ACTA ODONTOLOGICA SCANDINAVICA
2019, VOL. 77, NO. 7, 541–551
https://doi.org/10.1080/00016357.2019.1614217

Taylor & Francis
Taylor & Francis Group

REVIEW ARTICLE

Which procedures and materials could be applied for full pulpotomy in permanent mature teeth? A systematic review

M. Zanini[a,b,c], M. Hennequin[a,d] and PY. Cousson[a,d]

[a]University Clermont Auvergne, CROC EA 4847 Clermont-Ferrand, France; [b]University Paris Diderot, Dental faculty, Paris, France; [c]Groupe Hospitalier Pitié Salpêtrière, Service Odonto-Stomatologie et Chirurgie Maxillo-Faciale, APHP, Paris, France; [d]CHU Clermont-Ferrand, Service d'Odontologie, Clermont-Ferrand, France

ABSTRACT

Objective: Coronal pulpotomies were recently re-investigated as an alternative to root canal treatment in vital permanent teeth. General dentists may be interested in knowing how to perform full pulpotomy, in particular in face of difficult endodontic cases of vital teeth.

Material and methods: A systematic review was undertaken on the PubMed and Cochrane databases in order to determine which procedure should be applied for pulp capping and coronal restoration in routine dental practice. Fifty-three publications were included and allocated to one of two methodological categories: histological and clinical studies.

Results and conclusions: There is no evidence to recommend one single procedure for full pulpotomy in vital permanent teeth that can be indicated for different pulpal diagnoses which differ greatly in terms of the inflammation process from healthy teeth to irreversible pulpitis. For each clinical case, all actions aiming to prevent pre-operative contamination, to control per-operative infection and to achieve a complete seal above the radicular pulp sections are unavoidable steps that should be complied with. Reproducing procedures adopted in high quality trials could insure high success rates.

ARTICLE HISTORY
Received 16 October 2018
Revised 13 April 2019
Accepted 27 April 2019

KEYWORDS
Endodontics; pulpotomy; permanent teeth; materials; coronal restoration; procedure

Introduction

Dogmas are changing with the evolution of knowledge. For several decades, the widespread view was that full pulpotomies should not be indicated as definitive treatments in permanent mature teeth. Full pulpotomies in vital permanent teeth are now, however, promoted as an alternative to root canal treatment, aiming to preserve pulpal vitality, to reduce the risks for failure of root canal treatment and for economic reasons. A previous quantitative synthesis review including six studies reported [1] that the weighted mean success rate of full pulpotomy reached at least 90% in treating carious vital pulp exposure of permanent mature teeth with closed root apices. It concluded that full pulpotomy could be considered as a substitute to extraction or root canal treatment in specific conditions. Many general dentists may be interested in knowing how to perform full pulpotomy, in face of difficult endodontic cases of vital teeth.

In previous experimental and clinical studies, statistical analyses considered the type of materials as a variable to explain the success of pulpotomy [2,3]. Alqaderi's meta-analysis confirms that differences in pulp capping and restoration materials did not significantly affect success rates [1]. It had already been suggested in historical studies conducted in rats [4,5], monkeys [6,7] and young adults [8] that sedation of the pulp and an aseptic operative technique are more important to clinical success than the type of pulp capping material. Indeed, the materials used for pulp capping and coronal restoration are only one of the factors contributing to the outcome of pulpotomies. Four other parameters control bacterial infection: (i) initial pulpal status, (ii) asepsis during the procedure; (iii) immediate seal of radicular pulp sections with a hydrophilic and dimensionally stable capping material; and (iv) immediate and long-term sealing of the coronal restoration. All these parameters are supposed to be controlled throughout the protocols for full pulpotomy. Recently, many clinical reports on full pulpotomy on vital permanent teeth have observed that detailing the protocols could help clinicians to perform full pulpotomy in their routine practice.

This study aims to review the procedures and materials reported in the literature for full pulpotomy in mature permanent teeth.

Methods

A systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocol (PRISMA-P) statement [9,10]. The research question could be formulated as follows: which procedure could be applied for full pulpotomy in permanent mature teeth?

CONTACT Martine Hennequin martine.hennequin@uca.fr Faculté de Chirurgie Dentaire, University Clermont Auvergne, 2, rue de Braga, Clermont-Ferrand 63000, France

Eligibility criteria

The search was designed to identify any publications reporting procedures and materials used for pulp capping and coronal restorations after full pulpotomy on permanent mature teeth with closed apices.

Information sources

In December 2018, a search on the PubMed, ScienceDirect and Cochrane databases were undertaken using the following Mesh terms or Keywords, respectively: [PULPOTOMY], [PERMANENT] AND [TEETH] AND [[MATERIALS] OR [CORONAL RESTORATIONS]]. Adding the term [PROCEDURE] did not produce any additional references.

Data collection process and study selection

The flow chart for study inclusion is presented in Figure 1. One single investigator (MZ) conducted the research on databases and for backward research. All three authors consensually agreed for abstracts to be excluded during the screening phase. During this screening phase, the criteria for exclusion were: not in English; *in vitro* studies; animal studies, reviews; comments; articles reporting pulpotomies on primary teeth, immature permanent teeth, or dens invaginatus; studies on vital direct pulp capping, partial excavation or partial pulpotomy; papers related to general issues in paediatric dentistry; studies related to the use of formocresol; articles retracted by the journal's editor.

A first group of 56 papers was selected after the removal of 37 duplicate publications. A backward search was performed from the references of these studies. This produced a group of 22 additional papers. Then, 78 papers were eligible for inclusion. The applied exclusion criteria were: letter to the editor [11]; articles reporting outcomes on deciduous teeth [12] or on immature teeth [13,14]; studies reporting direct pulp capping [15,16], partial pulpotomies [8,17,18] or pulpectomy [19–21]; experimental pulpotomies with original procedure or materials [22,23]; articles reporting outcomes of pulpotomy as a temporary treatment before pulpectomy [24]; studies not reporting the use of rubber dam or reporting not using it [25–29] and five reviews [30–34].

Finally, 53 articles were included, distributed in two methodological categories: 15 *ex vivo* histological studies [35–49] and 42 clinical studies, which included 15 case reports or case series [45,47,48,50–61], 17 cohort studies [3,43,62–76] and 10 clinical trials or randomized clinical trials [61,77–85]. Four references belonged to both the histological and the clinical studies categories [43,45,47,48].

The GRADE approach was used for grading the quality of evidence in the studies due to the differences of study design between histological and clinical studies according to the Oxford Centre for Evidence-Based Medicine [86] (Table 1).

Data extraction

A Microsoft Excel® chart file was created for data extraction. Any data characterizing the procedures used was considered as one variable and noted as a column label while the articles included were listed in the cells. A pre-piloted form was tested during the identification, screening and eligibility

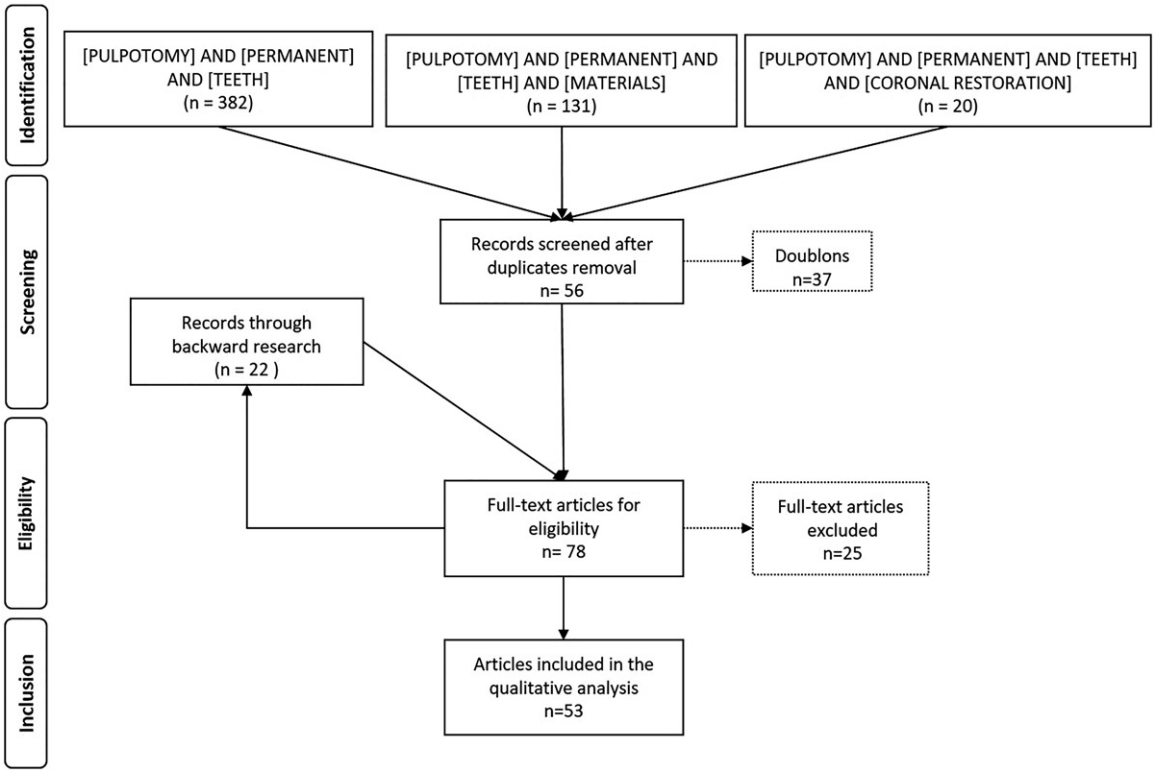

Figure 1. Flow chart for the selection of studies.

Table 1. Grade approach to the studies included.

Reference	Title	Evaluation	Success rate (teeth number)	Grade
James et al. [35]	Histologic response of amputated pulps to calcium compounds and antibiotics.	Histological	45% ($n = 20$)	5
Langer et al. [36]	Behaviour of human dental pulp to Calxyl with or without zinc oxide eugenol.	Histological	87.5% ($n = 16$) 94% ($n = 16$)	5
Schröder et al. [37]	Early reaction of intact human teeth to calcium hydroxide following experimental pulpotomy and its significance to the development of hard tissue barrier.	Histological	NA	5
Schröder [38]	Evaluation of healing following experimental pulpotomy of intact human teeth and capping with calcium hydroxide.	Histological	89% ($n = 15$)	5
Schröder et al. [39]	Scanning electron microscopy of hard tissue barrier following experimental pulpotomy of intact human teeth and capping with calcium hydroxide.	Histological	100% ($n = 2$)	5
Schröder [40]	Effect of an extra-pulpal blood clot on healing following experimental pulpotomy and capping with calcium hydroxide.	Histological	22% ($n = 18$)	5
Schröder et al. [41]	Transmission electron microscopy of tissue changes following experimental pulpotomy of intact human teeth and capping with calcium hydroxide.	Histological	NA	5
Russo et al. [42]	Effects of the dressing with calcium hydroxide under pressure on the pulpal healing of pulpotomized human teeth.	Histological	90% ($n = 20$)	5
Foreman [50]	Resolution of a periapical radiolucency following renewal of the pulpotomy dressing.	Clinical	100% ($n = 1$)	4
Russo et [43]	Radiographic and histological evaluation of the treatment of inflamed dental pulps.	Clinical Histological	100% $n = 30$	3
Moule et al. [51]	Resolution of periapical radiolucency following pulpotomy.	Clinical	100% ($n = 1$)	4
Caliskan [62]	Success of pulpotomy in the management of hyperplastic pulpitis.	Clinical	92%, ($n = 24$)	3
Calişkan [52]	Clinical reliability of the dentine bridge formed after pulpotomy: a case report.	Clinical	100 ($n = 1$)	4
Calişkan [63]	Pulpotomy of carious vital teeth with periapical involvement.	Clinical	92% ($n = 26$)	3
Inoue et al. [44]	Ultrastructural relation between nerve terminals and dentine bridge formation after pulpotomy in human teeth.	Histological	NA	5
Teixeira et al. [76]	Clinical and radiographic evaluation of pulpotomies performed under intrapulpal injection of anaesthetic solution	Clinical	85% ($n = 12$) 79% ($n = 12$)	3
McDougal. et al. [65]	Success of an alternative for interim management of irreversible pulpitis.	Clinical	89% ($n = 27$) 92% ($n = 25$) 56% ($n = 18$) 42% ($n = 19$)	3
Demarco et al. [64]	Influence of the restoration quality on the success of pulpotomy treatment: a preliminary retrospective	Clinical	43.5% ($n = 23$)	3
Nyerere et al. [67]	Emergency pulpotomy in relieving acute dental pain among Tanzanian patients.	Clinical	100% ($n = 44$) 97.1% ($n = 136$)	3
DeRosa [66]	A retrospective evaluation of pulpotomy as an alternative to extraction.	Clinical	94% ($n = 17$)	3
Asgary et al. [45]	Permanent molar pulpotomy with a new endodontic cement: A case series.	Clinical Histological	92%, $n = 12$	4–5
Eghbal. et al. [46]	MTA pulpotomy of human permanent molars with irreversible pulpitis.	Histological	86% ($n = 14$)	5
Chueh et al. [47]	Histology of Irreversible pulpitis premolars treated with mineral trioxide aggregate pulpotomy.	Clinical Histological	100% ($n = 1$)	4–5
Asgary et al. [87]	The effect of pulpotomy using a calcium-enriched mixture cement versus one-visit root canal therapy on postoperative pain relief in irreversible pulpitis: a randomized clinical trial	Clinical	87% ($n = 207$)	2
Asgary [53]	Calcium-enriched mixture pulpotomy of a human permanent molar with irreversible pulpitis and condensing apical periodontitis.	Clinical	100% ($n = 1$)	4
Hiremath et al. [54]	Second-generation platelet concentrate (PRF) as a pulpotomy medicament in a permanent molar with pulpitis: a case report.	Histological	100% ($n = 1$)	4
Barngkgei et al. [55]	Pulpotomy of symptomatic permanent teeth with carious exposure using mineral trioxide aggregate.	Clinical	100% ($n = 11$)	4
Nosrat et al. [48]	A preliminary report on histological outcome of pulpotomy with endodontic biomaterials vs calcium hydroxide.	Clinical Histological	66% ($n = 9$) 100% ($n = 4$) 100% ($n = 5$)	4–5
Asgary et al. [77]	One-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter, randomized, non-inferiority clinical trial.	Clinical	97.6% ($n = 163$)	2
Asgary et al. [78]	Treatment outcomes of pulpotomy in permanent molars with irreversible pulpitis using biomaterials: a multi-center randomized controlled trial.	Clinical	98% ($n = 167$) 98% ($n = 179$)	2
Simon et al. [68]	Should pulp chamber pulpotomy be seen as a permanent treatment? Some preliminary thoughts.	Clinical	82% ($n = 17$)	3
Asgary et al. [56]	Outcomes of different vital pulp therapy techniques on symptomatic permanent teeth: a case series.	Clinical	100% ($n = 9$)	4
Alqaderi et al. [69]	MTA pulpotomy as an alternative to root canal treatment in children's permanent teeth in a dental public health setting.	Clinical	90%, $n = 29$	3
Asgary et al. [79]	Two-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter randomized clinical trial.	Clinical	86.1% ($n = 166$)	2
Cousson et al. [70]	A follow-up of pulpotomies and root canal treatments performed under general anaesthesia.	Clinical	95% ($n = 19$) 100% ($n = 13$)	3
Asgary et al. [57]	Vital Pulp Therapy of a Mature Molar with Concurrent Hyperplastic Pulpitis, Internal Root Resorption and Periradicular Periodontitis: A Case Report.	Clinical	100% ($n = 1$)	4
Asgary et al. [80]	Five-year results of vital pulp therapy in permanent molars with irreversible pulpitis: a non-inferiority multicenter randomized clinical trial.	Clinical	78.1% ($n = 107$)	2
Solomon et al. [59]	Coronal Pulpotomy Technique Analysis as an Alternative to Pulpectomy for Preserving the Tooth Vitality, in the Context of Tissue Regeneration: A Correlated Clinical across 4 Adult Permanent Molars.	Clinical	87.5% ($n = 5$)	4
Borkar et al. [58]	Biodentine pulpotomy several days after pulp exposure: Four case reports.	Clinical	100% ($n = 4$)	4
Bhagat et al. [49]		Histological		5

(*continued*)

Table 1. Continued.

Reference	Title	Evaluation	Success rate (teeth number)	Grade
	A comparative evaluation of ProRoot mineral trioxide aggregate and Portland cement as a pulpotomy medicament.		60% ($n = 15$) 53% ($n = 15$)	
Kumar et al. [81]	Comparative evaluation of platelet-rich fibrin, mineral trioxide aggregate, and calcium hydroxide as pulpotomy agents in permanent molars with irreversible pulpitis: A randomized controlled trial.	Clinical	68.7% ($n = 14$) 37.5% ($n = 13$) 66.7% ($n = 18$) 44.4% ($n = 15$) 50% ($n = 14$) 35.7% ($n = 13$)	2
Soni [60]	Biodentine Pulpotomy in Mature Permanent Molar: A Case Report.	Clinical	100% ($n = 1$)	4
Asgary et al. [61]	Treatment Outcomes of Full Pulpotomy as an Alternative to Tooth Extraction in Molars with Hyperplastic/Irreversible Pulpitis: A Case Report.	Clinical	100% ($n = 2$)	4
Asgary et al. [88]	Long-term outcomes of pulpotomy in permanent teeth with irreversible pulpitis: a multi-center randomized controlled trial.	Clinical	84.6% ($n = 116$) 78.1% ($n = 107$)	2
Kunert et al. [3]	Permanent teeth pulpotomy survival analysis: retrospective follow-up.	Clinical	89%-63% ($n = 273$)	3
Linsuwanont et al. [71]	Treatment Outcomes of Mineral Trioxide Aggregate Pulpotomy in Vital Permanent Teeth with Carious Pulp Exposure: The Retrospective study	Clinical	81.8% ($n = 45$)	3
Qudeimat et al. [72]	Mineral trioxide aggregate pulpotomy for permanent molars with clinical signs indicative of irreversible pulpitis: a preliminary study .	Clinical	54% ($n = 13$)	3
Galani et al. [84]	Comparative Evaluation of Postoperative Pain and Success Rate after Pulpotomy and Root Canal Treatment in Cariously Exposed Mature Permanent Molars: a Randomized Controlled Trial.	Clinical	85% ($n = 26$)	2
Taha et al. [73]	Assessment of Mineral Trioxide Aggregate pulpotomy in mature permanent teeth with carious exposures.	Clinical	92.7% ($n = 51$)	3
Taha et al. [74]	Full Pulpotomy with Biodentine in Symptomatic Young Permanent Teeth with Carious Exposure.	Clinical	100% $n = 20$	3
Taha et al. [75]	Outcome of full pulpotomy using Biodentine in adult patients with symptoms indicative of irreversible pulpitis.	Clinical	98.4% ($n = 63$)	3
Awawdeh et al. [82]	Outcomes of Vital Pulp Therapy Using Mineral Trioxide Aggregate or Biodentine: A Prospective Randomized Clinical Trial.	Clinical	93.5% ($n = 31$) 93.1% ($n = 29$)	2
Asgary et al. [83]	Treatment Outcomes of 4 Vital Pulp Therapies in Mature Molars.	Clinical	93.5% ($n = 69$) 95.9% ($n = 65$)	2

(CH: calcium hydroxide; MTA: Mineral trioxyde Aggregate; CEM: Calcium enriched mixture cement; NA: not applicable).

steps for twenty articles. The table included the following variables: authors and date, type of study, reason for tooth extraction for histological studies, clinical diagnosis in accordance with the American Association of Endodontists (AAE) [89], type of teeth, number of teeth, methods of isolation, disinfection methods, techniques for coronal pulp removal, methods for hemostasis (duration for compression method, type of solution for irrigation method), pulp capping material, type of coronal restoration, follow-up duration and success rate. Depending on the articles, some variables were either not described (ND) or not available (NA). Data extracted from original studies were integrated into the extracted data chart.

Reporting data

Qualitative results were written as a narrative review, reporting the data for each type of study (histological and clinical) and discussing focus points. Success rate values were given in the text for studies reporting samples of more than 10 teeth.

Results

Overall, no study aimed to relate the procedure applied during full pulpotomy to the outcome of the treatment. In most of the cases, the pulpal status, or the pulp capping material were the considered variables to explain the success. Histological studies were designed to describe the effects of one or two materials on the pulp wound while clinical studies and case reports evaluated whether the teeth treated with one or several pulp capping material remained on the arch using radiographic and/or clinical criteria. The reported procedures varied sharply among studies.

Data from histological studies

The histological studies were based on performing pulpotomies in permanent human teeth that were indicated for extraction. Procedures and materials are described in Table 2.

Pulpotomies have been performed in teeth with varying clinical diagnoses (normal pulp, irreversible pulpitis with or without sign of apical periodontitis). Without considering the capping material, pulp healing was attempted in these different clinical situations.

The short-term studies included investigated the immediate effect of the capping material on pulp tissue and the first stages of pulp healing [35,37,40,41]. Long-term studies used the following criteria: (i) the presence and severity of inflammation; (ii) the organization of soft tissue; (iii) the formation of a dentinal bridge. Mineral Trioxide Aggregate (MTA) and Calcium-enriched mixture cement (CEM) have anti-inflammatory effects and are capable of inducing the formation of a complete and regular hard tissue barrier [48]. Short-term histological analysis reported that Calcium Hydroxide (CH)

Table 2. Procedures and materials described in histological studies.

Methods of preoperative disinfection	Chemical disinfection	30% hydrogen peroxide and 70% of alcohol and iodine	[37–41]
		Solution of tinture iodine	[35]
		0.12% chlorexhidine	[48]
Rubber dam isolation	Used		[35–49]
Per operative disinfection	Saline solution		[36–43,46,49]
	2.5% Sodium hypochlorite		[47]
Coronal pulp tissue removal	With Manual instrumentation (sharp blade curette)		[42,43,49]
	at low speed with a bur		[44,46]
	at high speed with a round diamant bur		[37–41,45,48]
	A sterilized new carbide fissure bur to a depth of 2-3 mm		[47]
Haemostasis	Compression	Dried cotton pellet	[49]
		Cotton pellet imbibed with hypochlorite solution	[48]
		Cotton pellet imbibed with saline solution	[45,46]
		Cotton pellet imbibed with haemostatic agent	[47]
	Irrigation	Saline solution	[38,40–42,45,46]
		Calcium hydroxide	[40]
Radicular pulp capping	CH		[35–44,48]
	MTA		[46–49]
	CEM		[45,48]
Coronal restoration	Immediate definitive fillings	Amalgam	[36]
		Zinc phosphate cement	[37–41]
		GIC + amalgam	[48]
		ZOE	[35,42,43]
		ZOE and RMGIC	[49]
		ZOE and amalgam	[36]
	Temporary intermediate fillings (GIC-Caviton® or ZOE)		[46,47]

(CH: Calcium Hydroxyde; MTA: Mineral Trioxide Aggregate; ZOE: Zinc Oxyde Eugenol; CEM: Calcium enriched Mixture cement; GIC: Glass ionomer cement; RMGIC: Resin modified Glass Ionomer cement).

induced superficial, multi-layered pulp necrosis [37]. Furthermore, CH resulted in the formation of a mineral bridge that could be complete or incomplete, with regular or irregular morphology.

Data from clinical studies and case reports

Procedures and materials described in clinical studies are reported in Table 3.

Pulpotomy was indicated for various clinical diagnoses or clinical situations: reversible pulpitis [3,55,58,68,69,73,83], irreversible pulpitis [45,53,54,59,60,65–67,71,73,76–81,83,88] and chronic pulpitis (either hyperplasic pulpitis or condensing osteitis) [43,57,62,63] were the reported diagnoses. The absence of a clear clinical diagnosis was reported in three studies [50,51,70]. The association of responsiveness to cold stimulation, tenderness to pressure and periapical radiolucency were considered to indicate vital pulp in one case report [50], while another case was noted without symptoms, radiological loss of lamina dura and normal bleeding [51]. Lack of symptoms and radiological signs for pulpal or periodontal disease associated with pulp bleeding when opening the pulp were used in a cohort study [70].

Procedures used for disinfection and especially for hemostasis vary widely among studies. Depending on the study, hemostasis was achieved by either irrigation or compression. The duration of compression varied greatly from 1–2 min [68], 2 min at least [67,73–75,82,84], 5 min [3,45,55,60,61,83], up to 6 min [74,75] and up to 10 min [48,71].

Radicular pulp capping was performed with CH, CH covered with Zinc Oxide Eugenol cement (ZOE) or IRM®, ZOE, CEM, MTA or Biodentine™. Three studies [54,59,81] report the use of a biological matrix obtained after centrifugation of the blood withdrawn from patients prior to capping the radicular pulp section with Biodentine™ [59] or MTA [54,81].

The resulting success rate varied greatly, ranging from 37% to 100% for CH [38,66,81] and CH covered with ZOE or IRM® [3,62,70], from 44% to 100% for MTA [68,69,71,73,81,82,84,88], from 80% to 100% for Biodentine™ [58,59,60], from 78% to 100% for CEM [77–80] and from 42% to 100% for ZOE [65,67].

Pulp conditioning with Platelet rich fibrin (PRF) before capping with Biodentine® or MTA resulted in 100% success rate [81]. Long-term follow-up studies were considered for postoperative follow-up more than 6 months [3,45,55,62–66,68–84,88,90]. Some studies suggested a reduced success rate over time [3,80], with one study reporting rates of 89% at one year to 63% at ten years [3]. However, neither the sealing of the coronal restoration nor the presence of root exposure due to periodontal disease was evoked to explain the increase of failure rate over time. The results of clinical studies highlight the importance of correctly sealing coronal restorations: resin composite restorations have an increased risk of failure for pulpotomy compared to prosthetic crown and amalgam restorations [1,3].

Discussion

This is the first review considering the procedure of full pulpotomy as the main factor that might influence the outcome of treatment in mature permanent teeth. It does not provide a clear answer to the research question due to the varying results of the studies included, nevertheless it is the basis for a discussion on the pertinence of controlling the different parameters that may vary during the operative procedure, and in turn may affect the success of full pulpotomy.

Table 3. Procedures and materials described in clinical trials and cases reports.

Methods of preoperative Disinfection	Chemical disinfection	Sodium hypochlorite	[73–75]
		Chlorhexidine	[48,58,82,85]
		Mouth rinsing	[53,61,77–80,88]
	Mechanical disinfection	Scaling, polishing	[62]
Rubber dam isolation	Systematic use		[3,43,46–48,52–54,58,59,61–65,68–82,84,85,88]
	When possible		[55]
Per operative disinfection	Saline solution		[43,58,60,62,63,83]
	Sodium hypochlorite		[47,67,68,70,75]
	Anionic detergent solution		[76]
Coronal pulp tissue removal	With Manual instrumentation	Sharp blade curette	[3,43,60,64,66,68,76,84]
	With low or High speed rotative instrumentation		[43,46–48,52–56,58,59,61–63,66,67,69,71–77, 79–81,83,85,88]
	Gates glidden		[70]
Haemostasis	Compression	Dried cotton pellet	[53,55,64,67]
		Cotton pellet imbibed with hypochlorite solution	[48,61,66,73–75,82–84]
		Cotton pellet imbibed with saline solution	[46,58–63,68,69,77,79,80,85]
		Cotton pellet imbibed with haemostatic agent	[47]
		Corticosteroid paste	[3]
		Cotton pellet imbibed with Chlorhexidine	[83]
	Irrigation	Saline solution	[3,46,52,54,57,58,61,77,79–81,85,88]
		Sodium hypochlorite	[71,72]
		Calcium hydroxide	[64]
Radicular pulp capping	CH		[3,43,48,50–52,62–64,66,70,76,81]
	CH covered with ZOE or IRM®		[3,51,62,63,66,70];
	MTA		[47,48,55,61,68,69,71–73,77,81,82,84,88]
	ZOE		[65,67]
	CEM		[45,48,53,56,57,61,77–80,85,88]
	Biodentine™		[54,58–60,74,75,81]
	PRF		[54,59,81]
Coronal restoration	Immediate definitive fillings	Composite resin	[52,58,59,68,70
		Amalgam	[51,53,61–63,66,80]
		GIC	[54,66,84]
		GIC bonded amalgam	[70]
		GIC and amalgam	[48]
		RMGIC	[74,75]
		Light cured GIC And composite resin	[83]
		Stainless steel crown sealed with GIC	[70]
	Temporary intermediate fillings (IRM®, ZOE, Cavit® or GIC)		[3,43,47,50,52,55,61,64,67,69,71–74, 76–82,85,88]

(CH: Calcium Hydroxyde; MTA: Mineral Trioxide Aggregate; ZOE: Zinc Oxyde Eugenol; CEM: Calcium enriched Mixture cement; PRF: Platelet Rich Fibrin; GIC: Glass ionomere cement; IRM®: Intermediate Restorative Material (reinforced zinc oxide eugenol); RMGIC: Resin modified Glass ionomer cement).

Clinical studies versus histological studies

One point of confusion concerning the study results might be the different methodological approaches, which have different endpoints. Histological studies measure the ability of the pulp cells to trigger tertiary dentinogenesis and to produce a dentinal bridge under the pulp dressing, while clinical studies are designed to evaluate whether the teeth are still asymptomatic after treatment. The criteria for histological and clinical success, however, are not related. The detection of dentine bridge formation after pulpotomy is an indicator of success and it could be a significant protective factor against failure [3]. It reflects immediate postoperative pulpal vitality, but not over the long term. In clinical studies, the barrier may be detected radiologically, but its quality, in terms of porosity and regularity, cannot be evaluated clinically without re-intervention. Consequently, the clinical success of full pulpotomy could be associated with histological failure when the treated teeth are asymptomatic after several years without evidence for the presence of a dentinal bridge [73]. On the other hand, histological success could be associated with clinical failure if the dentinal bridge is incomplete or porous, if a soluble capping material is used and if an adequate seal of the coronal restoration is not achieved; bacterial contamination then becomes possible in the medium term. Histological studies can be used to assess the biological properties of the material, but they do not predict the procedure's clinical success.

Both histological and clinical approaches demonstrate convergent results supporting tricalcium silicate cement as a valuable material for full pulpotomy [48]. Histological analyses have shown that MTA and CEM have an anti-inflammatory effect and may result in hard tissue formation of a high quality in terms of thickness and absence of defects [48]. Furthermore, they have excellent sealing abilities and dimensional stability [91–93]. The short-term tightness and the quality of the hard tissue bridge induced provide excellent protection of the underlying pulp against further recontamination, which accounts for the relatively high success rate.

Results of MTA, Biodentine™ and CEM pulpotomies are, therefore, predictable, which implies that MTA, Biodentine™ and CEM are the materials of choice for healthy pulp, irreversible and reversible pulpitis. In a recent meta-analysis, the weighted mean success rate after one and two years of follow-up for the MTA and MTA-like product group was higher than those of the CH group [1]. Contradictory clinical and histological results were reported. CH may induce hard tissue with incomplete formation and the presence of defects. Clinical success was, however, reported for pulpotomies performed with CH and CH covered with ZOE or IRM®, despite

Table 4. Synthesis of the procedure and materials that could be applied for pulpotomy in permanent mature teeth in clinical practice.

Objectives	Procedure steps	Proposals
Pulpal status		Healthy pulp Reversible pulpitis Irreversible pulpitis (Clinical diagnosis based on AAE 2013)
Asepsis control	Isolation	Systematic use of rubber dam
	Pre-operative disinfection	Scaling and polishing Irrigation with Betadine, Sodium hypochlorite, or Chlorhexidine 2% before and after caries excavation
	Per-operative disinfection	Systematic use of a new sterile bur for the cavity access (different from the bur used for caries excavation). Irrigation with Sodium hypochloride or Chlorhexidine 2%
Inflammation control	Radicular pulp section	High speed rotary instrumentation under irrigation with round ball drill at the canal opening Gates glidden bur on the 2–3 first millimeter
	Haemostasis	Irrigation with saline solution or sodium hypochlorite Compression with sterile cotton pellet Gates glidden bur on the 2–3 first millimetres inside the canal in case of persistent bleeding.
Pulp healing	Radicular pulp capping	***First choice:*** Calcium silicate cement (MTA, Biodentine™, CEM) ***Alternatives in case of persistent bleeding, limited intervention duration:*** • CH covered with ZOE or IRM
Sealing	Coronal restoration	***Over Calcium silicate cement:*** Depending on the setting time of the calcium silicate cement used: • Composite based on GIC in cases of non-immediate restorations • Any type of direct and indirect restoration. ***Over other pulp capping materials:*** No temporary cements Immediate direct definitive restoration in all cases

(ZOE: Zinc Oxide Eugenol Cement; GIC: Glass Ionomer Cement; CH: Calcium Hydroxide; MTA: Mineral Trioxide Aggregate; CEM: Calcium enriched Mixture cement).

the lack of formation of a regular mineral barrier covering the radicular sections. Consequently, the use of such materials resulted in acceptable clinical results in terms of the immediate and long-term seal of the coronal restoration [3,70].

For some investigators, pulpotomies can be considered a regenerative procedure [59], characterized by the ability of the treated pulp to produce a dentine like-tissue. Currently, as regenerative processing could not be verified without re-intervention in clinical studies, the phenomenon of 'regeneration' could only be verified in histological studies. The term could be used by extrapolation for clinical situations, providing all the procedural histological conditions were exactly the same as under clinical conditions. Most of the histological studies, however, were conducted in young teeth with healthy pulp presenting high reparation potential [36–44,46,48,49], possibly inducing an overestimation of success.

The procedure first

There is no evidence to report one single procedure from this review, but the synthesis of histological and clinical studies has enabled us to draw up some trends in Table 4. Full pulpotomy can be indicated for different pulpal diagnoses (reversible pulpitis, symptomatic and asymptomatic irreversible pulpitis) which differ greatly in terms of inflammation processes, but may induce pulp repair.

All actions aiming to control infection should be applied. Pre-operative decontamination, rubber dam isolation and per-operative irrigation with sodium hypochlorite or Chlorhexidine solutions are unavoidable steps to be followed. The practitioner may choose the control of haemostasis, the material used for pulp capping and the type of coronal restoration depending on each clinical situation.

Bleeding and haemostasis

The ability to control bleeding after pulp amputation has been suggested as an important factor for procedural success. Bleeding during operative procedures for full pulpotomy can be discussed for two different aspects. Heavy bleeding produces a film that opposes contact between the dentine and the pulp capping material. This marginal gap could constitute suitable access for further bacterial contamination. For this reason, hemostasis should be obtained quickly after radicular pulp section. This review noted that the type of haemostatic agent and the method of haemostasis varied among studies. It should be noted, however, that the use of a true haemostatic agent (ferric sulphate, hydrogen peroxide for example) must be avoided, as it would 'mask' the true inflammatory state of the radicular pulp. There is no scientific data to determine precisely the time needed beyond which haemostasis will not be achieved and pulpotomy should be performed [73]. Nevertheless, it was found that the 'time to stop bleeding' has statistically no effect on full pulpotomy outcomes [69–71,88].

Pulp inflammation progresses from the crown to the apex [94]. Thus, the probability of finding healthy tissue increases if the amputation is performed apically [95]. Therefore, when bleeding cannot be stopped after removal of the entire bulbous portion of the pulp chamber, the pulpal inflammation can be considered to have spread to the radicular part of the pulp and an amputation at a lower level should be performed [8]. For this reason, some authors used a drill or a Gates-Glidden bur for sectioning the radicular pulp beyond

the first millimetres of the canal [70]. Nevertheless, it is impossible to determine the level of inflammation and, in some cases, bleeding persists after sectioning the radicular pulp. The goal of full pulpotomy is not to proceed more than the 2–3 mm inside the canal. Consequently, depending on the level of the inflammation's progression into the canal, the pulp capping material may be in contact either with the section of the radicular pulpal parenchyma or with the blood clot. These situations are favourable for the pulpotomy's success, as both the pulpal tissue and the blood clot contain the inflammatory mediators that orchestrate the inflammatory process needed for pulp repair [96].

Pulp capping

Overall, the clinical and biological effects of pulp capping materials are not related, except for calcium silicate cements that can result in both pulp healing and clinical success. Positive clinical results were also reported with CH or CH covered with ZOE or IRM®, despite the lack of regular tertiary dentinogenesis induction [36,62,63,65,66]. The setting time of the pulp capping material may be considered before using it in clinical routine. For example, the setting time of MTA is rather long, more than two hours, leading to a delay in the permanent restoration and increasing the risk of immediate post-operative contamination [92]. Recent commercial forms of MTA, such as MTA Angelus® or MM-MTA®, CEM and Biodentine® (Septodont, St Maur des Fossés) have a faster setting time [97]. Calcium silicate-based cements are expensive and economic considerations could limit the routine use of MTA or Biodentine®. In such situations, the use of CH or CH covered with zinc oxide eugenol materials (ZOE or IRM®) could be a valuable alternative in combination with an immediate and long-term seal of the coronal restoration.

Coronal restoration

Coronal restoration is implicit in the success of the procedure [64]. The results of clinical studies highlight the importance of correctly sealing coronal restorations, with the prosthetic crown and amalgam restorations having the smallest failure rate in comparison to resin composite restorations that increase the risk of full pulpotomy failure [1,3]. Dental amalgams have excellent longevity due to corrosion products that protect against the risk of secondary caries [98]. For environmental reasons, however, many countries decided to limit the use of amalgam in October 2013 [99]. For these reasons, restoration with amalgams can no longer be considered after full pulpotomy. Indirect restoration with crowns or onlays and direct restoration with composite could be indicated for coronal restoration after full pulpotomy. The combination of full pulpotomy with tricalcium silicate cements and CAD/CAM (Computer-aided design and computer-aided manufacturing) coronal restoration crowns could be solutions for a single chairside intervention. The time to place the permanent restoration was shown to be a factor affecting treatment outcome [71]. Indeed, the association between the delayed placement of restoration and unfavourable outcomes has been detected in this clinical study [64]. So, a definitive coronal restoration is recommended as soon as possible after a full pulpotomy.

Limitations

As previously explained, histological and clinical studies have different outcome criteria and thus have different endpoints. The inclusion of histological studies in our analysis can be justified because of their legitimacy in explaining both the underlying biological mechanism of pulp repair after pulpotomy treatments and the mechanisms of action of pulp capping materials. Furthermore, the success criteria for such studies are strictly histological criteria (presence of inflammatory pulp infiltrate, hard tissue formation) and the results of these studies cannot be extrapolated for clinical outcomes. Gathering all the results from different approaches, however, illustrates the difficulties involved in controlling all factors related to the success rate of full pulpotomies.

Grey literature and non-peer-reviewed articles were not considered for inclusion in this review. This could result in bias due to possibly valuable missing data. Grey literature was explored during a systematic review when the topic was not as prominent in peer-reviewed journals [100,101]. In the present search, however, a large quantity of data was selected through an ascendant search, and it is uncertain whether using grey literature would have enriched the search with valuable data for qualitative synthesis. Moreover, grey references are widely dispersed among web sites on endodontic clinical practices, making it impossible to carry out an exhaustive search.

Lastly, the performance of selection and eligibility phases by a single investigator may also be a limitation of this review.

Conclusion

All actions aiming to control pre-operative decontamination, per- and post-operative infection are unavoidable steps for full pulpotomy in permanent mature teeth that should be complied with. Further clinical studies into the conditions for full pulpotomy procedures in permanent teeth are needed before conducting a meta-analysis of the relative indications for pulp capping and coronal restorations procedures.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

M. Hennequin http://orcid.org/0000-0001-8173-2606

References

[1] Alqaderi H, Lee C, Borzangy S, et al. Coronal pulpotomy for cariously exposed permanent posterior teeth with closed apices: a systematic review and meta-analysis. J Dent. 2016;44:1–7.

[2] Tabarsi B, Parirokh M, Eghbal MJ, et al. A comparative study of dental pulp response to several pulpotomy agents. Int Endod J. 2010;43:565–571.
[3] Kunert G, Kunert I, da Costa Filho L, et al. Permanent teeth pulpotomy survival analysis: retrospective follow-up. J Dent. 2015; 43:1125–1131.
[4] Cotton WR. Bacterial contamination as a factor in healing of pulp exposures. Oral Surg Oral Med Oral Pathol. 1974;38: 441–450.
[5] Kakehashi S, Stanley HR, Fitzgerald RJ. The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surg Oral Med Oral Pathol. 1965;20:340–349.
[6] Cvek M, Granath L, Cleaton-Jones P, et al. Hard tissue barrier formation in pulpotomized monkey teeth capped with cyanoacrylate or calcium hydroxide for 10 and 60 minutes. J Dent Res. 1987;66:1166–1174.
[7] Möller AJ, Fabricius L, Dahlén G, et al. Influence on periapical tissues of indigenous oral bacteria and necrotic pulp tissue in monkeys. Scand J Dent Res. 1981;89:475–484.
[8] Englander H, Massler M, Curter W. Clinical evaluation of pulpotomy in young adults. J Dent Children. 1956;23:48–53.
[9] Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4:1.
[10] Shamseer L, Moher D, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. Br Med J. 2015;349:g7647.
[11] Zafar K, Khan FR. The need for more evidence for MTA pulpotomy in mature permanent teeth with periapical rarefaction. Int Endod J. 2017;50:1104.
[12] Chien MM, Setzer S, Cleaton-Jones P. How does zinc oxide-eugenol compare to ferric sulphate as a pulpotomy material? SADJ. 2001;56:130–135.
[13] Goldberg F, Massone EJ, Spielberg C. Evaluation of the dentinal bridge after pulpotomy and calcium hydroxide dressing. J Endod. 1984;10:318–320.
[14] Khayat A, Abbasi A, Tanideh N. A comparative study of dentin bridge formation following pulpotomy using calcium hydroxide and mineral trioxide aggregate in young dogs. Iran J Vet Med. 2004;5:47–54.
[15] Kozlov M, Massler M. Histologic effects of various drugs on amputated pulps of rat molars. Oral Surg Oral Med Oral Pathol. 1960;13:455–469.
[16] Oguntebi BR, DeSchepper EJ, Taylor TS, et al. Postoperative pain incidence related to the type of emergency treatment of symptomatic pulpitis. Oral Surg Oral Med Oral Pathol. 1992;73: 479–483.
[17] Wolner SZ. Permanent tooth pulpotomy-report of a case. NYJ Dent. 1975;45:6–7.
[18] Yilmaz Y, Guler C, Sahin H, et al. Evaluation of tooth-fragment reattachment: a clinical and laboratory study. Dent Traumatol. 2010;26:308–314.
[19] Holland R, de Souza V, de Mello W, et al. Healing process of the pulp stump and periapical tissues in dog teeth. I. Histopathological findings following pulp extirpation. Rev Fac Odontol Aracatuba. 1977;6:47–57.
[20] Holland R, de Souza V, de Mello W, et al. Healing process of the pulp stump and periapical tissues in dog teeth. II. Histopathological findings following root filling with zinc oxide-eugenol. Rev Fac Odontol Aracatuba. 1977;6:59–67.
[21] Holland R, de Souza V, de Mello W, et al. Healing process of the pulp stump and periapical tissue in dog teeth. III. Histopathological findings following root filling with calcium hydroxide. Rev Fac Odontol Aracatuba. 1978;7:25–37.
[22] Granath LE, Hagman G. Experimental pulpotomy in human bicuspids with reference to cutting technique. Acta Odontol Scand. 1971;29:155–163.
[23] Mohammad SG, Raheel SA, Baroudi K. Histological evaluation of *Allium sativum* oil as a new medicament for pulp treatment of permanent teeth. J Contemp Dent Pract. 2015;16:85–90.
[24] Sheikh-Nezami M, Mokhber N, Shamsian K, et al. Management of a midroot and complicated crown fracture: a case report. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;107: e65–67.
[25] Massone JE, Goldberg F, Barros RE. Histological evaluation of the effect of intrapulpal anesthesia in pulpotomies. Dent Traumatol. 1987;3:259–262.
[26] Wang G, Wang C, Qin M. Pulp prognosis following conservative pulp treatment in teeth with complicated crown fractures - A retrospective study. Dent Traumatol. 2017;33:255–260.
[27] Santini A. Assessment of the pulpotomy technique in human first permanent mandibular molars. Use of two direct inspection criteria. Br Dent J. 1983;155:151–154.
[28] Santini AH. Intraoral comparison of calcium hydroxide (Calnex) alone and in combination with Ledermix in first permanent mandibular molars using two direct inspection criteria. J Dent. 1985;13:52–59.
[29] Santini A. Long-term clinical assessment of pulpotomies with calcium hydroxide containing Ledermix in human permanent premolars and molars. Acta Odontol Pediatr. 1986;7:45–50.
[30] Berk H. Maintaining vitality of injured permanent anterior teeth. J Am Dent Assoc. 1954;49:391–401.
[31] Berk H, Krakow AA. A comparison of the management of pulpal pathosis in deciduous and permanent teeth. Oral Surg Oral Med Oral Pathol. 1972;34:944–955.
[32] Yazdani S, Jadidfard M, Tahani B, et al. Health technology assessment of CEM pulpotomy in permanent molars with irreversible pulpitis. Iran Endod J. 2014;9:23–29.
[33] Asgary S, Shirvai A. Pulpotomy with calcium hydroxide may be an effective alternative to root canal therapy in vital teeth. J Evid Based Dent Pract. 2016;16:64–66.
[34] Bimstein E, Rotstein I. Cvek pulpotomy – Revisited. Dent Traumatol. 2016;32:438–442.
[35] James VE, Englander HR, Massler M. Histologic response of amputated pulps to calcium compounds and antibiotics. Oral Surg Oral Med Oral Pathol. 1957;10:975–986.
[36] Langer M, Ulmansky M, Sela J. Behaviour of human dental pulp to Calxyl with or without zinc oxide eugenol. Arch Oral Biol. 1970;15:189–194.
[37] Schröder U, Granath LE. Early reaction of intact human teeth to calcium hydroxide following experimental pulpotomy and its significance to the development of hard tissue barrier. Odontol Revy. 1971;22:379–395.
[38] Schröder U. Evaluation of healing following experimental pulpotomy of intact human teeth and capping with calcium hydroxide. Odontol Revy. 1972;23:329–340.
[39] Schröder U, Granath LE. Scanning electron microscopy of hard tissue barrier following experimental pulpotomy of intact human teeth and capping with calcium hydroxide. Odontol Revy. 1972;23:211–220.
[40] Schröder U. Effect of an extra-pulpal blood clot on healing following experimental pulpotomy and capping with calcium hydroxide. Odontol Revy. 1973;24:257–268.
[41] Schröder U, Sundström B. Transmission electron microscopy of tissue changes following experimental pulpotomy of intact human teeth and capping with calcium hydroxide. Odontol Revy. 1974;25:57–68.
[42] M de C R, De Souza V, Holland R. Effects of the dressing with calcium hydroxide under pressure on the pulpal healing of pulpotomized human teeth. Rev Fac Odontol Aracatuba. 1974;3: 303–311.
[43] Russo MC, Holland R, de Souza V. Radiographic and histological evaluation of the treatment of inflamed dental pulps. Int Endod J. 1982;15:137–142.
[44] Inoue H, Taniguchi K, Okamura K, et al. Ultrastructural relation between nerve terminals and dentine bridge formation after pulpotomy in human teeth. Arch Oral Biol. 1995;40:669–675.
[45] Asgary S, Ehsani S. Permanent molar pulpotomy with a new endodontic cement: a case series. J Conserv Dent. 2009;12: 31–36.

[46] Eghbal M, Asgary S, Baglue R, et al. MTA pulpotomy of human permanent molars with irreversible pulpitis. Aust Endod J. 2009; 35:4–8.
[47] Chueh L, Chiang C. Histology of Irreversible pulpitis premolars treated with mineral trioxide aggregate pulpotomy. Oper Dent. 2010;35:370–374.
[48] Nosrat A, Peimani A, Asgary S. A preliminary report on histological outcome of pulpotomy with endodontic biomaterials vs calcium hydroxide. Restor Dent Endod. 2013;38:227.
[49] Bhagat D, Sunder R, Devendrappa S, et al. A comparative evaluation of ProRoot mineral trioxide aggregate and Portland cement as a pulpotomy medicament. J Indian Soc Pedod Prev Dent. 2016;34:172–176.
[50] Foreman PC. Resolution of a periapical radiolucency following renewal of the pulpotomy dressing. Int Endod J. 1980;13:41–43.
[51] Moule AJ, Oswald RJ. Resolution of periapical radiolucency following pulpotomy. J Endod. 1983;9:388–389.
[52] Calişkan MK. Clinical reliability of the dentine bridge formed after pulpotomy: a case report. Int Endod J. 1994;27:52–55.
[53] Asgary S. Calcium-enriched mixture pulpotomy of a human permanent molar with irreversible pulpitis and condensing apical periodontitis. J Conserv Dent. 2011;14:90–93.
[54] Hiremath H, Saikalyan S, Kulkarni SS, et al. Second-generation platelet concentrate (PRF) as a pulpotomy medicament in a permanent molar with pulpitis: a case report. Int Endod J. 2012;45: 105–112.
[55] Barngkgei I, Halboub E, Alboni R. Pulpotomy of symptomatic permanent teeth with carious exposure using mineral trioxide aggregate. Iran Endod J. 2013;8:65–68.
[56] Asgary S, Fazlyab M, Sabbagh S, et al. Outcomes of different vital pulp therapy techniques on symptomatic permanent teeth: a case series. Iran Endod J. 2014;9:295–300.
[57] Asgary S, Kemal Çalışkan M. Vital pulp therapy of a mature molar with concurrent hyperplastic pulpitis, internal root resorption and periradicular periodontitis: a case report. Iran Endod J. 2015;10:284–286.
[58] Borkar SA, Ataide I. Biodentine pulpotomy several days after pulp exposure: four case reports. J Conserv Dent. 2015;18:73–78.
[59] Solomon R, Faizuddin U, Karunakar P, et al. Coronal pulpotomy technique analysis as an alternative to pulpectomy for preserving the tooth vitality, in the context of tissue regeneration: a correlated clinical study across 4 adult permanent molars. Case Rep Dent. 2015;2015:916060.
[60] Soni H. Biodentine pulpotomy in mature permanent molar: a case report. J Clin Diagn Res. 2016;10:ZD09–ZD11.
[61] Asgary S, Verma P, Nosrat A. Treatment outcomes of full pulpotomy as an alternative to tooth extraction in molars with hyperplastic/irreversible pulpitis: a case report. Iran Endod J. 2017;12: 261–265.
[62] Caliskan MK. Success of pulpotomy in the management of hyperplastic pulpitis. Int Endod J. 1993;26:142–148.
[63] Calişkan MK. Pulpotomy of carious vital teeth with periapical involvement. Int Endod J. 1995;28:172–176.
[64] Demarco F, Rosa M, Tarquínio S, et al. Influence of the restoration quality on the success of pulpotomy treatment: a preliminary retrospective study. J Appl Oral Sci. 2005;13:72–77.
[65] McDougal RA, Delano EO, Caplan D, et al. Success of an alternative for interim management of irreversible pulpitis. J Am Dent Assoc. 2004;135:1707–1712.
[66] DeRosa TA. A retrospective evaluation of pulpotomy as an alternative to extraction. Gen Dent. 2006;54:37–40.
[67] Nyerere J, Matee M, Simon E. Emergency pulpotomy in relieving acute dental pain among Tanzanian patients. BMC Oral Health. 2006;6:1.
[68] Simon S, Perard M, Zanini M, et al. Should pulp chamber pulpotomy be seen as a permanent treatment? Some preliminary thoughts. Int Endod J. 2013;46:79–87.
[69] Alqaderi H, Al-Mutawa S, Qudeimat M. MTA pulpotomy as an alternative to root canal treatment in children's permanent teeth in a dental public health setting. J Dent. 2014;42: 1390–1395.
[70] Cousson P, Nicolas E, Hennequin M. A follow-up study of pulpotomies and root canal treatments performed under general anaesthesia. Clin Oral Invest. 2014;18:1155–1163.
[71] Linsuwanont P, Wimonsutthikul K, Pothimoke U, et al. Treatment outcomes of mineral trioxide aggregate pulpotomy in vital permanent teeth with carious pulp exposure: the retrospective study. J Endod. 2017;43:225–230.
[72] Qudeimat MA, Alyahya A, Hasan AA, et al. Mineral trioxide aggregate pulpotomy for permanent molars with clinical signs indicative of irreversible pulpitis: a preliminary study. Int Endod J. 2017;50:126–134.
[73] Taha NA, Ahmad MB, Ghanim A. Assessment of mineral trioxide aggregate pulpotomy in mature permanent teeth with carious exposures. Int Endod J. 2017;50:117–125.
[74] Taha NA, Abdulkhader SZ. Full pulpotomy with biodentine in symptomatic young permanent teeth with carious exposure. J Endod. 2018;44:932–937.
[75] Taha NA, Abdelkhader SZ. Outcome of full pulpotomy using Biodentine in adult patients with symptoms indicative of irreversible pulpitis. Int Endod J. 2018;51:819–828.
[76] Teixeira LS, Demarco FF, Coppola MC, et al. Clinical and radiographic evaluation of pulpotomies performed under intrapulpal injection of anaesthetic solution. Int Endod J. 2001;34:440–446.
[77] Asgary S, Eghbal M, Ghoddusi J, et al. One-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter, randomized, non-inferiority clinical trial. Clin Oral Invest. 2013;17:431–439.
[78] Asgary S, Eghbal M. Treatment outcomes of pulpotomy in permanent molars with irreversible pulpitis using biomaterials: a multi-center randomized controlled trial. Acta Odontol Scand. 2013;71:130–136.
[79] Asgary S, Eghbal M, Ghoddusi J. Two-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter randomized clinical trial. Clin Oral Invest. 2014;18:635–641.
[80] Asgary S, Eghbal M, Fazlyab M, et al. Five-year results of vital pulp therapy in permanent molars with irreversible pulpitis: a non-inferiority multicenter randomized clinical trial. Clin Oral Invest. 2015;19:335–341.
[81] Kumar V, Juneja R, Duhan J, et al. Comparative evaluation of platelet-rich fibrin, mineral trioxide aggregate, and calcium hydroxide as pulpotomy agents in permanent molars with irreversible pulpitis: a randomized controlled trial. Contemp Clin Dent. 2016;7:512–518.
[82] Awawdeh L, Al-Qudah A, Hamouri H, et al. Outcomes of vital pulp therapy using mineral trioxide aggregate or biodentine: a prospective randomized clinical trial. J Endod. 2018;44: 1603–1609.
[83] Asgary S, Hassanizadeh R, Torabzadeh H, et al. Treatment outcomes of 4 vital pulp therapies in mature molars. J Endod. 2018;44:529–535.
[84] Galani M, Tewari S, Sangwan P, et al. Comparative evaluation of postoperative pain and success rate after pulpotomy and root canal treatment in cariously exposed mature permanent molars: a randomized controlled trial. J Endod. 2017;43: 1953–1962.
[85] Asgary S, Eghbal MJ. A clinical trial of pulpotomy vs. root canal therapy of mature molars. J Dent Res. 2010;89:1080–1085.
[86] OCEBM Levels of Evidence Working Group. The Oxford 2011 Levels of Evidence [Internet]. Oxford Centre for Evidence-Based Medicine; 2011. [cited 12 avr 2019] Available from: https://www.cebm.net/wp-content/uploads/2014/06/CEBM-Levels-of-Evidence-2.1.pdf
[87] Asgary S, Eghbal MJ. The effect of pulpotomy using a calcium-enriched mixture cement versus one-visit root canal therapy on postoperative pain relief in irreversible pulpitis: a randomized clinical trial. Odontology. 2010;98:126–133.

[88] Asgary S, Eghbal MJ, Bagheban AA. Long-term outcomes of pulpotomy in permanent teeth with irreversible pulpitis: a multicenter randomized controlled trial. Am J Dent. 2017;30:151–155.
[89] American Association of Endodontists. Endodontic Diagnosis [Internet]. 2013 [cited 12 avr 2019] p. 1–6. Available from: https://www.aae.org/specialty/newsletter/endodontic-diagnosis/
[90] European Society of Endodontology. Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. Int Endod J. 2006;39:921–930.
[91] Asgary S, Eghbal M, Parirokh M, et al. Sealing ability of three commercial mineral trioxide aggregates and an experimental root-end filling material. Iran Endod J. 2006;1:101–105.
[92] Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review–Part I: chemical, physical, and antibacterial properties. J Endod. 2010;36:16–27.
[93] Utneja S, Nawal RR, Talwar S, et al. Current perspectives of bioceramic technology in endodontics: calcium enriched mixture cement - review of its composition, properties and applications. Restor Dent Endod. 2015;40:1–13.
[94] Heyeraas KJ. Pulpal, microvascular, and tissue pressure. J Dent Res. 1985;64:585–589.
[95] Langeland K. Tissue response to dental caries. Dent Traumatol. 1987;3:149–171.
[96] Zanini M, Meyer E, Simon S. Pulp inflammation diagnosis from clinical to inflammatory mediators: a systematic review. J Endod. 2017;43:1033–1051.
[97] Duarte MAH, Marciano MA, Vivan RR, et al. Tricalcium silicate-based cements: properties and modifications. Braz Oral Res. 2018;32:e70.
[98] Opdam NJ, Bronkhorst EM, Loomans BA, et al. 12-year survival of composite vs. amalgam restorations. J Dent Res. 2010;89:1063–1067.
[99] UNEP. Global Mercury Assessment 2013: Sources, emissions, releases, and environmental transport [Internet]. Geneva, Switzerland: UNEP Chemicals Branch; 2013; [cité 16 janv 2019]. Disponible sur: https://wedocs.unep.org/handle/20.500.11822/7984
[100] Mahood Q, Van Eerd D, Irvin E. Searching for grey literature for systematic reviews: challenges and benefits. Res Synth Methods. 2014;5:221–234.
[101] Yaylali IE, Alaçam T. Critical assessment of search strategies in systematic reviews in endodontics. J Endod. 2016;42:854–860.