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Review Article

Pulpotomy of mature teeth: A systematic analysis of the failed cases

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ABSTRACT

Pulp therapy aims to maintain the health and integrity of teeth and their supporting tissue and preserve the vitality of the tooth pulp affected by dentinal caries or severe traumatic injury. Thus, the best clinical practice provides pulpal health or pathosis diagnosis and various therapeutic interventions evidenced in both the deciduous and permanent dentition for endodontic treatment. The pulp health status determines the type of pulpal therapy used. Vital pulp therapies for primary teeth include protective liners, pulp capping, and pulpotomy for reversible pulpitis; for permanent teeth, pulpotomy can be considered for irreversible pulpitis.

For reversible or irreversible pulpitis, invasive management of decayed teeth has traditionally been performed. However, at present, coronal pulpotomy-like vital pulp therapy has led to successful treatment outcomes that are less invasive. Compared to root canal treatments, coronal pulpotomy is cost-effective, less time-consuming, and less technically demanding.

The success of a pulpotomy depends on the clinician's experience, appropriate clinical techniques, and materials used. This narrative review provides insights into the systematic analysis of pulpotomy failure, causes and signs of failure, and alternative endodontic interventions.

1. Introduction

In today's era, in which a paradigm shift toward conservative dentistry has occurred, pulpotomy for managing teeth with irreversible pulpitis is considered a minimally invasive approach. Its aim is to remove the pulpal portion with irreversible and degenerative damage after achieving hemostasis, leaving healthy tissue and ultimately preserving pulp vitality (Zafar K et al., 2020).

Pulpotomy of the primary and permanent teeth is a treatment intervention for teeth with deep dentinal caries or traumatic injury. Pulpotomy is better than root canal therapy in terms of preserving vitality and proprioception and maintaining neurosensory ability. It is also less expensive, requires minimal time without complications, and provides a better assessment of the pulpal tissue inflammatory change based on hemostasis (Zanini et al., 2016).

Pulpotomy primarily aims to preserve the radicular pulpal tissues of immature permanent teeth, which facilitate apexogenesis. An asymptomatic radicular pulp should not present with clinical signs or symptoms, such as pain, sensitivity, or swelling, as well as radiographic indication of external root resorption. Self-limiting internal root resorption may be present and need to be monitored. Further, the affected tooth should be removed if perforation occurs without damaging the erupting tooth (American Academy of Pediatric Dentistry, 2020).

Pulpotomy is a less invasive technique in which the inflamed pulpal tissue from the coronal pulp chamber is removed and covered with a biomaterial that promotes repair and establishes pulp vitality. The procedure can be partial (coronal pulp of 2–3 mm removed) or complete (coronal pulp entirely removed). Coronal pulpotomy is recommended as an emergency pain-relief procedure before root canal therapy for permanent teeth (Cushley S et al., 2019).

In immature permanent teeth, revitalization and apexification of the diseased pulp help in disease elimination; however, evidence suggests that the root walls may remain very thin and fracture-prone (Duggal et al., 2017). Whether revitalization of a tooth can be moved orthodontically remains questionable; hence, the treatment goal should be to maintain pulp vitality (Chaniotis, 2018).

Pediatric endodontics focuses on preserving deciduous tooth space by preventing physiological resorption due to premature pulpal loss (Junqueira et al., 2018). For pulpotomy, an ideal material should be bactericidal to ensure radicular pulp healing without causing physiological root resorption (Coll et al., 2017).

Thus, a position paper from the American Association of Endodontists and the European Society of Endodontology (ESE) has stated that irreversible pulpitis as a pretreatment diagnosis is not necessary for a pulpectomy procedure, leading to an era of minimally invasive vital

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pulp therapy (VPT) for permanent teeth. Thus, pulpotomy is considered a proper treatment modality for teeth exhibiting irreversible pulpitis, carious exposure, or traumatic injury, suggesting a paradigm shift (Duncan HF et al., 2019).

2. Pulpotomy and its etiological factors

Pulpal tissue is categorized as normal pulp (response to pulp vitality test), reversible pulpitis (pulp that can heal), symptomatic or asymptomatic irreversible pulpitis (inflamed vital pulp that cannot heal), or necrotic pulp (Silva et al., 2022).

Pulpotomy is a procedure in which the vital pulp coronal portion is removed to preserve the remaining radicular portion vitality (Sadaf et al., 2020). Thus, the guidelines of the American Academy of Pediatric Dentistry (AAPD) state that "a pulpotomy is performed in a tooth with extensive caries without radicular pathology evidence when caries removal results in a carious or mechanical pulp exposure" (Ricucci et al., 2019).

The pathways mediating pulp defense mechanisms include: i) pulp fibroblasts activating the complement system expressing significant anti-inflammatory potential and by recruiting pulp progenitors that also contribute to tissue regeneration; ii) pulpal fibroblasts inducing direct cariogenic bacteria lysis; iii) injured pulp tissue releasing chemokines that attract pulpal stem cells (DPSCs) differentiating into odontoblastic cells, inducing tertiary dentin formation; and iv) antimicrobial peptides being synthesized and released by DPSCs (Lundy et al., 2020).

Pulpal inflammation is a double-edged sword in that irreversible pulpitis is not a single path leading to pulpal necrosis, and the right balance of inflammation results in pulpal healing and repair. However, uncontrolled pulpal inflammation may lead to the infection of the pulp cavity and pulpal necrosis (Philip et al., 2022).

Untreated dentinal caries progresses, inducing dental pulp inflammation, thereby leading to pain, pulpal necrosis, and periapical abscess formation. Thus, the dental pulp tissue reacts to caries, known as reversible or irreversible pulpitis, via a complex inflammatory response (Cushley et al., 2019). Decayed primary teeth or unsuccessful treatment can lead to sepsis (Fig. 1). In addition, early loss of primary teeth leads to a midline shift, malocclusion, and embedded or ectopic permanent teeth. Moreover, space maintainers used after early primary tooth loss have several drawbacks. With restorative treatment, primary tooth maintenance provides good space maintenance for erupting teeth (Kulkarni et al., 2021).

In dental practice, the mostly commonly observed cases are dental traumatic injuries. Trauma is most commonly observed in children aged between 6 and 12 years with immature permanent teeth involving the maxillary central and lateral incisors. Crown fractures most commonly affect the maxillary central incisor, accounting for up to one-third of all traumatic dental injuries, and involve pulpal exposure. Root fractures occur mostly in immature teeth; hence, in young patients with completely formed roots, the preservation of pulp vitality allows secondary and tertiary dentin deposition in the cervical area, reducing the risk of root fracture (Donnelly et al., 2022).

Pulpectomy and root canal treatment have previously been used to treat irreversible pulpitis. Although root canal treatment can be successful if performed properly, it is technically demanding, expensive, and time-consuming. The tooth structure is weakened by the removal of pulp tissue, leading to fracture followed by infection. This demonstrates the clinical need to develop minimally invasive biological solutions to demonstrate the necessity of maintaining vitality in pulpal health and restorative dentistry (Duncan et al., 2019).

Fig. 1. Stages of tooth decay.

Thus, indications for a deciduous tooth pulpotomy procedure are reversible pulpitis when caries removal results in pulpal exposure or traumatic pulp exposure, and the radiographic absence of infection or pathologic resorption. Vital radicular pulpal tissue without suppuration, purulence, necrosis, or hemorrhage, which is uncontrolled by a cotton roll following coronal tissue amputation, is required. Endodontic complications due to iatrogenic causes can also be reduced by using this procedure (Fuks et al., 2019).

3. Treatment protocols and medicaments

VPT is required for teeth exhibiting provoked short-duration pain relieved by analgesics, brushing, or stimulus removal with a clinical diagnosis of reversible pulpitis. Teeth exhibiting signs or symptoms such as unprovoked spontaneous pain, soft tissue inflammation, mobility, furcation or apical radiolucency, sinus tract, or internal or external resorption radiographically with a clinical diagnosis of irreversible pulpitis require nonvital pulp therapy. Moreover, regenerative endodontics may be needed for immature permanent teeth with apical periodontitis, necrotic pulp, or an immature apex (American Academy of Pediatric Dentistry, 2020).

In mature permanent teeth, pulpotomy treatment considerations include the following parameters: correct diagnosis, strict aseptic technique, bioactive hydrophilic medicaments, disinfection, hemostasis, and proper coronal restoration in mature permanent teeth predicting pulpotomy outcomes (Philip et al., 2022).

Partial or Cvek pulpotomy (Cvek, 1978) is recommended for young traumatic vital permanent teeth with an incompletely formed apex. It aims to eradicate the diseased coronal pulpal tissue without inflammatory changes, leaving a healthy radicular pulp. Therefore, removal of the exposed pulp should result in vital pulpal tissue (Fong & Davis, 2002). No pain, sensitivity, or swelling and no radiographic signs such as internal or external resorption, canal calcification, or periapical radiolucency should occur postoperatively (American Academy of Pediatric Dentistry, 2020).

Full pulpotomy is recommended as an interim procedure for immature permanent teeth with carious pulpal exposure to allow continuous development of the root. Until definitive root canal treatment for temporary symptom relief is an emergency procedure, pulpotomy can be performed. The remaining radicular pulp vitality is preserved, and it also prevents negative clinical signs and symptoms of proper root development, periradicular tissue breakdown, and resorptive defects or canal calcification observed radiographically (American Academy of Pediatric Dentistry, 2020).

The advantages of partial pulpotomy over complete pulpotomy include coronal pulp tissue preservation, leading to better healing and continued dentin deposition in the cervical area, which could be weak and fracture-prone (Fig. 2) (Donnelly et al., 2022).

Materials can be classified into three groups based on their mechanisms of action as follows (Kulkarni et al., 2021): formocresol (FC), electrosurgery, and laser for fixation; ferric sulfate and glutaraldehyde for protection; and mineral trioxide aggregate (MTA) and calcium hydroxide for regeneration.

3.1. FC

Sweet introduced the FC pulpotomy technique in 1930. FC is the gold standard for all medications as reported in literature. It exhibits both bactericidal and devitalizing effects. Meligy et al. have reported 100 % clinical and 98.1 % radiographic success rates with FC pulpotomy at a follow-up period of 12 months. However, the toxicity and carcinogenicity of FC in humans have raised concerns (Fig. 3) (Meligy et al.,

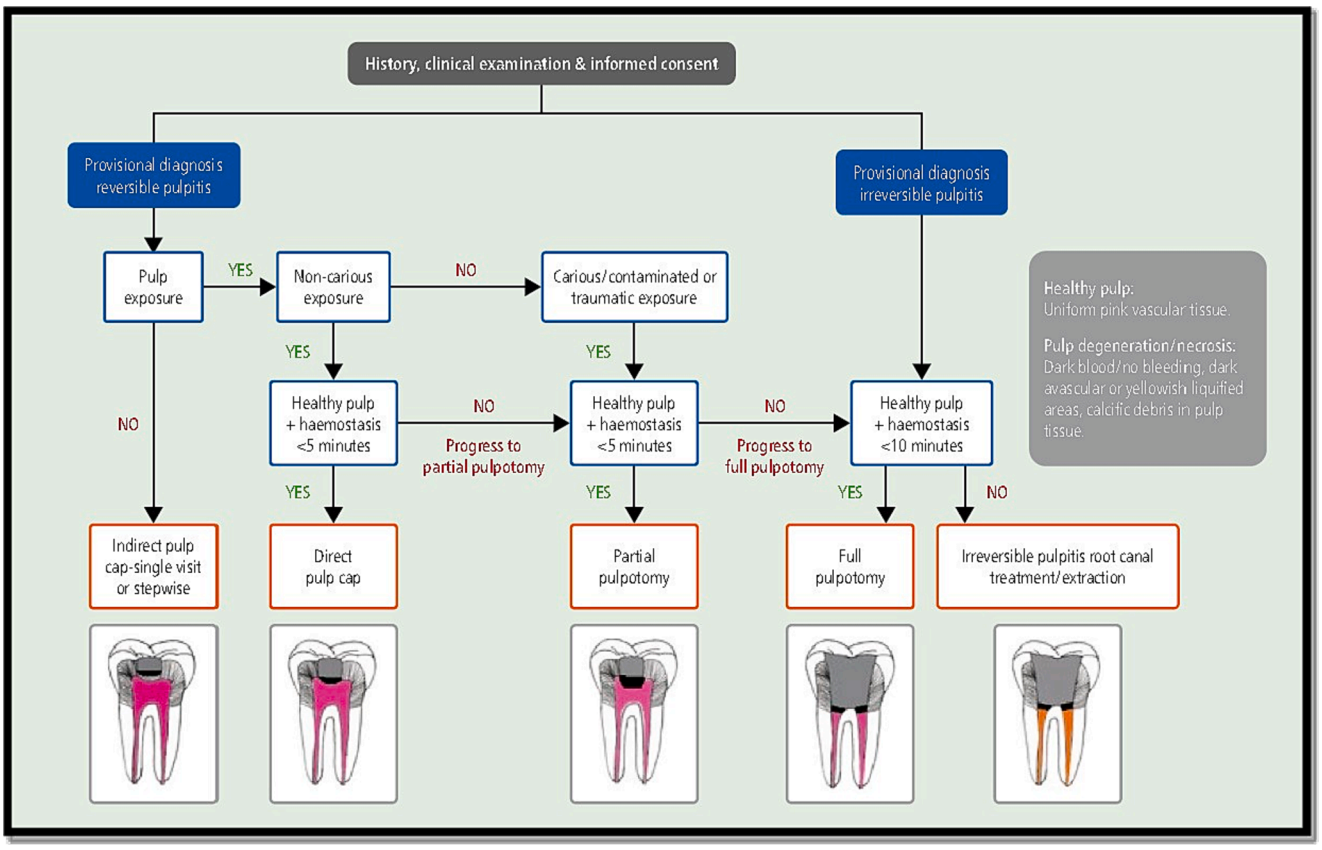

Fig. 2. Decision tree for mature permanent teeth for inflamed vital pulp (Yong et al., 2021).

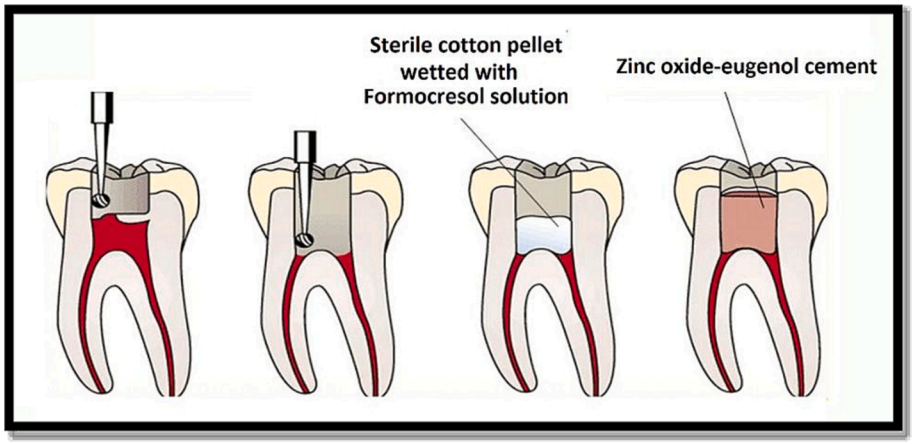

Fig. 3. Pulpotomy medicaments.

2019).

3.2. Zinc oxide eugenol (ZOE)

ZOE limits microleakage and recurrent infections and provides an effective seal. In 1965, James Berger, using ZOE, observed an active inflammatory reaction. FC pulpotomy demonstrated a 99 % clinical success rate when FC is mixed in the zinc oxide-eugenol sub-base (Fig. 3) (Jha et al., 2021).

3.3. Glutaraldehyde

S'Gravenmade used glutaraldehyde in 1975. Of the ferric sulfate and mineral trioxide aggregates, 2 % buffered glutaraldehyde was the least effective. An inadequate fixation to sub-base irritation left a deficient barrier against internal resorption (Sa'diyah et al., 2021).

3.4. Calcium hydroxide

In 1930, Herman introduced Calxyl for pulp capping and pulpotomy. Calcium hydroxide pulpotomy causes internal resorption in deciduous teeth. It is the material of choice for direct pulp capping and permanent tooth pulpotomy (McDonald, 1996) (Cosme-Silva et al., 2022).

3.5. MTA

MTA was first introduced by Mohmond Torabinajad at Atlomalinda University in 1993 as a novel endodontic cement for repairing root perforations. The American Academy of Pediatric Dentistry recommends MTA for primary tooth pulpotomy for reversible pulpitis and traumatic pulp exposure. Molars treated with MTA were better than those treated with FC as reported by Farsi et al. (Jha et al., 2021).

3.6. Biodentin

In 2009, biodentin was introduced as a "dentin replacement" agent and is commercially available as Septodont. Nasseh et al. (2018) evaluated biodentin pulpotomy outcomes after a 12-month follow up in primary molars with root resorption and reported 100 % clinical and radiographic success rates (Nasseh et al., 2018).

3.7. Calcium enriched mixture (CEM)

The CEM cement was introduced by Asgaryet et al. in 2006. Comparing MTA with CEM pulpotomy at 6 and 12 months of follow-up, Nosrat et al. have reported 100 % clinical and radiographic success rates (Jha et al., 2020).

3.8. Portland cement

In 1824, Joseph Aspdin introduced Portland cement from limestone calcination of Portland and silicon materials. Thus, bismuth oxide was the only difference between the Portland cement and MTA. Owing to its low cost, Portland cement is considered a possible MTA substitute (Sa'diyah et al., 2021).

3.9. Platelet concentrate

Platelet-rich fibrin (PRF) was developed by Choukroun et al. in France in 2001. In 2018, Mostafa et al. performed PRF pulpotomy and reported clinical success rates of 89.5 % and 78.9 %, respectively, indicating that PRF can be used as an alternative FC pulpotomy agent (Saikiran et al., 2018).

3.10. Enamel matrix derivative (EMD)

Emdogain gel (Straumann, Switzerland) for the pulpotomy of non-infected teeth has been used in animal studies. In addition, a similar clinical and radiographic success rate of EMD was reported by Yildirim et al. for MTA and FC (Jha et al., 2021).

3.11. Bone morphogenetic protein (BMP)

The BMP, a pulpotomy agent was introduced in 1991 by Nakashima. Pulpotomy using BMP-7 was performed on dog teeth; however, mineralized tissue deposition and unsatisfactory periapical responses (Jha et al., 2021).

3.12. Enriched collagen

Michaeli (1984) used it as a pulpotomy material to study pulp healing in baboons, resulting in vital pulpal tissue and dentin bridging formation in the pulp chamber in 80 % of the teeth (Jha et al., 2021).

Natural alternatives, such as honey, *Nigella sativa*, *Curcuma longa*, turmeric, aloevera, and *Thymus vulgaris*, may be possible replacements for FC (Saikiran et al., 2018).

4. Prognosis and treatment outcomes

The clinical diagnosis of the pulpotomy procedure is derived from the report of Fuks et al. (2019).

- proper medical history regarding systemic illness
- dental history and previous and past treatments
- patient complaints on the site, location, intensity, duration, and stimuli.
- extraoral and intraoral examinations
- radiographic diagnosis of the apical or radicular changes of the periapex
- palpation, percussion, and mobility tests, as well as pulp vitality tests, such as electric pulp and cold tests

The prognosis of pulpotomy failure in primary teeth was based on the report of Kulkarni et al. (2021).

- incomplete coronal pulp removal from the pulpal chamber
- incomplete carious structure removal and formation of secondary decay
- presence of undiagnosed periapical chronic infection
- tissue irritant materials, such as ZOE, directly placed at the pulpal tissue contact lead to chronic inflammatory reactions
- microleakage caused infection in teeth fillings with severe proximal decay

The severity of pulpal inflammation and hemostasis acquired after the removal of inflamed tissue influences the pulpotomy outcome. Cavity flushing with chlorhexidine or sodium hypochlorite (NaOCl) solution after pulp exposure can reduce the bacterial load. Pulp amputation should be performed with copious amounts of irrigation using a sterile high-speed rotatory bur. Pulp vitality assessment is also required after pulp exposure. Placement of the amputated pulp using either an NaOCl-soaked sterile cotton pellet or passive irrigation hemostasis was achieved. NaOCl 0.5 %–5% concentration in direct pulpal contact does not compromise the formation of reparative dentin. It also removes biofilms and disinfects the dentin–pulp interface (Philip et al., 2022).

The most critical factor for favorable outcomes is that the remnant pulp tissue is accurately sealed with medication and adequate coronal restoration. For the tooth to be retained for $\geq$ 24 months, only MTA and FC are recommended. MTA and CEM have good biocompatibility and excellent sealing abilities, thereby increasing their success rates. Immediate coronal restoration placement is also recommended to prevent microleakage, protect the medication, and reduce sensitivity. Stainless-steel crown success rates are reported to be greater than both composite and amalgam restoration; amalgam has a higher success rate for proximal restorations than composite. In addition, a waiting period of 3–6 months is recommended before full cusp coverage preparation (Qudeimat et al., 2017).

The ESE recommends that VPT teeth be assessed postoperatively, both at 6 and 12 months, clinically, radiographically, with sensibility testing, and for up to 4 years annually (Table 1) (Duncan et al., 2019). Clinical outcome measures of pulpotomy success include no palpation or tenderness on percussion and absence of swelling or sinus tract formation, leading to an asymptomatic functional tooth. No internal root resorption or periapical pathology was observed on radiography. In addition, a normal response should be observed in the sensitivity tests of partially pulpotomy-treated teeth (Taha et al., 2020).

5. Why does pulpotomy fail?

The causes of failure associated with the final restorations have been determined as follows (Kulkarni et al., 2021):

- Overfilled or underfilled material for restoration
- Poor sealing between the tooth and restorative material
- Inadequate stainless-steel adaptation of crown to cement–enamel junction

Table 1
Systematic reviews.

Author	Population	Intervention	Studies included	Conclusion
Alqaderi et al. (2016)[28]	Cariously exposed pulp on posterior vital matured teeth	Full pulpotomy (FP)	6	Favorable outcome for managing carious pulpal exposure
Li et al. (2019)[29]	Irreversible pulpitis (IP) on cariously exposed posterior vital mature teeth	FP	21	FP is successful in managing carious pulp exposures
Cushley et al. (2019)[4]	Symptomatic IP on mature posterior teeth	FP	8	High success rate for FP
Elmsmari et al. (2019)[30]	Cariously exposed pulp on posterior vital matured teeth	Partial pulpotomy (PP)	11	PP up to two years had favorable outcomes in managing cariously exposed tooth
Santos et al. (2021)[31]	Symptomatic IP on mature posterior teeth	FP and PP	12	FP and PP had favorable outcomes

- Adhesive cement lost under the stainless-steel crown

In zinc phosphate cement, a greater rate of microleakage was observed. AAPD is recommended over calcium hydroxide used for pulpotomy. An increased rate of microleakage and secondary decay was observed in composite restorations. Fractures have been reported in amalgamation and composite restorations.

Early pulpotomy-treated tooth failures (within 3–6 duration) are attributed to endodontic causes, whereas restorative causes tend to reflect later failures, as reported in recent clinical trials. In mature tooth pulpotomies, the only prognostic predictive factors are preoperative pain (for early failures) and coronal restoration type (for late failures) in mature teeth pulpotomy (Taha et al., 2022).

In defective coronal restorations, coronal pulpotomy failure has been observed, mostly leading to microleakage. Between biocompatible materials and coronal restorations, proper sealing is the most crucial factor in VPT, resulting in favorable outcomes. The survival rate of pulpotomies is affected by microleakages during restoration over time. Additionally, microleakage has a marginal effect on pulpal inflammation, as reported in the literature. Poor restorative marginal adaptation is a known cause of microbiota entering the pulpal tissue, causing infection. Hence, regular follow-up evaluations are critical to ensure marginal integrity of the restoration and repair of defective restorations (Tan et al., 2020).

Primary teeth at a higher risk of breakage have greater tooth loss, and stainless-steel crowns have a higher success rate than other restorative materials. Increased decay among children and lower success rates have been observed in wide-surface restorations. The common reasons for failure include restoration fractures and secondary decay. Amalgam restorations have a lower rate of secondary decay than composite restorations (American Academy of Pediatric Dentistry, 2020).

To assess pulpal inflammation during pulpotomy, the time required to achieve hemostasis can be a better outcome measure. If hemostasis is achieved within 1–10 min, inflammation may be limited to the coronal pulp. Moreover, periapical rarefaction healing is important for teeth with irreversible pulpitis. Neurogenic inflammation preceding pulpal necrosis in the irreversibly inflamed pulp is associated with periapical calcification (Zafar et al., 2020).

In a 5-year study, Asgary et al. reported no significant difference in the success rate between CEM coronal pulpotomy and root canal treatment (Zadaf et al., 2020).

Holan et al. have reported that microleakage and bacterial pulpal penetration are caused by poor marginal adaptation of stainless-steel crowns or amalgam restorations. In addition, incomplete sealing with the composite resin was caused by incomplete resin curing and due to resin shrinkage during curing. Studies have reported a 6-month timeframe for pulpotomy success; however, long-term follow-up is required with respect to complications such as necrosis, root resorption, and periapical lesion development (Kulkarni et al., 2021).

6. Signs of pulpotomy failure

A few common symptoms of pulpotomy failure include:

- Pain
- Sensitivity
- Swelling
- Pus discharge
- Tooth discoloration
- Boil on the jaw
- Sinus tract

These are the commonly observed signs of failure:

- Coronal seal breakdown: If the seal is compromised, the tooth can be reinfected with bacteria and contaminants.
- Crown breakdown: If there is a delay between the procedure and crown placement, bacteria can re-enter the tooth. In addition, a crown can suffer from cracks or other damages after completing the procedure.
- Decay or trauma: In a new injury to the tooth, bacteria can re-enter, leading to additional decay and exposure of tooth-sensitive areas to new infection.

7. Alternative endodontic interventions

7.1. Protective liner

Indications: The protective liner may be applied in deep preparation areas to reduce pulpal injury, promote pulpal tissue healing, and reduce postoperative sensitivity after caries removal from normal pulp teeth (American Academy of Pediatric Dentistry, 2020).

Objective: Placement of liners in deep preparation areas helps preserve tooth vitality, promote pulpal tissue healing and tertiary dentin formation, and reduce bacterial microleakage. Negative clinical signs or symptoms such as sensitivity, pain, or swelling should not occur postoperatively (American Academy of Pediatric Dentistry, 2020).

7.2. Indirect pulp treatment

Indirect pulp treatment is a procedure performed in a deep carious lesion approximating the pulp but without radicular pathology. To avoid pulpal exposure, the deepest caries are left adjacent to the undisturbed pulp. Thus, dentin affected by caries to produce a biological seal is dressed using a biocompatible material (Dhar et al., 2017).

7.3. Interim therapeutic restorations

Indications: Deciduous teeth with deep dentinal caries without pulpitis; to avoid pulpal exposure when the deepest carious dentin is not removed in cases of reversible pulpitis.

Objective: Restorative materials should completely seal dentin from the external environment to preserve tooth vitality. Negative postoperative signs or symptoms such as sensitivity, pain, or swelling as well as radiographic evidence of external or internal root resorption or other pathological changes should be absent. In addition, no injury to the succedaneous erupting teeth occurred (Santos et al., 2021).

7.4. Direct pulp capping

Indications: The primary tooth following a mild pulpal exposure has a normal pulp.

Objective: Maintenance of pulp vitality in the absence of post-operative signs or symptoms, such as sensitivity, pain, or swelling, results in pulpal healing and tertiary dentin formation. No radiographic signs of external or internal root resorption, or periapical radiolucency were observed. Additionally, no injury to the succedaneous erupting tooth occurred (American Academy of Pediatric Dentistry, 2020).

7.5. Pulpectomy

Indications: In deciduous teeth with irreversible pulpitis or necrosis and for pulpotomy-planned teeth, the radicular pulp exhibits clinical signs of irreversible pulpitis or pulpal necrosis such as purulence and suppuration. Roots should exhibit minimal or no resorption (Coll et al., 2020a).

Objective: The radiographic infectious process should resolve within 6 months, as evidenced by bone deposition in pretreatment radiolucent areas, and the pretreatment clinical signs and symptoms should resolve within a few weeks. Successful radiographic restorations should be performed without gross overextension or underfilling. Thus, treatment should allow primary root resorption and normal eruption of the succedaneous teeth. In addition, pathological root resorption or periapical radiolucency should be absent (Li et al., 2019).

7.6. Lesion sterilization/tissue repair (LSTR)

The AAPD recommends that tetracycline antibiotic mixtures should not be included in LSTR.

Indications: For a primary tooth with signs of irreversible pulpitis or necrosis and for a planned pulpotomy, the radicular pulp exhibits clinical signs of irreversible pulpitis or pulpal necrosis. Root resorption and tooth arch positioning should also be considered prior to treatment. LSTR is preferred over pulpectomy when a tooth exhibits root resorption and should be maintained for approximately 12 months (Coll et al., 2020b; Elmsmari et al., 2019).

Objective: Following treatment, pretreatment signs and symptoms and radiographically visible periapical infection should be resolved in the pretreatment radiolucent areas, as evidenced by bone deposition (Alqaderi H et al., 2016).

7.7. Regenerative endodontics

Regenerative endodontics is a biological procedure to replace the diseased tooth structure physiologically, including both the dentin and pulp–dentin complex (American Academy of Pediatric Dentistry, 2020).

Indications: Used for nonvital permanent teeth with an incomplete root formation.

Objective: The goal is to treat apical periodontitis, which is the resolution of teeth with an immature apex and necrotic pulp, and eliminate clinical signs or symptoms. An additional goal is to achieve root canal wall thickening and continuous root maturation. In addition, there was an absence of external root resorption, root fracture, or breakdown of periradicular tissues following therapy (American Academy of Pediatric Dentistry, 2020).

For the management of three seventy-five teeth with complicated crown fractures treated with pulp capping, Wang et al. (2017) have reported a significantly higher pulp necrosis rate compared to both partial and complete pulpotomy procedures. In 1993, Fuks et al. demonstrated the long-term success rate of partial pulpotomies in both mature and immature teeth. In 2020, Bourguignon et al. recommended either pulp capping or partial pulpotomy as the treatment of choice, and ESE 2021 advised for large exposures the partial pulpotomy procedure and pulp capping for minor exposures and during treatment delay within the first few hours after trauma (Bourguignon et al., 2020; Vinagre et al., 2021).

8. Conclusion

Pulpotomy for both patients and dentists is a simple procedure, with minimal invasion, lower cost, and less time consumption. Coronal pulpotomy is a safe and appropriate alternative to root canal therapy for irreversible pulpitis.

The success of pulpotomy depends on the pulpotomy agents, final restoration, proper sterile techniques, and clinician experience. Pulpotomy is the treatment of choice for immature and mature teeth with complicated crown fractures. Furthermore, partial pulpotomy should be the preferred treatment option because of its advantages, wherever possible.

In permanent teeth, coronal pulpotomy-related limitations include pulpal status uncertainty at the time of treatment, lack of predictability, and absence of long-term follow-up, which affect its success rate. The reasons for failure include incomplete coronal pulpal tissue removal during the proximal step and poor sealing at the final restoration.

9. Ethical statement

The current manuscript is a narrative review and the ethical approval is required.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sdentj.2024.01.005.

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