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Progress in Comparative Studies on the Efficacy of Different Calcium Silicate-Based Materials in the Apical Barrier Technique

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Abstract

This study systematically reviews the progress of comparative studies on the clinical efficacy, physicochemical properties, and handling performance of different calcium silicate-based bioceramic materials, such as mineral trioxide aggregate (MTA), iRoot BP Plus, and Biodentine, in the apical barrier technique, in order to provide a basis for clinical material selection. By retrieving relevant literature from China and other countries, this study summarizes and compares calcium silicate-based materials in terms of material composition, setting characteristics, marginal sealing ability, biocompatibility, antibacterial activity, handling convenience, and long-term efficacy. Existing studies show that MTA and several new calcium silicate-based materials can achieve relatively high clinical success rates in the apical barrier technique, mostly around 90%. Among them, iRoot BP Plus and Biodentine have certain advantages in operation time, setting speed, and tooth discoloration, but differences from MTA still exist in sealing ability, fracture resistance, and other aspects. Different calcium silicate-based materials have their own characteristics in the apical barrier technique. Clinical selection should comprehensively consider the condition of the affected tooth, the operating environment, and the expected restorative method. In the future, more high-quality comparative studies with long-term follow-up are still needed to optimize material application strategies.

Keywords

calcium silicate-based materials, apical barrier technique, MTA, iRoot BP Plus, Biodentine

1. Introduction

The apical barrier technique (ABT) is a key technique for treating teeth with open apices or apical resorption. It aims to establish a physical barrier in the apical region to seal the root canal system, prevent infection of periapical tissues, and provide support for subsequent root canal filling [1]. Traditional barrier materials, such as calcium hydroxide and MTA, have achieved certain therapeutic effects, but they also have shortcomings, including long setting time, easy discoloration, and limited biocompatibility [2-3].

In recent years, bioceramic materials with calcium silicate as the main component, such as MTA, Biodentine, and iRoot BP Plus, have been increasingly used in the apical barrier technique. These materials not only have excellent sealing ability, biocompatibility, and osteogenic induction ability, but also show faster setting speed and better antibacterial performance than traditional materials [4-5]. However, different silicate-

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based materials have significant differences in physicochemical properties, handling performance, and clinical efficacy, and systematic comparative studies are currently lacking. Therefore, this study aims to review the progress of comparative studies on the efficacy of different silicate-based materials in the apical barrier technique and analyze their advantages and disadvantages. In view of this, this study intends to review the progress of comparative studies on the efficacy of different calcium silicate-based materials in the apical barrier technique, with emphasis on analyzing their physicochemical characteristics, biological performance, and advantages and disadvantages in clinical application, so as to provide reference for clinical material selection and subsequent research.

2. Analysis of the Characteristics of Different Calcium Silicate-Based Materials

2.1 Physicochemical and Setting Characteristics

Calcium silicate-based materials use tricalcium silicate and dicalcium silicate as the main active components [6]. The setting time of MTA is approximately 160-180 min. Its sealing stability and compressive strength are excellent, and a moist environment has little influence on its performance. However, because it contains bismuth oxide as a radiopacifier, it can easily cause cervical tooth discoloration [7-8].

iRoot BP Plus is a premixed nano-bioceramic material with a setting time of approximately 45 min and a shorter working window. It uses zirconium oxide and tantalum oxide as radiopacifiers and basically does not cause tooth discoloration. Its Vickers hardness is lower than that of MTA, and when the thickness is ≤6 mm, a moist environment does not affect its surface microhardness [9-10].

Biodentine is a modified calcium silicate cement. Its initial setting time is approximately 12-20 min, and it can reach clinical operating strength at 45 min. Its mechanical properties are close to those of natural dentin, with small setting shrinkage and good marginal adaptation. However, complete setting and strength stability still require several hours, and time needs to be planned reasonably for clinical single-visit treatment [11-12].

2.2 Biological and Antibacterial Characteristics

MTA, iRoot BP Plus, and Biodentine all have good bioactivity and biocompatibility. They can induce dentin bridge and apical cementum formation and promote the adhesion and proliferation of stem cells from the apical papilla and periodontal ligament cells [6,13]. Among them, MTA has the most sufficient evidence for biocompatibility and the longest history of clinical application [7]. iRoot BP Plus does not contain aluminum, has lower cytotoxicity, and is more suitable for young permanent teeth and pulp regeneration treatment [9]. Biodentine is called a “dentin substitute” and has good bone-bonding ability and soft-tissue compatibility [11]. Biodentine is called a “dentin substitute” because of its mechanical and biological characteristics, and it has good compatibility with both bone tissue and soft tissue.

In terms of antibacterial activity, all three materials exert antibacterial effects through high pH values and are effective against common root canal pathogens such as Enterococcus faecalis and Staphylococcus aureus. The iRoot series has inhibitory effects on both planktonic bacteria and biofilms. Biodentine can improve antibacterial ability by adding antibacterial components without impairing physicochemical properties. MTA has stable antibacterial effects, but its onset is relatively slow and depends on complete setting and maintenance of a high-pH environment [13].

2.3 Handling and Application Characteristics

MTA is mixed from powder and liquid. It easily aggregates into clumps, is relatively difficult to deliver and compact, requires a high level of operator experience, sets slowly, and often requires two visits to complete the apical barrier and root canal filling [7,12].

iRoot BP Plus is a premixed injectable material. It can be delivered directly and is easy to compact. The operation time is shortened by approximately 50% compared with MTA, which significantly reduces chairside time [9].

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After mixing, Biodentine has moderate flowability, good plasticity and marginal adaptation, and fast initial setting. It is suitable for emergency treatment and single-visit treatment, but the operating time must be strictly controlled to avoid timeout setting [11-12].

3. Comparison of the Clinical Efficacy of Calcium Silicate-Based Materials in the Apical Barrier Technique

3.1 Overall Comparison of Clinical Success Rates

A meta-analysis on the clinical efficacy of three calcium silicate-based materials showed that, compared with MTA, the relative risk (RR) of the iRoot BP Plus group at 12-24 months after treatment was 1.04, 95% confidence interval (CI): 0.97-1.11, P=0.30. The RR of the Biodentine group at 12-36 months after treatment was 0.99, 95% CI: 0.93-1.05, P=0.66. The treatment success rates of the three materials during follow-up did not show statistically significant differences [14]. Overall, the clinical success rates of MTA, iRoot BP Plus, and Biodentine in the apical barrier technique are all relatively ideal and can meet the needs of clinical application [14].

3.2 Efficacy Advantages and Shortcomings of Different Materials

MTA has good biocompatibility and does not irritate the apex. The apatite crystals on its surface can produce a chemical reaction with dentin, thereby significantly improving sealing ability. At the same time, MTA can coordinate with the alkaline environment of the apex itself, thereby playing a certain antibacterial and bactericidal role [15].

However, MTA has relatively high technical sensitivity. It has high requirements for the adjustment of the powder-liquid ratio and the degree of compaction, and the material itself is not adhesive. It is easy to scatter or remain on the root canal wall, which significantly increases the difficulty of operation for medical personnel [3].

iRoot BP Plus also has good biocompatibility and can reduce irritation. Its antibacterial ability helps the repair and regeneration of periapical tissues and improves tissue resistance to injury. This material can produce a good chemical reaction with the canal wall and improve the stability of the apical barrier [16]. Its operation is simpler, the time is shorter, and postoperative recovery is faster [17]. In addition, it helps reduce the number of treatments, shorten the treatment cycle, improve masticatory function and satisfaction, and reduce the incidence of adverse reactions [18].

However, in the operation of using iRoot BP Plus to seal 5 mm of the apical region, when the diameter of the apical foramen reaches 0.7 mm or above, microleakage may occur, and the larger the diameter of the apical foramen, the greater the possibility of microleakage [19]. In addition, if the operator chooses to place iRoot BP Plus in the apical region under the assistance of an oral surgical microscope to construct a 3-5 mm isolation barrier, this process not only has specific requirements for operating technique but may also lead to problems such as prolonged mouth-opening time for the patient [20].

Biodentine shows outstanding sealing ability, can effectively exert the role of an apical barrier, and significantly reduces the incidence of microleakage [21]. This material sets relatively quickly and helps improve the fracture resistance, acid resistance, and antibacterial ability of dentin [22]. However, because Biodentine has been used clinically for a relatively short time, high-quality evidence on its long-term adverse reactions and long-term clinical performance remains relatively limited.

3.3 Differences in Long-Term Follow-Up Efficacy

Existing literature shows that iRoot BP Plus bioceramic material combined with long-term calcium hydroxide medication was used to treat 74 permanent teeth with chronic apical periodontitis and open apices. The mean postoperative follow-up was 18.5 months, the total effective rate reached 97.3%, and the cure rate was 82.4% [23]. In comparative treatment with iRoot BP Plus and MTA, the satisfaction of children and their families from six months to one year after treatment was higher in the iRoot BP Plus group than in the MTA group, and the difference was statistically significant [24].

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Biodentine can promote the generation of phosphate stone, and its calcified barrier formation effect is outstanding [25]. At present, the clinical success rate of Biodentine in pulpotomy of permanent teeth is 70.7-94.4%, and the success rate in traumatized teeth exceeds 90%. Pain on the first postoperative day is more obvious than that after MTA. It has been reported that individual cases showed surface healing but developed internal root resorption and were judged as failures. In young permanent teeth, dentin bridge formation and continued root development were observed in 91% of teeth, reflecting regenerative potential [26].

4. Factors Influencing the Clinical Selection of Calcium Silicate-Based Materials

4.1 Factors Related to the Affected Tooth

For anterior teeth, iRoot BP Plus and MTA show comparable short-term efficacy, and both are superior to conventional calcium hydroxide paste [27]. However, iRoot BP Plus has obvious advantages in promoting bone tissue recovery, improving long-term efficacy, and reducing the risk of complications [28].For posterior teeth, Kuang Rong et al. [29] treated chronic apical periodontitis of a left maxillary posterior tooth with MTA through the apical barrier technique and achieved good efficacy. Although MTA takes a long time, it is easier to compact irregularly shaped areas, whereas iRoot BP is slightly adhesive to instruments.

When iRoot BP Plus and MTA were used respectively to repair permanent teeth with incomplete root development, iRoot BP Plus was more effective than MTA, and the operating time (8.51±1.38 min) was shorter than that of MTA (15.48±2.09 min) [30].

Compared with MTA, iRoot BP Plus has better efficacy in the treatment of permanent teeth with incomplete root development, and the operation duration (8.51±1.38 min) is significantly shorter than that of MTA (15.48±2.09 min) [30].

When applied in vital pulpotomy for children with pulp exposure caused by dental trauma, Shi Yongping et al. [31] found that iRoot BP Plus can improve gingival health, help reduce inflammatory reactions, result in a lower total incidence of complications in children, and provide better safety. By contrast, MTA may irritate surrounding tissues, aggravate local inflammation, and more easily cause root canal calcification, resulting in a lower total incidence of complications in children and better safety. By contrast, MTA may irritate surrounding tissues, aggravate local inflammation, and more easily cause root canal calcification.

In addition, Biodentine also shows good efficacy when applied in pulpotomy of young permanent teeth. It can effectively maintain pulp vitality and provide a new treatment option for preserving dental function in adolescence and young adulthood [24].

4.2 Operating Factors

From the perspective of handling characteristics, MTA has relatively sensitive problems in mixing, delivery, and compaction. The powder-liquid ratio and compaction force have a relatively large influence on the final sealing effect, and the setting time is long [3,24]. Overall, the operating process has high requirements for the operator's experience and technique.

As a premixed injectable bioceramic material, iRoot BP Plus can be directly injected into the root canal and moderately compacted. Compared with MTA, it significantly shortens chairside time [17,24], and the operation process is relatively simplified, which is conducive to promotion in outpatient settings. At the same time, data show that Biodentine requires approximately an additional 45 min of operating time [32]. However, when iRoot BP Plus is applied in the apical barrier technique with microscope assistance, for molar cases with relatively long root canals or limited mouth opening, accurate material delivery and compaction still have certain difficulties, and the learning curve is relatively steep [20].

Existing studies show that both iRoot BP Plus and MTA can achieve relatively high success rates in the apical barrier technique, but the former can significantly reduce postoperative adverse reactions and complications [33]. Therefore, on the basis of comprehensive consideration of the operator's technical level, operating environment, and equipment conditions, clinical practice may give priority to MTA with stronger plasticity in complex apical morphology or microsurgical environments, while iRoot BP Plus with more convenient operation may be selected more often in routine chairside apical barrier procedures.

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4.3 Prognostic Factors

iRoot BP Plus, MTA, and Biodentine all have good clinical efficacy, but iRoot BP Plus shows better recovery, a lower incidence of inflammatory reactions, the ability to shorten the duration of postoperative pain, and promotion of rapid recovery, and the entire treatment process is simpler and more efficient [17]. This material also obtained higher satisfaction among patients' family members than MTA ($P<0.05$) [24]. Yue Yarui et al. [30] compared postoperative complications: no tooth discoloration occurred in the iRoot BP Plus group, and only 1 case of pain was observed (2.50%); in the MTA group, there were 4 cases of tooth discoloration and 4 cases of pain (20.00%), and the difference between the two groups was statistically significant ($P<0.05$).

In terms of esthetic prognosis, Wang Yitian et al. [34] found that Biodentine had better stability than MTA under conditions of long-term contact with blood. After immersion in deionized water for 1 day and 7 days and immersion in defibrinated sheep blood for 7 days, the color difference values of Biodentine were all lower than those of MTA, suggesting that Biodentine has an advantage in color stability. Other studies have also confirmed that Biodentine has better esthetic performance than MTA and is more suitable for anterior esthetic areas with high requirements for tooth color.

5. Research Deficiencies and Future Prospects

5.1 Main Gaps in Current Research

Existing studies on the application of different calcium silicate-based materials in the apical barrier technique have generally confirmed that MTA, iRoot BP Plus, Biodentine, and other materials can all achieve relatively high clinical success rates and show good effects in apical sealing, biocompatibility, and promoting continued apical development [1-3,5]. However, judging from the overall situation of Chinese and international literature, current research still has the following shortcomings.

First, high-quality evidence is relatively insufficient. Most studies are single-center, small-sample retrospective case analyses or prospective cohort studies. The number of randomized controlled trials is limited, and the research design still has room for improvement in blinding implementation, sample size estimation, and confounding factor control [1-3]. Inclusion criteria, follow-up time, and endpoint evaluation are not completely consistent among different studies, which limits the comparability of results and the improvement of the level of evidence-based evidence.

Second, the follow-up time is generally short. A large number of reports have follow-up times concentrated at 1-2 years, and a few studies have extended to more than 3 years [2,5], but there are few studies that truly reach long-term follow-up of more than 5 years. Therefore, it is difficult to comprehensively evaluate the long-term stability of different calcium silicate-based materials after the apical barrier technique, recurrent apical periodontitis, and late complications. Especially for new materials such as Biodentine, because the clinical application time is short, sufficient evidence is still lacking to support their long-term efficacy and the quality of long-term apical and periodontal tissue repair.

Third, the evaluation index system is not yet unified. Existing literature mostly uses periapical radiographic healing, disappearance of clinical symptoms, presence or absence of sinus tracts, and changes in mobility as the main outcome indicators [1-3], and some studies have added records of complications such as tooth discoloration and postoperative pain [3]. However, objective indicators such as the three-dimensional morphology of the apical barrier structure, microleakage at the interface between the material and the root canal wall, and changes in the mechanical properties of teeth are relatively insufficiently reported. Imaging still mostly relies on two-dimensional X-ray films, and studies using cone-beam computed tomography (CBCT) or three-dimensional quantitative analysis are relatively few. An objective and quantitative evaluation system needs to be improved.

In addition, the heterogeneity of affected teeth in different age groups and with different etiologies is relatively large. Previous studies have mostly used young permanent teeth with incomplete root development caused by trauma as the main research object [2-3], and evidence is limited for chronic periapical inflammation, retreatment cases, teeth with complex root canal anatomy, and cases related to systemic diseases. There may

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be differences in periapical tissue repair ability and material response under different ages and different underlying disease states, but relevant stratified analysis and individualized evidence are still insufficient.

5.2 Optimization and Research and Development Directions of Calcium Silicate-Based Materials

At present, calcium silicate-based materials such as MTA have good physical properties, but their handling convenience is inferior to that of iRoot BP Plus [3], and their color stability is inferior to that of Biodentine [35]. Therefore, future calcium silicate-based materials can optimize the handling convenience of materials and the "ideal restorative material" with color stability on the basis of ensuring the physical properties of the material, so as to improve patients' esthetic satisfaction and long-term prognosis.

At the same time, existing studies show that calcium silicate-based materials such as iRoot BP Plus have certain antibacterial ability and can effectively reduce the risk of postoperative inflammation [3]. In the future, new materials may be endowed with active, broad-spectrum, and long-lasting antibacterial ability through precise incorporation of antibacterial components such as silver nanoparticles and chlorhexidine, thereby inhibiting bacterial colonization in the root canal from the source and significantly reducing the risk of postoperative infection and inflammation.

In China, Yu Qian et al. [36] have studied the combined use of growth factors and MTA in root canal treatment and achieved good clinical efficacy, which can effectively improve apical and root canal conditions. If calcium silicate-based carrier materials capable of loading antibiotics and growth factors are developed, the synergistic effect of "physical barrier + drug sustained release + tissue induction" can be realized, which may provide a new solution for regenerative repair of the pulp-dentin complex.

In addition, price is also one of the important factors affecting the clinical promotion and application of new materials [37]. By optimizing the raw material synthesis process, simplifying the production process, and realizing large-scale preparation, it is expected that the cost threshold of high-end calcium silicate-based materials can be significantly reduced, promoting their transformation and popularization from specialized high-value materials to routine clinical consumables.

5.3 Trends in Clinical Research on Materials for the Apical Barrier Technique

Future clinical research should be strengthened and expanded in the following aspects:

First, single-center clinical studies should be transformed into multicenter collaborative studies, sample sizes should be expanded, and follow-up periods should be extended, with emphasis on long-term prognosis. At the same time, head-to-head direct comparative studies among different materials should be carried out to provide higher-level evidence-based medical evidence for clinical material selection.

Second, three-dimensional imaging techniques such as CBCT should be introduced to conduct more accurate quantitative evaluation of apical sealing effects and surrounding tissue repair. At the same time, patient-reported outcomes (PROs) should be included in the evaluation system, and treatment effects should be comprehensively considered from multiple dimensions, such as pain perception, esthetic satisfaction, functional recovery, and quality of life, so as to improve the overall satisfaction of patients and their family members with treatment.

Third, in line with the development trend of artificial intelligence (AI) and big data technology, intelligent decision-making models should be constructed based on large-sample clinical data, and AI-assisted analysis should be used to analyze the anatomical structure, lesion characteristics, and individual systemic conditions of affected teeth, so as to customize the most suitable barrier material and treatment plan for each patient and realize precise and individualized treatment, thereby further optimizing prognosis and improving clinical experience.

6. Conclusion

At present, the three existing calcium silicate-based materials, MTA, iRoot BP Plus, and Biodentine, can all achieve relatively high clinical treatment success rates, have certain antibacterial effects, and have good prognosis. However, the three materials have their own advantages and disadvantages in physicochemical

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characteristics, handling characteristics, and long-term prognosis. MTA has excellent sealing performance and is suitable for apical regions with complex anatomical morphology, but it has a long setting time, difficult operation, and easily causes tooth discoloration. iRoot BP Plus is a premixed injectable type, with convenient operation, a short treatment cycle, low risk of tooth discoloration, strong antibacterial ability, and higher patient satisfaction, but there is a risk of microleakage when the apical foramen diameter is large. Biodentine sets quickly, has good color stability, and has mechanical properties close to natural dentin, making it suitable for affected teeth with high esthetic requirements, but long-term clinical follow-up evidence for this material is currently relatively limited.

Therefore, when selecting materials clinically, the tooth location, apical foramen size, root canal anatomical conditions, and other factors should be comprehensively considered, while individualized design should be carried out in combination with the operator's technical level, equipment conditions, and the patient's requirements for esthetics and prognosis. At present, this field still lacks high-quality clinical studies with large samples and long-term follow-up. In the future, the clinical evaluation system needs to be further improved, and calcium silicate-based materials can be modified to develop new materials with excellent physicochemical and setting characteristics, convenient operation, and strong antibacterial ability, while promoting individualized precision treatment and improving the long-term therapeutic effect of the apical barrier technique.

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Conflicts of Interest

The authors declare no conflict of interest.

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