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Review

Clinical Applications of Mineral Trioxide Aggregate in Dental Procedures

Waleed Khalid Alshargawi[1], Abeer Abdulaziz Alomari[2], Ali Obaid Alharbi[3], Sliman Mohamad Alhowimel[4], Muhannad Waleed Alawbthani[5], Lujain Qassim Alasiri[6], Ahmed Abdulrahman Alreshaid[7]

[1] *Department of Endodontics, Al Thager Hospital, Jeddah, Saudi Arabia*
[2] *Dental Department, Al Thager Hospital, Jeddah, Saudi Arabia*
[3] *Department of Endodontics, Qassim Regional Dental Center, Qassim, Saudi Arabia*
[4] *Dental Department, Afif General Hospital, Riyadh, Saudi Arabia*
[5] *College of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia*
[6] *College of Dentistry, King Khalid University, Abha, Saudi Arabia*
[7] *College of Dentistry, Qassim University, Riyadh, Saudi Arabia*

Correspondence should be addressed to **Waleed Khalid Alshargawi**, Department of Endodontics, Al Thager Hospital, Jeddah, Saudi Arabia. Email: waldosh55@hotmail.com

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Abstract

Mineral Trioxide Aggregate (MTA) is a widely utilized material in modern dentistry, known for its exceptional biocompatibility, bioactivity, and versatility. Initially developed for root-end filling, its applications have expanded to include pulp therapy, root canal sealing, perforation repair, and regenerative endodontics. MTA's bioactivity is attributed to its ability to release calcium ions upon hydration, promoting hydroxyapatite formation and creating an environment conducive to tissue regeneration. These properties, coupled with its excellent sealing ability and antibacterial activity, make it a reliable choice for challenging clinical scenarios. In pulp therapy, MTA has demonstrated superior outcomes in direct pulp capping and apexogenesis, ensuring the preservation of pulp vitality and promoting dentinal bridge formation. Its role in root canal sealing and repair is equally significant, with studies confirming its effectiveness in achieving a tight seal and minimizing bacterial infiltration. MTA's bioactive and biocompatible nature also enhances its success in repairing perforations and managing resorptive defects, where it supports the regeneration of surrounding tissues and stabilizes the tooth structure. In regenerative endodontics, MTA plays a pivotal role in pulp revitalization and the treatment of necrotic immature teeth. Its ability to foster revascularization and support tissue growth bridges traditional endodontics and tissue engineering. Despite its advantages, challenges such as prolonged setting time, handling difficulties, and cost remain. However, advancements in formulation and technique have mitigated these limitations, expanding its clinical utility. The effectiveness of MTA across diverse applications underscores its significance in advancing dental care. Its unique properties not only improve treatment outcomes but also offer innovative solutions for preserving natural dentition. As research continues to refine its applications and address existing limitations, MTA is poised to remain a cornerstone material in modern dentistry.

Keywords: *Mineral Trioxide Aggregate, bioactivity, pulp therapy, regenerative endodontics, perforation repair*

Introduction

Mineral Trioxide Aggregate (MTA) has been a transformative material in modern dentistry since its development in the 1990s. Initially designed as a root-end filling material, MTA quickly gained widespread recognition for its superior properties, including exceptional biocompatibility, sealing ability, and versatility in various dental procedures. Its primary composition, derived from Portland cement with bismuth oxide for radiopacity, offers a unique combination of bioactivity and antibacterial effects, making it a critical material in endodontics and restorative dentistry (1). Over the years, MTA has been utilized in challenging clinical situations, where its reliability and effectiveness have set it apart.

One of MTA's most notable features is its ability to form a bond with dentin while promoting tissue regeneration. In the presence of physiological fluids, MTA undergoes a hydration reaction, forming calcium hydroxide, which then reacts to produce hydroxyapatite. This process not only ensures an excellent seal but also fosters an environment conducive to dentinogenesis and periapical healing (2). Its alkaline pH further contributes to its antibacterial properties, which are particularly valuable in addressing infections during pulp therapy, root resorption, and apexification. This bioactive behavior positions MTA as an ideal choice for regenerative endodontics, a field gaining momentum for its potential to restore dental function and aesthetics (3). The clinical applications of MTA span pulp capping, perforation repairs, apexification, and even regenerative procedures like revitalization of immature teeth with necrotic pulps. Studies have demonstrated its efficacy in pulp therapy, where it consistently outperforms traditional materials in maintaining pulp vitality and long-term outcomes. Its ability to form a hermetic seal and resist microleakage has significantly improved success rates in root canal and retrograde filling procedures. Furthermore, MTA has shown promising results in managing iatrogenic perforations, where its biocompatibility and sealing properties help preserve the integrity of the tooth structure (4).

Despite its many advantages, MTA is not without limitations. Prolonged setting time, tooth discoloration (in its original gray formulation), and handling challenges have been frequently cited concerns. Additionally, the cost of the material can be a barrier, particularly in regions with limited healthcare resources. However, innovations in its formulation, such as the development of white MTA and accelerated setting techniques, have mitigated many of these issues and continue to expand its clinical applications. This review explores the wide-ranging applications of MTA in dental procedures, with a focus on its role in pulp therapy, root canal repair, perforation management, and regenerative endodontics.

Review

MTA has become a cornerstone material in various dental applications due to its bioactive properties, biocompatibility, and sealing ability. Its role in pulp therapy is particularly significant, where it serves as an effective agent for direct pulp capping, promoting pulp vitality and forming a dentin bridge that enhances long-term treatment outcomes. MTA's bioactivity, which enables the release of calcium ions, facilitates hydroxyapatite formation, creating a favorable environment for tissue regeneration and reducing inflammation. These properties have solidified its position as a reliable material for preserving pulp health in restorative and endodontic procedures (5). In root canal therapy, MTA is invaluable for its superior sealing properties, which minimize microleakage and prevent bacterial reinfection. Its use in apexification and root perforation repairs demonstrates remarkable clinical success rates, even in cases of severe structural compromise. Studies have highlighted its ability to promote periapical healing, further demonstrating its effectiveness in challenging clinical situations. Despite its advantages, practical limitations, such as its extended setting time and high cost, remain challenges that can affect its clinical utility (6). However, advancements in formulation and application techniques are addressing these issues, ensuring MTA continues to evolve as an essential material in modern dentistry.

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Role of Mineral Trioxide Aggregate in Pulp Therapy

MTA has emerged as a game-changer in pulp therapy, offering unparalleled advantages in maintaining pulp vitality and ensuring successful outcomes in restorative procedures. Its unique bioactive properties enable it to interact with biological tissues, fostering the regeneration of dentin and minimizing the inflammatory response. The material's ability to form a hard barrier and its superior sealing properties make it an indispensable component in direct and indirect pulp capping and pulpotomies (7). The primary mechanism underlying MTA's success in pulp therapy is its interaction with tissue fluids, leading to the formation of calcium hydroxide. This reaction not only creates a protective layer against bacterial penetration but also stimulates the release of growth factors from dentin, promoting dentin bridge formation. Unlike calcium hydroxide, which has traditionally been used in pulp therapy, MTA exhibits enhanced stability and longevity, reducing the chances of failure due to material degradation. The ability of MTA to maintain an alkaline pH over time also contributes to its antibacterial properties, effectively reducing the microbial load in the treated area (8).

Clinical studies have consistently demonstrated the efficacy of MTA in direct pulp capping procedures, where its application results in higher success rates compared to traditional materials. For instance, in teeth with exposed pulps due to trauma or carious lesions, MTA not only ensures proper sealing but also supports the natural healing of the pulp tissue. A randomized clinical trial evaluating MTA and calcium hydroxide in direct pulp capping found MTA to be superior in terms of long-term pulp vitality and absence of radiographic pathology (9). This makes it a preferred material in situations where the preservation of the pulp is critical for maintaining the structural and functional integrity of the tooth. In pediatric dentistry, MTA has gained significant traction for use in pulpotomies, particularly in primary teeth. The material's biocompatibility minimizes adverse reactions, while its ability to form a durable seal prevents microbial reinfection. The high clinical success rates of MTA pulpotomies are attributed to its capacity to induce a reparative dentin layer, safeguarding the remaining pulp tissue. A comparative study involving MTA and formocresol as pulpotomy agents revealed that MTA showed superior results, with a higher percentage of teeth remaining symptom-free and radiographically normal over extended follow-up periods (10).

However, despite its effectiveness, certain challenges limit the widespread adoption of MTA in pulp therapy. These include its high cost, which may not be feasible in low-resource settings, and its prolonged setting time, which can complicate treatment in busy clinical practices. The aesthetic concerns associated with discoloration in its gray formulation have been largely mitigated with the introduction of white MTA, though the latter may still pose a risk of marginal discoloration in anterior teeth. Continued research into improving the material's handling properties and reducing costs will likely expand its accessibility and usage across diverse clinical settings.

Applications in Root Canal Sealing and Repair

The success of root canal treatment heavily relies on achieving a hermetic seal to prevent microbial ingress and ensure long-term clinical outcomes. MTA has emerged as an ideal material for root canal sealing and repair due to its exceptional sealing ability, biocompatibility, and bioactivity. These properties have positioned MTA as a preferred material in cases requiring root-end filling, apexification, and management of perforations and resorption defects (11). One of the defining features of MTA is its superior sealing capacity, attributed to its ability to expand slightly upon setting, thereby filling voids and irregularities within the root canal system. This sealing capability is especially beneficial in root-end filling procedures, where it is crucial to create a barrier against apical microleakage. Studies comparing MTA with traditional materials like amalgam and intermediate restorative material have consistently demonstrated MTA's superior performance. For instance, an in vitro study assessing the apical seal of various materials reported that MTA exhibited significantly

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lower leakage rates, highlighting its effectiveness in maintaining a tight seal even under challenging conditions (12).

MTA's role in apexification, particularly in immature teeth with open apices, has been transformative. Its bioactivity promotes the formation of a hard tissue barrier, enabling the preservation of the natural tooth structure while facilitating endodontic treatment. Unlike calcium hydroxide, which requires multiple visits and extended treatment times, MTA allows for single-visit apexification, significantly reducing patient discomfort and treatment duration. Clinical trials have confirmed its efficacy, showing predictable outcomes with hard tissue formation at the apex in the majority of cases. Additionally, its ability to resist resorption ensures the stability of the repair over time (13). Perforation repair is another area where MTA has demonstrated remarkable success. Iatrogenic or pathological perforations pose significant challenges in endodontic practice, as they compromise the integrity of the tooth and increase the risk of treatment failure. MTA's biocompatibility and sealing properties make it an excellent choice for repairing perforations, even in complex cases involving furcations or lateral canals. The material's alkaline pH and antibacterial properties contribute to reducing inflammation and promoting healing in the surrounding tissues. Case reports and clinical studies have highlighted its effectiveness, with high success rates reported for perforation repairs using MTA, particularly when the material is applied directly to the defect under controlled conditions (14).

The use of MTA in resorption management further underscores its versatility. In cases of external or internal root resorption, MTA provides a reliable option for sealing resorptive defects while promoting periapical healing. Its ability to form a stable bond with dentin and resist degradation ensures the longevity of the repair. Experimental studies have shown that MTA not only halts the resorptive process but also facilitates the regeneration of periodontal ligament and cementum, emphasizing its role as a bioactive material in endodontic repair (15). While MTA's advantages in root canal sealing and repair are well-documented, practical challenges such as handling difficulties and cost remain pertinent. However, continuous advancements in material formulations, such as fast-setting MTA and pre-mixed versions, are addressing these limitations and making the material more accessible for routine clinical use. By offering unparalleled biocompatibility, sealing properties, and bioactivity, MTA has redefined the standards of care in root canal treatment and repair procedures.

Use of MTA in Perforation Management

Perforations are among the most challenging complications in endodontic practice, often compromising the prognosis of the affected tooth. The introduction of MTA has provided an effective solution for managing such defects, primarily due to its biocompatibility, bioactivity, and exceptional sealing properties. MTA has become the material of choice for repairing iatrogenic or pathological perforations, even in complex anatomical locations like furcations and lateral canals (16).

One of the most critical factors in perforation management is achieving a reliable seal to prevent bacterial contamination and subsequent treatment failure. MTA excels in this regard because of its ability to adapt to irregularities in the perforation site and form a tight, hermetic seal. This sealing property is enhanced by MTA's capacity to expand slightly upon setting, effectively closing gaps and minimizing microleakage. Studies comparing various materials for perforation repair consistently demonstrate that MTA outperforms alternatives like amalgam, glass ionomer, and composite resins in maintaining a bacterial-tight seal (17). The bioactivity of MTA is another crucial attribute that supports its application in perforation management. When MTA comes into contact with tissue fluids, it releases calcium ions that promote the formation of hydroxyapatite. This bioactivity fosters the regeneration of surrounding hard tissues, such as cementum, and encourages periodontal ligament reattachment. This property is particularly valuable in cases of furcation perforations, where the regeneration of the supporting structures is critical for tooth stability and function. Clinical evaluations

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have shown high success rates for MTA in repairing furcation perforations, with minimal inflammatory response and radiographic evidence of healing (18).

Beyond its sealing and bioactive properties, MTA's alkaline pH contributes to its effectiveness in perforation management. The alkaline environment created by MTA application inhibits microbial growth and neutralizes endotoxins, reducing the risk of persistent inflammation at the perforation site. This characteristic is particularly beneficial in cases involving chronic infections or large perforations with extensive tissue damage. Experimental models have demonstrated that MTA can significantly reduce bacterial counts in the perforation area while maintaining its structural integrity, even under challenging conditions (19). The handling properties of MTA, however, present certain challenges during perforation repair. The material's prolonged setting time can complicate clinical procedures, especially in cases requiring immediate stabilization of the perforation site. Advances in MTA formulations, such as the development of fast-setting variants, have addressed this limitation to some extent, improving the efficiency of the repair process. Another practical concern is the potential for discoloration, particularly with gray MTA. Although white MTA has mitigated this issue, care must be taken to minimize discoloration risks in anterior teeth or other aesthetically sensitive areas (20).

Despite these challenges, the clinical success of MTA in perforation management is well-documented. Long-term studies and case reports highlight its ability to preserve the structural and functional integrity of teeth with perforations, even in cases previously deemed unsalvageable. Its unique combination of sealing ability, biocompatibility, and bioactivity makes it an indispensable material for endodontic repairs involving perforations, ensuring predictable and favorable outcomes.

Effectiveness of MTA in Regenerative Endodontics

Regenerative endodontics represents a paradigm shift in dental treatment, focusing on the restoration of biological function in non-vital or immature teeth. MTA has emerged as a cornerstone in this field, playing a pivotal role in procedures such as pulp revitalization, apexogenesis, and the treatment of immature teeth with necrotic pulps. Its bioactive properties, biocompatibility, and ability to induce tissue regeneration have made it an indispensable material in modern regenerative endodontics (21).

The bioactivity of MTA enables it to interact with periapical tissues and stimulate the release of bioactive molecules, creating an environment conducive to healing and tissue regeneration. When placed in contact with tissue fluids, MTA releases calcium ions, which react with phosphate ions to form hydroxyapatite. This hydroxyapatite layer not only seals the treated area but also promotes the proliferation and differentiation of stem cells into odontoblast-like cells, facilitating the formation of dentin and pulp tissue. This property has been leveraged extensively in pulp revitalization procedures, where MTA provides a biological scaffold to support cell growth and tissue repair (22).

One of the most significant applications of MTA in regenerative endodontics is in apexogenesis, where it is used to preserve the vitality of the pulp and enable continued root development in immature teeth. Its sealing ability ensures that the pulp is protected from microbial infiltration, while its bioactive properties promote the deposition of dentinal bridge material. Clinical studies comparing MTA with calcium hydroxide in apexogenesis consistently report better outcomes with MTA, including thicker dentinal bridges and fewer instances of pulp necrosis. These findings underline MTA's role in ensuring the structural and functional integrity of the tooth over time (23).

MTA has also been instrumental in regenerative procedures for necrotic immature teeth, a scenario where traditional root canal therapy often fails to achieve favorable outcomes. By creating a tight seal at the apex and fostering a bioactive environment, MTA supports the revascularization of the pulp space and encourages the ingrowth of new tissues. Case series and clinical trials have documented the

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successful regeneration of pulp-like tissues in immature teeth treated with MTA as part of a regenerative protocol. The material's role in these procedures highlights its ability to bridge the gap between endodontics and tissue engineering, offering predictable and biologically driven outcomes (24).

Despite its effectiveness, certain limitations must be addressed when using MTA in regenerative endodontics. The material's prolonged setting time can be a drawback in procedures requiring immediate stabilization. Innovations such as fast-setting formulations have mitigated this issue to some extent, improving the ease of use in clinical practice. Additionally, while MTA is generally well-tolerated by periapical tissues, its alkaline nature can cause mild irritation in some cases. Proper handling techniques and careful placement are essential to minimize these effects and ensure optimal outcomes (25). The success of MTA in regenerative endodontics is a testament to its versatility and bioactivity, making it a cornerstone material in procedures aimed at restoring both the form and function of natural teeth. As research continues to expand our understanding of the material's properties and applications, MTA's role in regenerative endodontics is expected to grow even further.

Conclusion

MTA has proven to be a transformative material in modern dentistry, offering unparalleled bioactivity, biocompatibility, and versatility across various clinical applications. From pulp therapy to regenerative endodontics, MTA's ability to seal, promote healing, and support tissue regeneration has established it as a gold standard in dental care. Despite minor limitations such as cost and handling challenges, ongoing advancements continue to enhance its usability and accessibility. MTA remains a cornerstone in achieving predictable, long-term success in complex endodontic and restorative procedures.

Disclosure

Conflict of interest

There is no conflict of interest.

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Ethical Consideration

Not applicable.

Data Availability

Data that supports the findings of this study are embedded within the manuscript.

Author Contribution

The authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

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