esthetic requirement to preserve the labial contour. An adequate ferrule in anterior restorations not only improves fracture resistance but also enhances the longevity of the post–core–crown complex, especially under non-axial loading conditions commonly encountered in functional and parafunctional activities. Maintaining periodontal health and ensuring controlled occlusion is essential, with a minimum recommended ratio of 1:1 deemed necessary to handle lateral forces effectively (Mannocci et al., 2022).

This diagram (Figure 2.1) and Table 2.1 provide 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.

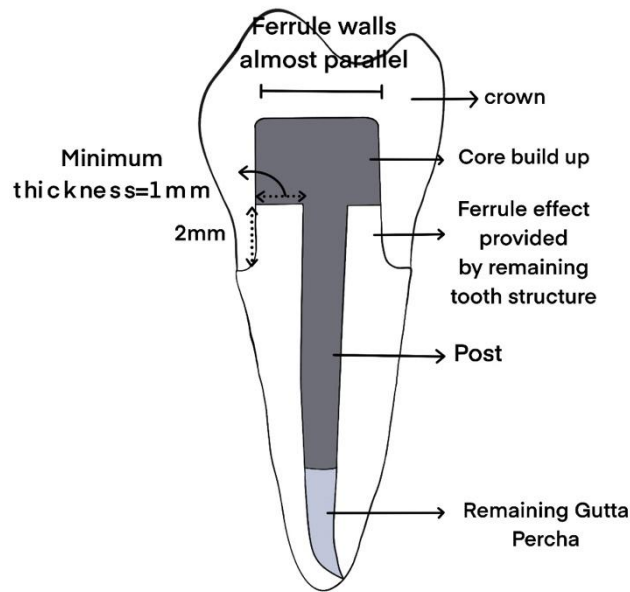


Figure 2.1 Schematic Diagram Illustrating the Ferrule Effect

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 2.1 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.

2.3.1(b) 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 (Aquilino & Caplan, 2002; Nagasiri & Chitmongkolsuk, 2005).

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 (Tait Bds et al., 2005). The Nayyar core technique, which utilizes the spacious pulp chamber for direct composite restoration, offers an effective alternative to using posts (Reddy et al., 2016).

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 (Mohammadi et al., 2009). 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 (Yazdi, Sohrabi & Mostofi, 2020).

When fewer than two cavity walls remain intact, the integration of glass fiber posts substantially bolsters the fracture resistance of the tooth (Mangold & Kern, 2011). 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 2.2), 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.

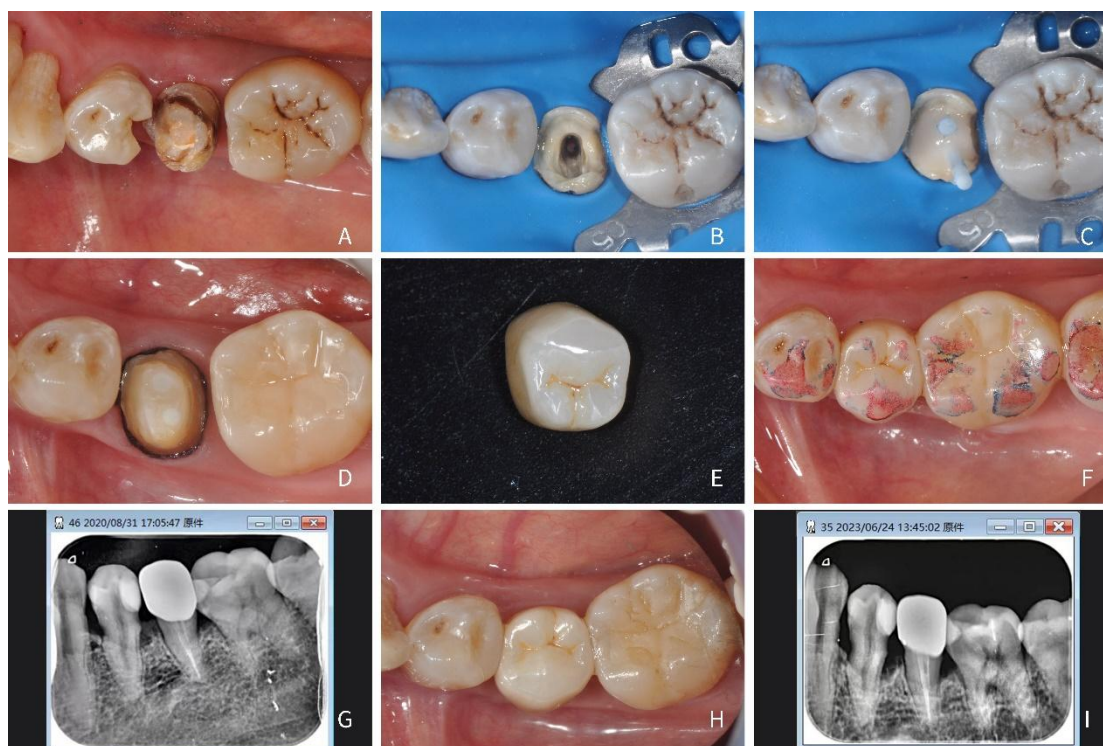


Figure 2.2 Clinical and radiographic sequence illustrating the restoration of tooth #35 following endodontic treatment with glass fiber post placement and full crown coverage, arranged in chronological order for improved clarity.

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.

2.3.1(c) 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 implemented⁴⁷. 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 (Khaled Aboel-Fadl, Adelel-Desoky & Adelel-Desoky, 2017).

2.3.1(d) 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