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APEXIFICATION IN IMMATURE PERMANENT TEETH USING BIOACTIVE MATERIALS: A COMPARATIVE REVIEW OF MINERAL TRIOXIDE AGGREGATE AND BIODENTINE

Skurtu Marian[1],Doriana Agop Forna[2*], Paula Manole[2*], Vasilica Toma[2]

[1] UIC Barcelona International University of Catalonia

2Grigore T. Popa University of Medicine and Pharmacy Iasi, 16 Universitatii Str., 700115, Romania

Corresponding author: Doriana Agop Forna – drdorianaagopforna@gmail.com

Paula Manole - manole_paula@yahoo.com

Abstract

Apexification is an essential endodontic procedure for treating immature permanent teeth with pulp necrosis and open apex. Recent advances in bioactive calcium silicate-based materials have significantly improved treatment predictability and reduced clinical time compared with traditional calcium hydroxide techniques. **Objective:** To analyze the biological mechanisms, physico-chemical properties, and clinical outcomes of Mineral Trioxide Aggregate (MTA) and Biodentine in modern apexification procedures. **Methods:** A narrative review of recent literature (2021–2026) focusing on clinical studies, systematic reviews, and in vitro investigations evaluating the performance of MTA and Biodentine in apexification of immature permanent teeth. **Results:** Both materials demonstrate high clinical success rates exceeding 90%, promoting mineralized apical barrier formation and periapical healing. Biodentine shows advantages in handling properties, reduced setting time, and improved esthetic outcomes. **Conclusions:** MTA and Biodentine represent reliable biomaterials for apexification. Biodentine offers clinical advantages in single-visit protocols, while MTA remains extensively validated in long-term studies.

Keywords: apexification; immature teeth; Biodentine; Mineral Trioxide Aggregate; bioactive materials.

1. INTRODUCTION

Apexification represents a fundamental therapeutic procedure in modern endodontics, used for the treatment of immature permanent teeth with pulp necrosis and an open apex. The absence of a physiological apical constriction makes it impossible to achieve a predictable conventional obturation seal, increasing the risk of extrusion of filling materials into the periapical tissues and potentially compromising the long-term prognosis.

Dental trauma and complicated caries are the main causes of pulp necrosis in the young permanent dentition, most frequently affecting maxillary incisors in children and adolescents. Interruption of root development results in thin dentinal walls that are more susceptible to fracture, which complicates the therapeutic approach and necessitates the use of bioactive materials capable of promoting tissue regeneration.

The traditional apexification technique using calcium hydroxide required prolonged treatment periods, sometimes extending from 6 to 18 months, and has been associated with an increased risk of root fracture due to structural changes in dentin (1).

The introduction of calcium silicate-based bioceramic materials, such as Mineral Trioxide Aggregate (MTA) and Biodentine, has significantly improved the management of immature necrotic teeth. These materials exhibit high biocompatibility, superior sealing ability, and bioactive properties that stimulate cellular differentiation and mineralized tissue formation (2).

Recent literature highlights that modern apexification procedures can often be completed in a single clinical visit, reducing patient discomfort and minimizing the risk of root canal reinfection (3).

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2. BIOLOGICAL CHARACTERISTICS OF IMMATURE PERMANENT TEETH

Immature permanent teeth present distinct morphological characteristics compared with fully developed teeth, including thin radicular walls, a wide root canal lumen, and an open apical foramen. Incomplete root development results in a less mineralized dentinal structure and reduced mechanical strength, increasing susceptibility to fracture, particularly under functional or traumatic stress. In addition, the absence of a physiological apical constriction complicates working length control and the achievement of a three-dimensional hermetic obturation, increasing the risk of extrusion of filling materials into the periapical tissues (4).

When pulp vitality is lost before completion of root development, the processes of dentin and cementum formation are interrupted, leaving the canal walls thin and structurally fragile. This clinical situation represents a significant therapeutic challenge, as the insufficiently matured root structure does not provide adequate biomechanical support for long-term functional restoration. Moreover, the wide root canal space facilitates bacterial contamination and may compromise proper sealing in the absence of an artificial apical barrier (4).

The periapical tissues associated with immature teeth exhibit a high biological potential due to the presence of mesenchymal stem cells capable of differentiating into cementoblasts, osteoblasts, and odontoblast-like cells. These cells play a crucial role in tissue repair and regeneration when stimulated by appropriate biological conditions. Modern calcium silicate-based bioactive materials take advantage of this regenerative potential through the release of calcium ions (Ca^{2+}) and the maintenance of an alkaline environment, which promotes the expression of factors involved in mineralization and cellular differentiation. The alkaline pH also contributes to reducing the bacterial load and creates a microenvironment favorable to periapical tissue healing (5).

The interaction between bioceramic materials and radicular dentin leads to the formation of an interfacial layer rich in hydroxyapatite, which contributes to improved sealing ability and mechanical stability of the root canal filling. This biochemical process is considered essential for the long-term success of apexification, as it promotes integration of the material within the dental structure and reduces the risk of bacterial microleakage (5).

Histological studies have demonstrated that the use of materials such as MTA and Biodentine induces the formation of a mineralized apical barrier composed of hard tissue similar to cellular cementum. This barrier exhibits an organized structure and allows the achievement of an effective apical seal, supporting the healing of periapical lesions. The formation of such mineralized tissue confirms the ability of bioceramic materials to promote biological regeneration and support natural tissue repair processes (6).

Therefore, the biological characteristics of immature permanent teeth justify the use of bioactive materials in apexification, as these materials not only provide mechanical closure of the open apex but also stimulate biological processes involved in periapical tissue regeneration and reinforcement of the radicular structure.

3. PRINCIPLES OF MODERN APEXIFICATION

Modern apexification represents a predictable and effective therapeutic approach for the management of immature permanent teeth with pulp necrosis, based on the use of bioactive bioceramic materials capable of inducing the formation of a stable mineralized apical barrier. The procedure involves the placement of an apical plug with a thickness of approximately 3–5 mm in the apical portion

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of the root canal, using calcium silicate–based materials such as Mineral Trioxide Aggregate (MTA) or Biodentine. This artificial apical barrier provides both mechanical support and biological stimulation, allowing proper three-dimensional obturation of the root canal system with gutta-percha and endodontic sealer. The presence of the apical plug prevents extrusion of filling materials into the periapical tissues and ensures an adequate long-term seal.

Compared with the traditional calcium hydroxide apexification technique, which required multiple dressing changes over extended periods of time, modern apexification significantly reduces treatment duration. In many cases, the procedure can be completed in a single clinical visit. Shortening the treatment time decreases the risk of bacterial contamination of the root canal between appointments and improves patient compliance, an aspect particularly important in children and adolescents. Furthermore, avoiding the long-term use of calcium hydroxide reduces the risk of structural alterations in dentin, which may weaken radicular walls and increase susceptibility to fracture (7).

Bioceramic materials used in apexification exhibit important bioactive properties, including the release of calcium ions and the creation of an alkaline environment that promotes mineralization and tissue regeneration. The interaction between these materials and radicular dentin leads to the formation of an interfacial hydroxyapatite layer, which improves marginal adaptation and contributes to the long-term stability of the root canal filling. Consequently, apical sealing is superior compared with traditional methods, reducing the risk of bacterial microleakage and reinfection of the root canal system.

Another important advantage of modern apexification is the reduction in the number of clinical visits, which decreases patient discomfort and optimizes clinical management, especially in pediatric dentistry. The creation of a stable artificial apical barrier allows immediate obturation of the root canal and functional restoration of the tooth within a shorter treatment period, contributing to preservation of dental structure and prevention of further complications (7).

Clinical success of apexification is assessed using a combination of clinical and radiological criteria, including absence of pain, lack of signs of inflammation or infection, and healing or significant reduction of periapical lesions. Radiographic evaluation demonstrates the formation of a mineralized apical barrier, confirming treatment stability and the effectiveness of the material used. Periodic follow-up is essential for monitoring the healing process and confirming long-term therapeutic success (8).

Therefore, modern apexification based on bioactive bioceramic materials represents a safe and effective therapeutic method, allowing the formation of a stable apical barrier in a relatively short period of time and significantly improving the prognosis of immature permanent teeth with pulp necrosis, while preserving the structural integrity of the tooth over the long term.

4. MINERAL TRIOXIDE AGGREGATE (MTA)

Mineral Trioxide Aggregate (MTA) is considered the reference material in apexification procedures due to its well-documented biological, physico-chemical, and clinical properties, supported by numerous experimental and long-term clinical studies. The introduction of MTA into endodontic practice represented a significant advancement in the management of immature permanent teeth with pulp necrosis, as this material exhibits high biocompatibility, superior sealing ability, and bioactive characteristics that promote tissue repair and regeneration processes.

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MTA is mainly composed of tricalcium silicate, dicalcium silicate, and tricalcium aluminate, with the addition of bismuth oxide, which provides radiopacity and allows radiographic assessment of the position and adaptation of the apical plug after placement.

When in contact with tissue fluids, MTA undergoes a hydration reaction that leads to the formation of a calcium silicate hydrate gel and the release of calcium hydroxide. This reaction results in an increase in the local pH, creating an alkaline environment that is favorable for cellular proliferation and inhibition of bacterial growth. The alkaline pH contributes to the activation of biological mechanisms involved in osteogenesis and cementogenesis, stimulating the expression of proteins associated with cellular differentiation and mineralized tissue formation. Consequently, MTA functions not only as a filling material but also as a biologically active mediator capable of inducing the formation of a stable mineralized apical barrier resembling cellular cementum, which explains the high clinical success rates reported in the literature (9).

Another important advantage of MTA is its ability to form an interfacial hydroxyapatite layer at the contact surface with radicular dentin. This phenomenon contributes to improved marginal sealing and reduces the risk of bacterial microleakage. Good adaptation to the root canal walls and dimensional stability after setting allow the formation of an effective apical seal, which is essential for preventing reinfection of the root canal system and maintaining long-term therapeutic success.

However, the clinical use of MTA also presents certain limitations. The relatively long setting time may prolong the clinical procedure and requires protection of the material from oral fluids before complete hardening occurs. Handling characteristics may sometimes be challenging due to its consistency, which can influence the precision of apical plug placement. In addition, the presence of bismuth oxide in the composition of MTA may lead to discoloration of dental tissues, particularly in the anterior region, potentially affecting the esthetic outcome of the final restoration. This discoloration potential represents one of the main disadvantages of MTA when used in anterior teeth, where esthetic demands are higher (10).

Despite these limitations, MTA remains one of the most extensively studied and widely used materials for apexification, due to its ability to induce the formation of a stable mineralized apical barrier and to ensure a favorable long-term prognosis.

5. BIODENTINE

Biodentine is a newer-generation bioceramic material developed to overcome some of the limitations associated with the use of Mineral Trioxide Aggregate (MTA), particularly regarding handling characteristics and setting time. This calcium silicate–based cement exhibits bioactive properties comparable to those of MTA, while offering additional clinical advantages that facilitate its use in apexification procedures, especially in situations where treatment needs to be completed within a shorter period of time.

The composition of Biodentine includes tricalcium silicate, calcium carbonate, and zirconium oxide, which provides radiopacity and allows radiographic assessment of the adaptation of the apical plug. The presence of specific additives in its formulation improves handling properties and significantly reduces the setting time to approximately 12 minutes, enabling apexification to be performed in a single clinical visit. This characteristic represents an important advantage in clinical practice, as it decreases the risk of bacterial contamination of the root canal between appointments and improves patient comfort, particularly in pediatric patients (11).

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Biodentine demonstrates high bioactivity, being capable of releasing calcium ions that stimulate differentiation of mesenchymal stem cells and promote the formation of an interfacial hydroxyapatite layer at the interface with radicular dentin. This interaction contributes to improved marginal sealing and reduces bacterial microleakage, ensuring long-term stability of the treatment. Experimental studies have shown that Biodentine exhibits excellent marginal adaptation, facilitating the formation of an effective apical seal and reducing the risk of treatment failure.

The mechanical properties of Biodentine are comparable to those of natural dentin after maturation of the material, contributing to reinforcement of the fragile radicular structure characteristic of immature teeth. Adequate mechanical resistance is essential for preventing root fractures and maintaining the structural integrity of the tooth over time (12).

Another important advantage of Biodentine is its color stability, as the material presents a reduced risk of tooth discoloration compared with MTA. This aspect is particularly relevant in the treatment of anterior teeth, where the esthetic outcome plays an important role in patient satisfaction and in the overall success of the final restoration.

Therefore, Biodentine represents a modern and effective alternative to MTA, providing similar biological properties while offering advantages related to handling characteristics, shorter setting time, and improved esthetic performance. These features contribute to achieving more stable and reproducible clinical outcomes.

6. DISCUSSION

The results of studies published in recent years confirm that both Mineral Trioxide Aggregate (MTA) and Biodentine provide predictable outcomes in apexification procedures, being associated with high clinical and radiological success rates. Both bioceramic materials demonstrate the ability to induce the formation of a stable mineralized apical barrier and to promote healing of periapical tissues, contributing to preservation of radicular structural integrity and prevention of root canal reinfection. The bioactivity of calcium silicate–based cements is related to the release of calcium ions and the creation of an alkaline environment that supports cellular differentiation and mineralized tissue formation, mechanisms that are essential for achieving a favorable long-term prognosis.

Recent meta-analyses evaluating the clinical performance of bioceramic materials used in apexification have shown no statistically significant differences between MTA and Biodentine in terms of periapical healing, formation of the apical barrier, or overall treatment success rates. Comparative analysis of available clinical studies indicates that both materials provide adequate sealing ability and stimulate biological processes involved in periapical tissue regeneration, confirming their therapeutic effectiveness in the management of immature permanent teeth with pulp necrosis (13).

However, certain clinical differences may become relevant depending on the therapeutic context, particularly in pediatric dentistry, where patient compliance plays an essential role in treatment success. Reducing the number of clinical visits and shortening treatment duration are important factors in minimizing patient anxiety and improving cooperation throughout the procedure. In this regard, Biodentine presents a clinical advantage due to its reduced setting time, which allows apexification to be completed in a single visit, decreasing the risk of bacterial contamination of the root canal between appointments and optimizing therapeutic management.

Another relevant aspect in material selection is esthetic performance, especially in anterior teeth, where discoloration may influence the final restorative outcome.

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Recent studies have shown that MTA may present discoloration potential due to the presence of bismuth oxide in its composition, which can negatively affect esthetic results, particularly in young patients. Biodentine demonstrates superior color stability and a lower risk of tooth discoloration, making it more suitable in clinical situations where esthetics represent an important consideration in treatment planning (14).

Furthermore, the easier handling properties of Biodentine contribute to reducing the risk of operator-related errors and allow more precise placement of the material at the apical level. Its homogeneous consistency and controlled setting time facilitate adaptation to the root canal walls, which may improve marginal sealing and stability of the apical plug. These characteristics may have a positive influence on the predictability of the procedure and on long-term therapeutic success.

Overall, recent literature supports the conclusion that both MTA and Biodentine represent effective materials for apexification. The choice between the two materials is more often influenced by specific clinical considerations, such as treatment duration, handling characteristics, and esthetic requirements, rather than by significant differences in biological effectiveness.

7. LIMITATIONS

Current limitations of the available literature include heterogeneity of clinical protocols, relatively small sample sizes, and limited follow-up periods. Most studies evaluate treatment outcomes over observation intervals of 12–24 months, while data regarding long-term stability are still insufficient. Differences in treatment protocols, variations in apical plug thickness, and the use of different obturation techniques may influence the comparability of results reported in the literature.

Standardization of clinical procedures, application techniques, and evaluation criteria is necessary in order to allow direct comparisons between materials and to improve the quality of evidence. Future well-designed randomized clinical studies with longer follow-up periods are required to provide more robust data regarding the long-term performance of bioceramic materials used in apexification.

8. CONCLUSIONS

Bioactive calcium silicate–based materials have significantly improved the prognosis of apexification in immature permanent teeth with pulp necrosis. Both Mineral Trioxide Aggregate (MTA) and Biodentine provide predictable clinical outcomes and promote the formation of a stable mineralized apical barrier, contributing to periapical healing and preservation of radicular structure.

Biodentine offers several clinical advantages related to handling properties, shorter setting time, and improved esthetic performance, making it a preferable option in certain clinical situations, particularly when reduced treatment duration and optimal esthetic outcomes are desired.

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