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Advances in Vital Pulp Therapy for Primary and Immature Permanent Teeth: From Calcium Hydroxide to Bioceramics

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ABSTRACT

Vital pulp therapy (VPT) has long served as a cornerstone of pediatric and conservative endodontics. Its objective is the preservation and maintenance of pulp vitality following exposure to caries, trauma, or restorative procedures. Over the decades, treatment philosophies have shifted from devitalizing to biologically conservative methods aimed at promoting regeneration rather than replacement. This narrative review traces the evolution of materials used in VPT—from calcium hydroxide (CH), the historical gold standard, to modern calcium-silicate-based bioceramics such as mineral trioxide aggregate (MTA) and Biodentine. Advances in understanding pulp biology, biomaterial science, and the regenerative potential of the dental pulp have transformed clinical approaches, resulting in improved success rates and long-term outcomes.

INTRODUCTION

Vital pulp therapy (VPT) refers to a spectrum of conservative treatment modalities designed to maintain the vitality of the dental pulp in both primary and immature permanent teeth. The main goal of VPT is to promote healing and preserve the functional pulp tissue that contributes to continued root development in young permanent teeth and to maintain space and function in primary teeth. Historically, materials such as formocresol and calcium hydroxide were the mainstay for pulpotomy and direct pulp capping; however, recent developments in bioceramic materials have redefined the biological and clinical paradigms for pulp preservation (1,2). The paradigm shift from cytotoxic to bioactive materials has led to a dramatic improvement in long-term treatment outcomes and has strengthened the philosophy of minimally invasive pediatric endodontics.

Clinical Decision-Making in Vital Pulp Therapy

The choice of treatment modality depends on the degree of pulpal inflammation, tooth maturity, and the type of exposure (mechanical, carious, or traumatic). The process begins with thorough clinical and radiographic evaluation, including assessment of symptoms, pulp status, and root development. Diagnostic vitality tests, radiographic evidence of periapical health, and hemorrhage control during access are critical in selecting appropriate therapy (3,4). When the pulp is reversibly inflamed, techniques such as indirect pulp capping, direct pulp capping, or partial pulpotomy are indicated, whereas irreversible pulpitis may require pulpectomy or extraction. A comprehensive overview of the decision-making pathway is shown in Figure 1.

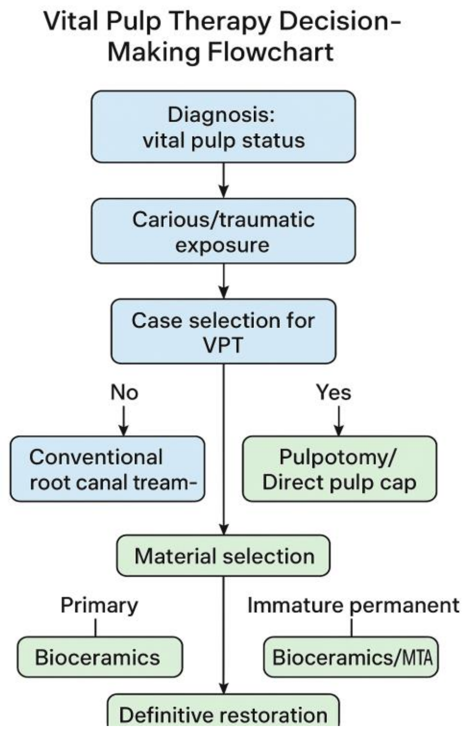

Figure 1. Decision-making flowchart for vital pulp therapy (VPT) in primary and immature permanent teeth. This flowchart illustrates the clinical assessment and material selection steps based on pulp vitality and root development status.

Evolution of Materials in Vital Pulp Therapy

The materials used in VPT have undergone a remarkable evolution over the last century. Calcium hydroxide (CH), introduced by Hermann in 1920, remained the benchmark material for decades due to its antibacterial properties and ability to stimulate reparative dentin formation (5). However, its limitations—poor sealing ability, high solubility, and tendency to form tunnel defects—prompted the development of alternative materials. The introduction of mineral trioxide aggregate (MTA) in the 1990s marked a significant milestone in endodontics (6). MTA demonstrated excellent sealing, high biocompatibility, and the ability to induce hard tissue formation without the drawbacks of CH. Later, calcium-silicate-based bioceramics such as Biodentine and iRoot BP Plus emerged, offering faster setting times, superior handling, and improved bioactivity (7,8). Figure 2 illustrates material evolution, highlighting the transition from CH to MTA and modern calcium-silicate bioceramics. The figure summarizes key physicochemical properties, clinical performance indicators, and ideal tooth applications.

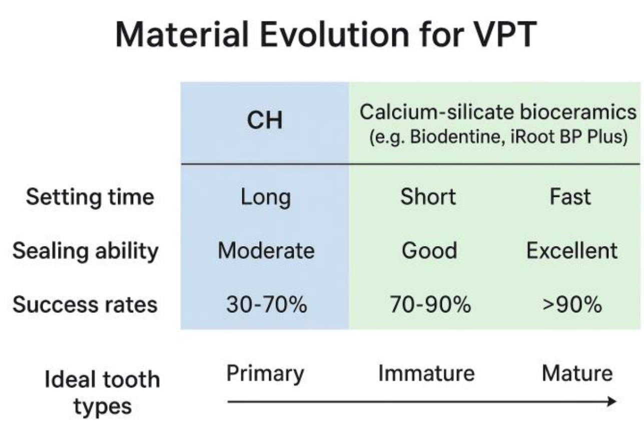

Figure 2. Material evolution in vital pulp therapy (VPT): Calcium Hydroxide (CH) → Mineral Trioxide Aggregate (MTA) → Calcium-silicate bioceramics (e.g., Biodentine, iRoot BP Plus). The table compares setting time, sealing ability, success rates, and ideal tooth indications (primary, immature, mature).

Biological Basis of Vital Pulp Therapy

Successful VPT relies on maintaining or re-establishing the natural balance of pulp healing and repair. When a pulp exposure occurs, an inflammatory cascade begins, leading to recruitment of immune cells and progenitor cells. Bioceramic materials interact with these cells to stimulate mineralization through release of calcium and hydroxide ions. The elevated pH environment inhibits bacterial proliferation and favors differentiation of pulp cells into odontoblast-like cells (9,10). These cells deposit reparative dentin bridges that protect the pulp and restore its integrity. The bioactivity of modern materials such as Biodentine and MTA is attributed to their ability to form hydroxyapatite at the material–dentin interface, ensuring a tight seal and promoting biological compatibility.

Clinical Outcomes and Success Rates

Numerous clinical and histological studies have validated the superior performance of bioceramic materials compared to traditional calcium hydroxide. Meta-analyses show success rates ranging between 85–95% for MTA and 90–98% for Biodentine, compared to 65–75% for CH in primary teeth (11–13). These differences are attributed to improved sealing ability and enhanced bioactivity of newer materials. Similarly, in immature permanent teeth undergoing partial pulpotomy, calcium-silicate materials show predictable continued root development and apical closure (14,15). Figure 3 presents a visual comparison of success rates among CH, MTA, and Biodentine, derived from multiple clinical studies.

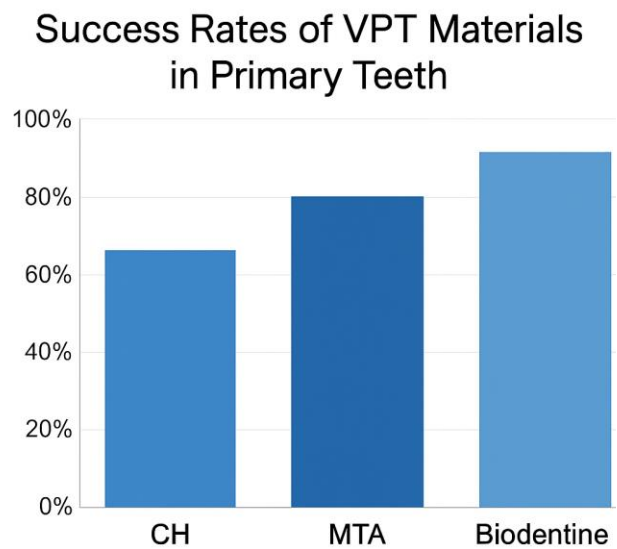

Figure 3. Bar graph comparing success rates of VPT materials in primary teeth. Clinical studies demonstrate mean success rates of approximately 65–70% for calcium hydroxide, 80% for MTA, and over 90% for Biodentine.

DISCUSSION

The transition from calcium hydroxide to modern bioceramic materials represents a paradigm shift from repair to regeneration in pediatric endodontics. While CH offered a cost-effective solution, its poor sealing and mechanical weakness limited its longevity. MTA revolutionized VPT by offering superior sealing, reduced bacterial penetration, and biocompatibility. However, its long setting time and potential discoloration spurred further innovation. Biodentine, with its improved handling and mechanical strength, has demonstrated exceptional clinical outcomes and has emerged as a preferred alternative for both primary and immature permanent teeth (16–18).

Despite significant progress, challenges persist. Operator variability, moisture sensitivity, and patient cooperation remain crucial determinants of clinical success. Future directions involve integrating regenerative endodontic principles with VPT through scaffold-mediated pulp regeneration and controlled release of bioactive molecules. Emerging materials with tailored nanostructures and ion-releasing profiles are likely to enhance healing responses and minimize failure rates.

CONCLUSION

Vital pulp therapy remains a cornerstone of pediatric endodontics, and material science continues to play a pivotal role in determining its success. The evolution from calcium hydroxide to mineral trioxide aggregate and bioceramic materials such as Biodentine has transformed clinical outcomes by enhancing biological compatibility, sealing ability, and success rates.

As research progresses, the future of VPT is likely to merge with regenerative concepts, ensuring not only preservation but restoration of pulp vitality in its truest sense.

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