Clinical and radiographic success of (partial) pulpotomy and pulpectomy in primary teeth: A systematic review

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DOI 10.23804/ejpd.2021.22.04.4

Abstract

Aim The aim of this systematic review was to evaluate the clinical outcome of partial pulpotomy, pulpotomy and pulpectomy for treating primary teeth with normal or infected pulp or with irreversible pulpitis.

Methods Two reviewers on Pubmed and ISI Web of Science performed a comprehensive literature review of publications from 1966 until July 2019. Pico outline was used to facilitate literature research. Among abstracts, publications were selected according to the following criteria: prospective clinical study, correct indication for the performed treatment, clear definition of clinical and/or radiographic success criteria and at least 6-month follow-up period. The strict selection criteria under the keywords "pulpotomy", "partial pulpotomy" and "pulpectomy" resulted in a limited amount of randomised controlled trials (RCT) or controlled clinical trials (CT). Qualitative assessment of the selected clinical studies and level of evidence was included according to the criteria described by the Oxford Centre for Evidence-Based Medicine (CEBM).

Results Seventy-five clinical studies were included and levels of evidence for papers ranged from Ia to IIa. Several clinical-based recommendations for partial pulpotomy, pulpotomy and pulpectomy were given.

Conclusion Prerequisites for a successful pulpotomy are symptom-free teeth, sterile removal of coronal pulp and haemostasis. Both MTA and formocresol perform well for partial pulpotomies after caries exposure. Formocresol had been the most popular amputation material for pulpotomies. Due to the potential side effects, other medicaments, such as ferric sulfate, mineral trioxide aggregate (MTA) or NaOCl are suggested. Grey and white MTA yeld the same results. Lasers are not recommended due to their large diversity. Regarding pulpectomy, the conditions, procedures, and evaluation for the treatment were not well defined in the studies. Nevertheless, there is evidence to use calcium hydroxide, zinc oxide eugenol paste or iodoform based pastes as root filling materials for non-vital molars. Pulpectomies showed better success rates than pulpotomies. Stainless steel crowns are recommended as definite restorations after both endodontic treatments. Longer follow-up periods, further clinical studies with comparable conditions and clear definition of evaluation criteria are needed to further confirm the results of endodontic treatment in primary teeth.

KEYWORDS Pulpotomy, Pulpectomy, Pulpitis, Primary teeth, Endodontic treatment, Child.

Introduction

Despite measureable successes in caries prevention, caries remains an unsolved problem all over the world [Bagramianet al., 2009]. In the field of paediatric dentistry, this is especially true when early childhood caries is considered [Peretz et al., 2003]. In most cases and due to several socioeconomic reasons, children arrive too late at the dentist's office, therefore caries is already frequently associated with pulpitis which—when irreversible —may even lead to premature extractions [Alsheneff and Hughes, 2001]. Pulp treatments combine a treatment technique and a medicament. Depending on the severity of the disease, three pulp treatment techniques are available: pulp capping (direct or indirect) [Boutsiouki et al., 2018], pulpotomy, and pulpectomy [Smail-Faugeron et al., 2018]. Choice of therapy mainly depends on pulp vitality. In cases of vital pulp an indirect or direct pulp capping [Boutsiouki et al., 2018] or pulpotomy is indicated [Coll et al., 2017]. Loss of pulp vitality, due to irreversible pulpitis or necrosis, results in non-vital pulp treatment, namely pulpectomy. The American Academy of Paediatric Dentistry [2008] states that teeth exhibiting spontaneous and unprovoked pain, soft tissue inflammation not being attributable to gingivitis or periodontitis, irregular mobility not being due to trauma or exfoliation, sinus tract, interradicular or apical radiographical translucency, or X-ray evidence of internal or external resorption need to be subjected to non-vital pulp treatment.

Partial pulpotomy

Partial pulpotomy is indicated when the pulp is exposed accidentally or during caries excavation suffering partial chronic pulpitis [Robertson et al., 2000]. The superficial part of the sound, not infected pulp is removed and an appropriate coverage is applied (e.g. calcium hydroxide) [Cvek et al., 1982; Schroder, 2001]. In comparison to cervical pulpotomy, it is more conservative as it causes less damage to the pulp and to the surrounding hard tissues, making the tooth easier to restore [Schroder, 2001]. Clinical studies for partial pulpotomy mainly deal with post-traumatic therapy of primary anterior teeth with calcium hydroxide [Robertson et al., 2000; Blanco,

1996] as this was its initial indication. However, according to AAPD best practice recommendations, partial pulpotomy is also suggested for carious pulp exposure with controlled bleeding, however in permanent teeth. Regarding other capping materials, formocresol and MTA have been reported in a single study with primary teeth [Nematollahi et al., 2018].

Pulpotomy

Pulpotomy is not only the most frequent treatment in primary teeth endodontics, but also the most controversial [Sabbarini et al., 2008]. Its main indication is when radicular pulp is not irreversibly inflamed and prerequisites are asymptomatic tooth or reversible pain of a carious or non-carious pulp exposure [Huth et al., 2005] with no radiographic signs of infection or pathologic resorption. Pulpotomy is performed in three steps: a) devitalization, removal of the vital tissue; b) preservation, the maximum amount of vital tissue is kept along with no induction of reparative dentin; c) regeneration; stimulation of dentine bridge [Elliott et al., 1999]. In order for these to happen, the exposed area has to be covered with one of the following medicaments for long-term clinical success: Formocresol (devitalization), calcium hydroxide (regeneration), ferric sulfate (preservation), and mineral trioxide aggregate or MTA (regeneration) [Coll et al., 2017]. Application of enamel matrix derivative (EMD), obtained from embryonic enamel of amelogenin, was also used in a single clinical trial over a 6-month period [Sabbarini et al., 2008]. Electrosurgery for coronal pulp removal was reported to be successful [Liu, 2006; Durmus and Tanboga, 2014]. On the other hand, the effect of lasers (carbon dioxide laser, Er:YAG laser, diode laser, low level laser therapy) is not clearly and unanimously reported so far [Huth et al., 2005; Liu, 2006; Durmus and Tanboga, 2014; Fernandes et al., 2015; Odabas et al., 2011].

A natural plant extract (Ankaferd Blood Stopper®) is also investigated as an alternative medicament. It contains Thymus vulgaris, Glycyrrhiza glabra, Vitis vinifera, Alpinia officinarum, Urtica dioica and acts by creating an encapsulated protein network providing focal points for vital erythrocyte aggregation [Yaman et al., 2012; Ng and Messer, 2008].

The success of pulpotomies is estimated clinically by a symptom-free radicular pulp with no sensitivity, pain, or swelling. Radiographically, no signs of pathological external root resorption should be present. Internal root resorption may be self-limiting and remains unchanged over time. The clinician should monitor internal resorption, removing the affected tooth if perforation causes loss of supportive bone and/or clinical signs of infection and inflammation are present. Any harm to the succedaneous tooth should be avoided [Rodd et al., 2006].

Pulpectomy

Irreversibly infected or necrotic pulp due to caries or trauma requires pulpectomy as root canal procedure. Another indication are teeth planned for pulpotomy at which the radicular pulp exhibits clinical signs of irreversible pulpitis (e.g., excessive haemorrhage being not controlled with a damp cotton pellet applied for several minutes) or pulp necrosis (e.g., suppuration, purulence). The roots should exhibit minimal or no resorption.

Infected tissue has to be removed up to 2 mm from the radiological apex [Siqueira et al., 2007] and root canal walls have to be cleaned with K or H files. With irrigants alone, an effective disinfection of the root canal is impossible. However, irrigants (1% NaOCl and/or chlorhexidine) are important additional measures for optimal disinfection of the root canal [Siqueira et al., 2007; Kleier et al., 2008]. Due to possibly open apices, irrigants have to be limited to the canal lumen exclusively, as overpressing is dangerous for surrounding tissues [Holan and Fuks, 1993]. After drying the root canal, a resorbable material has to be used for obturation. Appropriate root canal sealers for primary teeth are non-reinforced zinc/oxide eugenol [Chawla et al., 1998], iodoform paste (KRI) [Chawla et al., 1998; Mendoza et al., 2010; Nurko and Garcia-Godoy, 1999], calcium hydroxide [Mendoza et al., 2010; Nurko and Garcia-Godoy, 1999], or a combination paste of iodoform and calcium hydroxide (Vitapex, Endoflax) [Mortazavi and Mesbahi, 2004; Nakornchai et al. 2005; Ozalp et al., 2005; Nakornchai et al., 2010]. For treatment of pulp necrosis with additional furcation or apical radiolucency, an antibiotic combination (3Mix) and Vitapex was investigated, however, with low radiographical success rates after 12 months of clinical service [Primoch et al., 2005]. After treatment, x-ray control is recommended. Inflammations should be healed after 6 months and clinical symptoms should disappear within some weeks. Root canals should not be over- or underfilled [Nakornchai et al., 2010; Heneghan, 2009], no pathologic root resorption or furcation/apical radiolucency should be present and the treatment should not affect natural resorption and exfoliation.

Since the most recent systematic reviews on the subject were published in 2017 [Coll et al., 2017] and 2018 [Smail-Faugeron et al., 2018] and since they do not investigate partial pulpotomy and pulpotomy separately, the present paper attempts to add more knowledge. The purpose of this investigation was to perform a systematic review of partial pulpotomy, pulpotomy and pulpectomy in carious primary teeth after a minimum of 6 months to determine and compare the clinical and radiographic success rates.

Materials and methods

A systematic review protocol was written and the PRISMA checklist [Downs and Black, 2008] was followed in the planning and conducting of the review.

Focused question: What is the clinical and radiographic success of partial pulpotomy, pulpotomy and pulpectomy in the primary dentition?

The PICO outline was as follows.

- Population: Subjects with vital or non-vital primary teeth as a result of caries in need of partial pulpotomy, pulpotomy or pulpectomy.
- Intervention: Partial pulpotomy, pulpotomy or pulpectomy.
- Comparisons: Subjects with vital or non-vital primary teeth as a result of caries where a treatment with a different material was performed, or a different treatment approach was used.
- Outcomes: More than 6-month clinical success (function, absence of symptoms such as pain and discomfort) and radiographical success (signs of pathologic changes on radiograph).

Inclusion criteria were the following.

- Prospective clinical study.
- Randomised controlled trials (RCTs) or controlled clinical trials (CTs).
- Correct indication of the performed treatment.
- Clear definition of clinical and/or radiographic success criteria.
- At least 6-month follow-up.

Exclusion criteria: Any publication not fulfilling the above criteria was excluded. The present systematic review reports data only relative to human studies. Reports that were non-relevant for the review question as well as case reports, *in vitro*, animal studies, histological studies, studies in the field of trauma, retrospective studies, studies with permanent teeth and studies without English full-text were excluded.

Literature search strategy

A structured search was conducted for papers written in English and published from 1966 until July 2019 through the electronic databases Pubmed and ISI Web of Science and was complemented by a search through the reference lists of included studies. Narrative or systematic reviews on the subject, although not included, were also searched to identify suitable papers. Key words were combined for topics of interest and three text blocks were used: Text block A involved primary teeth, primary molars, primary dentition, deciduous teeth, or deciduous molars. Text block B consisted of pulp therapy or endodontic therapy. Text block C was considered for the treatment strategy and was combined with A and B. Keywords were: partial pulpotomy (P-POT); pulpotomy (POT); pulpectomy (PET).

Study selection

Study selection was carried out by two independent reviewers in the following stages.

1. Initial screening of potential papers according to the inclusion criteria, resulting in a complete database by merging studies included at least by one reviewer.
2. Screening of the full-text papers identified as possibly relevant to the question of the review.

Disagreements between reviewers were resolved by consensus-based discussion.

Qualitative assessment of the studies

The qualitative assessment of the selected RCT studies was carried out using the criteria described by the Oxford Centre for Evidence-based Medicine Levels of Evidence (CEBM) [Allen and Stokes, 1987]. Qualitative assessment of the included trials was carried out independently and in duplicate by two reviewers without blinding the name of authors, institutions and journals. Grading for the recommendations in evidence considering all included studies was performed according to the CEBM 2009 [Alles and Stokes, 1987]. In addition, the methodological quality of each paper was assessed using the criteria of Downs and Black for internal validity (bias and selection bias) [Aminabadi et al., 2008].

Data collection

Data from the selected studies were recorded from the abstracts and entered into RefMan (2003) software for further analysis. Full-text articles were obtained from or ordered through the University of Giessen library, if the title or the abstract did not provide enough information about the study to make a decision or there was no abstract available. For each selected trial the following data were recorded.

- Year of publication and country of origin.
- Sample size, age of participants and drop outs/withdrawals.
- Clinical and radiographic success rates.
- Detailed description of interventions, techniques and materials used.
- Signs and symptoms pre- and post-treatment.
- Duration of studies.

Types of participants

Young patients presenting vital or non-vital teeth as a result of caries in primary teeth. Since diagnosis of pulp status in primary teeth can be difficult due to the age and/or the compliance of the children [Howley et al., 2012], diagnosis should depend on dental history and one or more clinical signs and symptoms.

Absence of the following clinical signs and symptoms was linked with reversible pulpitis [Siqueira et al., 2007].

- Spontaneous pain, primarily during night time.
- Percussion (cavity: food impaction after proximal breakdown).
- Local analgesia required.
- Progressive caries with breakdown of the marginal ridge.
- Evidence of abscess or fistula.

Following diagnostic tools should be used [Siqueira et al., 2007].

- Palpation for detection of affected teeth.
- Sensitivity testing (is questionable for primary molars and should be avoided in order not to cause pain to the child and lead to a lack of cooperation).
- Radiographs are mandatory for estimating pathological processes (depth of carious lesion, distance to the pulp, degree of physiological and pathological root resorption, presence of any peri-radicular pathology, permanent tooth).

Results

Description of studies

Altogether, 720 papers were identified of which 279 articles were excluded from further analysis due to the following reasons: 90 reviews, 45 case reports, 16 were *in vitro* studies, 20 dealt with trauma, 18 were based on histology, 24 were retrospective trials, 18 measured microbiological numbers. Another 351 manuscripts were excluded manually due to missing matches with the topic or estimation criteria. Altogether, 90 randomised clinical trials (RCT) or clinical trials (CT) remained. Of these articles further exclusions were made when considering multiple publications of single trials (without any addition to existing knowledge), short observation time (<6 months) or a retrospective design of the study, therefore finally 75 studies were selected (Table 1).

Partial pulpotomy

Studies for partial pulpotomy

The treatment option of partial pulpotomy after caries excavation was subjected to a single RCT with 2-year follow-up [Nematollahi et al. 2018]. According to that, both MTA and formocresol performed equally well, exhibiting 90.9-100% clinical and 90.5-95.2% radiographic success rates (Table 2).

Pulpotomy

Completed searches from the selected sources identified 492 papers (Table 1). Among 101 RCTs and CTs, 70 studies were selected for assessment (Tables 1, 2). Level of evidence for papers ranged from Ia to IIa. Observation time was 6-60 months. Seven studies had an observation time <12 months. Three papers compared pulpotomy and pulpectomy in anterior teeth [Daher et al., 2015; Markovic et al., 2005; Rivera et al., 2003] and one in molars [Bahrololoomi et al., 2008]. The main reasons for exclusion of teeth/participants from the selected

studies were: spontaneous pain, swelling, tenderness to percussion, pathological mobility, pre-operative radiographic pathology such as resorption, periradicular or furcal radiolucency, widened periodontal ligament space, physiological root resorption of more than one-third, initially unsuccessful haemostasis.

Pulpotomy results

The following issues were addressed: pulpotomy vs. pulpectomy, treatment of exposed tissue, amputation material (formocresol, glutaraldhyde, LPDP, EMD, ZNO, calcium hydroxide, calcium hydroxide-iodoform, calcium hydroxide-RMGIC-Resin modified glass ionomer cement, MTA, Biodentine), use of laser, electrosurgery, and type of restoration. All selected clinical studies carried out both clinical (absence of pain, sinus tract, swelling, and abnormal mobility) and radiographic (lack of internal or external root resorption, periapical or furcal radiolucency) analyses. Failure was defined when internal or external root resorption, furcation, or periapical bone destruction, pain, swelling, or fistula occurred. Preparation, pulp exposure, and trepanation was made using high-speed bur or diamond under water rinsing. Coronal pulp tissues were predominantly removed with spoon-shaped excavators or slow speed round burs, only one study reported the use of sterile diamond burs under saline irrigation [Khorakian et al., 2014]. Some studies involved lasers [Huth et al., 2005; Durmus and Tanboga 2014; Fernandes et al., 2015; Odabas et al., 2011] exhibiting 93–100% clinical and 75-94.1% radiographic success, electrosugery [Durmus and Tanboga, 2014; Fishman et al., 1996; Fei et al., 1991; Akcay and Sari, 2014] exhibiting 95-100% clinical and 84-95.2% radiographic success; or electrofulguration [Shumayrikh and Adenubi, 1999] with 77.39–81% clinical 54.6–57.3% radiographic success, for amputation (Table 2). In all cases, haemostasis was required as fundamental prerequisite using saline wetted or damp cotton pellets for 15 sec – 5 minutes. Some studies used dry cotton pellets [Khorakian et al., 2014; Fei et al., 1991; Casas et al., 2003; Casas et al., 2004], 3% hydrogen peroxide [Subramaniam et al., 2009] or water rinsing [Percinoto et al., 2006; Redig 1968; Tannure et al., 2011] for haemostasis. Percinoto et al. [2006] applied a corticoid/antibiotic solution for 48 hours prior to sealing [Bawazir and Salama, 2006], however, without significant effect. Sodium hypochlorite and saline [Casas et al., 2004] were directly compared. Formocresol was the most frequent medicament reported (Table 2), and was mainly used diluted 1:5 and usually served as control group. Formocresol application time ranged from 1 min [Tannure et al., 2011] to 72–120 hours [Ramar and Mungara, 2010]. Clinical success rate of formocresol was 67–100% and radiographic success was 13–100%. MTA and calcium hydroxide on the other hand demonstrated 80-100% and 33.3–100% clinical, and 66.7–100% and 33.3–96.4% radiographical success rates respectively. Ferric sulfate showed 53.8-100% clinical success and 19–100% radiographic success (Table 2). Success rates showed a great range since different restorative materials (Cavit, RMGIC, ZOE, IRM), different definite restorations (SSC-stainless steel crown, amalgam, composite resin) and different coronal pulp removal protocols were used.

Pulpectomy

Studies for pulpectomy

Completed searches from the selected sources identified 228 papers (Table 1). Eight papers were selected for assessment (Table 3). Levels of evidence for papers ranged from Ia to IIa. Observation time was 6–36 months. Three studies reached an observation time <12 months. The selected studies defined inclusion and/or exclusion criteria based on clinical and radiographic examination and either non-vital teeth or teeth with degenerating pulpal change were included. Only one study investigated pulpectomy at anterior teeth [Saltzman et al., 2005]. The main reasons for exclusion of teeth/participants were: unrestorable tooth, high mobility of the tooth (grade III), inadequate bone support, obliteration

TABLE 1

Search criteria	Papers relevant for pulpotomy / partial pulpotomy	Papers relevant for pulpectomy	Total
Initial citation search[2]	492	228	720
review[1]	64	26	
case report[1]	22	23	
in vitro[1]	12	4	
fracture/trauma*[1]	11	9	
histo*[1]	5	13	
retrospective[1]	16	8	
bacteria*[1]	0	18	
LA-jpn[1] LA-spa[1] LA-ita[1] LA-dan[1] LA-hrv[1] LA-swe[1] LA-chi[1]	9 3 1 4 1 1	2 3 0 0 0 1 1	11 6 1 4 1 2 1
anaesth*[1]	17	5	17
titles and abstracts examined for relevance	326	115	441
pre-selected studies	174	37	211
randomised clinical trials (RCTs) clinical trials (CTs)	61 43	20 15	78 58
definitive selection	70	8	75

Reference (Level of evidence)	Number of Teeth (total)	Age (yrs)	Pulp dressing Material	Number of Teeth		Type of coronal pulp removal	Definitive restoration	Type of teeth	Oberservation time (months)	Success rate (%)	
				Study begin	Study end					Clinical	Radiographic
Aeinehchi et al. 2007 (1)	126	5–9	MTA (ProRoot) FC (3min) + ZOE	51 75	43 57	Spoon-shaped excavator + saline-wetted cotton pellet: haemostasis	Amalgam or GIC	molar	6	100 100	89.5 100
Agamy et al. 2004 (1)	60	4–8	Gray MTA (ProRoot) White MTA (ProRoot) FC + IRM	24 24 24	19 20 20	Spoon-shaped excavator + water-moistened cotton pellet: haemostasis	SSC	molar	12	100 80 90	100 80 90
Airen et al. 2012	70	6–8	MTA + ZOE FC + ZOE	35 35	30 30	Spoon excavator + water irrigation + cotton pellet: haemostasis	SSC	molar	24	97 85	88.6 54.3
Alacam et al. 2009 (1)	105	4–8	FC (3min) + IRM Ca(OH)2 + IRM Ca(OH)2/Iodoform + IRM	35 35 35	29 33 29	Sterile spoon-shaped excavator + saline-wetted cotton pellet (3-5min): haemostasis	SSC	molar	12	89.7 33 17.2	89.7 33.3 13.8
Al-Mutairi and Bawazir 2013	82	4–8	5% NaOCl + IRM 20% FC + IRM	41 41	40 40	Low speed large round bur + saline + sterile cotton pellet (5min): haemostasis	SSC	molar	12	94.6 92.1	86.5 86.8
Akcay and Sari 2014	128	Ø 8	Ca(OH)2 + 5% NaOCl (30sec) + IRM Ca(OH)2 + saline + IRM MTA + 5% NaOCl (30sec) + IRM MTA + saline + IRM	31 31 31 31	31 31 31 31	Sterile spoon-shaped excavator + dry cotton pellet (5min): haemostasis	SSC	molar	12	100 96.8 100 100	84 74 97 100
Aminabadi et al. 2008 (1)	100	3–4	FC (5min) + ZOE RCTR: x-ray 2 mm short of apex; NaCl + ZOE	50 50	45 46	Sharp excavator + saline-wetted cotton pellet (5min): haemostasis	GIC + self-cure resin	incisor	24	86.9 95.6	76.1 91.3
Ansari & Ranjpour 2010 (1)	40	4–9	FC (5min) + ZOE MTA (ProRoot)	20 20	15 15	Sharp spoon-shaped excavator + saline-wetted cotton pellet: haemostasis	SSC	molar	24	70[1] 95	90 95
Atasever et al. 2018	80	6–9	Ferric sulfate + ZOE Ferric sulfate + Ca(OH)2 NaOCl + ZOE NaOCl + Ca(OH)2	20 20 20 20	20 18 19 19	Slow speed steel round bur + saline irrigation + cotton pellet (5min): haemostasis	GIC + SSC	molar	12	95 100 100 89.5	80 88.9 78.9 84.2
Bahrololoomi et al. 2008 (1)	100	5–10	Electrosurgery + ZOE FC (5min) +ZOE	35 35	33 35	Electrosurgery vs. Hand instrument or bur (dry) + dry cotton pellet: haemostasis!	Amalgam	molar	9	96 100	84 96.8
Cardoso-Silva et al. 2011	233		Grey MTA White MTA	74 136	74 134	Low speed round bur + sterile cotton pellet: haemostasis	RMGIC + SSC	molar	84	100 98.5	97.1
Casas et al. "Two-year…" 2003 (1)	291	Ø 4	Ferric Sulfate (15s) + ZOE RCTR: short of apex; water + ZOE	182 109	73 43	Sterile low-speed round bur + Ferric sulfate- + water-syringe: haemostasis	SSC	molar	24	96 98	19 50
Casas et al. "Long-term …" 2004 (1)	291	Ø 4	Ferric Sulfate (15s) + ZOE RCTR: short of apex; water + ZOE	182 109	15 14	Sterile low-speed round bur + Ferric sulfate- + water-syringe: haemostasis	SSC	molar	36	62 92	54 72
Casas et al. "Outcomes of…" 2004 (1)	133	Ø 3	Ferric Sulfate (15s) + ZOE RCTR: short of apex; water + ZOE	64 69	41 36	Sterile low-speed round bur + Ferric sulfate- + water-syringe: haemostasis	Etch&rinse (phosph. a.) Resin composite	incisor	24	78 100	78 100
Celik and Sari 2016	50	6–9	Carious exposure + MTA + IRM Mechanical exposure + MTA + IRM	24 26	22 24	Low-speed bur + saline +moistened cotton pellets (5min): haemostasis	SSC	molar	18	100 100	100 100
Celik et al. 2019	44	5–9	MTA + IRM Biodentine + IRM	24 20	22 17	Low-speed instrument with water spray + saline irrigation + saline moistened cotton pellet (5min): haemostasis	SSC	molar	24	100 89.4	

[1] Calculation by the authors - RCTR: Root Canal Treatment

Continued ➢

Reference (Level of evidence)	Number of Teeth (total)	Age (yrs)	Pulp dressing Material	Number of Teeth		Type of coronal pulp removal	Definitive restoration	Type of teeth	Oberservation time (months)	Success rate (%)	
				Study begin	Study end					Clinical	Radiographic
Daher et al. 2015	53	4–8	Chloramphenicol, tetracycline, zinc oxude, eugenol RCTR: calcium hydroxide paste	37 16	27 7	Sterile excavator + cotton pellet: haemostasis	GIC + resin composite	molar	24	27 68.7	
Dean et al. 2002 (1)	50	Ø 5	Electrosurgery + ZOE FC (5min) + ZOE	25 25	25 25	Electrosurg. vs. Hand instrument or bur (dry) + control of haemostasis after ES/FC	SSC	molar	Ø 10.9 Ø 11.5	96 100	84 92
Doyle et al. 2010	270	Ø 4	Ferric sulfate + IRM Eugenol-free ferric sulfate + Cimpat S MTA + IRM Ferric sulfate/MTA + IRM	58 78 57 77	46 64 47 70	Round bur + control of haemostasis (15s) by ferric sulfate or moistened cotton pellets	SSC	molar	24	89.1 87.5 100 100	74 52 96 87
Durmus and Tanboga 2014	120	5–9	FC + ZOE Ferric sulfate + ZOE Diode laser + ZOE	40 40 40	40 39 40	Slow speed burs + spoon excavator + dry cotton pellet. haemostasis	GIC + SSC	molar	12	97 95 100	87 79 75
Eidelman et al. 2001 (1)	45	5–12	MTA + IRM FC (5min) +IRM	17 15	17 15	Round bur + control of haemostasis	SSC	molar	6-30	100 100	100 96.9
Erdem et al. 2011	128	5–7	MTA Ferric sulphate FC ZOE	25 25 25 25	25 25 25 25	Spoon excavator + saline irrigation + moistened cotton pellets: haemostasis	amalgam	molar	24	96 88 88 68	
Farsi et al. 2005 (1)	120	3–8	MTA + IRM FC (5min) + IRM	60 60	36 38	Round bur + damp sterile cotton pellet: haemostasis	SSC	molar	24	98.6 100	86.8 100
Farsi et al. 2015	81	4–8	NaOCl + ZOE FC + ZOE Ferric sulfate + ZOE	27 27 27	24 25 23	Sterile low speed carbide bur + moist sterile cotton pellet (5min): haemostasis	SSC	molar	18	83.3 96 87	91.7 100 95.7
Fei et al. 1991 (1)	83	3–10	Ferric Sulfate + IRM FC (5min) + IRM	83	28 27	Sterile sharp spoon-shaped excavator or slow speed round bur + dry cotton pellet for haemostasis control	SSC	molar	12	100 96.3	96.55 81.48
Fernandez et al. 2013	100	5–9	FC + IRM Ferric sulfate (15s) + IRM NaOCl + IRM MTA + IRM	25 25 25 25	21 13 17 12	Sterile slow speed round bur + moistened cotton pellets (5min): haemostasis	SSC	molars	24	100 92 96 100	95 100 75 93
Fernandes et al. 2015	60	5–9	FC + ZOE Ca(OH)2 + ZOE Low level laser + IRM Low level laser + Ca(OH)2 + IRM	15 15 15 15	15 9 15 12	Excavator + saline irrigation + dry cotton pellet (5min): haemostasis	RMGIC	molars	18	100 100 100 100	100 66.7 73.3 75
Fishman et al. 1996 (1)	47	3–8	Electrofulguration + ZOE Electrofulg. + Ca(OH)2	24 23	21 22	Electrofulguration + control of haemostasis	SSC	molar	6	77.39 81	54.6 57.3
Howley et al. 2012	100	1,5–5	FC + ZOE RCTR: Vitapex	50 50	30 30	Spoon excavator + water dampened cotton pellet: haemostasis	SSC	incisors	23	100 100	89 73
Huth et al. 2005 (1)	200	2–8	ER:YAG + IRM Ca(OH)2 + KerrLife + IRM Ferric Sulfate (15s) + IRM FC (5min)+IRM	50 50 50 50	39 34 42 46	Laser vs. Sterile hand excavator and slow speed round bur + 5min saline-wetted cotton pellet: haemostasis	GIC + SSC or GIC + Composite	molar	24	93 87 100 96	87 70 86 90
Huth et al. 2012	200	2–8	FC (5min)+IRM ER:YAG + IRM Ca(OH)2 + KerrLife + IRM Ferric Sulfate (15s) + IRM	50 50 50 50	22 24 15 34	Laser vs. Sterile hand excavator and slow speed round bur + 5min saline-wetted cotton pellet: haemostasis	GIC + SSC or GIC + Composite	molar	36	72 73 46 76	
Ibricevic & al-Jame 2000 (1)	70	3–6	Ferric Sulfate (15s) + IRM FC (5min) + IRM	35 35	?	Sterile round bur + control of haemostasis?	SSC after 5 days	molar	20	100 100	97.2 97.2

Reference (Level of evidence)	Number of Teeth (total)	Age (yrs)	Pulp dressing Material	Number of Teeth		Type of coronal pulp removal	Definitive restoration	Type of teeth	Oberservation time (months)	Success rate (%)	
				Study begin	Study end					Clinical	Radiographic
Jabbarifar et al. 2004 (1)	64	5–8	FC (5min) + ZOE MTA (ProRoot) + ZOE	32 32	32 32	Sharp spoon excavator + control of haemostasis	SSC	molar	12	90.2 93.7	
Kalaskar & Damle 2004 (2)	56	4–7	LPDP2 + ZOE Ca(OH)2+ GIC	28 28	28 27	spoon excavator + 5min sterile pledget of moist cotton: haemostasis	SSC	molar	6	100 96.4	100 96.4
Khorakian et al. 2014	102	4–6	Calcium-enriched mixture cement + GIC Electrosurgery+ ZOE	51 51	40 42	Slow speed sterile round bur, cotton pellet moistened with saline: haemostasis	SSC	molar	24	100 100	90 95.2
Liu 2006 (2)	137	4–7	Nd:YAG + IRM FC (5min) + IRM	68 69	2 1	Laser vs. Sterile sharp spoon excavator + dry sterile cotton pellet: haemostasis	Composite or SSC	molar	> 60	97 85.5	94.1 78.3
Liu et al. 2011	40	4–9	MTA + GIC Ca(OH)2 + GIC	20 20	17 17	Round bur + saline moistened cotton pellets: haemostasis	Composite	molar	56	94.1 64.7	
Malekafazli et al. 2011	80	4–8	Calcium-enriched mixture cement MTA	40 40	40 40	Low speed round bur with saline irrigation + saline wetted cotton pellet: haemostasis	SSC or amalgam	molar	24	100 100	85 80
Markovic et al. 2005 (1)	104	4–9	FC (5min) + Ca(OH)2 Ca(OH)2 Ferric Sulfate(15s)+ Ca(OH)2	34 33 37	5 8 7	Sterile diamond bur with saline irrigation + water rinse, dry pellet: haemostasis?	GIC + Amalgam	molar	18	90.9 82.3 89.2	84.8 76.5 81
Marques et al. 2015	30	5,2–8	Portland cement + IRM Portland cement + iodoform + IRM Portland cement + zirconium oxide + IRM	10 10 10	10 10 10	Excavator + saline irrigation + dry sterile cotton pellet (5min): haemostasis	RMGIC	molars	24	100 100 100	100 100 100
Mohamed 2008 (2)	38	3–10	Ferric Sulfate (15s) + Dycal Ferric Sulfate (15s) + ZOE	16 22	13 19	Sterile hand excavator or slow speed round bur + damp cotton pellet + control haemostasis	Amalgam	molar	6	53.8 94.7	50 81.3
Moretti et al. 2008 (1)	45	5–9	FC (5min)+ZOE+IRM Ca(OH)2 + IRM Gray MTA (Angelus) + IRM	15 15 15	15 14 14	Hand excavator + continuously irrigated with saline solution until haemostasis	RMGIC + not specified restoration	molar	24	100[2] 36 100	100 36 100
Nematollahi et al. 2018	50	5–8	MTA partial pulpotomy + ZOE FC partial pulpotomy + ZOE	25 25	22 21	High speed diamond round bur with water irrigation + moist cotton: haemostasis	SSC	molar	24	90.9 100	90.5 95.2
Noorollahian 2008 (1)	60	5–7	white MTA (ProRoot) + ZOE diluted FC (5min) + ZOE	29 27	18 18	Round bur + control of haemostasis	After 24h SSC vs. immediately. SSC	molar	24	100 100	94.4 100
Odabas et al. 2011	40	4–8	Ca(OH)2 + IRM Ca(OH)2 + Ankaferd Blood Stopper® + IRM	20 20	18 19	Spoon excavator + saline irrigation + saline wetted cotton pellet: haemostasis	SSC	molar	12	90 95	90 95
Odabas et al. 2012	93	5–10	Ferric sulfate + IRM MTA + IRM	51 42	46 38	Spoon excavator + saline wetted cotton pellet (3-5min): haemostasis	SSC	molar	12	84.7 94.7	78.2 92.1
Olatosi et al. 2015	50	4–7	FC + ZOE MTA + ZOE	25 25	21 25	Slow round bur + moistened cotton pellets: haemostasis	SSC	molar	12	81 100	81 96
Percinoto et al. 2006 (2)	90	3–8	Ca(OH)2 + Dycal MTA (ProRoot) + Dycal	45 45	45 45	Spoon excavator and round bur + damp sterile cotton pellets to control haemostasis Corticosteroid/ antibiotic +ZOE Pulpotomy after 48 h	RMGIC + composite	molar	12	86.7 95.6	

Continued ➢

[2] Calculation by the authors - LPDP = lyophilized freeze-dried platelet-derived preparation - RCTR = Root Canal Treatment

Reference (Level of evidence)	Number of Teeth (total)	Age (yrs)	Pulp dressing Material	Number of Teeth		Type of coronal pulp removal	Definitive restoration	Type of teeth	Oberservation time (months)	Success rate (%)	
				Study begin	Study end					Clinical	Radiographic
Rajasekharan et al. 2017	81	3–8	Biodentine™ + GIC ProRoot® MTA + GIC Iodoform-based paste Tempophore™ + GIC	25 29 27	19 22 17	Spoon excavator + cotton pellet (4min): haemostasis	SSC	molar	18	95.2 100 95.65	94.4 90.9 82.4
Redig 1968 (3)	40	3–6	Type I FC (5min) + ZOE/FC Type II FC (3–5d) + ZOE/FC	20 20	20 20	Spoon excavator + dry sterile cotton pellets to control haemostasis	SSC	molar	18	85 90	
Rivera et al. 2003 (2)	80	4–7	FC (5min)+ZOE+IRM Electrosurg.+ ZOE + IRM	40 40	40 39	Instrument not specified vs. ES; control of haemostasis in both groups	Amalgam	molar	6	100[3] 95	92.5 92.5
Ruby et al. 2013	65	3–10	NaOCl + ZOE FC + ZOE	34 31	15 10	Spoon excavator + sterile cotton pellet (5min): haemostasis	SSC	molar	12	100 100	80 90
Sabbarini et al. 2008 (1)	30	4–7	FC (5min) + Cavit enamel matix derivate + RMGIC	15 15	15 15	Sterile sharp spoon excavator + moist cotton pellet for a few minutes: haemostasis!	RMGIC + SSC	molar	6	67 93	13 60
Sakai et al. 2009 (1)	30	5–9	MTA (Angelus) + IRM Portland cement (Votorantim-Cimentos) + IRM	15 15	12 12	Excavator + saline irrigation until control of haemostasis	RMGIC (Vitremer)	molar	24	100 100	100 100
Saltzman et al. 2005 (1)	26	3–8	FC (5min) – ZOE diode laser–ProRoot+RMGIC	24 24	13 7	hand excavator and slow speed round bur vs. diode laser + saline irrigation until haemostasis	SSC	molar	15.7	100 100	84.6 71.4
Silva et al. 2019	45	5–8	MTA Ca(OH)2 + saline Ca(OH)2 + polyethylene glycol	15 15 15	14 15 11	Excavator + saline irrigation: haemostasis	RMGIC	molar	12	100 92.9 100	100 33.3 72.7
Shumayrikh & Adenubi 1999 (1)	61	5–9	2% Glutaraldehyde (3min)+IRM 2% Glutaraldehyde (3min)+Dycal	30 31	29 28	Instrument not specified + saline irrigation + 3% hydrogen peroxide until haemostasis	SSC	molar	12	96.5 89.2	75.8 71.4
Sonmez & Duruturk 2010 (2)	154	4–9	Ca(OH)2 + ZOE Ca(OH)2 + ZOE	84 70	67 42	Sterile diamond bur + water irrigation + excavator + 5min saline-wetted cotton pellet: haemostasis	SSC vs. Amalgam	molar	12	79.9 60	
Sonmez et al. 2008 (1)	80	4–9	FC (5min) + ZOE Ferric Sulfate (10-15s) + ZOE Ca(OH)2 + GIC MTA (ProRoot) + ZOE	20 20 20 20	13 15 13 15	Diamond round bur + 5min saline-wetted cotton pellet: haemostasis	Amalgam (MTA group: 1 day later)	molar	24	84.6[4] 100 92.3 86.7	76.9 73.3 46.2 66.7
Srinivasan and Jayanthi 2011	100	4–6	FC + ZOE MTA + ZOE	50 50	46 47	Spoon excavator + saline irrigation + moist cotton pellet: haemostasis	GIC + SSC	molar	12	91.3 100	78.3 95.7
Subramaniam 2009 (2)	40	6–8	FC (1min) + ZOE MTA (ProRoot) + ZOE	20 20	20 20	High speed diamond bur with water irrigation	GIC + SSC	molar	24	100 100	85 95
Sushynski et al. 2012	252	2,5–10	FC + IRM MTA + IRM	133 119	66 65	Slow speed round bur + spoon excavator + sterile cotton pellet: haemostasis	SSC	Molar	24	99 100	76 95
Trairatvorakul and Koothiratrakarn 2012	86	3–7	Ca(OH)2 + IRM FC + IRM	43 43	32 31	High speed diamond bur with water irrigation + sterile irrigation + dry cotton pellets: haemostasis	SSC	molar	36	100 100	75 74.2

[3-4] Calculation by the authors

➢ Continued

Reference (Level of evidence)	Number of Teeth (total)	Age (yrs)	Pulp dressing Material	Number of Teeth		Type of coronal pulp removal	Definitive restoration	Type of teeth	Oberservation time (months)	Success rate (%)	
				Study begin	Study end					Clinical	Radiographic
Vargas et al. 2006 (1)	60	4–9	5%NaOCl (30s) + ZOE Ferric Sulfate (15s) + ZOE	32 28	14 13	Low speed round carbide bur (dry) 5min saline-wetted cotton pellet: haemostasis	SSC	molar	12	100 85	79 62
Waterhouse et al. 2000 (1)	84	3.3–12.5	FC (5min) + ZOE Ca(OH)2 + ZOE	46 38	44 35	Sterile non-end cutting low-speed bur + excavator – control of haemostasis?	GIC or compomer (Dyract) or SSC	molar	Ø22.5 clinical Ø18.9 radiolo-graphical	90.9[5] 88.5	84.1 77.1
Yaman et al. 2012	60	6–9	FC + ZOE Ankaferd Blood Stopper® + ZOE	30 30	28 28	Spoon excavator + saline irrigation, no haemostasis control	Amalgam	molar	12	100 100	94.7 92.9
Zealand et al. 2010 (1)	252	2.5–10	FC (5min) + IRM gray MTA (ProRoot)+ IRM	133 119	97 100	Slow-speed round bur + spoon excavator – control of haemostasis	SSC	molar	6	97 100	86 95
Zurn & Seale 2008 (1)	34	2.3–8.5	Ca(OH)2 LC (Ultrablend) FC (5min) + ZOE	97 94	97 79	Round bur + water-dampened cotton pellet: haemostasis	RMGIC (Vitremer) + SSC	molar	12-24	97 84	97 72

[5] Calculation by the authors

TABLE 2 Characteristics of controlled studies for pulpotomy/partial pulpotomy.

of the root canal, tooth with pathological lesion extending to the successor's tooth germ, tooth with evidence of extensive internal/external pathological root resorption, less than two-thirds of the root intact.

Pulpectomy results

Some studies used rubber dam isolation [Tannure et al., 2011; Saltzman et al., 2005; Srinivasan et al., 2006; Yoon et al., 2008].

All studies used hand files for root canal preparation (H or K files). Working length was kept 1–2 mm short of the radiographic apex. One study used an electronic apex locator [Yoon et al., 2008]. Root canals were irrigated with physiological saline solution, with combination of saline and NaOCl or NaOCl and chlorhexidine, or with citric acid for smear layer removal. NaOCl concentrations ranged between 2.25–2.5%. Additional treatment of the canals was carried out in one study (placement of paper points slightly moistened with 1:5 diluted formocresol) [Srinivasan et al., 2006]. Six studies filled root canals with ZOE paste, two studies with calcium hydroxide and four studies with iodoform-based pastes. Success rates were: ZOE 82–100% clinical, 72–100% radiographic, calcium hydroxide 80–100% clinical, 72.5–100% radiographic, iodoform pastes 93.3–100% clinical, 72.5–90.3% radiographic (Table 3). Teeth were mainly restored with stainless steel crowns except one study where amalgam restorations and one study where composite restorations were placed.

Discussion

Partial pulpotomy

According to a single available RCT, both MTA and formocresol performed equally well at partial pulpotomies after carious exposure in 2 years [Nematollahi et al., 2018].

Recommendation

Since there are no other available studies, level of evidence is Ib. Grade of recommendation as best clinical practice is A [Alles and Stokes, 1987].

Pulpotomy

Treatment of exposed tissue

Studies with electrosurgery used for pulp amputation of exposed pulp tissues covered with ZOE vs. formocresol pulpotomy, exhibit no significant differences at 6–12 months [Durmus and Tanboga, 2014; Fei et al., 1991; Akcay and Sari, 2014]. Fishman et al. [1996] used electrofulguration, with both ZnOE and calcium hydroxide as medicaments. Facing a slightly more than 50% success rate after 6 months, this technique cannot be recommended [Shumayrikh and Adenubi, 1999]. Use of lasers (Er:YAG laser radiation, wavelength 2.94 µm; Nd:YAG laser at 2W, 20Hz, 100mJ; 980 nm diode laser) for amputation/haemostasis followed by ZOE [Huth et al., 2005; Durmus and Tanboga, 2014; Yoon et al., 2008], MTA pulpotomy or formocresol pulpotomy showed no significant differences. No difference was demonstrated comparing lasers and calcium hydroxide or ferric sulfate [Huth et al., 2005]. Liu [2006] reported a significant difference regarding survival, however with 49% drop out in the laser group and 20% drop out for formocresol. A significant difference was also reported for diode laser and formocresol or ferric sulphate, however only with clinical criteria and according to the authors no replacement can be suggested [Fernandes et al., 2015]. Low level laser therapy before calcium hydroxide application showed favourable results to calcium hydroxide alone [Odabas et al., 2011]. Based on those data, a positive recommendation for laser treatment cannot be given, due to the large diversity between the parameters of each device and therefore their effects.

Pulpotomy medicaments/pastes

Formocresol, being the most widely used medicament, showed clinical and radiological success rates 13%–100%. However the study with the low 13% radiographic success, presented an observation time of 6 months and a relatively low sample size (n=15) [Sabbarini et al., 2008]. If this is not taken into consideration overall success rates of formocresol are 54.3–100% (Table 2). Twelve studies revealed failure rates of <10% after 6–30 months, so formocresol may serve

Reference (Level of evidence)	Age	Number of teeth		X –Ray		Length determination	Root canal preparation	Irrigant	Root Canal filling	Definitive Restoration	Observation time (months)	Success rate (%)	
	(yrs)	Total	per group	Pre	Post							clinical	radiogr.
Arikan et al. 2016	4–9	50	25 25	x	x	x-ray	H-file	NaOCl saline	$Ca(OH)_2$ /iodoform + MTA $Ca(OH)_2$ /iodoform + IRM	SSC	18	76 64	
Bawazir & Salama 2006	4.5–9	50	25 25	x	x	x-ray	H-file	saline	Hand-held or handpiece lentulo spiral and ZOE	SSC	6	96 92	91 72
Nadkarni & Damle 2000	4–8	70	35 35	x	x	x-ray	H-file	NaOCl saline	$Ca(OH)_2$ ZOE	SSC	9	94.3 88.6	
Özalp et al. 2005	4–9	80	20 20 20 20	x	x	x-ray	H-file	NaOCl	ZOE Sealapex Calcicur Vitapex	Amalgam	18	100 90 80 100	
Ramar & Mungara 2010	4–7	93	31 31 31	x	x	x-ray	H-file	NaOCl CHX	Metapex RC Fill Endoflas	SSC	9	96.8 100 100	72.5 81.1 90.3
Subramaniam & Gilhotra 2011	5–9	45	15 15 15	x	x	x-ray	H-file	NaOCl saline	Endoflas ZOE Metapex	SSC	18	93.3 93.3 100	93.3 93.3 100
Tannure et al. 2011	3–5	36	18 18	x	x	x-ray	K-file	NaOCl +saline 6% citric acid	ZOE	Composite resin	36	88 82	
Trairatvorakul & Chunlasikaiwan 2008	3.3–7.75	54	27 27	x	x	electronic	K-file	NaOCl	ZOE Vitapex	SSC	12	85 89	

TABLE 3 Characteristics of controlled studies for pulpectomy.

as reference. The pertinent discussion about adverse side-effects of formocresol however, does not allow its clinical recommendation for paediatric dentistry [Sushinski et al., 2012; Farsi et al., 2015] despite the fact that 61% of certified paediatric dentists in USA use it [Ruby et al., 2013]. Since in 2004, formaldehyde was classified as carcinogenic by the International Agency for Research on Cancer [Farsi et al., 2015], alternatives should be sought. Recent studies showed no difference of formocresol to ferric sulfate, NaOCl or MTA after 19–24 months [Nematollahi et al., 2018; Odabas et al., 2011; Srinivasan and Jayanthi, 2011; Airen et al., 2012]. Ruby et al. [2013] supported the same (formocresol vs NaOCl) however with high drop-out percentages (50%). A natural plant extract also showed the same success rate of formocresol [Ng and Messer, 2008]. On the other hand, in two studies MTA is presented as superior, both clinically and radiographically, compared to formocresol [Atasever et al., 2019; Doyle et al., 2010], also developing less internal resorption [Doyle et al., 2010].

Ferric sulfate was also evaluated as a medicament for pulpotomies with the vast majority of clinical trials on deciduous molars. A 15.5% ferric sulfate solution was used for 15s for haemostasis and one not recent investigation did not inform the reader about application time [Casas et al., 2003]. To allow safe diagnosis of sound pulp tissues, application time should be limited to 15s anyway [Siqueira et al., 2007]. With ZOE success rates were 62–100% clinically and 19–97% radiographically. Casas evaluated the radiological effect of ferric sulfate with ZOE after 2 and 3 years [Percinoto et al., 2006; Redig, 1968] with low success rates after two years (19%) and three years (54%). After two years, only 73% of teeth were radiologically evaluated, and 42% of failures were judged as "pathologic radiographic change not requiring immediate extraction". Also, non-sterile water rinsing was carried out. In the anterior teeth, the same experimental group found higher success rates (78%) at 2 years, following the same treatment protocol. In all other studies, ferric sulfate + ZOE resulted in 85–100% clinical and 73.3–100% radiological success. Dycal after ferric sulfate gave worse results with 50% success after 6 months [Liu et al., 2011] and cannot be recommended. However when pure calcium hydroxide was used, results were better (89.2% clinical and 81% radiographic success rates) [Khorakian et al., 2014]. No difference was noted between ZOE and calcium hydroxide in another study [Sonmez et al., 2008]. Even better results were exhibited with ferric sulfate and MTA (100% clinical and 87% radiographic success rates) [Cardoso-Silva et al., 2011], therefore it can be recommended.

MTA as amputation medicament after haemostasis with ZOE shows success rates of 80–100% clinically and 66.7–100% radiographically. Application of GIC after MTA also showed high overall success rates, greater to calcium hydroxide [Silva et al., 2019]. Regarding the study which demonstrated 66.7% radiographic success of MTA after two years, its small sample size (n=20) and 25% drop-out should be taken into consideration. Moreover the definitive restoration in MTA groups was delayed for 1 day [Olatosi et al., 2015]. All the other studies exhibited radiographic success rates same as the clinical ones (80-100%). No significant difference was noted between grey and white MTA, however grey MTA was associated with more cases with dentinal bridge formation [Erdem et al. 2011]. Compared to the other

medicaments, MTA was superior to ferric sulfate with or without eugenol [Cardoso-Silva et al. 2011], to calcium hydroxide [Silva et al., 2019; Celik and Sari, 2016], to formocresol [Srinivasan and Jayanthi, 2011; Atasever et al., 2019; Doyle et al. 2010; Celik et al., 2019], or ZOE base alone [Fernandez et al., 2013] and may thus be a suitable replacement. MTA exhibits high success rates during carious or mechanical exposure [Rajasekharan et al., 2017]. Biodentine, which is similar in composition with MTA, showed no significant difference when compared to it [Waterhouse et al., 2000]. On the contrary, a few studies exist that show no difference of MTA compared to the other amputation materials [Nematollahi et al., 2018; Odabas et al., 2011; Casas et al., 2004; Srinivasan and Jayanthi, 2011; Fernandez et al., 2013; Moretti et al., 2008; Zurn and Seale, 2008]. Drawbacks could be crown discoloration [Silva et al., 2019] and its high cost.

Calcium hydroxide was evaluated in a few studies, however some did not give information about time spent for hemostasis [Huth et al., 2005; Bawazir and Salama 2006; Trairatovkul and Koothiratrakarn 2012; Malekafzali et al., 2011; Alacam, 1989]. Pure calcium hydroxide covered with ZOE resulted in radiological failures of 23–67% while auto-cured calcium hydroxide suffered 13–30% failures. Some studies showed no difference of calcium hydroxide to other amputation materials [Casas et al., 2004] or electrosurgery [Akcay and Sari, 2014]. After 3 years, calcium hydroxide exhibited favourable results compared to formocresol [Marques et al., 2015] and a calcium-enriched cement showed same behavior as MTA [Al-Mutairi and Bawazir, 2013]. In another study, calcium hydroxide showed worse results than MTA [Celik and Sari, 2016]. Due to this data scatter, it seems to be extremely dependent on operators' skills and on the product, how effective the treatment is. No specific recommendation can be given.

Iodoform paste was used either after calcium hydroxide with lower than 15% success rates [Kalaskar and Damle, 2004], after Portland cement with small sample size (n=10) and 100% success rate [Sakai et al., 2009] or as a dressing material alone with 95% clinical success and 82% radiographic success [Zurn and Seale, 2008]. Combination of iodoform with either calcium hydroxide or Portland cement cannot be recommended.

NaOCl pulpotomies have shown to be equally successful to MTA, ferric sulfate and formocresol, without the potential cytotoxicity and carcinogenicity of formocresol [Airen and Shigli, 2012; Mohamed, 2008; Sonmez et al., 2008; Moretti et al., 2008; Sonmez and Duruturk 2010], however with lower radiographic success rates than the other materials [Moretti et al., 2008]. NaOCl used with MTA or calcium hydroxide, improved the performance of the amputation materials [Casas et al., 2004]. Therefore NaOCl cannot be recommended as an alternative medicament for pulpotomies, but as an aid in combination with another amputation material.

For all other methodologies (LPDP [Subramaniam et al., 2011], enamel matrix derivative [Sabbarini et al. 2008], glutaraldehyde [Subramaniam et al. 2009]) single studies for each procedure are published, so there is not enough information for any recommendation. For Ankaferd Blood Stopper®, studies show no significant difference to calcium hydroxide [Yaman et al., 2012] or to formocresol [Ng and Messer, 2008], however, sample size is small (n=20-30). Portland cement showed 100% clinical and radiographic success rates in two studies [Sakai et al., 2009; Arikan et al., 2016], however sample size was again small (n=10-15). Therefore, no recommendation can be given for both due to lack of more studies.

Restoration type

After endodontic treatment, mainly SSC and less amalgam and resin composite were used as definitive restorations. Use of GIC (n=1) or RMGIC (n=2) was exceptional. Only one trial compared the effect of different restoration types after pulpotomy [Arikan et al., 2016] with SSC (80%) being more successful than amalgam (60%). According to the studies, SSC can be recommended as a definite restoration after pulpotomies.

Recommendation

Based on the findings, a successful pulpotomy is possible in clinically and radiographically symptom-free cases. Removal of coronal pulp tissues should be carried out with sterile hand instruments and/or slow speed round burs or sterile diamond bur with saline irrigation. Hemostasis is a prerequisite. MTA revealed the highest success rates irrespective of its color (grey vs white). NaOCl can be used to increase success rates of amputation materials. Ferric sulfate + ZOE is a viable alternative. Formocresol should be replaced with alternative medicaments. SSC is recommended as a definite restoration after pulpotomy. All other treatment regimens are less promising. Level of evidence for pulpotomy studies is Ib. Grade of recommendation as best clinical practice is A [Allen and Stokes, 1987].

Pulpectomy

Primary goal of a pulpectomy is to preserve the tooth in the oral cavity until normal exfoliation. Criteria for clinical evaluation were defined in each study. One study judged the quality of root canal fillings (underfilling, optimal filling or overfilling) and gave clear clinical criteria (no abnormal mobility; no sensitivity or percussion; no swelling) and radiographic (preoperative pathological interradicular and/or periapical radiolucencies; no new postoperative pathological radiolucencies developed; no pathological internal or external root resorption) in comparison to baseline evaluations [Srinivasan et al., 2006]. Clinical and radiographic success rates of the studies ranged between 72% and 100%. Despite the high success rates, due to different baseline situations (resorption and extent of pathological changes), barely comparable clinical procedures (irrigation/disinfection of root canals prior to obturation), and partially small sample sizes combined with differently defined evaluation criteria, no clear recommendation can be given. There is no study available directly comparing different root canal irrigants or definite restoration materials after pulpectomies. Calcium hydroxide and ZOE as root canal filling materials do not show great differences in success rates (calcium hydroxide: 72–94% after 9 to 18 months; ZOE: 72–100% after 6 to 18 months). A combination of calcium hydroxide and iodoform pastes (Vitapex, Endoflas) showed a smaller scatter of overall success rates (89–100%). However, no difference was noted between Endoflas, ZOE and Metapex in 9–18 months [Yoon et al., 2008]. Overfilling and voids were more common with Metapex. Removal of smear layer with citric acid after irrigations [Saltzman et al., 2005] as well as coverage of the pulpal wall with MTA vs IRM after pulpectomy, had no effects on success of the treatment.

Recommendation

Based on the findings, a successful pulpectomy is possible, however clinical and radiographic criteria of baseline situation as well as the clinical technique need to be well defined in order for the studies to be comparable. Determination of working length is mainly performed via x-ray. Pre- and post-treatment radiographic control is crucial. Root canals are irrigated with saline and/or NaOCl. Root canal filling with ZOE showed acceptable clinical and radiographic success rates and was widely used in most of the studies. Metapex and Endoflas can also be suggested as alternatives. Stainless steel crowns were placed as permanent restorations. Due to the limited number of studies and the different study criteria, the level of evidence is IIb and grade of recommendation is B [Allen and Stokes, 1987].

Pulpotomy vs. pulpectomy

Direct comparison of pulpotomy and pulpectomy was investigated. Three studies dealt with deciduous incisors [Markovic et al., 2005; Rvera et al., 2003] and other three with deciduous molars [Bahrololoomi et al., 2008; Percinoto et al., 2006; Redig 1968]. After RCT, in both areas success rates were higher, except from the radiographic evaluation of Howley et al. [2003]. Ferric sulfate resulted in a 19–78% radiological success rates [Percinoto et al., 2006; Tannure et al., 2011; Casas et al., 2004], however haemostasis with water did not guarantee sterile conditions. Pulpectomy was more successful compared to pulpotomy with an antibiotic paste [Bahrololoomi et al., 2008] and no significant difference was shown compared to formocresol pulpotomy [Rvera et al., 2003]. Another study with formocresol demonstrates less successful results of pulpotomies in two years (76% radiological success) compared to pulpectomy [Markovic et al., 2005].

Recommendation

Generally pulpectomies were more successful treatments than pulpotomies and can be recommended. Level of evidence of the studies is IIa and level of recommendation is B due to follow up rate <80% [Allen and Stokes, 1987].

Conclusion

Numerous studies report success with pulpotomies and pulpectomies in primary teeth after carious exposure, however only one dealing with partial pulpotomy. Facing radiographic success analyses, results are often worse than clinical rates and the most common reason for failure is internal root resorption. Partial pulpotomies demonstrate 90.9–100% clinical and 90.5–95.2% radiographic success rates. Pulpotomy with lasers showed 93–100% clinical and 75–94.1% radiographic success, with electrosurgery 95–100% clinical and 84–95.2% radiographic success and with electrofulguration with 77.39–81% clinical 54.6–57.3% radiographic success. Pulpotomies showed the following success rates, regarding pulp dressing materials: formocresol 67–100% clinical, 13–100% radiographic; MTA 80–100% clinical, 66.7–100% radiographic; calcium hydroxide 33.3–100 % clinical, 33.3–96.4% radiographic; ferric sulfate 53.8–100% clinical, 19–100% radiographic success. MTA revealed the highest success scores and ferric sulfate + ZOE is a viable alternative. Formocresol should be replaced with alternative medicaments. NaOCl can be used to increase success rates of amputation materials. Pulpectomies showed the following success rates according to the root canal filling material used: ZOE 82–100% clinical, 72–100% radiographic, calcium hydroxide 80–100% clinical, 72.5–100% radiographic, iodoform pastes 93.3–100% clinical, 72.5–90.3% radiographic. Root canal filling with ZOE showed acceptable clinical and radiographic success rates, while Metapex and Endoflas can also be suggested as alternatives. Generally, pulpectomies were more successful treatments than pulpotomies. Success rates for the same material ranged largely both in pulpotomies and pulpectomies, leading to the observation that clearly structured study protocols, exact documentations and standardized evaluation criteria are scarce.

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