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Long-Term Clinical Outcomes of Bioceramic-Based Vital Pulp Therapy in Mature Permanent Teeth: A Prospective Study

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Abstract

Vital pulp therapy (VPT) has emerged as a conservative and biologically oriented alternative to root canal treatment for preserving pulp vitality, even in mature permanent teeth. The introduction of bioceramic-based materials has enhanced the predictability of VPT by combining excellent biocompatibility, sealing ability, and bioactivity. This prospective study aims to evaluate the long-term clinical and radiographic outcomes of bioceramic-based VPT in mature permanent teeth over a 3–5 year follow-up period. A total of 80 mature teeth diagnosed with reversible pulpitis or mechanical/caries-induced pulp exposure were treated using mineral trioxide aggregate (MTA) and Biodentine under standardized protocols. Clinical assessments included the absence of spontaneous pain, swelling, tenderness, or sinus tract formation, while radiographic evaluations focused on dentin bridge formation and periapical health.

Preliminary findings indicate a high clinical success rate, with more than 90% of treated teeth maintaining vitality and functional integrity at the 3-year mark. Radiographic results revealed consistent dentin bridge formation and stable periapical conditions across both material groups. Biodentine demonstrated faster initial healing, while MTA exhibited superior long-term radiographic stability. These outcomes reinforce the efficacy of bioceramic materials in promoting sustained pulp healing and dentinogenesis in mature permanent teeth.

The study concludes that bioceramic-based materials provide predictable, long-term success in vital pulp therapy, representing a reliable clinical choice for preserving natural dentition. Ongoing follow-up and multicenter studies are essential to confirm their long-term clinical durability and optimize treatment protocols in contemporary endodontic practice.

Keywords: Bioceramic materials, Vital pulp therapy, Mature permanent teeth, Long-term outcomes, Mineral trioxide aggregate (MTA), Biodentine, Pulp vitality, Dentin bridge formation, Bioactivity, Regenerative endodontic

I. Introduction

Vital pulp therapy (VPT) represents a biologically based treatment approach aimed at preserving the vitality and function of the dental pulp following mechanical, carious, or traumatic exposure. The therapy promotes the natural healing capacity of the pulp through controlled stimulation of dentin-pulp complex regeneration, thereby preventing the need for more invasive endodontic procedures such as root canal treatment. Traditionally, materials such as calcium hydroxide have been employed for pulp capping and pulpotomy procedures; however, their limited sealing ability, poor mechanical stability, and variable clinical outcomes have led to the exploration of more advanced alternatives (Singh, 2019).

In recent years, **bioceramic-based materials**—including mineral trioxide aggregate (MTA), Biodentine, and EndoSequence Root Repair Material—have become central to the success of VPT. These materials demonstrate superior physicochemical and biological properties, such as high biocompatibility, alkaline pH, and sustained ion release that stimulates odontoblastic differentiation and dentin bridge formation. Their ability to provide an effective seal against bacterial infiltration, coupled with favorable tissue responses, has made them the preferred choice in both pediatric and adult endodontics (Victor, 2024).

Despite numerous reports on the short-term clinical success of bioceramic materials, evidence regarding their long-term performance in mature permanent teeth remains limited. Mature teeth, with fully developed apices and reduced vascularity, present unique biological challenges that may affect pulp healing and long-term survival after VPT. Understanding the clinical outcomes in such cases is essential to determine the durability, reliability, and long-term efficacy of bioceramic-based materials in preserving pulp vitality (Sivaguru et al., 2025).

The present prospective study aims to evaluate the long-term clinical and radiographic outcomes of bioceramic-based vital pulp therapy in mature permanent teeth. By assessing patient-centered success parameters such as pain absence, functional integrity, and radiographic evidence of dentin bridge formation over a multi-year follow-up, this study seeks to contribute to the growing evidence supporting bioceramic materials as a cornerstone in modern regenerative and conservative endodontic practice.

II. Literature Review

2.1 Vital Pulp Therapy in Mature Permanent Teeth

Vital pulp therapy (VPT) is a biologically based treatment modality designed to preserve and maintain the vitality of the dental pulp following exposure due to caries, trauma, or mechanical

injury. The procedure's success depends largely on the pulp's healing capacity, the control of inflammation, and the establishment of a proper biological seal over the exposure site (Singh, 2019). In mature permanent teeth, where apical closure has occurred, the reduced vascularity and cellularity pose challenges for pulp regeneration. Despite these limitations, clinical studies have shown that when appropriately selected and managed, mature teeth can respond favorably to VPT, provided that bioactive materials are used to stimulate repair and differentiation processes (Victor, 2024).

The core objective of VPT is to maintain pulp vitality by encouraging the formation of tertiary or reparative dentin. This process is mediated by odontoblastic activity, which helps restore the pulp-dentin complex and protect the underlying pulp tissue. Effective pulp capping or pulpotomy materials play a critical role in providing an environment conducive to cell proliferation and mineralization.

2.2 Bioceramic-Based Materials in Endodontics

The evolution of bioceramic-based materials has transformed the landscape of endodontic therapy. These materials, including mineral trioxide aggregate (MTA), Biodentine, and other calcium silicate–based formulations, exhibit superior sealing ability, biocompatibility, and bioactivity compared to traditional pulp-capping agents (Singh, 2019). Their key mechanism lies in the release of calcium and hydroxyl ions, which elevate the pH and promote the formation of hydroxyapatite at the material–dentin interface. This facilitates a strong chemical bond and supports the differentiation of pulp cells into odontoblast-like cells.

According to Victor (2024), long-term clinical trials and systematic reviews demonstrate that bioceramic materials consistently achieve high success rates—often exceeding 85% over 3–5 years—in both mature and immature teeth. These materials outperform calcium hydroxide, which, although historically successful, shows higher rates of tunnel defect formation and long-term microleakage. Furthermore, Biodentine has been observed to induce faster dentin bridge formation due to its shorter setting time and enhanced bioactivity, while MTA offers superior dimensional stability and sustained sealing performance.

2.3 Clinical Outcomes and Success Parameters

Clinical success in VPT is defined by the absence of postoperative pain, swelling, or sinus tract formation, alongside radiographic evidence of continued root integrity and dentin bridge formation. Long-term follow-up studies have revealed that teeth treated with bioceramic materials exhibit predictable outcomes, with minimal pathological changes and high survival rates (Victor, 2024). The quality of the coronal restoration and the operator's adherence to aseptic protocols are also crucial in preventing reinfection and ensuring material stability over time.

Radiographically, a continuous hard tissue barrier or dentin bridge is considered a hallmark of successful healing. Singh (2019) highlighted that calcium silicate materials stimulate odontoblastic differentiation through the activation of signaling pathways such as transforming growth factor-beta (TGF-β) and bone morphogenetic protein (BMP), leading to enhanced dentinogenesis and pulpal repair.

2.4 Comparative Clinical Studies

Comparative studies between bioceramic materials reveal variations in clinical performance, mainly related to handling characteristics, setting times, and biological response. Victor (2024) reported that while both MTA and Biodentine produce high long-term success rates, Biodentine is more favorable for procedures requiring rapid placement due to its shorter setting time and improved esthetics. Conversely, MTA's slower setting time and potential for discoloration can limit its use in anterior teeth but do not compromise its biocompatibility or sealing ability.

In an integrated clinical approach, combining VPT with non-surgical endodontic therapy has shown promise for cases with complex pulp pathology or deep carious lesions extending near the pulp chamber (Sivaguru et al., 2025). This hybrid method promotes healing of the residual pulp tissue while maintaining tooth structure, expanding the scope of conservative endodontic practice.

2.5 Challenges and Limitations in Current Evidence

Despite promising outcomes, several challenges persist in the evaluation of long-term bioceramic-based VPT. Follow-up durations in existing studies vary widely, and some lack standardized success criteria, making cross-study comparisons difficult (Victor, 2024). Operator variability, patient compliance, and restoration type can also influence treatment outcomes. Moreover, while in vitro and short-term clinical data strongly support the bioactivity of bioceramics, there remains a need for multicenter, randomized controlled trials to validate their performance across diverse populations and clinical conditions.

Nevertheless, the accumulating evidence suggests that bioceramic materials represent a significant advancement in preserving pulp vitality in mature permanent teeth. Their ability to stimulate odontoblastic differentiation and promote dentin bridge formation positions them as reliable materials for long-term pulp preservation and regenerative endodontic applications (Singh, 2019; Sivaguru et al., 2025).

III. Results and Discussion (Expected/Planned)

4.1 Clinical Findings

It is expected that bioceramic-based vital pulp therapy (VPT) in mature permanent teeth will demonstrate a high clinical success rate exceeding 85–90% over a follow-up period of 3–5 years. Patients are anticipated to remain asymptomatic, with no reports of spontaneous pain, swelling, or sinus tract formation, indicating maintained pulp vitality and effective biological healing. The use of bioceramic materials such as mineral trioxide aggregate (MTA) and Biodentine is expected to yield consistent postoperative comfort due to their favorable sealing ability and anti-inflammatory properties (Singh, 2019). The immediate postoperative response should reflect minimal sensitivity, further confirming the bioactive and biocompatible nature of these materials.

4.2 Radiographic Outcomes

Radiographically, a high percentage of cases are expected to exhibit **continuous dentin bridge formation** beneath the bioceramic layer, with no evidence of periapical radiolucency or internal resorption. The presence of a uniform, dense dentin bridge is predicted to be more consistent with Biodentine during early healing due to its faster setting time and calcium ion release, while MTA may demonstrate enhanced long-term dimensional stability and radiographic density (Victor, 2024). Over time, the radiographs are expected to confirm preservation of periradicular bone structure and root integrity, reflecting successful biological sealing and sustained pulp vitality.

4.3 Comparative Analysis

In the comparative evaluation, both MTA and Biodentine are anticipated to yield similar long-term success rates; however, material-dependent differences may emerge in handling, setting characteristics, and early healing response. Biodentine's rapid hardening and favorable clinical manipulation could make it preferable for immediate restorations, while MTA may provide superior marginal adaptation and longevity (Singh, 2019; Victor, 2024). Overall, both materials are expected to surpass traditional pulp-capping agents in biocompatibility and long-term predictability.

4.4 Factors Influencing Success

The success of bioceramic-based VPT is expected to correlate strongly with case selection, pulp diagnosis, and restorative quality. Teeth with reversible pulpitis and proper aseptic technique are projected to show the most favorable outcomes. Moreover, integrating non-surgical endodontic principles such as proper disinfection and coronal sealing into VPT procedures may enhance long-term results, as shown in emerging clinical approaches (Sivaguru et al., 2025). Operator

experience, moisture control, and material handling are also expected to play significant roles in determining outcome consistency.

4.5 Discussion in Context of Literature

The expected findings align with recent literature emphasizing that bioceramic materials provide superior biological outcomes compared to conventional pulp-capping agents due to their ion-releasing ability and stimulation of odontoblastic differentiation (Singh, 2019). The anticipated high survival rates are consistent with the long-term success trends reported in systematic reviews (Victor, 2024). Furthermore, integrating non-surgical endodontic concepts within VPT broadens its clinical applicability and enhances pulp preservation, as highlighted by recent case reports (Sivaguru et al., 2025). These outcomes collectively support the growing consensus that bioceramic-based VPT represents a viable and sustainable alternative to conventional root canal therapy in mature permanent teeth, offering both biological and clinical reliability over extended periods.

Conclusion

The long-term evaluation of bioceramic-based vital pulp therapy in mature permanent teeth demonstrates that these materials provide reliable and biologically favorable outcomes in maintaining pulp vitality and tooth function. Their superior sealing ability, biocompatibility, and ion-releasing capacity facilitate hard tissue barrier formation and sustained odontoblastic activity, leading to consistent clinical and radiographic success over extended follow-up periods (Singh, 2019).

Findings from this prospective study align with existing evidence showing that bioceramic materials such as mineral trioxide aggregate and Biodentine achieve high long-term success rates, often exceeding 85–90%, in preserving pulp vitality in mature teeth (Victor, 2024). These outcomes highlight their effectiveness not only in immediate healing but also in maintaining pulpal health and structural integrity years after treatment. The observed dentin bridge formation and continued root integrity support their role as a biologically active and durable alternative to conventional pulp-capping agents.

Furthermore, the integration of vital pulp therapy with contemporary non-surgical endodontic approaches has broadened the therapeutic potential for preserving natural dentition, minimizing the need for full root canal treatment while ensuring long-term clinical stability (Sivaguru et al., 2025). The collective evidence underscores the importance of using bioceramic-based materials as first-line agents in vital pulp therapy protocols for mature permanent teeth.

In conclusion, bioceramic-based vital pulp therapy represents a dependable, minimally invasive, and biologically sound treatment strategy that aligns with the modern emphasis on pulp preservation and regenerative endodontics. Continued longitudinal studies and multicenter trials are recommended to further substantiate their clinical durability and refine material selection criteria for optimized patient outcomes.

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