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Comparative Performance of Commercial Biocompatible Dental Materials in Primary Tooth Pulpectomy: Systematic Review of Efficacy and Tissue Compatibility

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Abstract: *Pulpectomy in primary teeth is a widely accepted endodontic procedure aimed at preserving arch integrity and function until natural exfoliation, and its success largely depends on the biological and physicochemical properties of the root canal filling material, which must combine antimicrobial efficacy, biocompatibility, and a resorption pattern compatible with physiological root resorption. This systematic review aimed to evaluate and compare the clinical and radiographic outcomes of different obturation materials used in pulpectomy of primary teeth. A comprehensive literature search was conducted in PubMed, Scopus, Web of Science, and the Cochrane Library. Clinical studies evaluating pulpectomy outcomes in primary teeth were included, while in vitro studies, animal studies, case reports, and narrative or systematic reviews were excluded. The methodological quality of the included studies was assessed using established risk-of-bias tools, and eligible studies were synthesized through a qualitative analysis. Five clinical studies met the inclusion criteria and were included in the qualitative synthesis. All investigated materials demonstrated acceptable clinical success rates. Calcium hydroxide–iodoform pastes showed favorable short- to medium-term outcomes but exhibited a tendency toward faster intracanal resorption, whereas zinc oxide–eugenol–based materials were associated with delayed resorption and lower biological compatibility. Emerging clinical evidence suggests that bioceramic calcium silicate–based materials may offer high clinical and radiographic success rates, although long-term data remain limited. Within the limitations of the available evidence, both calcium hydroxide–iodoform pastes and bioceramic materials appear to be effective for pulpectomy in primary teeth; however, the limited number of eligible clinical studies and the heterogeneity of study designs and follow-up periods restrict the strength of definitive conclusions, highlighting the need for further well-designed, long-term randomized clinical trials to clarify resorption dynamics and potential effects on permanent tooth eruption. This systematic review was conducted in accordance with the PRISMA 2020 guidelines and was registered in the PROSPERO database (CRD1283772); no external funding was received.*

Keywords: *Pulpectomy, primary teeth, calcium hydroxide, iodoform paste, bioceramic materials, root canal filling*

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1. Introduction

1.1. Rationale

Pulpectomy in primary teeth is a critical endodontic procedure in pediatric dentistry, performed to remove necrotic or irreversibly inflamed pulp tissue and to maintain the tooth's function and esthetics until its natural exfoliation. The main objective is to eliminate infection while preserving the tooth as a space maintainer for permanent dentition. Successful outcomes depend heavily on the choice of root canal filling materials, which must be biocompatible, resorbable at a rate similar to the physiological resorption of primary teeth, and capable of providing an effective seal to prevent reinfection [1,2].

The premature loss of primary teeth, particularly molars, can lead to several undesirable consequences. These include loss of arch length, insufficient space for erupting premolars, mesial tipping of the permanent molars, and potential malocclusion. Such outcomes can complicate future orthodontic treatment and may necessitate the use of space maintainers or other interventions to correct the resulting dental issues. Pulpectomy serves as a conservative treatment approach to prevent these complications, ensuring either normal shedding or long-term survival in instances of retention. It is indicated in children with deep carious lesions, pulp necrosis, or irreversible pulpitis without adequate response to pulpotomy, and in cases of trauma affecting primary molars or anterior teeth. Clinical evaluation involves assessment of pulp vitality, presence of abscesses, sinus tracts, radiographic evidence of periapical pathology, and the patient's overall medical and behavioral status. The pulpectomy procedure is performed under local anesthesia and with rubber dam isolation in order to maintain asepsis. The pulp tissue is completely removed from the pulp chamber and root canals using hand or rotary files. The canals are irrigated with antimicrobial solutions such as sodium hypochlorite (NaOCl) or chlorhexidine. Between appointments, calcium hydroxide ($Ca(OH)_2$) is often used as an intracanal medicament because of its strong antimicrobial properties; however, its rapid resorption limits its long-term use, and it is generally replaced in subsequent sessions with resorbable filling pastes such as Vitapex® (Neo Dental, Japan) or Metapex® (META Biomed, Republic of Korea) [3–6].

Historically, a wide variety of root canal filling materials have been employed for pulpectomy procedures in primary teeth. Zinc oxide-eugenol (ZOE) was among the first to be used, valued for its antimicrobial properties and sealing ability, but it was later found to resorb much more slowly than the physiological resorption of primary roots and to possess potential cytotoxicity [4,5].

In the following decades, calcium hydroxide-based materials became the preferred option due to their high pH, antibacterial properties, and better biocompatibility. However, pure calcium hydroxide pastes were often resorbed too rapidly, leading to voids or reinfection risks. To overcome these limitations, calcium hydroxide/iodoform mixtures such as Vitapex, Metapex, and Forendo® (Septodont, France) were developed. These materials demonstrated improved radiographic and clinical outcomes, as well as a more balanced resorption rate compared with ZOE [6,7].

Over the past two decades, the emergence of bioceramic materials has represented a significant advancement in pediatric endodontics. Mineral Trioxide Aggregate (MTA®; Dentsply Sirona, USA), introduced in the 1990s, is a calcium silicate-based material known for its excellent sealing properties, biocompatibility, and ability to promote periradicular tissue healing and hard tissue formation [8,9].

Despite these advantages, MTA presents challenges such as long setting time, discoloration potential, and handling difficulties. Newer calcium silicate-based bioceramics such as Biodentine® (Septodont, France) and NeoPUTTY® (NuSmile, USA) have been developed to address these shortcomings, offering better handling, faster setting, and improved aesthetic properties while maintaining bioactivity and biocompatibility [9–15].

In recent years, NeoPUTTY, among others, has emerged as a promising bioceramic material for pulpectomy in primary teeth. It is a premixed bioactive bioceramic root and pulp treatment material consisting of an extremely fine, inorganic powder of tricalcium/dicalcium silicate in a water-free organic liquid. Unlike resin-based materials containing some MTA, NeoPUTTY is bioactive, releasing calcium

and hydroxide ions from the surface to promote the formation of hydroxyapatite, ensuring bioactive sealing [11,13].

It is formulated with pure tri/dicalcium silicate powder and a radiopacifier, offering superior handling properties and dimensional stability. NeoPUTTY is biocompatible, non-cytotoxic, and more versatile, having more treatment indications. Its firm, non-tacky consistency and wash-out resistance make it a preferred material for pulpectomy procedures [14,15].

From a biological perspective, calcium silicate-based materials exhibit high biocompatibility and low cytotoxicity toward periodontal ligament and pulp-derived stem cells, while supporting mineralization and tissue repair processes [11–13]. These properties support their increasing application in pediatric endodontics.

Despite the promising properties of bioceramic materials, there is a need for a comprehensive evaluation of their efficacy in pulpectomy procedures for primary teeth. Previous systematic reviews have focused on individual materials or specific aspects of pulpectomy, but a holistic comparison encompassing various bioceramic materials is lacking [1,16].

1.2. Objectives

This systematic review aims to fill this gap by assessing the clinical and radiographic success rates, resorption compatibility, and cytotoxicity of different root canal filling materials used in pulpectomy of primary teeth, thereby providing evidence-based guidance for clinical practice.

2. Materials and methods

2.1. Protocol

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. A completed PRISMA flow diagram and the corresponding PRISMA 2020 checklist are provided as Supplementary Materials [17]. This review has been registered in PROSPERO database in date 12/01/2026 with number 1283772. However, the review question and methodology were defined a priori, and the eligibility criteria were established before the literature search.

2.2. Elegibility criteria

Studies were selected according to the PICO framework:

- Population (P): Children with primary teeth requiring pulpectomy due to necrotic or irreversibly inflamed pulp tissue.
- Intervention (I): Pulpectomy performed using bioceramic materials (MTA®, Biodentine®, NeoPUTTY®, among others) or calcium hydroxide-based pastes (e.g., Vitapex®, Metapex®).
- Comparison (C): Comparison between different materials, if applicable, or assessment of a single material's clinical/radiographic outcomes.
- Outcome (O): Clinical and radiographic success rates, biocompatibility, resorption compatibility, and cytotoxicity.

Inclusion criteria: randomized or non-randomized clinical studies, prospective or retrospective clinical studies published in English, evaluating pulpectomy outcomes in primary teeth.

Exclusion criteria: *in vitro* studies, animal studies, narrative reviews, case reports, conference abstracts, studies involving permanent teeth only and studies focused exclusively on pulpotomy procedures.

2.3. Information sources

A comprehensive literature search was conducted in the following electronic databases: PubMed/MEDLINE, Scopus, Web of Science, and Cochrane Library. The search included articles published up to September 2025. Additional references were identified through manual screening of bibliographies from included articles and relevant systematic reviews.

2.4. Search strategy

The following keywords and Boolean operators were used:

"pulpectomy" AND "primary teeth" AND ("MTA" OR "Biodentine" OR "NeoPUTTY" OR "calcium hydroxide" OR "Vitapex" OR "Metapex" OR "Forendo") AND ("clinical success" OR "radiographic success" OR "biocompatibility" OR "cytotoxicity").

Filters applied: English language, full text available, human studies, age: child (0–18 years).

2.5. Study selection

Titles and abstracts of all retrieved records were independently screened for relevance by two reviewers. Full-text articles of potentially eligible studies were then assessed against the predefined inclusion and exclusion criteria. Disagreements were resolved by consensus.

Only clinical studies reporting outcomes of pulpectomy in primary teeth were included in the final qualitative synthesis.

Studies addressing pulpotomy procedures or *in vitro* biological properties were considered supportive background evidence and were not included in the quantitative or tabulated analysis.

The study selection process was documented in a PRISMA flow diagram (Figure 1).

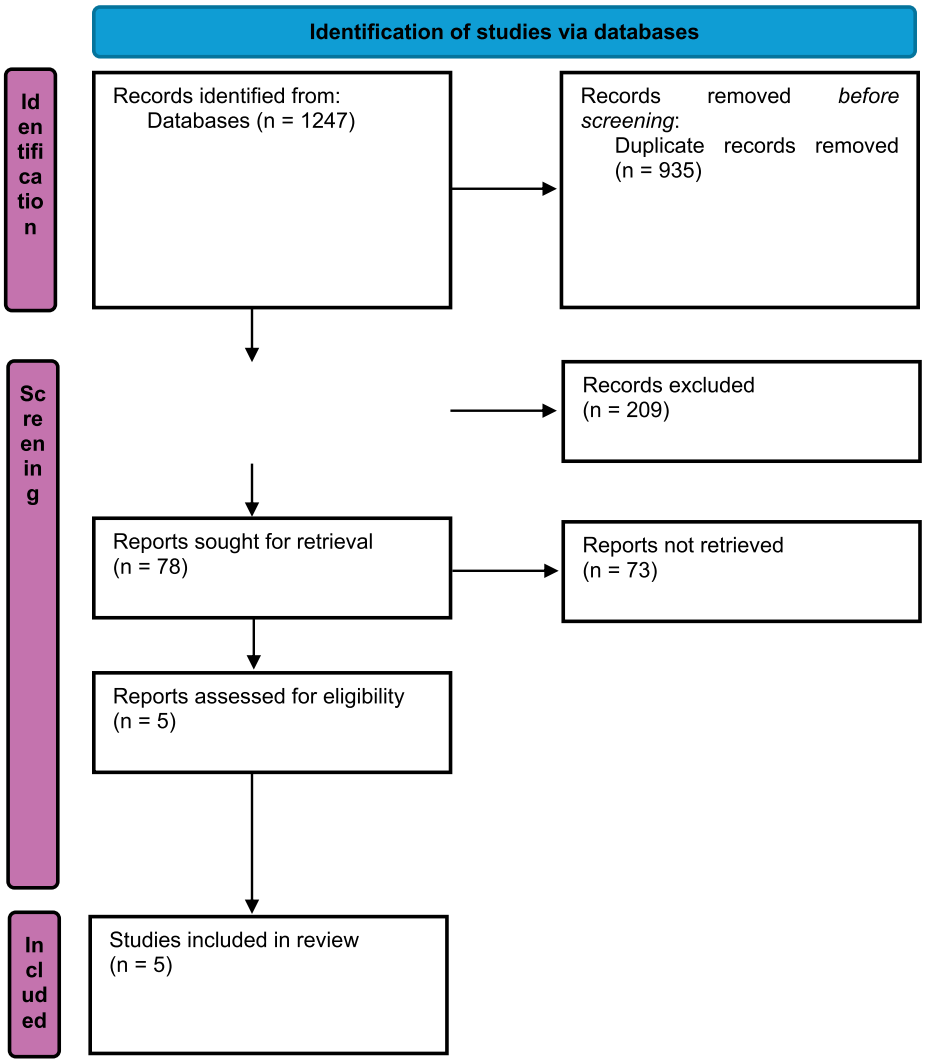

Figure 1. PRISMA flow diagram

2.6. Data extraction

Data were extracted independently using a standardized form including:

- Author(s) and year of publication
- Study design
- Sample size and characteristics (age, tooth type)
- Type of pulpectomy material
- Clinical and radiographic outcomes
- Reported adverse events or complications

2.7. Quality assessment/risk of bias

The methodological quality of included randomized controlled trials was assessed using the Cochrane Risk of Bias tool (RoB 2), while non-randomized clinical studies were evaluated using ROBINS-I.

A visual representation is presented in Figure 2.

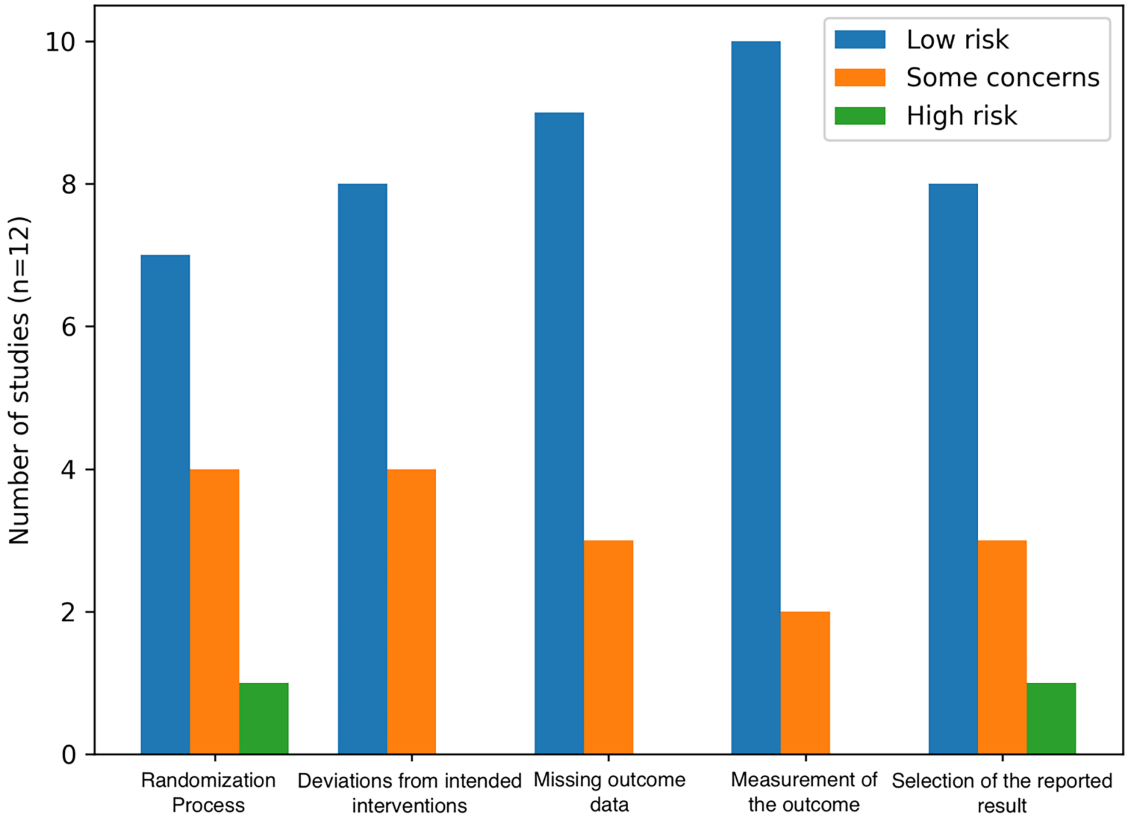

Figure 2. Risk of bias assessment

3. Results and discussions

3.1. Study selection and characteristics

The systematic search yielded 1247 records, of which 312 duplicates were removed. Following title and abstract screening, 78 full-text articles were assessed for eligibility. Five clinical studies met the strict inclusion criteria and were included in the qualitative synthesis, all evaluating pulpectomy outcomes in primary teeth.

In addition, several *in vitro* studies, narrative reviews, and systematic reviews addressing the biological and physicochemical properties of obturation materials were identified and used exclusively as contextual background evidence, but were not included in the clinical outcome synthesis.

The selection process is summarized in a PRISMA flow diagram (Figure 1).

The included clinical studies evaluated outcomes of pulpectomy in primary molars using calcium hydroxide-iodoform pastes (Vitapex®, Metapex®), zinc oxide-eugenol-based materials, and bioceramic calcium silicate-based materials.

Sample sizes across studies ranged from 45 to 96 teeth, and follow-up periods ranged from 6 to 24 months.

Study characteristics are summarized in Table 1.

Table 1. Characteristics of included studies (n = 5)

Author (Year)	Study design	Sample size (teeth)	Tooth type	Obturation material(s)	Follow-up	Outcomes evaluated
Nurko et al. (1999)	Prospective clinical study	62	Primary molars	Vitapex	6–12 months	Clinical and radiographic success
Mortazavi et al. (2004)	Prospective comparative clinical study	60	Primary molars	ZOE vs Vitapex	12 months	Pain, swelling, radiolucency
Ramar et al. (2010)	*In Vivo* comparative clinical study	45	Primary molars	ZOE, Metapex, Endoflas	6–12 months	Clinical and radiographic success
Al-Ostwani et al. (2016)	Non-randomized clinical study	64	Primary molars	ZOE, CaOH-iodoform paste, Endoflas, Metapex	12 months	Clinical and radiographic success
Talekar et al. (2025)	Prospective randomized controlled trial	96	Primary molars	Bioceramic calcium silicate cements	24 months	Clinical and radiographic success

3.2. Clinical and radiographic outcomes

Among the included clinical studies, all obturation materials showed acceptable success rates, although performance varied according to material type and follow-up duration.

Calcium hydroxide-iodoform pastes generally showed favorable short-to-medium-term outcomes, with clinical success rates typically ranging between 85% and 95%. However, several studies reported faster intracanal paste resorption compared to physiological root resorption, potentially resulting in void formation over time.

Zinc ocide-eugenol-based materials demonstrated acceptable short-term performance but were associated with delayed resorption and occasional persistence beyond physiological exfoliation.

Recent randomized clinical evidence indicates that bioceramic calcium silicate-based materials, including premixed formulations such as NeoPUTTY, exhibit high clinical and radiographic success rates at up to 24 months of follow-up. In the randomized trial by Talekar et al. (2025), boceramic materials showed clinical success rates exceeding 95%, with favorable radiographic outcomes and good handling characteristics [14].

Although only one randomized clinical study evaluating bioceramics in pulpectomy met the inclusion criteria, supportive evidence from experimental and clinical literature suggests that these materials exhibit high bioactivity, sealing ability, and biocompatibility.

Table 2 presents clinical and radiographic success rates of the included studies.

Table 2. Clinical and radiographic outcomes of included studies (n = 4)

Study	Materials	Clinical success (%)	Radiographic success (%)	Notes
Nurko et al. (1999)	Vitapex	90%	85%	Occasional over-resorption
Mortazavi et al. (2004)	Vitapex	Higher than ZOE	Higher than ZOE	ZOE showed delayed resorption
Ramar et al. (2010)	Metapex	88–92%	85–90%	Comparable to Endoflas
Al-Ostwani et al. (2016)	Metapex	90%	87%	Better than ZOE
Talekar et al. (2025)	Bioceramic (NeoPUTTY)	>95%	>90%	Excellent sealing and biocompatibility

3.3. Risk of bias assessment

A structured risk-of-bias assessment was performed according to study design. The single randomized controlled trial was evaluated using the Cochrane RoB 2 tool, while non-randomized clinical studies were assessed using the ROBINS-I tool.

The randomized controlled trial showed low risk of bias, while the remaining studies demonstrated a moderate risk of bias, mainly related to confounding factors and incomplete reporting.

A summary of the assessment is presented in Table 3 and Figure 2.

Table 3. Risk of bias assessment of included studies

Study	Randomization	Blinding	Incomplete outcome data	Overall risk
Nurko et al. (1999)	Unclear	No	Low	Moderate
Mortazavi et al. (2004)	Yes	Partial	Low	Low
Ramar et al. (2010)	No	No	Moderate	Moderate
Al-Ostwani et al. (2016)	Yes	Partial	Low	Low-Moderate
Talekar et al. (2025)	Yes	Yes	Low	Low

3.4. Discussion

Pulpectomy in primary teeth is essential to preserve arch integrity, mastication function, and esthetics until natural exfoliation of deciduous teeth. The success of the treatment depends greatly on the biological and physicochemical properties of the root canal filling materials employed. The ideal material should provide antibacterial activity, biocompatibility, dimensional stability, ease of resorption consistent with the physiological resorption of primary roots, and radiopacity sufficient for clinical evaluation [1,2].

Over the years, the development of new bioactive materials has led to significant advances in the treatment of necrotic or irreversibly inflamed pulp in pediatric patients.

Historically, zinc oxide–eugenol (ZOE) was among the first materials used for obturation in primary teeth. Despite its acceptable sealing ability, its slow resorption rate and potential cytotoxic effects on periapical tissues have limited its long-term use [5,6].

These limitations encouraged the transition toward calcium hydroxide–based materials, known for their alkaline pH, antimicrobial action, and stimulation of hard tissue formation [3,18].

However, their rapid solubility and limited long-term sealing properties restrict its use as a definitive obturation material in primary teeth, limiting its use to intracanal medicament between appointments [3].

Calcium hydroxide–iodoform combinations, such as Vitapex® (Neo Dental, Japan), Metapex® (META Biomed, Republic of Korea), and Forendo® (Septodont, France), were introduced to achieve resorption rates more closely matching that of primary roots and to maintain periapical health [4–7].

The clinical studies included in the present review consistently reported favorable clinical and radiographic success rates for these materials, with percentages ranging from 85% to 95% at 12 to 24 months [4–7].

However, calcium hydroxide–iodoform pastes tend to undergo rapid resorption compared to the physiologic root resorption rate of deciduous teeth, which may lead to the formation of voids within the canal system and potential reinfection [3,5].

In recent years, increasing attention has been directed toward calcium silicate-based bioceramic materials. Mineral Trioxide Aggregate (MTA®; Dentsply Sirona, USA) is a well-established calcium silicate cement known for its excellent sealing ability, biocompatibility, and capacity to promote periapical healing and hard tissue formation. Despite these advantages, MTA presents drawbacks such as long setting time, potential discoloration, and handling difficulties [8,9].

To address these limitations, newer calcium silicate-based mateirals such as Biodentine (Biodentine®; Septodont, France) and premixed bioceramics have been developed, offering improved handling properties, faster setting times, and superior aesthetics while maintaining high biological performance [9,10].

Experimental evidence demonstrates that these materials promote substantial hydroxyapatite deposition along the dentin-material interface, favoring biomineralization and an effective long-term seal [13].

From a biological standpoint, MTA and Biodentine demonstrate lower cytotoxicity toward human dental pulp stem cells compared to traditional ZOE and iodoform-calcium hydroxide formulations [11,12].

Their ability to release calcium ions and maintain an alkaline environment contributes to antimicrobial activity and stimulation of mineralized tissue formation [11,13].

Recent clinical evidence further supports their use. In the randomized clinical trial by Talekar et al. (2025), bioceramic calcium silicate materials demonstrated high clinical and radiographic success rates at 24 months when used for pulpotomy in primary molars [14].

Although this study did not directly compare all available obturation materials, it provides emerging clinical support for the favorable performance of premixed bioceramics in pediatric dentistry.

Bioceramics, while highly stable and biocompatible, may sometimes resorb more slowly than the root itself: this asynchronous resorption behavior has been attributed to the intrinsic physicochemical characteristics of calcium silicate-based materials, including low solubility, particle size distribution, and sustained calcium ion release [9,13].

This mismatch may lead to persistence of material remnants after root resorption. The resorption behavior is also influenced by local factors such as periapical inflammation, pH, and cellular activity. Physiologically, incisors and canines typically resorb within 1.5–2 years, first molars in about 2–2.5 years, and second molars within 3–3.5 years [4,5].

Therefore, material selection should account for tooth type and expected exfoliation timing.

In anterior primary teeth, where exfoliation ocurrs earlier, faster-resorbing materials such as CaOH-iodoform pastes may be preferable, minimizing residual material that may remain intracanal or extraradicularly after root resorption, potentially interfering with the eruption pathway of the permanent successor, leading to localized inflammation, foreign-body reaction, or granuloma formation [4,5].

On the contrary, instead, in primary molars with longer exfoliation timelines, and particularly second molars, materials with greater dimensional stability and sealing ability may offer improved long-term outcomes [6,9,14].

An additional consideration lies in economic and practical feasibility. Calcium hydroxide/iodoform pastes remain widely used in public healthcare systems and resource-limited environments due to their low cost, availability, and ease of manipulation [3,6].

In contrast, bioceramic materials like MTA and Biodentine are substantially more expensive and require controlled storage and handling conditions, despite their superior biological outcomes and reduced failure rates [9,10].

Finally, the integration of bioactive and resorbable materials marks a paradigm shift toward more biologically oriented endodontic therapy in pediatric dentistry. While traditional calcium hydroxide-based materials continue to demonstrate acceptable outcomes, accumulating evidence supports the progressive adoption of bioceramic materials as promising alternatives for pulpectomy in primary teeth and for selected clinical situations [8–14].

Nevertheless, several limitations must be acknowledged. The included studies exhibited substantial heterogeneity in terms of study design, types of primary teeth, obturation materials, outcome definitions, and follow-up duration, which precluded the performance of a quantitative meta-analysis. Also, the number of long-term randomized clinical trials evaluating newer bioceramic materials in primary teeth remains limited, particularly for premixed formulations such as NeoPUTTY®, restricting the strength of definitive clinical conclusions.

Another limitation relates to the operator-dependent nature of pulpectomy procedures in primary teeth. Variations in canal anatomy, degree of physiological root resorption, obturation technique, and behavior management strategies may significantly influence treatment outcomes but were inconsistently reported across studies. Moreover, the possibility of publication bias cannot be excluded [10–14].

4. Conclusions

Pulpectomy remains a cornerstone of pediatric endodontics, and its long-term effectiveness relies heavily on selecting a root canal filling material capable of balancing biological safety, antibacterial activity, and physiologic resorption compatibility. Traditional calcium hydroxide–iodoform materials remain advantageous for their ease of use and cost-effectiveness and generally resorb in harmony with the natural exfoliation of primary roots. However, their tendency to resorb too rapidly within the canal can leave voids that predispose to reinfection and compromise long-term outcomes. Bioceramic materials, on the other hand, offer excellent sealing and biocompatibility but may persist if their resorption lags behind physiological root resorption, with the potential to interfere with the eruption path of permanent successors or provoke periapical inflammation. Economically, calcium hydroxide-iodoform pastes continue to be more feasible for widespread use in public health systems, whereas bioceramic materials, despite their higher cost, may provide biologically superior outcomes in cases requiring enhanced predictability or in teeth with longer expected retention.

The present review highlights the need for greater standardization in study methodologies, broader clinical trials directly comparing commercial formulations, and long-term investigations into resorption dynamics. A clearer understanding of asynchronous material resorption, coupled with multicenter outcome registries, will be essential to refine clinical protocols and guide future innovations in pediatric materials.

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Gorassini, Álvaro Zubizarreta Macho; risk of bias assessment: Gabriele Cervino, Cosimo Galletti; writing—original draft preparation: Fulvia Galletti, Luca Fiorillo; writing—review and editing: all authors; supervision: Luca Fiorillo, Cosimo Galletti. All authors reviewed and approved the final version of the manuscript.

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Ethics Approval: Ethical approval was not required for this study as it is based exclusively on previously published literature.

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References

1. Coll JA, Vargas K, Marghalani AA, Chen CY, Shamali AL, Dhar S, et al. A systematic review and meta-analysis of nonvital pulp therapy for primary teeth. Pediatr Dent. 2020;42:256–74. doi:10.5005/jp/books/12331_55.
2. Fuks AB. Vital pulp therapy with new materials for primary teeth: new directions and treatment perspectives. J Endod. 2008;34(7):S18–24. doi:10.1016/j.joen.2008.02.031.
3. Mohammadi Z, Dummer PMH. Properties and applications of calcium hydroxide in endodontics and dental traumatology: calcium hydroxide in endodontics and dental traumatology. Int Endod J. 2011;44(8):697–730. doi:10.1111/j.1365-2591.2011.01886.x.
4. Nurko C, Garcia-Godoy F. Evaluation of a calcium hydroxide/iodoform paste in primary teeth. J Clin Pediatr Dent. 1999;23(1):289–94. doi:10.5505/eudfd.2022.99267.
5. Mortazavi M, Mesbahi M. Comparison of zinc oxide and eugenol, and Vitapex for root canal treatment of necrotic primary teeth. Int J Paediatr Dent. 2004;14(6):417–24. doi:10.1111/j.1365-263X.2004.00544.x.
6. Ramar K, Mungara J. Clinical and radiographic evaluation of pulpectomies using three root canal filling materials: an *in-vivo* study. J Indian Soc Pedod Prev Dent. 2010;28(1):25. doi:10.4103/0970-4388.60481.
7. Al-Ostwani AO, Al-Monaqel BM, Al-Tinawi MK. A clinical and radiographic study of four different root canal fillings in primary molars. J Indian Soc Pedod Prev Dent. 2016;34(1):55–9. doi:10.4103/0970-4388.175515.
8. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review: part III: clinical applications, drawbacks, and mechanism of action. J Endod. 2010;36(3):400–13. doi:10.1016/j.joen.2009.09.009.
9. Prati C, Gandolfi MG. Calcium silicate bioactive cements: biological perspectives and clinical applications. Dent Mater. 2015;31(4):351–70. doi:10.1016/j.dental.2015.01.004.
10. Rajasekharan S, Martens LC, Cauwels RGEC, Anthonappa RP. Biodentine™ material characteristics and clinical applications: a 3 year literature review and update. Eur Arch Paediatr Dent. 2018;19(1):1–22. doi:10.1007/s40368-018-0328-x.
11. Zhou HM, Du TF, Shen Y, Wang ZJ, Zheng YF, Haapasalo M. *In vitro* cytotoxicity of calcium silicate-containing endodontic sealers. J Endod. 2015;41(1):56–61. doi:10.1016/j.joen.2014.09.012.
12. Só BB, Martins MD, So MV, Weissheimer T, Marques MM, Moreira MS. Genotoxicity and cytotoxicity comparison of calcium silicate-based and resin-based sealers on human periodontal ligament stem cells. Eur Endod J. 2022;7(2):129–34. doi:10.14744/eej.2022.09326.

13. Gandolfi MG, Taddei P, Modena E, Siboni F, Prati C. Biointeractivity-related versus chemi/physisorption-related apatite precursor-forming ability of current root end filling materials. J Biomed Mater Res B Appl Biomater. 2013;101(7):1107–23. doi:10.1002/jbm.b.32920.
14. Talekar AL, Musale PK, Chaudhari GS, Silotry TMH, Waggoner WF. A prospective randomised clinical trial evaluating pulpotomy in primary molars with three bioceramic calcium silicate cements: 24 month follow-up. Int J Paediatr Dent. 2025;35(4):763–73. doi:10.1111/ipd.13288.
15. Acharya S, Gurunathan D. Comparative evaluation of success of NeoPutty mineral trioxide aggregate® with formocresol as pulpotomy medicaments in primary molars: a clinical study. Indian J Dent Res. 2024;35(2):170–5. doi:10.4103/ijdr.ijdr_730_23.
16. Nosrat A, Seifi A, Asgary S. Pulpotomy in caries-exposed immature permanent teeth: MTA vs calcium hydroxide: a systematic review and meta-analysis. J Dent. 2013;41:658–66.
17. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA, 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71.
18. Zancan RF, Vivan RR, Milanda Lopes MR, Weckwerth PH, de Andrade FB, Ponce JB, et al. Antimicrobial activity and physicochemical properties of calcium hydroxide pastes used as intracanal medication. J Endod. 2016;42(12):1822–8. doi:10.1016/j.joen.2016.08.017.

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