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Pulp Therapy of Primary Dentition; its Relevance despite Insufficient Histological Evidence: A Review

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Pulp treatment in primary dentition is generally divided into vital and non-vital pulp therapies and assists in the preservation of pulpally involved primary teeth in the dental arch until the affected tooth naturally exfoliates. The success of pulp therapies depends on several factors; *e.g.* proper case selection, accurate diagnosis and good coronal seal. To date, studies on the success and failure rates of pulp treatments are based on clinical signs and symptoms, radiographic findings and histological analysis. However, the clinical and radiographic evidence may not completely portray the true status of the dental pulp. Histological evidence remains the gold standard in the assessment of pulp condition, whether it is in a healthy or adverse state. The aims of the current research were to summarise the treatment outcomes of pulp therapy in primary dentition based on clinical, radiographic and histological criteria, and to support its relevance in the presence of limited histological evidence to measure authentic treatment success. An electronic database search of dental literature from 1990 to 2022 was carried out using the MEDLINE, *i.e.* PubMed, database. Current dental literature showed that the success rates of primary tooth pulp therapy are high. The obtained results were based largely on clinical and radiographic studies with narrow histological investigations to assess the treatment outcome(s) of pulp therapy in primary dentition. Despite the scarcity of histological evidence, pulp therapies in primary teeth are still practical due to their statistically empirical success compared to their failure. Consequently, pulp therapy of primary dentition is still relevant, and should continue to be indicated as an important treatment option.

Keywords: Histological Evidence; Primary Dentition; Pulp Therapy; Success Rate; Treatment Outcome

Introduction

In primary dentition, different treatment modalities of vital pulp therapy (VPT) are available, namely indirect pulp treatment, direct pulp capping and pulpotomy. The objective of VPT is to treat reversible pulpal inflammation, and preserve pulp vitality and function(s) [1]. The early diagnosis of pulp and periradicular status, preservation of pulp vitality and decent pulp vascularization are essential for the success of VPT [2]. Non-vital pulp therapy conserves primary teeth which would, otherwise, be lost from tooth extraction when the pulp is irreversibly inflamed [3].

To date, assessments on the success or failure of pulp treatment in primary dentition have been based upon clinical and/or radiographic evidence [4]. Criteria for clinical success include a tooth which does not show any signs or symptoms; e.g. abscess, pain, swelling, fistula, tenderness to percussion and excessive mobility [5]. Furthermore, radiographic success is measured based on the absence of radicular and/or periapical radiolucency, internal root resorption and cystic development as well as healthy supporting tissues, normal physiologic resorption and primary tooth exfoliation, and normal formation and eruption of successor permanent tooth [5]. However, the stated criteria are not the actual indicators of treatment success. The true benchmark and the most reliable criteria in determining success or failure in pulp therapy is based on histological evidence [6].

Although histological analysis remains the true "gold standard" of pulp status [6], clinicians make treatment decisions based on the already-set criteria to determine treatment success

or failure. Majority of scientific literature has reported success or failure rates using clinical and radiographic criteria [7-13]. However, the aforementioned criteria may not be the reflection of true success or failure in the treatment which combines clinical, radiographic and histological evidence. It is not possible to carry out a histological examination of the pulp in treated teeth during recall appointments [14]. However, the sole use of clinical and/or radiographic findings as standard criteria to be considered a true measure for the treatment outcome, in the scarcity of histological data, is yet to be investigated.

A search strategy of electronic databases was performed using MEDLINE (PubMed). A combination of keywords, including ("indirect pulp therapy" OR "direct pulp capping" OR "pulpotomy" OR "pulpectomy") AND ("primary tooth" OR "primary teeth") AND ("children" OR "paediatric" OR "pediatric"), were used. Twenty nine articles were retrieved from the combination search of "(indirect pulp therapy) AND (primary tooth OR primary teeth) AND (children OR paediatric OR pediatric)"; 23 articles from the combination search of "(direct pulp capping) AND (primary tooth OR primary teeth) AND (children OR paediatric OR pediatric)"; 175 articles from the combination search of "(pulpotomy) AND (primary tooth OR primary teeth) AND (children OR paediatric OR pediatric)", and 127 articles from the combination search of "(pulpectomy) AND (primary tooth OR primary teeth) AND (children OR paediatric OR pediatric)". The current study included clinical trials, randomised controlled trials, literature reviews, systematic reviews, and meta-analyses on the pulp therapy of primary dentition published from January 1990 until October 2022. The database search was limited to references in English language only. No other additional filters were involved in the search.

The present review aims to summarize the treatment outcome(s) of pulp therapy in primary dentition based on the clinical, radiographic and histological criteria, and to support its relevance in the presence of limited histological evidence. Therefore, the current study could assist clinicians to make sound clinical decisions when carrying out pulp therapy in primary dentition.

Vital Pulp Therapy

Vital pulp therapy is defined as a treatment which aims to preserve and maintain the dental pulp connective tissue that has been compromised; nevertheless, the pulp has not become degenerated and/or necrotic by caries, trauma or restorative procedures [15, 16]. The selection of different treatment modalities in VPT depends on the exposure of the dental pulp. If the cavity is extensive with no pulp exposure, indirect pulp treatment would be the treatment of choice; however, direct pulp capping or partial/full pulpotomy are indicated for the exposed vital pulp [17].

Indirect pulp treatment

Indirect pulp treatment (IPT) is performed in a tooth with a deep carious lesion approximating the pulp but without signs or symptoms of pulpal degeneration [18]. The modality involves the removal of gross caries whilst allowing sufficient caries to remain over the pulp horn/chamber to avoid pulp exposure. The cavity is usually sealed with a biocompatible material [19], while a liner is placed over the remaining carious dentine to allow pulp to repair itself [17]. Contemporary liner materials include glass ionomer cement (GIC), resin-modified glass ionomer cement (RMGIC), adhesive resin, calcium hydroxide [20], mineral trioxide aggregate (MTA),and silicate cement [21].

Clinical and radiographic studies

The decision on how much carious dentine needs to be removed, particularly in deep caries risking pulp exposure, remains controversial. Long-term studies on IPT have demonstrated a high 3-year survival rate of 96% in primary molars [22]. Researchers have shown that high clinical and radiographic success rates could still be accomplished with incomplete excavation of deep caries, leaving behind affected dentine. [22]. In addition, partial caries removal represents a better approach compared to complete caries removal in deep lesions to reduce the risk of pulp exposure; however, the necessity (to re-enter) for further excavation could not be justified due to scarce evidence [23].

The high success rate of IPT in primary dentition has been reported by many authors (Table 1). Farooq *et al.* [24] demonstrated the normal exfoliation of all primary molars treated with IPT, while 38% of formocresol pulpotomy group demonstrated early exfoliation. Comparable studies showed 36% of formocresol treated teeth exfoliated early compared to 2% of IPT group [25]. At three-year follow up, Wunsch *et al.* [7] found that IPT had a significant survival rate (96.2%) compared to formocresol pulpotomy (65.8%) and ferric sulphate pulpotomy (62.9%) of primary molars. Similarly, a significantly higher overall success rate was observed in IPT (93.0%) in comparison to ferric sulphate pulpotomy at 4-year follow-up studies [26].

Apart from accurate diagnosis, appropriate case selection and technique of treatment, achieving an optimal marginal seal is imperative for the longevity of IPT [27, 28]. Moreover, the use of a base over a calcium hydroxide liner and the placement of a stainless steel crown (SSC) have considerably increased the success of IPT [28].

Table 1. Studies on indirect pulp treatment

Author	Materials	Follow-up period	Sample size	Treatment outcome
Farooq *et al.* [24]	IPT (GIC) *vs* FC pulpotomy	2-7 years	133 primary molars	Overall success rate: IPT=93% FC=74%
Falster *et al.* [29]	Adhesive resin *vs* CaOH	24 months	48 primary molars	Success rate: Adhesive resin=96%; CaOH=83% Interradicular/periapical lesions: Adhesive resin=4%; CaOH=13%
Al-Zayer *et al.* [28]	CaOH	2 weeks-73 months	187 primary molars	Overall success rate=95%
Vij *et al.* [25]	IPT *vs* FC pulpotomy		226 primary molars	Overall success rate: IPT=94%; FC=70%
Franzon *et al.* [30]	IPT (CaOH *vs* gutta-percha)	36 months	39 primary molars	Overall success rate: CaOH=73.3%; Gutta-percha=85.7%
Buyukgural & Cehreli [31]	Adhesive resin *vs* CaOH	24 months	240 primary molars	Clinical and radiographic success rates: Adhesive resin=100%; CaOH=100%
Gruythuysen *et al.* [22]	RMGIC	3 years	125 primary molars 45 permanent teeth	Overall success rate: Primary molars=96%; Permanent teeth=93%
Rosenberg *et al.* [27]	RMGIC	1 year	60 primary molars	Clinical and radiographic success rates: 3-month=100%; 6-month=98%; 12-month=97%
Trairatvorakul & Sastararuji [20]	IPT (CaoH) *vs* antibiotic sterilization (3Mix-MP)	6-29 months	82 primary molars	Overall success rate: At 6-11 months; IPT=82%; 3Mix-MP =81% At 12-29 months IPT=94%; 3Mix-MP =78%
Mathur *et al.* [32]	IPT (CaOH, GIC, MTA)	8 weeks, 6 and 12 months	109 primary molars	At 12 months Clinical and radiographic success rate: CaOH=93.6%; GIC=97%; MTA=100%
Boddeda *et al.* [33]	IPT (Biodentine, RMGIC, CaOH)	3-12 months	54 primary molars	At 3 months Clinical success rate: Biodentine=100%; RMGIC=94.4%; CaOH=100% Radiographic success rate: Biodentine=100%; RMGIC=94.4%; CaOH=100% At 6 months Clinical success rate: Biodentine=100%; RMGIC=100%; CaOH=100% Radiographic success rate: Biodentine=100%; RMGIC=100%; CaOH=100% At 12 months Clinical success rate: Biodentine=100%; RMGIC=100%; CaOH=94.4% Radiographic success rate: Biodentine=100%; RMGIC=100%; CaOH=94.4%
Sahin *et al.* [34]	IPT (CaOH, Biodentine, TheraCal LC)	6-24 months	109 primary molars	At 24 months Clinical and radiographic success rates: CaOH=100%; Biodentine=100%; TheraCal LC=93.3%
Kalaskar *et al.* [35]	IPT (Ozonoid olive oil *vs* CaOH)	6 and 12 months	30 primary molars	Clinical and radiographic success rates: Olive oil=93.3%; CaOH=100%
Saber *et al.* [36]	CHX *vs* MTA	12 months	80 primary molars	Overall success rate: CHX=97%; MTA=97%

IPT=Indirect Pulp Treatment, CaOH=calcium hydroxide, CHX=chlorhexidine gluconate, FC=formocresol, GIC=glass ionomer cement, IPT=indirect pulp treatment, MTA=mineral trioxide aggregate RMGIC=resin-modified glass ionomer cement,

Histological studies

Histological evaluations of dentine and pulp tissue responses in primary teeth receiving IPT are scanty. Sahin *et al.* showed that the clinical and radiographic success rates of primary teeth receiving different pulp capping materials in IPT were high. However, resin-based tricalcium silicate did not exhibit a favourable histological response to the pulp compared to hard-setting calcium hydroxide or bioactive tricalcium silicate [34]. Lutfi *et al.* [37] investigated the presence and characterization of stem cells derived from the remaining dental pulp of 50 exfoliated primary molars, which had

calcium hydroxide or GIC as liner for indirect pulp capping. The results obtained from immunocytochemistry and flow cytometry showed non-significant differences in the proliferation rate of stem cells between control, calcium hydroxide and GIC groups indicating favourable response of pulp cells to both materials. The positive reactivity of stem cells for CD105 and CD166 antibodies proved the presence of mesenchymal stem cells in the remaining dental pulp. In addition, histological examination of teeth from both groups revealed the formation of reactionary dentine by remaining viable odontoblasts and from the buffering effects of residual dentine.

Direct pulp capping

Direct pulp capping (DPC) is advocated when there is a pin-point mechanical pulp exposure during cavity preparation or as a consequence of dental trauma in an asymptomatic tooth [38] free from oral contaminants [39]. It is recommended that carious pulp exposure in primary teeth should not be pulp capped [39], although there has been promising evidence in mature teeth [40].

Clinical and radiographic studies

Several materials have been proposed for DPC in the primary tooth; including mineral trioxide aggregate (MTA), calcium hydroxide, bioactive glass, calcium enriched mixture (CEM) cement and enamel matrix derivative (Table 2). Apart from its use in pulpotomy, formocresol has been proposed as a premedication in the DPC of pulp carious exposed human primary molars. Researchers have found that after a 2-year follow-up, both clinical and radiographic success rates of premedicated DPC using formocresol were significantly higher compared to conventional DPC using calcium hydroxide powder [41].

Comparative studies of MTA as a DPC agent in primary teeth have been promising. Caicedo *et al.* [14] demonstrated favourable clinical and radiographic responses in 80% of primary teeth pulp-capped with MTA. A novel pulp capping material, *i.e.* 3Mixtatin (combination of simvastatin and 3Mix), has been compared with MTA, 3Mix (combination of metronidazole, minocycline and ciprofloxacin) and simvastatin to treat traumatic non-caries pulp exposure in 160 primary molars [42]. The treatment outcomes between MTA and 3Mixtatin have not been statistically significant; however, the latter has shown statistically excellent results compared to 3Mix and simvastatin individually.

Table 2. Studies on direct pulp capping

Author	Materials	Follow- up period	Sample size	Treatment outcome
Caicedo *et al.* [14]	DPC (CaOH) *vs* MTA pulpotomy	1, 2, 3, 4 and 5 months	21 primary teeth (DPC=10, pulpotomy=11)	Post-operative pain & signs of pulp degeneration: MTA=9.1%; CaOH=20% Radiographic success rate: MTA=100%; CaOH=100%
Aminabadi *et al.* [41]	FC vs CaOH	6- and 12-months intervals for 2 years	120 primary molars (CaOH=60, FC=60)	Clinical success rate: CaOH=61.7%; FC=90% Radiographic success rate: CaOH=53.3%; FC=85%
Fallahinejad Ghajari *et al.* [44]	CEM cement *vs* MTA	6 months	42 primary molars	Clinical success rate: CEM cement=94.8%; MTA=100%
Kotsanos *et al.* [45]	CaOH	21 months	60 primary molars	Overall success rate=88.3%
Ulusoy *et al.* [43]	CaOH *vs* CSH	1 week-12 months	40 primary molars	Overall success rate: CaOH=81.2%; CSH=70.6%
Asl Aminabadi *et al.* [42]	MTA, 3Mixtatin, 3Mix, and Simvastatin	2, 6, and 12 months	160 primary molars	Overall success rate: MTA=93.8%; 3Mixtatin=91.9% 3Mix=62.5%; Simvastatin=57.1%
Songsiripradubboon *et al.* [46]	Acemannan *vs* CaOH	6 months	42 primary molars	Overall success rate: Acemannan=72.7%; CaOH=70.0%
Erfanparast *et al.* [47]	TheraCal *vs* MTA	12 months	92 primary molars	Overall success rate: MTA=94.5%; TheraCal=91.8%
Dimitraki *et al.* [48]	DPC (MTA) *vs* pulpotomy (MTA)	12, 24 and 36 months	97 primary molars	Overall success rate: At 12 months=79.7% At 24 months =66.0% At 36 months =66.0%
Ali & Raslan [49]	3Mix-MP *vs* CaOH	3-12 months	44 primary molars	Overall success rate: 3Mix-MP=54.5%; CaOH=77.3%
Chatzidimitriou *et al.* [50]	CaOH, Portland cement, and Biodentine	13 months	79 primary molars	Overall failure rate=16%

DPC=Direct Pulp Capping, CaOH=calcium hydroxide, CEM=calcium enriched mixture, CSH=calcium sulfate hemihydrate, FC=formocresol, MTA=mineral trioxide aggregate

At 12-month follow-up, DPC with calcium hydroxide and/or calcium sulphate hemihydrate has demonstrated a lower overall success rate of 75% [43]. Due to insignificant differences in the success rates between the mentioned materials, calcium sulphate hemihydrate has been regarded comparable to calcium hydroxide as a DPC agent for primary teeth.

Internal resorption and chronic pulp inflammation have been reported as frequent consequences when calcium hydroxide is used as a capping material in primary teeth [51]. The high failure rate of DPC in primary teeth may be associated with its high pulpal cellular content [52]; however, Kotsanos *et al.* demonstrated that 88.3% of primary molars treated with calcium hydroxide as DPC agent survived for 21.0 (+9.0) months, and the 4-year cumulative survival rate was 80.0%. Additionally, the high success rate of DPC in deep, carious primary molars using calcium hydroxide justified future work on the initial diagnosis of the reversibility of pulpal inflammation [45]. Nonetheless, and until then, DPC should be reserved in the primary teeth with exposed pulp which are expected to exfoliate within one or two years in older children [39]. There is insufficient data to support or refute any specific material for DPC in primary teeth [53]. An updated systematic review can warrant DPC in the primary teeth based on its favourable success rates [54].

Histological studies

Similar to IPT, histological studies regarding the effects of DPC on dentine and pulp in primary teeth are scarce. Haghgoo *et al.* [55] compared the pulp responses of two endodontic biocompatible materials, calcium-enriched mixture cement and bioactive glass, following direct pulp capping of primary canine teeth, and showed that the inflammation scores and hard tissue bridge formation were not significantly different between both groups. Similarly, previous studies have shown no significant differences in the pulp responses of primary canine teeth treated with MTA against bioactive glass [56]. Cehreli *et al.* [57] evaluated the effects of total-etch technique on mechanically exposed primary teeth pulps directly capped with different types of adhesive resin systems. Histopathological evaluation demonstrated various responses; including attempted/no dentinal bridge formation and mild to severe histological responses [57]. Thus, the authors did not support the use of dentine bonding agents following total-etch technique in DPC for primary teeth.

In another study, although the pulp of primary teeth favourably responded to DPC in clinical and radiographic evaluations as well as to pulpotomies using MTA, a range of histological reactions, *e.g.* normal odontoblasts, irregular odontoblasts, intra-pulpal calcifications, dentinal bridges, cementum formation, internal resorption, inflammatory infiltrations and pulp necrosis, were observed [14]. Hence, despite the absence of supportive histological evidence, favourable clinical and radiographic outcomes are sufficient to indicate treatment success.

Pulpotomy

Pulpotomy is performed when the pulp of a primary tooth with extensive caries is exposed; nevertheless, there is no evidence of radicular pathology during caries removal resulting in carious or mechanical pulp exposure [38]. By amputating the inflamed coronal pulp, the radicular pulp heals and remains vital until the tooth exfoliates naturally. Then, the surface of radicular pulp is treated and dressed with a medicament [58].

In the last 80 years, formocresol has been widely accepted as a pulpotomy agent due to its high clinical and radiographic success. Formocresol pulpotomy has been regarded as the most universally taught and preferred technique [39, 59], although there have been concerns regarding its toxicity [60] and systemic distribution [61, 62]. Despite the emergence of newer pulpotomy agents and scrutiny over formocresol, Walker *et al.* observed no major shift from the clinical use of formocresol in postgraduate paediatric residency programs [63]. Evidence have shown that formocresol has been unlikely to pose any risk to children when it is used in the typical dose for pulpotomy [64]. Bagrizan *et al.* substantiated the mentioned findings and found no significant difference in the mean plasma level of formaldehyde in children pre-/post-pulpotomy under general anaesthesia [65].

There have been considerable studies on alternative materials; *e.g.* glutaraldehyde, calcium hydroxide, ferric sulphate, bone morphogenetic protein, enamel matrix derivative, electrosurgery, sodium hypochlorite, MTA, and Ankaferd Blood Stopper (Table 3).

Clinical and radiographic studies

A meta-analysis comparing formocresol, ferric sulphate, calcium hydroxide, MTA and laser pulpotomy of the primary molars as well as other studies have revealed that MTA can be considered the most preferred material for pulpotomy [66, 67]. Similarly, the latest Cochrane systematic review comparing the treatment outcomes of primary molar pulpotomies between MTA and calcium hydroxide, and between MTA and formocresol has shown significant reduction in clinical and radiographic failures in MTA group [68]. Ferric sulphate has been advocated as a substitute to formocresol because the success rates of both materials have been clinically and radiographically comparable [69-71]. Ferric sulphate and electrosurgery have demonstrated

Table 3. Studies on pulpotomy

Author	Materials	Follow- up period	Sample size	Treatment outcome
Fuks *et al.* [76]	2% glutaraldehyde	6, 12 and 25 months	53 primary molars	Overall failure rate: 6 months=5.7%; 12 months=9.6%; 25 months=18%
Fei *et al.* [77]	FS *vs* FC	3, 6 and 12 months	83 primary molars	Clinical and radiographic success rates: FS=96.5%; FC=77.8%
Fishman *et al.* [78]	ZOE *vs* CaOH	1, 3 and 6 months	47 primary molars	At 6 months Clinical success rate: ZOE=77.39%; CaOH=81.0% Radiographic success rate: ZOE=54.6%; CaOH=57.3%
Fuks *et al.* [79]	FS *vs* FC	6-34 months	96 primary molars	Overall success rate: FS=92.7%; DFC=83.8%
Elliott *et al.* [80]	FC *vs* laser (carbon dioxide)	28 and 90 days	30 primary canines	At 28-day Clinical success rate: FC=100%; Laser=100% Radiographic success rate: FC=87.5%; Laser=87.5% At 90-dayClinical success rate: FC=100%; Laser=100% Radiographic success rate: FC=100%; Laser=86.7%
Shumayrikh & Adenubi [81]	G/ZOE *vs* G/CaOH	12 months	61 primary molars	Clinical success rate: G/ZOE=96.5%; G/CaOH=89.2% Radiographic success rate: G/ZOE=75.8%; G/CaOH=71.4%
Ibricevic & al-Jame [82]	FS *vs* FC	3-20 months	70 primary molars	Clinical success rate: FS=100%; FC=100% Radiographic success rate: FS=97.2%; FC=97.2%
Waterhouse *et al.* [83]	CaOH *vs* FC	6-24 months	84 primary molars	Clinical success rate: CaOH=77%; FC=84% Radiographic success rate: CaOH=77%; FC=84%
Chien *et al.* [84]	ZOE *vs* FS	3 months	145 primary teeth	Clinical and radiographic success rate: ZOE=100%; FS=100%
Eidelman *et al.* [85]	MTA *vs* FC	6-30 months	45 primary molars	Pulp canal obliteration: MTA=41%; FC=13%
Dean *et al.* [86]	ES *vs* FC	5 months	50 primary molars	Clinical success rate: ES=96%; FC=84% Radiographic success rate: ES=84%; FC=92%
Holan *et al.* [87]	FC (SSC *vs* amalgam restorations)	6-103 months	341 primary molars	Radiographic failure rate: FC-SSC=13%; FC-Amalgam=20%
Casas *et al.* [88]	FS *vs* RCT	24 months	291 primary molars	Clinical success rate: FS=96%; RCT=98%
Ibricevic & Al-Jame [89]	FS *vs* FC	42-48 months	164 primary molars	Clinical success rate: FS=96.4%; FC=97.5% Radiographic success rate: FS=92%; FC=94.6%
Agamy *et al.* [90]	Gray MTA, White MTA and FC	1, 3, 6 and 12 months	60 primary molars	Clinical success rate: At 1 month Gray MTA=100%; White MTA=100%; FC=100% At 3 months Gray MTA=100%; White MTA=95%; FC=100% At 6 months Gray MTA=100%; White MTA=95%; FC=100% At 12 months Clinical success rate: Gray MTA=100%; White MTA=80%; FC=90% Radiographic success rate: Gray MTA=100%; White MTA=80%; FC=90%

Casas *et al.* [91]	FS *vs* RCT (ZOE)	24 months	133 primary incisors	Clinical success rate: FS=78%; ZOE=100%
Kalaskar & Damle [92]	LPDP *vs* CaOH	1, 3 and 6 months	55 primary molars	Cumulative success rate: At 1 month LPDP=100%; CaOH=96.4% At 3 months LPDP=100%; CaOH=96.4% At 6 months LPDP=100%; CaOH=96.4%
Farsi *et al.* [93]	MTA *vs* FC	24 months	120 primary molars	Clinical success rate: MTA=100%; FC=98.6% Radiographic success rate: MTA=100%; FC=86.8%
Holan *et al.* [94]	MTA *vs* FC	4-74 months	62 primary molars	Overall success rate: MTA=97%; FC=83%
Huth *et al.* [95]	Er:YAG laser, CaOH, FS and FC	6, 12, 18 and 24 months	200 primary molars	Overall success rate: Er:YAG laser=93%; CaOH=87%; FS=100%; FC=96%
Markovic *et al.* [69]	FC, FS and CaOH	18 months	104 primary molars	Clinical success rate: FC=90.9%; FS=89.2%; CaOH=82.3% Radiographic success rate: FC=84.8%; FS=81.1%; CaOH=76.5%
Naik & Hedge [96]	MTA *vs* FC	1, 3 and 6 months	50 primary molars	At 1, 3 and 6 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=100%; FC=100%
Saltzman *et al.* [97]	FC-ZOE *vs* laser-MTA	2.3, 5.2, 9.5 and 15.7 months	52 primary molars	At 2.3, 5.2, 9.5 and 15.7 months Clinical success rate: FC-ZOE =100%; Laser-MTA=100% At 2.3 months Radiographic success rate: FC-ZOE=100%; Laser-MTA=95.8% At 5.2 months Radiographic success rate: FC-ZOE=100%; Laser-MTA=95% At 9.5 months Radiographic success rate: FC-ZOE=95%; Laser-MTA=77.8% At 15.7 months Radiographic success rate: FC-ZOE=84.6%; Laser-MTA=71.4%
Vargas & Packham [98]	FS *vs* FC	6-61 months	85 primary molars	Radiographic success rate: FS=43%; FC=56%; FS+FC=55%
Caicedo *et al.* [14]	DPC (CaOH) *vs* MTA pulpotomy	1, 2, 3, 4 and 5 months	21 primary teeth (DPC=10, pulpotomy=11)	Post-operative pain & signs of pulp degeneration: MTA=9.1%; CaOH=20% Radiographic success rate: MTA=100%; CaOH=100%
Liu [99]	Nd:YAG laser *vs* FC	6-66 months	137 primary molars	Overall success rate: Clinical success rate: Nd:YAG laser=97%; FC=85.5% Radiographic success rate: Nd:YAG laser=94.1%; FC=78.3%
Vargas *et al.* [100]	5% NaOCl *vs* FS	6 and 12 months	6 months: 60 primary molars (NaOCl=32, FS=28) 12 months: 27 primary molars (NaOCl=14, FS=13)	At 6 months Clinical success rate: NaOCl=100%; FS=100% Radiographic success rate: NaOCl=91%; FS=68% At 12 months Clinical success rate: NaOCl=100%; FS=85% Radiographic success rate:

				NaOCl=79%; FS=62%
Aeinehchi *et al.* [101]	MTA *vs* FC	3 and 6 months	100 primary molars	At 3 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=100%; FC=98.2% At 6 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=100%; FC=89.5%
Aminabadi *et al.* [102]	FC pulpotomy *vs* RCT(ZOE)	12 and 24 months	100 primary incisors	Clinical success rates: FC=86.9%; RCT=95.6% Radiographic success rates: FC=76.08%; RCT=91.3%
Bahrololoomi *et al.* [103]	ES *vs* FC	3, 6 and 9 months	70 primary molars	At 9 months: Clinical success rate: ES=96%; FC=100% Radiographic success rate: ES=84%; FC=96.8%
Moretti *et al.* [104]	MTA, CaOH and FC	3, 6, 12, 18 and 24 months	45 primary molars	Clinical success rate: MTA=100%; CaOH=64%; FC=100% Radiographic success rate: MTA=100%; CaOH=64%; FC=100%
Noorollahian [105]	MTA *vs* FC	6,12 and 24 months	56 primary molars	At 6 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=100%; FC=100% At 12 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=96.5%; FC=100% At 24 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=94.4%; FC=100%
Sabbarini *et al.* [106]	EMD *vs* FC	2, 4, and 6 months	30 primary molars	Clinical success rate: EMD=93%; FC=67% Radiographic success rate: EMD=60%; FC=13%
Sonmez *et al.* [107]	MTA, CaOH, FS and FC	6, 12, 18 and 24 months	80 primary molars	Overall success rate: MTA=66.6%; CaOH=46.1%; FS=73.3%; FC=76.9%
Trairatvorakul & Chunlasikaiwan [108]	ZOE *vs* Vitapex	6 and 12 months	54 primary molars	Success rates at 6 months: ZOE=48%; Vitapex=78% Success rates at 12 months: ZOE=85%; Vitapex=89%
Zurn & Seale [109]	CaOH *vs* FC	12-24 months	68 primary molars	Overall success rate: CaOH=56%; FC=94%
Alaçam *et al.* [110]	FC, CaOH, and CaOH/iodoform	1, 3, 6, 9 and 12 months	105 primary molars	At 1 month Clinical success rate: FC=100%; CaOH=100%; CaOH/iodoform=100% Radiographic success rate: FC=100%; CaOH=81.8%; CaOH/iodoform=82.8% At 3 months Clinical success rate: FC=100%; CaOH=87.9%; CaOH/iodoform=86.2% Radiographic success rate: FC=100%; CaOH=57.6%; CaOH/iodoform=51.7%

				At 6 months Clinical success rate: FC=96.6%; CaOH=66.7%; CaOH/iodoform=48.3% Radiographic success rate: FC=96.6%; CaOH=48.5%; CaOH/iodoform=27.6% At 9 months Clinical success rate: FC=96.6%; CaOH=66.7%; CaOH/iodoform=48.3% Radiographic success rate: FC=93.1%; CaOH=48.5%; CaOH/iodoform=27.6% At 12 months Clinical success rate: FC=89.7%; CaOH=33.3%; CaOH/iodoform=17.2% Radiographic success rate: FC=89.7%; CaOH=33.3%; CaOH/iodoform=13.8%
Sakai *et al.* [111]	PC *vs* MTA	3, 12, 18 and 24 months	30 primary molars	At 3, 12, 18 and 24 months Clinical success rate: PC=100%; MTA=100% Radiographic success rate: PC=100%; MTA=100%
Subramaniam *et al.* [112]	MTA *vs* FC	24 months	40 primary molars	Overall success rate: MTA=95%;FC=85%
Ansari & Ranjpour [113]	MTA *vs* FC	6, 12 and 24 months	40 primary molars	At 24 months Clinical success rate: MTA=93.3%; FC =60.0% Radiographic success rate: MTA=93.3%; FC=60.0%
Sonmez & Duruturk [72]	CaOH (SSC *vs* amalgam restorations)	12 months	154 primary molars	Overall success rate: CaOH-SSC=79.9%; CaOH-Amalgam=60%
Zealand *et al.* [114]	Grey MTA *vs* FC	6 months	252 primary molars	Clinical success rate: Grey MTA=100%; FC=97% Radiographic success rate: MTA=95%; FC=86%
Malekafzali *et al.* [115]	CEM cement *vs* MTA	6, 12 and 24 months	80 primary molars	At 12 months Radiographic success rate: CEM=98.75%; MTA=96.25%
Erdem *et al.* [70]	MTA, FS, FC and ZOE	6, 12 and 24 months	128 primary molars	Overall success rate: MTA=96%; FS=88%; FC=88%; ZOE=68%
Kurji *et al.* [116]	FC	5 years	557 primary molars	Clinical success rate=99% Radiographic success rate=90% Cumulative 5-yr survival rate=87%
Liu *et al.* [117]	MTA vs CaOH	10-56 months	34 primary molars	Success rate: MTA=94.1%; CaOH=64.7%
Nematollahi *et al.* [118]	Electrosurgical (ZOE *vs* ZPC sub-base)	3, 6 and 12 months	120 primary second molars	At 12 months Clinical success rate: ES-ZOE=98.2%; ES-ZPC=96.2% Radiographic success rate: ES-ZOE=84.2%; ES-ZPC=75%
Srinivasan & Jayanthi [119]	MTA *vs* FC	3, 6, 9 and 12 months	100 primary second molars	At 3 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=100%; FC=100% At 6 months Clinical success rate: MTA=100%; FC=100% Radiographic success rate: MTA=100%; FC=90% At 9 months Clinical success rate:

				MTA=100%; FC=91.6% Radiographic success rate: MTA=95.7%; FC=81.25% At 12 months Clinical success rate: MTA=100%; FC=91.3% Radiographic success rate: MTA=95.7%; FC=78.2%
Airen *et al.* [120]	MTA *vs* FC	6, 12 and 24 months	70 primary molars	Clinical success rate: MTA=97%; FC=85% Radiographic success rate: MTA=88.6%; FC=54.3%
Howley *et al.* [11]	FC pulpotomy *vs* Vitapex pulpectomy	23 months	74 primary incisors	Radiographic success rate: FC pulpotomy=89%; Vitapex pulpectomy=73%
Huth *et al.* [121]	Er:YAG laser, CaOH, FS and FC	6, 12, 18, 24 and 36 months	200 primary molars	At 36 months Clinical success rate: Er:YAG laser=89%; CaOH=75%; FS=97%; FC=92%
Odabas *et al.* [12]	MTA *vs* FS	1, 3, 6, 9 and 12 months	93 primary molars	At 1 month Clinical success rate: MTA=100%; FS=98% Radiographic success rate: MTA=100%; FS=96.1% At 3 months Clinical success rate: MTA=97.6%; FS=95.9% Radiographic success rate: MTA=97.6%; FS=85.7% At 6 months Clinical success rate: MTA=97.6%; FS=91.7% Radiographic success rate: MTA=97.6%; FS=97.2% At 9 months Clinical success rate: MTA=97.4%; FS=91.7% Radiographic success rate: MTA=92.3%; FS=79.2% At 12 months Clinical success rate: MTA=94.7%; FS=84.8% Radiographic success rate: MTA=92.1%; FS=78.3%
Sushynski *et al.* [122]	FC *vs* Gray MTA	6, 12, 18 and 24 months	252 primary molars	Combined clinical success rate: FC=99%; Gray MTA=100% Combined radiographic success rate: FC=81%; Gray MTA=95% At 6 months Clinical success rate: FC=98%; Gray MTA=100% Radiographic success rate: FC=85%; Gray MTA=95% At 12 months Clinical success rate: FC=100%; Gray MTA=100% Radiographic success rate: FC=81%; Gray MTA=93% At 18 months Clinical success rate: FC=99%; Gray MTA=100% Radiographic success rate: FC=78%; Gray MTA=95%

				At 24 months Clinical success rate: FC=98%; Gray MTA=100% Radiographic success rate: FC=76%; Gray MTA=95%
Trairatvorakul & Koothiratrakarn [123]	FC *vs* CaOH (PP)	6-36 months	86 primary molars	Success rates: At 6 months CaOH=95.3%; FC=92.7% At 12 months CaOH=92.5%; FC=90% At 18 months CaOH=92.1%; FC=87.2% At 24 months CaOH=83.3%; FC=80.5% At 30 months CaOH=79.4%; FC=75.0% At 36 months CaOH=75%; FC=74.2%
Yaman *et al.* [124]	ABS *vs* FC	3, 6 and 12 months	60 primary molars	Total success rates: At 3 months ABS=100%; FC=100% At 6 months ABS=93.5%; FC=96.7% At 12 months ABS=85.7%; FC=89.3%
Al-Mutairi & Bawazir [125]	NaOCl *vs* FC	3, 6 and 12 months	82 primary molars	At 3 months Clinical success rate: NaOCl=100%; FC=100% At 6 months Clinical success rate: NaOCl=95%; FC=95% Radiographic success rate: NaOCl=87.5%; FC=95% At 12 months Clinical success rate: NaOCl=94.6%; FC=92.1% Radiographic success rate: NaOCl=86.5%; FC=86.8%
Celik *et al.* [126]	ProRoot MTA, MTA Angelus and CaOH	1, 3, 6, 12, 18 and 24 months	139 primary molars	At 24 months Cumulative clinical success rate: ProRoot MTA=98%; MTA Angelus=96%; CaOH=77% Cumulative radiographic success rate: ProRoot MTA=98%; MTA Angelus=91%; CaOH=45%
Fernández *et al.* [127]	FC, MTA, FS and NaOCl	6, 12, 18 and 24 months	100 primary molars	Overall success rate: FC=97.5%; MTA=96.5%; FS=98%; NaOCl=85% At 6 months Clinical success rate: FC=100%; MTA=100%; FS=92%;NaOCl=96% Radiographic success rate: FC=100%; MTA=100%; FS=95%; NaOCl=87% At 12 months Clinical success rate: FC=100%; MTA=100%; FS=92%; NaOCl=96% Radiographic success rate: FC=100%; MTA=100%; FS=89%; NaOCl=83% At 18 months Clinical success rate: FC=100%; MTA=100%; FS=92%; NaOCl=96% Radiographic success rate: FC=100%; MTA=100%; FS=100%; NaOCl=83% At 24 months Clinical success rate:

				FC=100%; MTA=100%; FS=92%; NaOCl=96% Radiographic success rate: FC=95%; MTA=93%; FS=100%; NaOCl=75%
Havale *et al.* [128]	FC, Glutaraldehyde and FS	3, 6, 9 and 12 months	90 primary molars	At 12 months Clinical success rate: FC=86.7%; Gluteraldehyde=100%; FS=96.7% Radiographic success rate: FC=56.7%; Gluteraldehyde=83.3%; FS=63.3%
Mettlach *et al.* [129]	MTA *vs* FC	6-42 months	270 primary molars	At 42 months Clinical success rate: MTA=99.8%; FC=99.1% Radiographic success rate: MTA=95%; FC=79.3%
Ruby *et al.* [130]	3% NaOCl *vs* FC	6 and 12 months	65 primary teeth 6 months: 47 primary molars (NaOCl=22, FC=25) 12 months: 25 primary molars (NaOCl=15, FC=10)	At 6 months Clinical success rate: NaOCl=100%; FC=100% Radiographic success rate: NaOCl=86%; FC=84% At 12 months Clinical success rate: NaOCl=100%; FC=100% Radiographic success rate: NaOCl=80%;FC=90%
Shabzendedar *et al.* [131]	3% NaOCl vs FC	6 and 12 months	100 primary molars	At 6 months Clinical success rate: NaOCl=100%; FC=100% Radiographic success rate: NaOCl=98%; FC=94% At 12 months Clinical success rate: NaOCl=100%; FC=100% Radiographic success rate: NaOCl=92%; FC=93%
Akcay & Sari [132]	CaOH *vs* MTA (NaOCl *vs* saline cleaning agent)	12 months	128 primary teeth	Radiographic success rates: CaOH-NaOCl=84%; CaOH-saline=74% MTA-NaOCl=97%; MTA-saline=100%
Khorakian *et al.* [133]	CEM cement *vs* ES/ZOE	6, 12 and 24 months	102 primary molars	At 24 months Clinical success rate: CEM=100%; ES/ZOE=100% Radiographic success rate: CEM=90%; ES/ZOE=95.2%
Farsi *et al.* [134]	5.25% NaOCl, FC and FS	6, 12 and 18 months	81 primary molars	At 6 months Clinical success rate: NaOCl=100%; FC=100%; FS=100% Radiographic success rate: NaOCl=100%; FC=100%; FS=100% At 12 months Clinical success rate: NaOCl=100%; FC=96%; FS=95.7% Radiographic success rate: NaOCl=95.8%; FC=100%; FS=100% At 18 months Clinical success rate: NaOCl=83.3%; FC=96%; FS=87% Radiographic success rate: NaOCl=91.7%; FC=100%; FS=95.7%
Kang *et al.* [135]	ProRoot MTA, OrthoMTA and RetroMTA	3, 6 and 12 months	151 primary molars	At 12 months Clinical success rate: ProRoot MTA=100%; OrthoMTA=97.4%; RetroMTA=100% Radiographic success rate: ProRoot MTA=94.7%; OrthoMTA=94.7%; RetroMTA=100%

Lourenço Neto *et al.* [136]	PC, PC+iodoform and PC+ZrO	6, 12 and 24 months	39 primary molars	At 6, 12 and 24 months Clinical success rate: PC=100%; PC+iodoform=100%; PC+ZrO=100% Radiographic success rate: PC=100%; PC+iodoform=100%; PC+ZrO=100%
Olatosi *et al.* [137]	FC *vs* MTA	12 months	50 primary molars	Clinical success rate: FC=81%; MTA=100% Radiographic success rate: FC=81%; MTA=96%
Cuadros-Fernandez *et al.* [138]	MTA *vs* Biodentine	6 and 12 months	90 primary molars	At 12 months Clinical success rate: MTA=92%; Biodentine=97% Radiographic success rate: MTA=97%; Biodentine=95%
El Meligy *et al.* [139]	Biodentine *vs* FC	3 and 6 months	112 primary molars	At 3 months Clinical success rate: Biodentine=100%; FC=100% Radiographic success rate: Biodentine=100%; FC=100% At 6 months Clinical success rate: Biodentine=100%; FC=100% Radiographic success rate: Biodentine=100%; FC=98.1%
Godhi &Tyagi [8]	MTA	3, 6, 12, 24 and 36 months	25 primary molars	At 3 months Clinical success rate=100% Radiographic success rate=96% At 6 months Clinical success rate=100% Radiographic success rate=96% At 12 months Clinical success rate=100% Radiographic success rate=96% At 24 months Clinical success rate=100% Radiographic success rate=100% At 36 months Clinical success rate=100% Radiographic success rate=100%
Musale & Soni [140]	CLOR, FC and White MTA	12 months	152 primary molars	Clinical success rate: CLOR=100%; FC=100%; White MTA=100% Radiographic success rate: CLOR=76%; FC=90.91%; White MTA=88.23%
Togaru *et al.* [141]	Biodentine *vs* MTA	3, 6, 9 and 12 months	90 primary molars	At 3 months Clinical success rate: Biodentine=100%; MTA=100% Radiographic success rate: Biodentine=100%; MTA=100% At 6 months Clinical success rate: Biodentine=100%; MTA=100% Radiographic success rate: Biodentine=100%; MTA=100% At 9 months Clinical success rate: Biodentine=97.8%; MTA=100% Radiographic success rate: Biodentine=97.8%; MTA=100% At 12 months Clinical success rate: Biodentine=97.8%; MTA=97.8% Radiographic success rate:

				Biodentine=97.8%; MTA=97.8%
Yildrim *et al.* [142]	FC, MTA, Portland cement and EMD	3, 6, 12, 18 and 24 months	140 primary molars	Clinical success rate: FC=96.9%; MTA=100% Portland cement=93.9% EMD=93.3% Radiographic success rate: FC=84.4%; MTA=93.9% Portland cement=96.7%; EMD=78.1%
Bani *et al.* [143]	Biodentine *vs* MTA	24 months	31 primary molars	Clinical success rate: Biodentine=96.8%; MTA=96.8% Radiographic success rate: Biodentine=93.6%; MTA=87.1%
Carti & Oznurhan [14]	Biodentine *vs* MTA	1, 3, 6 and 12 months	50 primary molars	At 1 month Clinical success rate: MTA=100%; Biodentine=100% Radiographic success rate: MTA=100%; Biodentine=100% At 3 months Clinical success rate: MTA=100%; Biodentine=100% Radiographic success rate: MTA=92%; Biodentine=800% At 6 months Clinical success rate: MTA=100%; Biodentine=100% Radiographic success rate: MTA=84%; Biodentine=68% At 12 months Clinical success rate: MTA=96%; Biodentine=96% Radiographic success rate: MTA=80%; Biodentine=60%
Chauhan *et al.* [144]	FC *vs* NaOCl	3 and 6 months	40 primary molars	At 3 months Clinical success rate: FC=100%; NaOCl=100% Radiographic success rate: FC=95%; NaOCl=90% At 6 months Clinical success rate: FC=100%; NaOCl=100% Radiographic success rate: FC=90%; NaOCl=85%
Guven *et al.* [145]	Biodentine, MTA-Plus, ProRoot MTA and FS	6, 12 and 24 months	116 primary molars	Total success rate: At 6 months Biodentine=100%; MTA-Plus=100% ProRoot MTA=100%; FS=100% At 12 months Biodentine=89.65%; MTA-Plus=96.55% ProRoot MTA=93.1%; FS=82.75% At 24 months Biodentine=82.75%; MTA-Plus=86.2% ProRoot MTA=93.1%; FS=75.86%
Kathal *et al.* [146]	Antioxidant mix *vs* MTA	6 and 12 months	40 primary molars	At 6 months Clinical success rate: Antioxidant=95%; MTA=100% Radiographic success rate: Antioxidant=95%; MTA=100% At 12 months Clinical success rate: Antioxidant=94.74%; MTA=88.89% Radiographic success rate: Antioxidant=94.74%; MTA=88.89%

Nguyen *et al.* [147]	FS+MTA pulpotomy vs RCT	12 and 18 months	172 primary incisors	At 12 months Radiographic success rate: FS+MTA=93%; RCT=79% At 18 months Radiographic success rate: FS+MTA=90%; RCT=79%
Ozmen & Bayrak [148]	ABS, FC and FS	6-24 months	45 primary molars	Overall success rate: Clinical: ABS=87%; FC=87%; FS=100% Radiographic: ABS=87%; FC=80%; FS=87%
Patidar *et al.* [149]	PRF *vs* MTA	1, 3 and 6 months	50 primary molars	Overall success rates: PRF=90%; MTA=92%
Rajasekharan *et al.* [150]	Biodentine, ProRoot White MTA and Tempophore	6, 12 and 18 months	81 primary molars	At 6 months Clinical success rate: Biodentine=96% ProRoot White MTA=100%; Tempophore=100% Radiographic success rate: Biodentine=96% ProRoot White MTA=100%; Tempophore=85% At 12 months Clinical success rate: Biodentine=96% ProRoot White MTA=100%; Tempophore=96% Radiographic success rate: Biodentine=96% ProRoot White MTA=92%; Tempophore=75% At 18 months Clinical success rate: Biodentine=95% ProRoot White MTA=100%; Tempophore=96% Radiographic success rate: Biodentine=94% ProRoot White MTA=91%; Tempophore=82%
Jamali *et al.* [151]	3Mixtatin, MTA and FC	6, 12 and 24 months	150 primary molars	Overall success rate clinical: 3Mixtatin=90.5%; MTA=88.1%; FC=78.9%
Junqueira *et al.* [152]	15.5% FS *vs* MTA	3, 6, 12 and 18 months	31 primary molars	At 3, 6 and 12 months Clinical success rate: FS=100%; MTA=100% Radiographic success rate: FS=100%; MTA=100% At 18 months Clinical success rate: FS=100%; MTA=100% Radiographic success rate: FS=85.7%; MTA=100%
Nematollahi *et al.* [153]	MTA *vs* FC	6, 12 and 24 months	50 primary molars	At 24 months Clinical success rate: MTA=90.9%; FC=100% Radiographic success rate: MTA=90.5%; FC=95.2% Overall success rate: MTA=81.8%; FC=95.2%
Alsanouni & Bawazir [154]	NeoMTA Plus vs ProRoot MTA	3, 6 and 12 months	80 primary molars	At 12 months Clinical success rate: NeoMTA Plus=100%; ProRoot MTA=97.4% Radiographic success rate: NeoMTA Plus=97.5%; ProRoot MTA=94.9%
Atasever *et al.* [155]	FS-ZOE, FS-CaOH, NaOCl-ZOE and NaOCl-CaOH	12 months	80 primary molars	Clinical success rate: FS-ZOE=95%; FS-CaOH=100% NaOCl-ZOE=100%; NaOCl-CaOH=89.5% Radiographic success rate: FS-ZOE=80%; FS-CaOH=88.9% NaOCl-ZOE=78.9%; NaOCl-CaOH=84.2%
Celik *et al.* [156]	MTA *vs* Biodentine	24 months	44 primary molars	Clinical success rate: MTA=100%; Biodentine=89.4% Radiographic success rate: MTA=100%; Biodentine=89.4%
Dimitraki *et al.* [48]	DPC (MTA) *vs* pulpotomy (MTA)	12, 24 and 36 months	97 primary molars	Overall success rate: At 12 months=79.7% At 24 months=66.0%; At 36 months=66.0%
El Meligy *et al.* [157]	Biodentine *vs* FC	3, 6 and 12 months	112 primary molars	At 12 months Clinical success rate: Biodentine=100%; FC=100% Radiographic success rate: Biodentine=100%; FC=98.1%

Luengo-Fereira et al. [158]	CTZ paste *vs* FC	6, 12 and 24 months	80 primary molars	At 24 months Clinical success rate: CTZ=100%; FC=94.3% Radiographic success rate: CTZ=97.4%; FC=94.3%
Rubanenko *et al.* [159]	Biodentine *vs* FC	2-4 years	72 primary molars	Overall success rate: Biodentine=97.3%; FC=91.4%
Silva *et al.* [160]	MTA, CaOH+saline, and CaOH+PEG	3, 6 and 12 months	44 primary molars	At 3 months Clinical success rate: MTA=100%; CaOH+saline=100%; CaOH+PEG=91.7% Radiographic success rate: MTA=100%; CaOH+saline=66.7%; CaOH+PEG=66.7% At 6 months Clinical success rate: MTA=100%; CaOH+saline=100%; CaOH+PEG=100% Radiographic success rate: MTA=100%; CaOH+saline=60.0%; CaOH+PEG=72.7% At 12 months Clinical success rate: MTA=100%; CaOH+saline=93.3%; CaOH+PEG=100% Radiographic success rate: MTA=100%; CaOH+saline=33.3%; CaOH+PEG=72.7%
Aripirala *et al.* [161]	Diode laser *vs* Simvastatin	3 and 12 months	100 primary molars	At 12 months Clinical success rate: Laser=76.1%; Simvastatin=80.4% Radiographic success rate: Laser=52.1%; Simvastatin=65.2%
Cordell *et al.* [162]	MTA *vs* FS	6 and 12 months	50 primary molars	At 6 months Clinical success rate: FS=95.2%; MTA=100% At 12 months Clinical success rate: FS=86.6%; MTA=100% Radiographic success rate: FS=60%; MTA=100%
Petel *et al.* [163]	Portland cement *vs* FC	2-4 years	136 primary molars	Overall success rate: Portland cement=100%; FC=91.1%
Yavagal *et al.* [164]	Laser *vs* FC	9 months	68 primary molars	Clinical success rate: Laser=94.1%; FC=97.05% Radiographic success rate: Laser=94.1%; FC=58.82%
Guang *et al.* [165]	Biodentine *vs* FC	6 and 12 months	66 primary molars	At 6 months Clinical success rate: Biodentine=100%; FC=100% Radiographic success rate: Biodentine=93.9%; FC=84.8% At 12 months Clinical success rate: Biodentine=100%; FC=100% Radiographic success rate: Biodentine=93.9%; FC=81.8%
Ildes *et al.* [166]	FC, FS and HA gel	1, 3, 6 and 12 months	130 primary molars	At 12 months Clinical success rate: FC=77.5%; FS=86.8%; HA=87.5% Radiographic success rate: FC=57.6%; FS=68.8%; HA=57.9%

ABS=Ankaferd blood stopper, CaOH=calcium hydroxide, CEM=calcium-enriched mixture, CLOR=Copaifera langsdorffii oil resin, CTZ=Chloramphenicol, Tetracycline and Zinc Oxide-Eugenol, DPC=direct pulp capping, EMD=enamel matrix derivative, Er:YAG=erbium:yttrium aluminium garnet, ES=electrosurgical, FC=formocresol, FS=ferric sulfate, G =glutaraldehyde. HA=hyaluronic acid, LPDP=lyophilized freeze dried platelet, MTA=mineral trioxide aggregate, NaOCl=sodium hypochlorite, PC=Portland cement, PEG=polyethylene glycol, PP=partial pulpotomy, PRF=platelet-rich fibrin, RCT=root canal therapy. SSC=stainless steel crown, ZOE=zinc oxide-eugenol, ZPC=zinc polycarboxylate cement, ZrO=zirconium oxide

comparable success to formocresol, introducing themselves as substitutes for the latter. Nonetheless, pulpotomy using calcium hydroxide is not recommended [71].

Besides the accurate diagnosis of pulp status, proper coronal restoration without leakage is an imperative criterion for the long-term prognosis/success of pulpotomy [3, 72]. *In vitro* microleakage evaluation of different filling materials in the restoration of pulpotomised primary molars has shown that resin-based restorative materials have not demonstrated marginal leakage [73]. The treatment success of pulpotomised primary molars receiving immediate stainless steel crown(s) has increased significantly (82.0%) compared to those temporised by an intermediate restorative material (IRM) (39%) [24]. Similar studies have shown greater treatment success in pulpotomised teeth restored with immediate stainless steel crown(s) (86%) in comparison with teeth temporarily restored with IRM (61%) or IRM-Ketac Molar (77%) after emergency pulpotomies [74, 75]. Sonmez and Duruturk found statistically significant differences in the success rates of calcium hydroxide pulpotomies in primary molars restored with stainless steel crown(s) (79.9%) compared to amalgam-based restorations (60.0%)[72].

Furthermore, the most recent evaluation of scientific evidence, involving randomised clinical trials comparing different VPT modalities in deciduous molars, has supported the idea that MTA may be the most superior medicament for pulpotomy [167]. Similarly, in a systematic review on VPT of primary dentition, Coll *et al.* [168] concluded that IPT and pulpotomy with MTA and formocresol for the treatment of deep carious lesions in primary teeth after 24 months are supported by the highest level of success and quality of literature evidence. The combined success rate for all pulpotomies on 1,022 primary teeth was 82.6% while the 24-month success rates for IPT and DPC were 94.4% and 88.8%, respectively. Although the success rates of DPC were similar to IPT and MTA or formocresol pulpotomy, it was based on a lower quality of literature evidence.

Histological studies

Studies on the dentine and pulp histology in pulpotomy have been carried out in human primary teeth and animals. Histological evaluation of MTA, as a pulpotomy agent in human primary molars, has shown signs of healthy pulp and calcified areas [8]. Although MTA or ferric sulphate pulpotomy have displayed absence of inflammation in the dentine-pulp complex connective tissue, the formation of hard tissue barrier surrounded by odontoblasts over the pulp stump has only been observed in MTA group. Agamy *et al.* has histologically compared white MTA, grey MTA and formocresol as pulpotomy agents, and has found that both types of MTA had been able to induce the formation of thick dentinal bridge at the pulp amputation site [90]. In addition, the pulp architecture of teeth in MTA group was close to normal pulp with few inflammatory cells. However, the dentine induced by formocresol was thin and poorly calcified [90]. In pulpotomy studies using laser, the higher the carbon dioxide laser energy used, the lesser the degree of pulp inflammation observed in human primary canines [80]. While in calcium-based (bio)materials (*e.g.* Biodentine) pulpotomised teeth, the teeth did not exhibit any necrosis, formocresol-treated teeth exhibited degrees of necrotic sites [165].

In animal studies, El-Meligy *et al.* compared the histology of pulpal and periapical tissue reactions of the primary teeth of dogs treated by electrosurgery with those of formocresol pulpotomy [169]. Electrosurgery pulpotomised teeth demonstrated less tissue reaction in comparison to the formocresol group. Additionally, the comparisons of pulpal reactions to ferric sulphate and formocresol pulpotomies in baboons' primary molars showed no statistically significant differences. Nevertheless, internal root resorption, external resorption and periapical abscesses were observed more frequently in the formocresol group. Therefore, investigators have concluded that pulpotomy can, still, be clinically successful even if the histological reactions are unfavourable [170].

Non-vital pulp therapy

Pulpectomy

Pulpectomy is a root canal procedure for the pulpal connective tissue that is irreversibly infected or necrotic due to carious lesion(s) and/or trauma [38]. Studies on different pulpectomy methods and medicaments have been constantly investigated (Table 4).

Clinical and radiographic studies

Zinc oxide eugenol (ZOE) has undergone several trials as a root filling material. Generally, pulpectomies filled short or to the apex have produced greater success compared to over-filled cases [171]. Although short-filled pulpectomies retained significantly less ZOE compared to the over-filled, ZOE particles were completely resorbed or showed reduction of filler size in 80% of the cases [172]. However, the overall higher success rate of KRI™ paste (iodoform-containing paste) compared to ZOE in necrotic primary molars has confirmed the efficiency of the former paste as an alternative root filling material [173]. Under-filled root canals with KRI™ paste and ZOE have demonstrated a lower failure rate (KRI™=14%, ZOE=17%) compared to over-filled root canals using similar

Table 4. Studies on pulpectomy

Author	Materials	Follow-up period	Sample size	Treatment outcome
Holan & Fuks [173]	ZOE vs KRI paste	12->48 months	78 primary molars	Overall success rates: ZOE=65%; KRI paste=84% Failure rate due to overfilled: ZOE=59%; KRI paste=21% Failure rate due to underfilled: ZOE=17%; KRI paste=14%
Sadrian & Coll [172]	ZOE	90.8 months (mean)	81 primary teeth (incisors=30, primary molars=51)	At 40.2 months: Retained ZOE=27.3%
Coll & Sadrian [171]	ZOE	90.8 months (mean)	81 primary teeth (incisors=30, primary molars=51)	Overall success rate=77.7% Enamel defect of succedaneous teeth=18.7% Anterior cross-bite/palatal eruption of succedaneous incisors=20% Ectopic eruption of premolars=21.6% Over-retention=35.8%
Casas et al. [88]	RCT vs FS pulpotomy	24 months	291 primary molars	Clinical success rate: RCT=98%; FS=96%
Casas et al. [91]	ZOE vs FS pulpotomy	24 months	133 primary incisors	Clinical success rate: ZOE=100%; FS=78%
Mortazavi & Mesbahi [179]	ZOE vs Vitapex	3-16 months	53 primary molars, 5 primary incisors	Overall success rate: ZOE=78.5%; Vitapex=100%
Aminabadi et al. [102]	RCT (ZOE) vs FC pulpotomy	12 and 24 months	100 primary incisors	Clinical success rates: RCT=95.6%; FC=86.9% Radiographic success rates: RCT=91.3%; FC=76.08%
Trairatvorakul & Chunlasikaiwan [108]	ZOE vs Vitapex	6 and 12 months	54 primary molars	At 6 months Clinical and radiographic success rates: ZOE=48%; Vitapex=78% At 12 months Clinical and radiographic success rates:ZOE=85%; Vitapex=89%
Ramar & Mungara [176]	RC Fill, Endoflas and Metapex	9 months	96 primary molars	Overall success rate: RC Fill=84.7%; Endoflas=95.1%; Metapex=90.5%
Subramanim & Gilhotra [177]	Endoflas, ZOE and Metapex	3, 6, 12 and 18 months	45 primary molars	Overall success rate: Endoflas=93.3%; ZOE=93.3%; Metapex=100%
Howley et al. [11]	Vitapex pulpectomy vs FC pulpotomy	23 months	74 primary incisors	Radiographic success rate: FC pulpotomy=89%; Vitapex pulpectomy=73%
Rewal et al. [175]	Endoflas vs ZOE	3, 6, and 9 months	50 primary molars	Overall success rate: Endoflas=100%; ZOE=83%
Akcay & Sari [132]	CaOH-NaOCl/ saline vs MTA-NaOCl/ saline	12 months	128 primary teeth	Radiographic success rates: CaOH-NaOCl=84%; CaOH-saline=74% MTA-NaOCl=97%; MTA-saline=100%
Pramila et al. [178]	RC Fill, Vitapex and Pulpdent	6, 12 and 30 months	129 primary molars	Overall success rate: RC Fill=94%; Vitapex=90%; Pulpdent=97%
Chen X et al. [180]	MPRCF (mixture of ZOE, iodoform, CaOH) vs ZOE vs Vitapex	6, 12 and 18 months	160 primary molars	At 6 months Clinical success rate: MPRCF=100%; ZOE=100%; Vitapex=100% Radiographic success rate: MPRCF=100%; ZOE=100%; Vitapex=94.5% At 12 months Clinical success rate: MPRCF=100%; ZOE=100%; Vitapex=80.4%

				Radiographic success rate: MPRCF=100%; ZOE=100%; Vitapex=60.7% At 18 months Clinical success rate: MPRCF=96.2%; ZOE=92.2%; Vitapex=71.4% Radiographic success rate: MPRCF=92.5%; ZOE=88.2%; Vitapex=53.6%
Nguyen et al. [147]	RCT vs FS+MTA pulpotomy	12 and 18 months	172 primary incisors	At 12 months Radiographic success rate: FS+MTA=93%; RCT=79% At 18 months Radiographic success rate: FS+MTA=90%; RCT=79%
Sahebalam et al. [181]	Conventional vs ES	6 months	50 primary molars	Overall success rate: Clinical ES=90.5%; Conventional=88.9% Radiographic ES=85.7%; Conventional=72.2%
Pandranki et al. [182]	Endoflas vs ZOE	3, 6, 9, 12 and 24 months	60 primary molars	Overall success rates: Clinical Endoflas=92%; ZOE=89% Radiographic Endoflas=72%; ZOE=63%
Zacharczuk et al. [183]	Maisto-Capurro vs 3Mix-MP	1, 3, 6,12 and 18 months	46 primary molars	Overall success rates: Clinical Maisto-Capurro=91.5% 3; Mix-MP=87.5% Radiographic Maisto-Capurro=88.3% 3; Mix-MP=82.3%
RojaRamya et al. [184]	ZOE-Propolis vs ZOE	6, 12 and 24 months	40 primary molars (ZOE-Propolis=20, ZOE=20)	Overall success rate: ZOE-Propolis =95%; ZOE=70%
Moura et al. [185]	LSTR vs ZOE	3, 6, 9 and 12 months	88 primary molars	Overall success rate: LSTR=70.5%; ZOE=72.7%
Bresolin et al. [186]	GP vs Vitapex	24 months	104 primary teeth	Overall success rate: GP=86.8%; Vitapex=78.4%

CaOH=calcium hydroxide, ES=electrosurgical, FS=ferric sulfate, GP=Guedes-Pinto (iodoform-based), LSTR = lesion sterilisation and tissue repair, MTA=mineral trioxide aggregate, RCT=root canal therapy, ZOE=zinc oxide eugenol

materials (KRI™=21%, ZOE=59%) [173]. Additionally, over-retention of ZOE particles has not increased the incidence of enamel defects to the succedaneous tooth; however, there was 20% possibility of change in the path of succedaneous tooth eruption [171]. Iodoform is introduced as an ingredient in root canal filling materials because it has shown to offer advantages; e.g. high success rates, quick resorption from the periapical tissues, no adverse effects to succedaneous teeth, radiopacity, maintenance of its consistency over time, and ease of use [174].

New materials, such as Endoflas (a mixture of ZOE, calcium hydroxide and iodoform), have also gained interest. Clinical and radiographic success rates of Endoflas and ZOE have revealed statistically significant differences between the two materials; however, the follow-up period was short (9 months) [175]. Conversely, comparative studies of Endoflas, ZOE, RC Fill (ZOE-iodoform), Metapex (calcium hydroxide-iodoform paste), Vitapex (calcium hydroxide-iodoform paste), and Pulpdent (ZOE-based) have not shown any statistically significant difference between the materials [176-178]. Nonetheless, a longer follow-up period, until the eruption of the succedaneous teeth, has been advocated for conclusive results [178]. Eighteen-month success rates showed that Endoflas andZOE ranked first and second, while iodoform was the lowest [187]. Additionally, a recent meta-analysis has reported significant treatment success of pulpectomy in teeth with or without root resorption compared to lesion sterilisation and tissue repair [187]. According to the latest Cochrane systematic review of pulp therapy in primary teeth with extensive caries, reviewers have not found any evidence to support any pulpectomy medicaments and techniques superior over the other ones [68]. Despite numerous research being carried out to evaluate materials for pulpectomy, reviewers have not been able to conclude any superior pulpectomy medicaments due to the limited number of studies available [188, 189]. Although there is inconclusive evidence, ZOE may be a better pulpectomy agent than Vitapex [167].

Apart from materials, the success rate of pulpectomy has also been affected by the techniques employed. Guelmann *et al.* [190] verified the advantages of using NaviTip system over Lentulo spiral and syringe techniques. The findings were supported by other studies, demonstrating superior results with NaviTip syringe and Lentulo spiral in relation to the length of obturation and limiting the amount of extruded pastes, respectively [191]. Moreover, use of electrosurgery in pulpectomy is still at its infant stage [192].

Histological studies

Histological studies of root canal treatment in human primary teeth are inadequate. The early works on the use of calcium hydroxide in pulpectomy were carried out on primary premolar teeth of dogs [193]. Clinical, radiographic and histologic comparisons were made between calcium hydroxide, ZOE and control groups. Calcium hydroxide performed significantly better as a root canal obturant compared to ZOE [193]. Histological investigations revealed less inflammation and resorption as well as more hard-tissue apposition in calcium hydroxide-treated canals.

On the contrary, Cleaton-Jones *et al.* [194] observed unfavourable histological responses in pulpitis-induced primary molars of baboons treated with calcium hydroxide compared with ZOE-treated teeth. Due to a higher prevalence of external root resorption, bacterial presence and periapical abscess in calcium hydroxide-treated pulpectomised primary molars, ZOE was recommended over calcium hydroxide for the treatment of primary molars with infected pulps in baboons. However, the results cannot be extrapolated in human because the induced pulpitis does not necessarily mimic the actual pulp inflammation caused by the natural caries process in humans.

Another study compared the reactions of exposed pulp in primary maxillary incisors based on aetiological factors; *i.e.* trauma group, caries group and caries/trauma group. Fewer inflammatory cells were noted in the root canals of teeth with exposed pulp due to trauma compared to caries and caries/trauma. The authors recommended pulpotomy for teeth with traumatic pulp exposure whereas pulpectomy or extraction was indicated in caries pulp exposed teeth or caries/traumatic exposed pulp [195].

Lesion sterilisation and tissue repair

Lesion sterilisation and tissue repair (LSTR) is an endodontic treatment that employs none or minimal instrumentation followed by the application of a mixture of broad-spectrum antibiotics to disinfect root canals [196]. It offers a substitute for conventional pulpectomy and extractions of primary teeth. Following disinfection by sterilisation, lesions caused by root canal infection undergo repair by the host's immune response. The most common drug mixture used in LSTR is the combination of metronidazole, ciprofloxacin and minocycline known as "3Mix paste" or "triple antibiotic paste (TAP)". By using a combination of antibiotics, the antimicrobial drug spectrum of each drug completes each other to achieve the best results of root canal sterilisation [197].

Clinical and radiographic studies

Clinical outcomes of 87 infected primary teeth using TAP (3Mix-MP/3Mix-sealer) have been studied. The research showed complete resolution of clinical signs and symptoms in 95.4% (83 out of 87) of treated teeth, whereas the remaining four had to be retreated with success [198]. In another study, scientists compared the clinical and radiographic success rates of two different antibiotic mixtures in 40 necrotic primary teeth [199]. Twenty teeth were treated with TAP while the other 20 were managed with Other Mix (ciprofloxacin, ornidazole, and minocycline). The clinical success rates for both groups were 100% at 3- and 6-month follow-ups. The radiographic success rates at 12-month follow-up were 81% and 92% in 3Mix and Other Mix treated groups, respectively; however, the difference was statistically insignificant [199].

A study has compared the root canal filling material used in conventional pulpectomy with that used in LSTR in 64 primary molars with irreversible pulpitis in a longer follow-up period. The clinical success rates of teeth in zinc oxide-ozonated oil, modified 3Mix-MP paste and Vitapex groups at 18 months were 95.5%, 89.5% and 100%, respectively whereas the radiographic success rates were 94.4%, 80.95% and 100%, respectively. The clinical and radiographic success rates were comparable and statistically insignificant. Thus, modified 3Mix-MP could be considered an alternative to conventional pulpectomy in primary teeth [200]. Nevertheless, the indication of LSTR is limited to non-vital teeth with resorbed roots [187].

Histological studies

To date, no histological studies have been carried out on LSTR.

Conclusions

The current review has highlighted the treatment outcomes of various pulp therapies in primary dentition based on clinical, radiographic and histological criteria. Although histological data on the treatment outcome of pulp therapies in primary teeth is scanty, existing dental literature has shown high success rates of pulp therapy in primary teeth.

Pulp therapies in primary teeth are still practical because they empirically succeed more often than they fail. The use of surrogate outcome measures, *viz* clinical and radiographic outcomes, has been and is indeed an acceptable and evidence-based approach amongst clinicians. Future investigations should address the gaps on the scarcity of histological-based pulpal studies. However, histological studies are only justified with the advent of new (bio)materials or novel instruments in different pulp therapy procedures of primary dentition prior to their applications in the clinical settings.

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References

1. Tziafas D. The future role of a molecular approach to pulp-dentinal regeneration. Caries Res. 2004;38(3):314-20.
2. Parisay I, Ghoddusi J, Forghani M. A review on vital pulp therapy in primary teeth. Iran Endod J. 2015;10(1):6-15.
3. Fuks AB. Current concepts in vital primary pulp therapy. Eur J Paediatr Dent. 2002;3(3):115-20.
4. Igna A. Vital Pulp Therapy in Primary Dentition: Pulpotomy-A 100-Year Challenge. Children (Basel, Switzerland). 2021;8(10):841.
5. American Academy of Pediatric Dentistry. Guideline on pulp therapy for primary and immature permanent teeth. The Reference Manual of Pediatric Dentistry. Pediatr Dent. 2021:399-407.
6. Hilton TJ. Keys to clinical success with pulp capping: a review of the literature. Operative dentistry. 2009;34(5):615-25.
7. Wunsch PB, Kuhnen MM, Best AM, Brickhouse TH. Retrospective study of the survival rates of indirect pulp therapy versus different pulpotomy medicaments. Pediatr Dent. 2016;38(5):406-11.
8. Godhi B, Tyagi R. Success rate of MTA pulpotomy on vital pulp of primary molars: a 3-year observational study. Int J Clin Pediat Dent. 2016;9(3):222-7.
9. Fernandes AP, Neto NL, Marques NCT, Moretti ABS, Sakai VT, Silva TC, Machado MAAM, Oliveira TM. Clinical and radiographic outcomes of the use of low-level laser therapy in vital pulp of primary teeth. IntJ Paediat Dent. 2015;25(2):144-50.
10. Tuzuner T, Alacam A, Altunbas DA, Gokdogan FG, Gundogdu E. Clinical and radiographic outcomes of direct pulp capping therapy in primary molar teeth following haemostasis with various antiseptics: a randomised controlled trial. Eur J Paediatr Dent. 2012;13(4):289-92.
11. Howley B, Seale NS, McWhorter AG, Kerins C, Boozer KB, Lindsey D. Pulpotomy versus pulpectomy for carious vital primary incisors: randomized controlled trial. Pediatr Dent. 2012;34(5):112-9.
12. Odabas ME, Alacam A, Sillelioglu H, Deveci C. Clinical and radiographic success rates of mineral trioxide aggregate and ferric sulphate pulpotomies performed by dental students. Eur J Paediatr Dent. 2012;13(2):118-22.
13. Frenkel G, Kaufman A, Ashkenazi M. Clinical and radiographic outcomes of pulpotomized primary molars treated with white or gray mineral trioxide aggregate and ferric sulfate--long-term follow-up. The Journal of clinical pediatric dentistry. 2012;37(2):137-41.
14. Caicedo R, Abbott PV, Alongi DJ, Alarcon MY. Clinical, radiographic and histological analysis of the effects of mineral trioxide aggregate used in direct pulp capping and pulpotomies of primary teeth. Aust Dent J. 2006;51(4):297-305.
15. Ghoddusi J, Forghani M, Parisay I. New approaches in vital pulp therapy in permanent teeth. Iran Endod J. 2014;9(1):15-22.
16. Parhizkar A, Asgary S. Local Drug Delivery Systems for Vital Pulp Therapy: A New Hope. Int J Biomater. 2021;2021:5584268.
17. Melo ME, Silva CA, de Souza Gomes WD, da Silva VF, Brandini DA, Poi WR, Castilho LR, Sonoda CK, Panzarini SR. Immediate tooth replantation in rats: effect of systemic antibiotic therapy with amoxicillin and tetracycline. Clin Oral Investig. 2016;20(3):523-32.
18. Fuks AB. Pulp therapy for the primary dentition. In: Pinkham JR, Casamassimo PS, Fields HWJ, McTigue DJ, Nowak A, editors. Pediatric Dentistry: Infancy Through Adolescence. 5th ed. St. Louis: Elsevier Saunders Co; 2013. pp. 331-51.
19. McDonald RE, Avery DR, Dean JA. Treatment of Deep Caries, Vital Pulp Exposure, and Pulpless Teeth. In: Dean JA, Avery DR, McDonald RE, editors. McDonald and Avery's Dentistry for the Child and Adolescent. 9th ed. Missouri: Mosby Elseveir; 2011. pp. 428-54.
20. Trairatvorakul C, Sastararuji T. Indirect pulp treatment vs antibiotic sterilization of deep caries in mandibular primary molars. Int J Clin Pediat Dent. 2014;24(1):23-31.
21. Hashem D, Mannocci F, Patel S, Manoharan A, Brown JE, Watson TF, Banerjee A. Clinical and radiographic assessment of the efficacy of calcium silicate indirect pulp capping: a randomized controlled clinical trial. J Dent Res. 2015;94(4):562-8.
22. Gruythuysen R, van Strijp G, Wu MK. Long-term survival of indirect pulp treatment performed in primary and permanent teeth with clinically diagnosed deep carious lesions. J Endod. 2010;36(9):1490-3.
23. Ricketts DN, Kidd EA, Innes N, Clarkson J. Complete or ultraconservative removal of decayed tissue in unfilled teeth. The Cochrane database of systematic reviews. 2006(3):Cd003808.
24. Farooq NS, Coll JA, Kuwabara A, Shelton P. Success rates of formocresol pulpotomy and indirect pulp therapy in the treatment of deep dentinal caries in primary teeth. Pediatr Dent. 2000;22(4):278-86.
25. Vij R, Coll JA, Shelton P, Farooq NS. Caries control and other variables associated with success of primary molar vital pulp therapy. Pediatr Dent. 2004;26(3):214-20.
26. Fang RR, Chang KY, Lin YT, Lin YJ. Comparison of long-term outcomes between ferric sulfate pulpotomy and indirect pulp therapy in primary molars. J Dent Sci. 2019;14(2):134-7.
27. Rosenberg L, Atar M, Daronch M, Honig A, Chey M, Funny MD, Cruz L. Observational: prospective study of indirect pulp treatment in primary molars using resin-modified glass ionomer and 2% chlorhexidine gluconate: a 12-month follow-up. Pediatr Dent. 2013;35(1):13-7.
28. Al-Zayer MA, Straffon LH, Feigal RJ, Welch KB. Indirect pulp treatment of primary posterior teeth: a retrospective study. Pediatr Dent. 2003;25(1):29-36.
29. Falster CA, Araujo FB, Straffon LH, Nor JE. Indirect pulp treatment: in vivo outcomes of an adhesive resin system vs calcium hydroxide for protection of the dentin-pulp complex. Pediatr Dent. 2002;24(3):241-8.

30. Franzon R, Casagrande L, Pinto AS, Garcia-Godoy F, Maltz M, de Araujo FB. Clinical and radiographic evaluation of indirect pulp treatment in primary molars: 36 months follow-up. Am J Dent. 2007;20(3):189-92.
31. Buyukgural B, Cehreli ZC. Effect of different adhesive protocols vs calcium hydroxide on primary tooth pulp with different remaining dentin thicknesses:24-month results. Clin Oral Invest. 2008;12(1):91-6.
32. Mathur VP, Dhillon JK, Logani A, Kalra G. Evaluation of indirect pulp capping using three different materials: A randomized control trial using cone-beam computed tomography. Indian J Dent Res. 2016;27(6):623-9.
33. Boddeda KR, Rani CR, Vanga NRV, Chandrabhatla SK. Comparative evaluation of biodentine, 2% chlorhexidine with RMGIC and calcium hydroxide as indirect pulp capping materials in primary molars: An in vivo study. J Indian Soc Pedod Prev Dent. 2019;37(1):60-6.
34. Sahin N, Saygili S, Akcay M. Clinical, radiographic, and histological evaluation of three different pulp-capping materials in indirect pulp treatment of primary teeth: a randomized clinical trial. Clin Oral Invest. 2021;25(6):3945-55.
35. Kalaskar RR, Badhe HK, Ninawe NS, Khade AV, Balasubramanian S, Kamki H. Comparative Evaluation of Ozonoid Olive Oil and Calcium Hydroxide as an Indirect Pulp Capping Agent in Primary Mandibular Second Molar: A Randomized Controlled Trial. **J** Contemp Dent Pract. 2022;23(2):208-14.
36. Saber A, El Meligy O, Alaki S, Felemban O. Clinical and Radiographic Success of 2% Chlorhexidine Gluconate with Mineral Trioxide Aggregate in Indirect Pulp Treatment of Primary Molars. J Dent Child (Chic). 2022;89(2):110-6.
37. Lutfi AN, Kannan TP, Fazliah MN, Jamaruddin MA, Saidi J. Proliferative activity of cells from remaining dental pulp in response to treatment with dental materials. Aust Dent J. 2010;55(1):79-85.
38. American Academy of Pediatric Dentistry. Reference manual guideline on pulp therapy for primary and immature permanent teeth. Pediatr Dent. 2015;37(6):244-52.
39. Fuks AB. Vital pulp therapy with new materials for primary teeth: new directions and treatment perspectives. Pediatr Dent. 2008;30(3):211-9.
40. Marques MS, Wesselink PR, Shemesh H. Outcome of direct pulp capping with mineral trioxide aggregate: a prospective study. J Endodont. 2015;41(7):1026-31.
41. Aminabadi NA, Farahani RMZ, Oskouei SG. Formocresol versus calcium hydroxide direct pulp capping of human primary molars: two year follow-up. J Clin Pediatr Dent. 2010;34(4):317-21.
42. Asl Aminabadi N, Satrab S, Najafpour E, Samiei M, Jamali Z, Shirazi S. A randomized trial of direct pulp capping in primary molars using MTA compared to 3Mixtatin: a novel pulp capping biomaterial. Int J Clin Pediatr Dent. 2016;26(4):281-90.
43. Ulusoy AT, Bayrak S, Bodrumlu EH. Clinical and radiological evaluation of calcium sulfate as direct pulp capping material in primary teeth. Eur J Paediatr Dent. 2014;15(2):127-31.
44. Fallahinejad Ghajari M, Asgharian Jeddi T, Iri S, Asgary S. Direct pulp-capping with calcium enriched mixture in primary molar teeth: a randomized clinical trial. Iran Endod J. 2010;5(1):27-30.
45. Kotsanos N, Arapostathis KN, Arhakis A, Menexes G. Direct pulp capping of carious primary molars. A specialty practice based study. J Clin Pediatr Dent. 2014;38(4):307-12.
46. Songsiripradubboon S, Banlunara W, Sangvanich P, Trairatvorakul C, Thunyakitpisal P. Clinical, radiographic, and histologic analysis of the effects of acemannan used in direct pulp capping of human primary teeth: short-term outcomes. Odontology. 2016;104(3):329-37.
47. Erfanparast L, Iranparvar P, Vafaei A. Direct pulp capping in primary molars using a resin-modified Portland cement-based material (TheraCal) compared to MTA with 12-month follow-up: a randomised clinical trial. Eur Arch Paediatr Dent. 2018;19(3):197-203.
48. Dimitraki D, Papageorgiou SN, Kotsanos N. Direct pulp capping versus pulpotomy with MTA for carious primary molars: a randomised clinical trial. Eur Arch Paediatr Dent. 2019;20(5):431-40.
49. Ali H, Raslan N. Direct pulp capping (DPC) in primary molars using (3Mix-MP) and the characteristics of the carious lesion as predictor factors for its success: a randomized controlled trial. Eur Arch Paediatr Dent. 2021;22(4):633-42.
50. Chatzidimitriou K, Vadiakas G, Koletsi D. Direct pulp capping in asymptomatic carious primary molars using three different pulp capping materials: a prospective clinical trial. Eur Arch Paediatr Dent. 2022;23(5):803-11.
51. Magnusson B. Therapeutic pulpotomy in primary molars-clinical and histological follow-up. I. Calcium hydroxide paste as wound dressing. Odontologisk revy. 1970;21(4):415-31.
52. Kennedy DB, Kapala JT. The dental pulp: biological considerations of protection and treatment. In: Braham RL, Morris E, editors. Textbook of Pediatric Dentistry Baltimore: Williams & Wilkins; 1985. pp. 237-43.
53. Schwendicke F, Brouwer F, Schwendicke A, Paris S. Different materials for direct pulp capping: systematic review and meta-analysis and trial sequential analysis. Clin Oral Invest 2016;20(6):1121-32.
54. Garrocho-Rangel A, Esparza-Villalpando V, Pozos-Guillen A. Outcomes of direct pulp capping in vital primary teeth with cariously and non-cariously exposed pulp: A systematic review. Int J Pediatr Dent. 2020;30(5):536-46.
55. Haghgoo R, Asgary S, Montazeri R. Histopathological Evaluation of Primary Teeth after Pulp Capping with Calcium-Enriched Mixture and Bioactive Glass. Iran Endod J. 2018;13(4):457-60.
56. Haghgoo R, Ahmadvand M. Evaluation of pulpal response of deciduous teeth after direct pulp capping with bioactive glass and mineral trioxide aggregate. Cont Clin Dent. 2016;7(3):332-5.
57. Cehreli ZC, Turgut M, Olmez S, Dagdeviren A, Atilla P. Short term human primary pulpal response after direct pulp capping with fourth-generation dentin adhesives. J Clin Pediatr Dent. 2000;25(1):65-71.
58. Farrokh Gisoure E. Comparison of three pulpotomy agents in primary molars: a randomised clinical trial. Iran Endod J. 2011;6(1):11-4.
59. Ansari G, Morovati SP, Asgary S. Evaluation of Four Pulpotomy Techniques in Primary Molars: A Randomized Controlled Trial. Iran Endod J. 2018;13(1):7-12.
60. Myers DR, Pashley DH, Whitford GM, Sobel RE, McKinney RV. The acute toxicity of high doses of systemically administered formocresol in dogs. Pediatr Dent. 1981;3(1):37-41.
61. Myers DR, Shoaf HK, Dirksen TR, Pashley DH, Whitford GM, Reynolds KE. Distribution of 14C-formaldehyde after pulpotomy with formocresol. J Am Dent Assoc. 1978;96(5):805-13.
62. Pashley EL, Myers DR, Pashley DH, Whitford GM. Systemic distribution of 14C-formaldehyde from formocresol-treated pulpotomy sites. J Dent Res. 1980;59(3):602-8.
63. Walker LA, Sanders BJ, Jones JE, Williamson CA, Dean JA, Legan JJ, Maupome G. Current trends in pulp therapy: a survey analyzing pulpotomy techniques taught in pediatric dental residency programs. J Dent Child. 2013;80(1):31-5.
64. Kahl J, Easton J, Johnson G, Zuk J, Wilson S, Galinkin J. Formocresol blood levels in children receiving dental treatment under general anesthesia. Pediatr Dent. 2008;30(5):393-9.
65. Bagrizan M, Pourgolshani P, Hosseinpour S, Jalalpour G,

Shahrestani MZ. Plasma level formaldehyde in children receiving pulpotomy treatment under general anesthesia. J Clin Pediatr Dent. 2017;41(2):95-101.
66. Lin PY, Chen HS, Wang YH, Tu YK. Primary molar pulpotomy: a systematic review and network meta-analysis. J Dent. 2014;42(9):1060-77.
67. Haghgoo R, Abbasi F. Clinical and Radiographic Success of Pulpotomy with MTA in Primary Molars: 30 Months Follow up. Iran Endod J. 2010;5(4):157-60.
68. Smaïl-Faugeron V, Glenny AM, Courson F, Durieux P, Muller-Bolla M, Fron Chabouis H. Pulp treatment for extensive decay in primary teeth. The Cochrane database of systematic reviews. 2018;5(5):Cd003220.
69. Markovic D, Zivojinovic V, Vucetic M. Evaluation of three pulpotomy medicaments in primary teeth. Eur J Paediatr Dent. 2005;6(3):133-8.
70. Erdem AP, Guven Y, Balli B, Ilhan B, Sepet E, Ulukapi I, Aktoren O. Success rates of mineral trioxide aggregate, ferric sulfate, and formocresol pulpotomies: a 24-month study. Pediatr Dent. 2011;33(2):165-70.
71. Stringhini Junior E, Vitcel ME, Oliveira LB. Evidence of pulpotomy in primary teeth comparing MTA, calcium hydroxide, ferric sulphate, and electrosurgery with formocresol. Eur Arch Paediatr Dent. 2015;16(4):303-12.
72. Sonmez D, Duruturk L. Success rate of calcium hydroxide pulpotomy in primary molars restored with amalgam and stainless steel crowns. Br Dent J. 2010;208(9):E18; discussion 408-9.
73. Guelmann M, Bookmyer KL, Villalta P, Garcia-Godoy F. Microleakage of restorative techniques for pulpotomized primary molars. J Dentist Child. 2004;71(3):209-11.
74. Guelmann M, Fair J, Bimstein E. Permanent versus temporary restorations after emergency pulpotomies in primary molars. Pediatr Dent. 2005;27(6):478-81.
75. Farokh-Gisour E, Parirokh M, Kheirmand Parizi M, Nakhaee N, Aminizadeh M. Comparison of Postoperative Pain Following One-Visit and Two-Visit Vital Pulpectomy in Primary Teeth: A Single-Blind Randomized Clinical Trial. Iran Endod J. 2018;13(1):13-9.
76. Fuks AB, Bimstein E, Guelmann M, Klein H. Assessment of a 2 percent buffered glutaraldehyde solution in pulpotomized primary teeth of schoolchildren. ASDC J Dent Child. 1990;57(5):371-5.
77. Fei AL, Udin RD, Johnson R. A clinical study of ferric sulfate as a pulpotomy agent in primary teeth. Pediatr Dent. 1991;13(6):327-32.
78. Fishman SA, Udin RD, Good DL, Rodef F. Success of electrofulguration pulpotomies covered by zinc oxide and eugenol or calcium hydroxide: a clinical study. Pediatr Dent. 1996;18(5):385-90.
79. Fuks AB, Holan G, Davis JM, Eidelman E. Ferric sulfate versus dilute formocresol in pulpotomized primary molars: long-term follow up. Pediatr Dent. 1997;19(5):327-30.
80. Elliott RD, Roberts MW, Burkes J, Phillips C. Evaluation of the carbon dioxide laser on vital human primary pulp tissue. Pediatr Dent. 1999;21(6):327-31.
81. Shumayrikh NM, Adenubi JO. Clinical evaluation of glutaraldehyde with calcium hydroxide and glutaraldehyde with zinc oxide eugenol in pulpotomy of primary molars. Endod Dent Traumatol. 1999;15(6):259-64.
82. Ibricevic H, al-Jame Q. Ferric sulfate as pulpotomy agent in primary teeth: twenty month clinical follow-up. J Clin Pediatr Dent. 2000;24(4):269-72.
83. Waterhouse PJ, Nunn JH, Whitworth JM, Soames JV. Primary molar pulp therapy--histological evaluation of failure. Int J Pediatr Dent. 2000;10(4):313-21.
84. Chien MM, Setzer S, Cleaton-Jones P. How does zinc oxide-eugenol compare to ferric sulphate as a pulpotomy material? SADJ : journal of the South African Dental Association=tydskrif van die Suid-Afrikaanse Tandheelkundige Vereniging. 2001;56(3):130-5.
85. Eidelman E, Holan G, Fuks AB. Mineral trioxide aggregate vs formocresol in pulpotomized primary molars: a preliminary report. Pediatr Dent. 2001;23(1):15-8.
86. Dean JA, Mack RB, Fulkerson BT, Sanders BJ. Comparison of electrosurgical and formocresol pulpotomy procedures in children. Int J Pediatr Dent. 2002;12(3):177-82.
87. Holan G, Fuks AB, Ketlz N. Success rate of formocresol pulpotomy in primary molars restored with stainless steel crown vs amalgam. Pediatr Dent. 2002;24(3):212-6.
88. Casas MJ, Layug MA, Kenny DJ, Johnston DH, Judd PL. Two-year outcomes of primary molar ferric sulfate pulpotomy and root canal therapy. Pediatr Dent. 2003;25(2):97-102.
89. Ibricevic H, Al-Jame Q. Ferric sulphate and formocresol in pulpotomy of primary molars: long term follow-up study. Eur J Paediatr Dent. 2003;4(1):28-32.
90. Agamy HA, Bakry NS, Mounir MM, Avery DR. Comparison of mineral trioxide aggregate and formocresol as pulp-capping agents in pulpotomized primary teeth. Pediatr Dent. 2004;26(4):302-9.
91. Casas MJ, Kenny DJ, Johnston DH, Judd PL, Layug MA. Outcomes of vital primary incisor ferric sulfate pulpotomy and root canal therapy. J Can Dent Assoc. 2004;70(1):34-8.
92. Kalaskar RR, Damle SG. Comparative evaluation of lyophilized freeze dried platelet derived preparation with calcium hydroxide as pulpotomy agents in primary molars. J Indian Soc Pedod Prev Dent. 2004;22(1):24-9.
93. Farsi N, Alamoudi N, Balto K, Mushayt A. Success of mineral trioxide aggregate in pulpotomized primary molars. J Clin Pediatr Dent. 2005;29(4):307-11.
94. Holan G, Eidelman E, Fuks AB. Long-term evaluation of pulpotomy in primary molars using mineral trioxide aggregate or formocresol. Pediatr Dent. 2005;27(2):129-36.
95. Huth KC, Paschos E, Hajek-Al-Khatar N, Hollweck R, Crispin A, Hickel R, Folwaczny M. Effectiveness of 4 pulpotomy techniques-randomized controlled trial. J Dent Res. 2005;84(12):1144-8.
96. Naik S, Hegde AH. Mineral trioxide aggregate as a pulpotomy agent in primary molars: an in vivo study. J Indian Soc Pedod Prev Dent. 2005;23(1):13-6.
97. Saltzman B, Sigal M, Clokie C, Rukavina J, Titley K, Kulkarni GV. Assessment of a novel alternative to conventional formocresol-zinc oxide eugenol pulpotomy for the treatment of pulpally involved human primary teeth: diode laser-mineral trioxide aggregate pulpotomy. Int J Pediatr Dent. 2005;15(6):437-47.
98. Vargas KG, Packham B. Radiographic success of ferric sulfate and formocresol pulpotomies in relation to early exfoliation. Pediatr Dent. 2005;27(3):233-7.
99. Liu JF. Effects of Nd:YAG laser pulpotomy on human primary molars. J Endodont. 2006;32(5):404-7.
100. Vargas KG, Packham B, Lowman D. Preliminary evaluation of sodium hypochlorite for pulpotomies in primary molars. Pediatr Dent. 2006;28(6):511-7.
101. Aeinehchi M, Dadvand S, Fayazi S, Bayat-Movahed S. Randomized controlled trial of mineral trioxide aggregate and formocresol for pulpotomy in primary molar teeth. Int Endod J. 2007;40(4):261-7.
102. Aminabadi NA, Farahani RM, Gajan EB. A clinical study of formocresol pulpotomy versus root canal therapy of vital primary incisors. J Clin Pediatr Dent. 2008;32(3):211-4.

103. Bahrololoomi Z, Moeintaghavi A, Emtiazi M, Hosseini G. Clinical and radiographic comparison of primary molars after formocresol and electrosurgical pulpotomy: a randomized clinical trial. Indian J Dent Res. 2008;19(3):219-23.
104. Moretti AB, Sakai VT, Oliveira TM, Fornetti AP, Santos CF, Machado MA, Abdo RC. The effectiveness of mineral trioxide aggregate, calcium hydroxide and formocresol for pulpotomies in primary teeth. Int Endod J. 2008;41(7):547-55.
105. Noorollahian H. Comparison of mineral trioxide aggregate and formocresol as pulp medicaments for pulpotomies in primary molars. Br Dent J. 2008;204(11):E20.
106. Sabbarini J, Mohamed A, Wahba N, El-Meligy O, Dean J. Comparison of enamel matrix derivative versus formocresol as pulpotomy agents in the primary dentition. J Endodont. 2008;34(3):284-7.
107. Sonmez D, Sari S, Cetinbas T. A comparison of four pulpotomy techniques in primary molars: a long-term follow-up. J Endodont. 2008;34(8):950-5.
108. Trairatvorakul C, Chunlasikaiwan S. Success of pulpectomy with zinc oxide-eugenol vs calcium hydroxide/iodoform paste in primary molars: a clinical study. Pediatr Dent. 2008;30(4):303-8.
109. Zurn D, Seale NS. Light-cured calcium hydroxide vs formocresol in human primary molar pulpotomies: a randomized controlled trial. Pediatr Dent. 2008;30(1):34-41.
110. Alaçam A, Odabaş ME, Tüzüner T, Sillelioğlu H, Baygin O. Clinical and radiographic outcomes of calcium hydroxide and formocresol pulpotomies performed by dental students. Oral surgery, oral medicine, oral pathology, oral radiology, and endodontics. 2009;108(5):e127-33.
111. Sakai VT, Moretti AB, Oliveira TM, Fornetti AP, Santos CF, Machado MA, Abdo RC. Pulpotomy of human primary molars with MTA and Portland cement: a randomised controlled trial. Br Dent J. 2009;207(3):E5; discussion 128-9.
112. Subramaniam P, Konde S, Mathew S, Sugnani S. Mineral trioxide aggregate as pulp capping agent for primary teeth pulpotomy: 2 year follow up study. J Clin Pediatr Dent. 2009;33(4):311-4.
113. Ansari G, Ranjpour M. Mineral trioxide aggregate and formocresol pulpotomy of primary teeth: a 2-year follow-up. Int Endod J. 2010;43(5):413-8.
114. Zealand CM, Briskie DM, Botero TM, Boynton JR, Hu JC. Comparing gray mineral trioxide aggregate and diluted formocresol in pulpotomized human primary molars. Pediatr Dent. 2010;32(5):393-9.
115. Malekafzali B, Shekarchi F, Asgary S. Treatment outcomes of pulpotomy in primary molars using two endodontic biomaterials. A 2-year randomised clinical trial. Eur J Paediatr Dent. 2011;12(3):189-93.
116. Kurji ZA, Sigal MJ, Andrews P, Titley K. A retrospective study of a modified 1-minute formocresol pulpotomy technique part 1: clinical and radiographic findings. Pediatr Dent. 2011;33(2):131-8.
117. Liu H, Zhou Q, Qin M. Mineral trioxide aggregate versus calcium hydroxide for pulpotomy in primary molars. Chin J Dent Res. 2011;14(2):121-5.
118. Nematollahi H, Sahebnasagh M, Parisay I. Comparison of electrosurgical pulpotomy with zinc oxide eugenol or zinc polycarboxylate cements sub-base. J Clin Pediatr Dent. 2011;36(2):133-7.
119. Srinivasan D, Jayanthi M. Comparative evaluation of formocresol and mineral trioxide aggregate as pulpotomy agents in deciduous teeth. Indian J Dent Res. 2011;22(3):385-90.
120. Airen P, Shigli A, Airen B. Comparative evaluation of formocresol and mineral trioxide aggregate in pulpotomized primary molars-2 year follow up. J Clin Pediatr Dent. 2012;37(2):143-7.
121. Huth KC, Hajek-Al-Khatar N, Wolf P, Ilie N, Hickel R, Paschos E. Long-term effectiveness of four pulpotomy techniques: 3-year randomised controlled trial. Clin Oral Invest. 2012;16(4):1243-50.
122. Sushynski JM, Zealand CM, Botero TM, Boynton JR, Majewski RF, Shelburne CE, Hu JC. Comparison of gray mineral trioxide aggregate and diluted formocresol in pulpotomized primary molars: a 6- to 24-month observation. Pediatr Dent. 2012;34(5):120-8.
123. Trairatvorakul C, Koothiratrakarn A. Calcium hydroxide partial pulpotomy is an alternative to formocresol pulpotomy based on a 3-year randomized trial. Int J Pediatr Dent. 2012;22(5):382-9.
124. Yaman E, Görken F, Pinar Erdem A, Sepet E, Aytepe Z. Effects of folk medicinal plant extract Ankaferd Blood Stopper(®) in vital primary molar pulpotomy. Eur Arch Paediatr Dent. 2012;13(4):197-202.
125. Al-Mutairi MA, Bawazir OA. Sodium hypochlorite versus Formocresol in primary molars pulpotomies: a randomized clinical trial. Eur J Paediatr Dent. 2013;14(1):33-6.
126. Celik B, Ataç AS, Cehreli ZC, Uysal S. A randomized trial of mineral trioxide aggregate cements in primary tooth pulpotomies. J Dent Child. 2013;80(3):126-32.
127. Fernández CC, Martínez SS, Jimeno FG, Lorente Rodríguez AI, Mercadé M. Clinical and radiographic outcomes of the use of four dressing materials in pulpotomized primary molars: a randomized clinical trial with 2-year follow-up. Int J Pediatr Dent. 2013;23(6):400-7.
128. Havale R, Anegundi RT, Indushekar K, Sudha P. Clinical and radiographic evaluation of pulpotomies in primary molars with formocresol, glutaraldehyde and ferric sulphate. Oral Health Dent Manag. 2013;12(1):24-31.
129. Mettlach SE, Zealand CM, Botero TM, Boynton JR, Majewski RF, Hu JC. Comparison of mineral trioxide aggregate and diluted formocresol in pulpotomized human primary molars: 42-month follow-up and survival analysis. Pediatr Dent. 2013;35(3):E87-94.
130. Ruby JD, Cox CF, Mitchell SC, Makhija S, Chompu-Inwai P, Jackson J. A randomized study of sodium hypochlorite versus formocresol pulpotomy in primary molar teeth. Int J Pediatr Dent. 2013;23(2):145-52.
131. Shabzendedar M, Mazhari F, Alami M, Talebi M. Sodium hypochlorite vs formocresol as pulpotomy medicaments in primary molars: 1-year follow-up. Pediatr Dent. 2013;35(4):329-32.
132. Akcay M, Sari S. The effect of sodium hypochlorite application on the success of calcium hydroxide and mineral trioxide aggregate pulpotomies in primary teeth. Pediatr Dent. 2014;36(4):316-21.
133. Khorakian F, Mazhari F, Asgary S, Sahebnasagh M, Alizadeh Kaseb A, Movahhed T, Sarraf Shirazi AR. Two-year outcomes of electrosurgery and calcium-enriched mixture pulpotomy in primary teeth: a randomised clinical trial. Eur Arch Paediatr Dent. 2014;15(4):223-8.
134. Farsi DJ, El-Khodary HM, Farsi NM, El Ashiry EA, Yagmoor MA, Alzain SM. Sodium hypochlorite versus formocresol and ferric sulfate pulpotomies in primary molars: 18-month follow-up. Pediatr Dent. 2015;37(7):535-40.
135. Kang CM, Kim SH, Shin Y, Lee HS, Lee JH, Kim GT, Song JS. A randomized controlled trial of ProRoot MTA, OrthoMTA and RetroMTA for pulpotomy in primary molars. Oral diseases. 2015;21(6):785-91.
136. Lourenço Neto N, Marques NC, Fernandes AP, Hungaro Duarte MA, Abdo RC, Machado MA, Oliveira TM. Clinical and radiographic evaluation of Portland cement added to radiopacifying agents in primary molar pulpotomies. Eur Arch Paediatr Dent. 2015;16(5):377-82.
137. Olatosi OO, Sote EO, Orenuga OO. Effect of mineral trioxide

aggregate and formocresol pulpotomy on vital primary teeth: a clinical and radiographic study. Niger J Clin Pract. 2015;18(2):292-6.
138. Cuadros-Fernandez C, Rodriguez AIL, Saez-Martinez S, Garcia-Binimelis J, About I, Mercade M. Short-term treatment outcome of pulpotomies in primary molars using mineral trioxide aggregate and Biodentine: a randomized clinical trial. Clin Oral Invest. 2016;20(7):1639-45.
139. El Meligy OA, Allazzam S, Alamoudi NM. Comparison between biodentine and formocresol for pulpotomy of primary teeth: A randomized clinical trial. Quintessence Int 2016;47(7):571-80.
140. Musale PK, Soni AS. Clinical Pulpotomy Trial of Copaifera Langsdorffii Oil Resin Versus Formocresol and White Mineral Trioxide Aggregate in Primary Teeth. Pediatr Dent. 2016;38(2):5-12.
141. Togaru H, Muppa R, Srinivas N, Naveen K, Reddy VK, Rebecca VC. Clinical and Radiographic Evaluation of Success of Two commercially Available Pulpotomy Agents in Primary Teeth: An in vivo Study. J Contemp Dent Pract. 2016;17(7):557-63.
142. Yildirim C, Basak F, Akgun OM, Polat GG, Altun C. Clinical and radiographic evaluation of the effectiveness of formocresol, mineral trioxide aggregate, Portland cement, and enamel matrix derivative in primary teeth pulpotomies: a two year follow-up. J Clin Pediatr Dent. 2016;40(1):14-20.
143. Bani M, Aktaş N, Çınar Ç, Odabaş ME. The Clinical and Radiographic Success of Primary Molar Pulpotomy Using Biodentine™ and Mineral Trioxide Aggregate: A 24-Month Randomized Clinical Trial. Pediatr Dent. 2017;39(4):284-8.
144. Chauhan SP, Gupta M, Ahmed H, Tongya R, Sharma D, Chugh B. Evaluation and Comparison between Formocresol and Sodium Hypochlorite as Pulpotomy Medicament: A Randomized Study. J Contemp Dent Pract. 2017;18(11):1029-33.
145. Guven Y, Aksakal SD, Avcu N, Unsal G, Tuna EB, Aktoren O. Success Rates of Pulpotomies in Primary Molars Using Calcium Silicate-Based Materials: A Randomized Control Trial. International BR. 2017;2017:4059703.
146. Kathal S, Gupta S, Bhayya DP, Rao A, Roy AP, Sabhlok A. A comparative evaluation of clinical and radiographic success rate of pulpotomy in primary molars using antioxidant mix and mineral trioxide aggregate: An in vivo 1-year follow-up study. J Indian Soc Pedod Prev Dent. 2017;35(4):327-31.
147. Nguyen TD, Judd PL, Barrett EJ, Sidhu N, Casas MJ. Comparison of Ferric Sulfate Combined Mineral Trioxide Aggregate Pulpotomy and Zinc Oxide Eugenol Pulpectomy of Primary Maxillary Incisors: An 18-month Randomized, Controlled Trial. Pediatr Dent. 2017;39(1):34-8.
148. Ozmen B, Bayrak S. Comparative evaluation of ankaferd blood stopper, ferric sulfate, and formocresol as pulpotomy agent in primary teeth: A clinical study. Niger J Clin Pract. 2017;20(7):832-8.
149. Patidar S, Kalra N, Khatri A, Tyagi R. Clinical and radiographic comparison of platelet-rich fibrin and mineral trioxide aggregate as pulpotomy agents in primary molars. J Indian Soc Pedod Prev Dent. 2017;35(4):367-73.
150. Rajasekharan S, Martens LC, Vandenbulcke J, Jacquet W, Bottenberg P, Cauwels RG. Efficacy of three different pulpotomy agents in primary molars: a randomized control trial. Int Endod J. 2017;50(3):215-28.
151. Jamali Z, Alavi V, Najafpour E, Aminabadi NA, Shirazi S. Randomized Controlled Trial of Pulpotomy in Primary Molars using MTA and Formocresol Compared to 3Mixtatin: A Novel Biomaterial. J Clin Pediatr Dent. 2018;42(5):361-6.
152. Junqueira MA, Cunha NNO, Caixeta FF, Marques NCT, Oliveira TM, Moretti ABS, Cosme-Silva L, Sakai VT. Clinical, Radiographic and Histological Evaluation of Primary Teeth Pulpotomy Using MTA And Ferric Sulfate. Braz Dent J. 2018;29(2):159-65.
153. Nematollahi H, Noorollahian H, Bagherian A, Yarbakht M, Nematollahi S. Mineral Trioxide Aggregate Partial Pulpotomy Versus Formocresol Pulpotomy: A Randomized, Split-Mouth, Controlled Clinical Trial with 24 Months Follow-Up. Pediatr Dent. 2018;40(3):184-9.
154. Alsanouni M, Bawazir OA. A Randomized Clinical Trial of NeoMTA Plus in Primary Molar Pulpotomies. Pediatr Dent. 2019;41(2):107-11.
155. Atasever G, Keceli TI, Uysal S, Gungor HC, Olmez S. Primary molar pulpotomies with different hemorrhage control agents and base materials: A randomized clinical trial. ***Niger J Clin Pract.*** 2019;22(3):305-12.
156. Çelik BN, Mutluay MS, Arıkan V, Sarı Ş. The evaluation of MTA and Biodentine as a pulpotomy materials for carious exposures in primary teeth. Clin Oral Invest. 2019;23(2):661-6.
157. El Meligy O, Alamoudi NM, Allazzam SM, El-Housseiny AAM. Biodentine(TM) versus formocresol pulpotomy technique in primary molars: a 12-month randomized controlled clinical trial. BMC oral health. 2019;19(1):3.
158. Luengo-Fereira J, Ayala-Jiménez S, Carlos-Medrano LE, Toscano-García I, Anaya-Álvarez M. Clinical and Radiographic Evaluation of Formocresol and Chloramphenicol, Tetracycline and Zinc Oxide-Eugenol Antibiotic Paste in Primary Teeth Pulpotomies: 24 month follow up. J Clin Pediatr Dent. 2019;43(1):16-21.
159. Rubanenko M, Petel R, Tickotsky N, Fayer I, Fuks AB, Moskovitz M. A Randomized Controlled Clinical Trial Comparing Tricalcium Silicate and Formocresol Pulpotomies Followed for Two to Four Years. Pediatr Dent. 2019;41(6):446-50.
160. Silva L, Cosme-Silva L, Sakai VT, Lopes CS, Silveira A, Moretti Neto RT, Gomes-Filho JE, Oliveira TM, Moretti A. Comparison between calcium hydroxide mixtures and mineral trioxide aggregate in primary teeth pulpotomy: a randomized controlled trial. J Appl Oral Sci. 2019;27:e20180030.
161. Aripirala M, Bansal K, Mathur VP, Tewari N, Gupta P, Logani A. Comparative evaluation of diode laser and simvastatin gel in pulpotomy of primary molars: A randomized clinical trial. J Indian Soc Pedod Prev Dent. 2021;39(3):303-9.
162. Cordell S, Kratunova E, Marion I, Alrayyes S, Alapati SB. A Randomized Controlled Trial Comparing the Success of Mineral Trioxide Aggregate and Ferric Sulfate as Pulpotomy Medicaments for Primary Molars. J Dent Child. 2021;88(2):120-8.
163. Petel R, Ziskind K, Bernfeld N, Suliman H, Fuks AB, Moskovitz M. A randomised controlled clinical trial comparing pure Portland cement and formocresol pulpotomies followed from 2 to 4 years. Eur Arch Paediatr Dent. 2021;22(4):547-52.
164. Yavagal CM, Lal A, Chavan Patil VV, Yavagal PC, Neelakantappa KK, Hariharan M. Efficacy of laser photobiomodulation pulpotomy in human primary teeth: A randomized controlled trial. J Indian Soc Pedod Prev Dent. 2021;39(4):436-41.
165. Guang J, Li J, Hao L. Clinical observation and histopathological evaluation of pulp after pulpotomy of primary teeth with formocresol and biodentine. Cell Mol Biol (Noisy-le-grand). 2022;68(5):83-8.
166. Ildeş G, Sezgin BI, Vieira AR, Mentes A. A randomized clinical trial of hyaluronic acid gel pulpotomy in primary molars with 1 year follow-up. Acta odontologica Scandinavica. 2022;80(4):273-80.
167. Waterhouse P. Are different pulp treatment techniques and associated medicaments effective for the treatment of extensive decay in primary teeth? Evidence-based dentistry. 2021;22(1):12-3.
168. Coll JA, Seale NS, Vargas K, Marghalani AA, Al Shamali S, Graham

L. Primary tooth vital pulp therapy: a systematic review and meta-analysis. Pediatr Dent. 2017;39(1):16-27.
169. El-Meligy O, Abdalla M, El-Baraway S, El-Tekya M, Dean JA. Histological evaluation of electrosurgery and formocresol pulpotomy techniques in primary teeth in dogs. J Clin Pediatr Dent. 2001;26(1):81-5.
170. Cleaton-Jones P, Duggal M, Parak M, William S, Setze S. Ferric sulphate and formocresol pulpotomies in baboon primary molars: histological responses. Eur J Paediatr Dent. 2002;3(3):121-5.
171. Coll JA, Sadrian R. Predicting pulpectomy success and its relationship to exfoliation and succedaneous dentition. Pediatr Dent. 1996;18(1):57-63.
172. Sadrian R, Coll JA. A long-term followup on the retention rate of zinc oxide eugenol filler after primary tooth pulpectomy. Pediatr Dent. 1993;15(4):249-53.
173. Holan G, Fuks AB. A comparison of pulpectomies using ZOE and KRI paste in primary molars: a retrospective study. Pediatr Dent. 1993;15(6):403-7.
174. Nurko C, Garcia-Godoy F. Evaluation of a calcium hydroxide/iodoform paste (Vitapex) in root canal therapy for primary teeth. J Clin Pediatr Dent. 1999;23(4):289-94.
175. Rewal N, Thakur AS, Sachdev V, Mahajan N. Comparison of endoflas and zinc oxide eugenol as root canal filling materials in primary dentition. J Indian Soc Pedod Prev Dent. 2014;32(4):317-21.
176. 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):25-9.
177. Subramaniam P, Gilhotra K. Endoflas, zinc oxide eugenol and metapex as root canal filling materials in primary molars-a comparative clinical study. J Clin Pediatr Dent. 2011;35(4):365-9.
178. Pramila R, Muthu MS, Deepa G, Farzan JM, Rodrigues SJL. Pulpectomies in primary mandibular molars: a comparison of outcomes using three root filling materials. Int Endod J. 2016;49(5):413-21.
179. Mortazavi M, Mesbahi M. Comparison of zinc oxide and eugenol, and Vitapex for root canal treatment of necrotic primary teeth. International journal of paediatric dentistry. 2004;14(6):417-24.
180. Chen X, Liu X, Zhong J. Clinical and radiographic evaluation of pulpectomy in primary teeth: a 18-months clinical randomized controlled trial. Head & Face Medicine. 2017;13(1):12.
181. Sahebalam R, Sarraf A, Jafarzadeh H, Jouybari-Moghaddam M, Seyed-Musavi S. Bull Tokyo Dent Coll. The Bulletin of Tokyo Dental College. 2017;58(2):77-83.
182. Pandranki J, Vanga NRV, Chandrabhatla SK. Zinc oxide eugenol and Endoflas pulpectomy in primary molars: 24-month clinical and radiographic evaluation. J Indian Soc Pedod Prev Dent. 2018;36(2):173-80.
183. Zacharczuk GA, Toscano MA, López GE, Ortolani AM. Evaluation of 3Mix-MP and pulpectomies in non-vital primary molars. Acta Odontol Latinoam. 2019;32(1):22-8.
184. RojaRamya KS, Vinay C, Uloopi KS, Chandrasekhar R. In vivo evaluation of zinc oxide-propolis mixture as root canal filling material in the primary molars: A 24-month follow-up randomized controlled trial. J Indian Soc Pedod Prev Dent. 2020;38(2):171-6.
185. Moura J, Lima M, Nogueira N, Castro M, Lima C, Moura M, Moura L. LSTR Antibiotic Paste Versus Zinc Oxide and Eugenol Pulpectomy for the Treatment of Primary Molars with Pulp Necrosis: A Randomized Controlled Trial. Pediatr Dent. 2021;43(6):435-42.
186. Bresolin CR, Marques RPS, Okamura B, Costa C, Moura-Netto C, Lara JS, Mello-Moura ACV, Mendes FM. Efficacy of an iodoform-based filling material for pulpectomy of primary teeth: A 24-month non-inferiority randomized clinical trial. Int J Pediatr Dent. 2022;32(5):668-77.
187. Coll JA, Dhar V, Vargas K, Chen CY, Crystal YO, AlShamali S, Marghalani AA. Use of Non-Vital Pulp Therapies in Primary Teeth. Pediatr Dent. 2020;42(5):337-49.
188. Smail-Faugeron V, Courson F, Durieux P, Muller-Bolla M, Glenny AM, Fron Chabouis H. Pulp treatment for extensive decay in primary teeth. The Cochrane database of systematic reviews. 2014(8):Cd003220.
189. Elkhadem A, Sami I. No clear evidence of superiority regarding pulp medicaments in primary molars. Evid Based Dent. 2014;15(4):100-1.
190. Guelmann M, McEachern M, Turner C. Pulpectomies in primary incisors using three delivery systems: an in vitro study. J Clin Pediatr Dent. 2004;28(4):323-6.
191. Memarpour M, Shahidi S, Meshki R. Comparison of different obturation techniques for primary molars by digital radiography. Pediatr Dent. 2013;35(3):236-40.
192. Sahebalam R, Sarraf A, Abdollahi M, Jafarzadeh H, Rajati H, Patil S. Evaluation of the effect of using electrosurgery in pulpectomy of deciduous teeth on succedaneous teeth: an animal study. J Contemp Dent Pract. 2015;16(3):183-6.
193. Hendry JA, Jeansonne BG, Dummett CO, Jr., Burrell W. Comparison of calcium hydroxide and zinc oxide and eugenol pulpectomies in primary teeth of dogs. Oral surg oral med oral pathol. 1982;54(4):445-51.
194. Cleaton-Jones P, Duggal M, Parak R, Williams S, Setzer S. Zinc oxide-eugenol and calcium hydroxide pulpectomies in baboon primary molars: histological responses. Eur J Paediatr Dent. 2004;5(3):131-5.
195. Raslan N, Wetzel WE. Exposed human pulp caused by trauma and/or caries in primary dentition: a histological evaluation. Dental traumatology : official publication of International Association for Dentl Traumatol. 2006;22(3):145-53.
196. Anila B, Murali H, Cheranjeevi J, Kapil RS. Lesion sterilization and tissue repair (LSTR): a review. J Scient Dent. 2014;4(2):49-55.
197. Sato I, Ando-Kurihara N, Kota K, Iwaku M, Hoshino E. Sterilization of infected root-canal dentine by topical application of a mixture of ciprofloxacin, metronidazole and minocycline in situ. Int Endod J. 1996;29(2):118-24.
198. Takushige T, Cruz EV, Asgor Moral A, Hoshino E. Endodontic treatment of primary teeth using a combination of antibacterial drugs. Int Endod J. 2004;37(2):132-8.
199. Nanda R, Koul M, Srivastava S, Upadhyay V, Dwivedi R. Clinical evaluation of 3 Mix and Other Mix in non-instrumental endodontic treatment of necrosed primary teeth. J Oral Biol Craniofac Res. 2014;4(2):114-9.
200. Doneria D, Thakur S, Singhal P, Chauhan D, Keshav K, Uppal A. In search of a novel substitute: clinical and radiological success of lesion sterilization and tissue repair with modified 3Mix-MP antibiotic paste and conventional pulpectomy for primary molars with pulp involvement with 18 months follow-up. Contemp Clin Dent. 2017;8(4):514-21.

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