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Direct Pulp Capping in Carious Primary Molars: A Literature Review

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ABSTRACT

Background: Direct pulp capping (DPC) in cariously exposed primary molars has historically been avoided due to concerns over pulp degeneration and internal resorption. However, recent advancements in biocompatible and bioactive materials such as mineral trioxide aggregate (MTA), Biodentine, and TheraCal LC have renewed interest in this conservative approach to pulp therapy.

Objective: To narratively synthesize clinical and radiographic outcomes of DPC in primary molars with carious exposures, with particular focus on material-specific success rates and influencing clinical factors.

Methods:A literature review was conducted using PubMed to identify studies published between 2000 and 2024 that evaluated DPC in carious primary molars. Search terms included "direct pulp capping," "primary molar," "dental caries" "MTA," "Biodentine," "Calcium Hydroxide," and "TheraCal LC." Clinical trials, randomized controlled trials, and prospective studies were included.

Results:MTA and Biodentine consistently demonstrated superior clinical (86–96%) and radiographic (85–95%) success rates up to 24 months, compared to calcium hydroxide (CH), which showed declining outcomes over time. TheraCal LC demonstrated comparable short-term outcomes (85–89%) but requires more long-term studies to validate its use.

Conclusion:DPC can be a viable option in carefully selected primary molars when newer biomaterials are used. MTA and Biodentine remain the preferred choices, while TheraCal LC shows potential. Clinical success is influenced by material properties, case selection, and coronal sealing. Long-term controlled trials are needed to establish definitive protocols.

Keywords: Direct pulp capping, primary molar, MTA, Biodentine, TheraCal LC, pulp vitality, carious exposure.

I. INTRODUCTION

The preservation of primary molars plays a crucial role in maintaining occlusal integrity, ensuring mastication, and guiding the eruption of permanent teeth [1]. Traditional treatments for pulpally involved primary molars include pulpotomy and pulpectomy. However, these procedures are technique-sensitive and often require advanced training, especially in pediatric populations [2]. Pulp capping is a conservative treatment approach designed to maintain the vitality of the dental pulp following exposure due to trauma, caries, or mechanical causes. This procedure aims to protect the pulp tissue and stimulate reparative dentinogenesis by applying a biocompatible material directly or indirectly over the exposed area. Two main types of pulp capping exist: **indirect pulp capping (IPC)**, where a thin layer of dentin is left to avoid direct exposure; and **direct pulp capping (DPC)**, where the capping agent is placed directly over an exposed pulp [3].

While direct pulp capping is widely accepted in permanent teeth, its use in primary teeth has been more controversialdue to fears of pulp necrosis and internal resorption [4]. Historically, treatments like pulpotomy or pulpectomy were favored in primary teeth with deep carious lesions due to concerns about pulp tissue's capacity to recover and the risk of internal resorption. However, advances in biocompatible materials and a better understanding of pulp biology have renewed interest in less invasive approaches like DPC, particularly in pediatric dentistry.

Nevertheless, the introduction of biocompatible and bioinductive materials like Mineral Trioxide Aggregate (MTA), Biodentine, and TheraCal LC has challenged traditional thinking. These materials facilitate reparative dentinogenesis and show promise in maintaining pulp vitality in cariously exposed teeth [5,6]. Given the renewed interest in conservative pulp therapy, this narrative review aims to explore the evidence for DPC in carious primary molars and synthesize the clinical and radiographic success associated with different capping materials.

II. HISTORICAL PERSPECTIVE AND BIOLOGICAL RATIONALE

Calcium hydroxide has traditionally been used for DPC due to its antibacterial properties and ability to induce mineralized tissue [6]. However,

limitations such as poor sealing, solubility, and tunnel defects in dentin bridges often compromise its long-term effectiveness [7].

MTA, a hydrophilic calcium silicate cement, introduced in the 1990s, demonstrated superior sealing ability and bioactivity, prompting its use in endodontic procedures including DPC [8]. Biodentine, another calcium silicate-based cement with improved handling and faster setting time, offers a suitable alternative with favorable biocompatibility and mechanical properties [9]. TheraCal LC, a resin-modified calcium silicate, is gaining traction due to its ease of placement and immediate light-activated setting [10].

The biological success of DPC hinges on the ability of the material to preserve the pulp's cellular integrity, control hemorrhage, and induce reparative dentin formation while preventing bacterial infiltration [11].

III. MATERIAL-SPECIFIC OUTCOMES

3.1 Calcium Hydroxide

Tuna and Olmez [12] reported a success rate of 78% at 24 months, while Katge et al. [13] found even lower rates with longer follow-up. The degradation and poor sealing capacity of CH materials result in bacterial infiltration and a higher incidence of internal resorption, undermining its long-term viability [14].

3.1 Mineral Trioxide Aggregate (MTA)

Multiple studies support the use of MTA for DPC in primary molars. Erdem et al. [15] found a 90% success rate at 12 months, while Farsi et al. [16] observed an 86% success rate over the same period. MTA consistently exhibits long-term dimensional stability, minimal microleakage, and excellent biocompatibility, contributing to its favorable outcomes.

3.2 Biodentine

Nowicka et al. [17] and Sabbarini et al. [18] demonstrated clinical and radiographic success rates of 92–96% at 12–18 months. Biodentine's faster setting time and handling ease make it particularly suited for pediatric applications. Its ability to stimulate tertiary dentin and maintain an effective seal enhances its clinical reliability [19].

3.4 TheraCal LC

Studies by Bakhtiar et al. [20] and Jalali et al. [21] show that TheraCal LC has short-term success rates (85–89%) comparable to MTA and Biodentine. However, its long-term outcomes remain less validated. Sahin et al. [22] reported 80% radiographic success at 24 months, though further research is needed to support its use in routine pediatric cases.

IV. INFLUENCING FACTORS FOR SUCCESS

4.1 Case Selection

Success in Direct Pulp Capping (DPC) is highly influenced by careful case selection, as not all pulpal exposures are equally amenable to this conservative treatment. Teeth diagnosed with reversible pulpitis—characterized by a healthy or mildly inflamed pulp, capable of healingare typically better candidates for DPC. These cases often present with minimal or no bleeding at the exposure site, and when bleeding does occur, it can be easily controlled within a few minutes using gentle pressure and sterile saline. This manageable hemostasis suggests that the underlying pulp tissue is not severely inflamed and retains its regenerative potential [23].

Furthermore, the absence of periradicular pathology, such as apical radiolucency or signs of periapical inflammation, is a critical indicator of a favorable pulpal status. Radiographic and clinical evaluations confirming the lack of such pathology provide additional reassurance that the pulp is likely to respond positively to direct capping.In contrast, uncontrolled or profuse bleeding from the exposure site, spontaneous pain, pathological mobility, tenderness to percussion, swelling, sinus tract formation, and radiographic evidence of internal/external root resorption or periradicular radiolucency often reflects irreversible pulpitis. In such cases, conservative procedures like DPC are unlikely to succeed. Thus, identifying the clinical signs that distinguish reversible from irreversible pulpitis is essential for determining whether DPC is an appropriate and potentially successful treatment option [24].

4.2 Pulp Status and Hemorrhage Control

Bleeding time exceeding five minutes is considered a contraindication for DPC [25]. Effective control of hemorrhage before placement of the capping material correlates with better healing outcomes and dentin bridge formation [26].

4.3 Coronal Seal

Inadequate sealing of the restored cavity following direct pulp capping (DPC) can critically compromise treatment outcomes. One of the most significant risks is microleakage, the infiltration of bacteria, fluids, and toxins from the oral environment into the pulp through gaps or imperfections at the restoration margins.

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Microleakage not only undermines the integrity and longevity of the capping material, such as calcium hydroxide or bioceramics, but also poses a direct threat to the vitality of the pulp by facilitating bacterial contamination and inflammation [27].

To mitigate this risk, it is essential to place an immediate and hermetically sealed restoration after pulp capping. A tight seal ensures that the pulp remains protected from oral microorganisms and environmental irritants, which is crucial for pulpal healing and dentin bridge formation. Materials with excellent sealing properties—such as resin-modified glass ionomers or composite resins used with appropriate bonding systems—are typically preferred [28].

Moreover, any delay in sealing or use of suboptimal restorative techniques increases the likelihood of reinfection, which can lead to treatment failure and necessitate further endodontic intervention. Therefore, achieving and maintaining a well-sealed coronal restoration is just as important as the choice of pulp capping material in ensuring the long-term success of DPC [29].

V. COMPARISON OF MATERIAL PROPERTIES

Material	Clinical Success (12 mo)	Radiographic Success (12 mo)	Handling	Setting Time	Sealability
MTA	86–91%	85–90%	Moderate	2–3 hours	High
Biodentine	92–96%	90–95%	Good	~12 minutes	High
TheraCal LC	85–89%	83–88%	Excellent	Immediate	Moderate
Calcium Hydroxide	65–78%	60–75%	Easy	Few minutes	Low

VI. DISCUSSION

Direct pulp capping (DPC) in cariously exposed primary molars has historically been met with skepticism due to concerns regarding the regenerative capacity of primary pulp and the risk of internal resorption. However, with the advent of advanced bioactive materials such as mineral trioxide aggregate (MTA), Biodentine, and TheraCal LC, there is a renewed interest in using DPC as a viable, conservative treatment modality in pediatric dentistry. This discussion elaborates on the clinical relevance of DPC, comparative outcomes of various materials, key factors influencing success, limitations of the current evidence, and potential directions for future research [30].

Re-evaluating DPC in Primary Teeth

Traditionally, pulpotomy and pulpectomy have been the mainstay treatments for pulpally involved primary molars. These procedures, although effective, are invasive and technique-sensitive, and often necessitate specialized training, especially in the management of pediatric patients. The idea of preserving pulpal vitality through DPC aligns with the current trend in dentistry toward minimally invasive and biologically oriented treatment approaches. Emerging evidence suggests that, under appropriate clinical conditions, DPC may provide satisfactory outcomes comparable to more invasive procedures, especially when bioactive materials are utilized [31].

Several clinical studies have shown that DPC, once considered contraindicated in primary molars, can lead to successful outcomes when stringent case selection criteria are followed. Recent systematic reviews and randomized controlled trials now support the notion that the primary pulp, though traditionally considered less capable of healing than permanent pulp, can recover if the inflammatory insult is not extensive and a proper seal is achieved. These findings challenge earlier assumptions and open the door to broader application of DPC in pediatric patients [32].

Material-Specific Considerations

The type of pulp capping material used is arguably the most critical determinant of the treatment outcome in DPC. Each material has distinct biological and mechanical properties that influence healing and long-term success [33].

Mineral Trioxide Aggregate (MTA) has emerged as the gold standard in vital pulp therapy. Its excellent sealing ability, biocompatibility, and ability to stimulate reparative dentin make it highly suitable for DPC. Multiple clinical trials have demonstrated high success rates for MTA, with outcomes consistently ranging between 86–91% for both clinical and radiographic measures over 12 to 24 months. MTA induces a favorable tissue response with minimal inflammation and promotes the formation of a thick, uniform dentin bridge. However, its limitations—such as a long setting time, difficult handling, and potential for discoloration—can be problematic in a pediatric setting [34].

Biodentine, another calcium silicate-based cement, offers comparable or even superior outcomes to MTA. Studies by Nowicka et al. and Sabbarini et al. showed success rates ranging from 92–96%. Its favorable properties—including a shorter setting time (~12 minutes), ease of manipulation, and high compressive strength—make it particularly suited for pediatric cases where patient cooperation may be limited. Additionally, Biodentine has been shown to induce biomineralization and maintain a tight seal against bacterial ingress, reducing the risk of reinfection and promoting long-term vitality of the pulp [35].

TheraCal LC, a resin-modified calcium silicate cement, represents a more recent development. Its key advantage lies in its ease of use and immediate light-curing capability, which significantly reduces chair time—a crucial factor in treating uncooperative pediatric patients. Initial studies report promising short-term success rates (85–89%). However, its long-term biocompatibility remains questionable. Some studies have reported pulpal irritation and cytotoxic effects attributed to the resin components. Until robust long-term data become available, TheraCal LC should be used cautiously and perhaps selectively in situations where traditional materials are not feasible [36].

Calcium Hydroxide (CH), while historically the most commonly used material for pulp capping, has shown declining efficacy over time. It is characterized by high solubility, poor sealing ability, and the tendency to induce incomplete dentin bridges with tunnel defects. These issues make it more susceptible to bacterial penetration and internal resorption. Long-term success rates with CH range from 60–78%, significantly lower than those achieved with MTA or Biodentine. Its use in primary teeth, therefore, is largely being phased out in favor of more reliable alternatives [37].

Key Factors Influencing Success

Beyond the choice of material, several clinical factors significantly influence the outcome of DPC in primary molars:

1. **Case Selection:**

Success in DPC is largely contingent upon accurate case selection. Teeth presenting with **reversible pulpitis**, less than 1mm pulp exposure, minimal bleeding, and no signs of periradicular pathology are ideal candidates. Clinical signs such as controlled bleeding and the absence of spontaneous pain suggest that the pulp is still vital and capable of healing. Conversely, uncontrolled hemorrhage—particularly bleeding lasting more than five minutes—may indicate irreversible pulpitis, necessitating more extensive intervention like pulpectomy [38].

2. **Hemorrhage Control:**

Effective management of pulp bleeding prior to the application of the capping material is essential. Studies have shown that bleeding control within five minutes is strongly correlated with better healing outcomes. Inadequate control may compromise the material's ability to adhere to the pulp and initiate reparative dentinogenesis. Gentle pressure with a moist cotton pellet and use of sterile saline are recommended for achieving hemostasis [39].

3. **Coronal Seal:**

One of the most critical factors in the success of DPC is achieving a **tight, hermetic coronal seal** to prevent microleakage. If the restoration fails to adequately seal the cavity, bacteria and oral fluids can infiltrate, leading to pulp reinfection and eventual failure of the procedure. Materials like resin-modified glass ionomer cement and composite resins used with appropriate bonding agents are preferred for their superior sealing properties. Immediate placement of a permanent and full coverage restoration following pulp capping significantly enhances the likelihood of success [39].

4. **Operator Skill and Clinical Protocol:**

The clinician's ability to follow proper technique—such as isolation with a rubber dam, complete caries removal without damaging the pulp, careful handling of materials, and precise placement—plays a vital role in outcomes. In pediatric dentistry, where behavioral challenges are common, the need for speed and precision makes material handling and procedural efficiency particularly important [40].

VII. LIMITATIONS OF EXISTING EVIDENCE

Despite growing support for DPC in primary teeth, current evidence has notable limitations. Most clinical studies evaluating DPC are small-scale, vary in methodology, and use different definitions of clinical and radiographic success. Moreover, **few studies include histological analysis**, which would provide more definitive insights into pulpal healing and dentin bridge formation [40.41].

There is also heterogeneity in follow-up duration, ranging from 6 months to 24 months, making direct comparisons difficult. Additionally,

publication bias may exist, as unsuccessful or equivocal studies may remain unpublished. The predominance of English-language studies indexed in PubMed may further restrict the comprehensiveness of this review, excluding potentially relevant research from other regions and languages.

VIII. IMPLICATIONS FOR CLINICAL PRACTICE

From a practical standpoint, DPC offers a minimally invasive, time-efficient alternative to pulpotomy or pulpectomy when the appropriate criteria are met. In clinical scenarios where MTA or Biodentine is available, and bleeding is easily controlled, DPC can be a viable first-line treatment. TheraCal LC may serve as a useful alternative in certain cases, particularly where rapid placement is needed, though its long-term reliability remains in question.

Practitioners must remain vigilant about **proper case selection**, **bleeding control**, and **coronal sealing** to optimize outcomes. While materials like Biodentine are more expensive than traditional CH, the improved long-term success and potential to preserve pulpal vitality may justify the cost, especially considering the benefits of retaining the primary tooth until natural exfoliation.

IX. FUTURE RESEARCH DIRECTIONS

There is a clear need for **long-term, multicenter randomized controlled trials** that evaluate not only clinical and radiographic outcomes but also **histological healing**. Studies should aim to standardize protocols, including criteria for case selection, follow-up periods, and definitions of treatment success. Future research comparing DPC to pulpotomy in matched patient groups may provide deeper insights into their respective indications and long-term implications.

Additionally, more investigation is needed into the **biological effects of newer materials**, particularly concerning their cytotoxicity and pulp compatibility over extended periods. Exploration of **cost-effectiveness analyses** and **patient-reported outcomes** may also help shape treatment guidelines and inform decision-making in pediatric dental care.

X. CONCLUSION

Direct pulp capping in cariously exposed primary molars can be a successful, minimally invasive procedure when guided by appropriate case selection and modern bioactive materials. MTA and Biodentine remain the gold standards in pediatric pulp therapy. TheraCal LC, while promising, requires more evidence to establish its safety and long-term effectiveness.

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