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Assessment of Mineral Trioxide Aggregate pulpotomy in mature permanent teeth with carious exposures

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Abstract

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Aim To assess the outcome of mineral trioxide aggregate (MTA) complete pulpotomy in permanent teeth with carious exposures.

Methodology Fifty-two permanent molar teeth with fully developed roots and vital pulps in 43 patients aged 11–51 years were included. Preoperative pulpal and periapical diagnosis was established. After informed consent, each tooth was anaesthetized, isolated with dental dam and disinfected with 5% NaOCl before caries excavation; subsequently, a full pulpotomy was performed. Haemostasis was achieved, and Grey MTA (Angelus, Londrina, Brazil) was placed as the pulpotomy agent; a moist cotton pellet was placed, and the tooth was temporized with the intermediate restorative material (IRM). Permanent restorations were placed 1 week later if the tooth was asymptomatic, and a postoperative periapical radiograph was taken. Clinical and radiographic evaluation was completed at 3 months, 6 months, 1 year and 3 years postoperatively.

Results Clinical signs and symptoms suggestive of irreversible pulpitis were established in 44/52 teeth, and periapical rarefaction was present in 14 teeth. Immediate failure occurred in one tooth. The recall rate ranged from 92% at 3 months to 80.3% at 3 years, with an overall 100% clinical and 97.5% radiographic success during the first year, and 92.7% success at 3 years. All cases with periapical rarefaction were associated with improvement in the periapical index (PAI) score. Two cases had new periapical rarefaction associated with dislodgment of the permanent restoration. A hard tissue barrier was detected radiographically in 5 cases and canal narrowing in 7 cases.

Conclusion MTA full pulpotomy was a successful treatment option for cariously exposed pulps in mature permanent molar teeth.

Keywords: deep caries, full pulpotomy, mineral trioxide aggregate, pulpitis.

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Introduction

Root canal treatment for teeth with vital pulps demonstrates a favourable success rate, approaching 100% if performed to high standards (Sjögren *et al.* 1990). However, epidemiological studies reveal a high incidence of technically inadequate root fillings and a high percentage of apical periodontitis in root filled teeth (Dugas *et al.* 2003, Frisk *et al.* 2008, Al-Omari *et al.* 2011, Moreno *et al.* 2013, Di Filippo *et al.* 2014). Furthermore, technical complications were the most common cause for endodontic malpractice claims in Denmark (Bjørndal & Reit 2008), which may favour more conservative approaches for the

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management of inflamed vital pulps, including partial or complete pulpotomy. Additionally, vital radicular pulps maintain their protective stress-reducing damping effect (Ou *et al.* 2009) and preserve the mechanoreceptor function of the dental pulp (Randow & Glantz 1986), which may reduce the incidence of tooth fracture from overloading.

Clinical signs and symptoms such as the degree and characteristics of pain do not reflect the actual histological status and subsequently the healing potential of the inflamed pulp. Histological studies found inflammation to be confined to the area next to the carious exposure and not extending beyond 2 mm from the exposure site (Seltzer *et al.* 1963). Radicular pulp was rarely inflamed. Furthermore, it was impossible in a histological study to classify accurately the pulpal condition of all painful teeth or to differentiate clearly between saveable and nonsaveable pulps (Dummer *et al.* 1980). Chronic partial pulpitis was present in 88% of painful cases and partial necrosis in 92% of the cases, without correlation between the nature or the character of pain and the histological diagnosis. Pain was actually present in 40% of the cases with saveable pulps. Therefore, if the infected and most severely inflamed tissue is removed and the pulp is dressed with an adequate material, the conservation of a remaining healthy pulp is potentially possible.

From history taking and clinical tests, the clinicians are able only to indicate the probable state of the pulp, whilst final diagnosis can be reached only after histological examination. Ricucci *et al.* (2014a) studied the correlation between clinical and histological pulp diagnosis; the clinical diagnosis of irreversible pulpitis corresponded to the histological diagnosis for this condition in 84.4% of the cases. In these teeth, areas of necrosis of varying extent were observed in the coronal pulp, whilst it was not infrequent to observe uninflamed pulp tissue with normal architecture in the contralateral pulp horn. The histological diagnosis in the remaining 15.6% was actually reversible pulpitis.

Proper case selection and treatment protocols are a key to the success of vital pulp therapy (VPT). In teeth with signs and symptoms suggestive of irreversible pulpitis, pulpal conditions have little chance to revert to normal only by the removal of irritants; most cases require partial or total excision of the affected pulp tissue (Ricucci *et al.* 2014a). The ability to control bleeding after amputation of the infected pulp tissue has been proposed as an indicator for the extent of inflammation and the healing potential of the remaining pulp tissue (Matsuo *et al.* 1996). The pooled success rate of pulpotomy in teeth with signs and symptoms clinically suggestive of irreversible pulpitis and periapical radiolucency has been reported to be 92.5% using calcium hydroxide (CH) over 2- to 3-year period (Aguilar & Linsuwanont 2011). This may suggest the need for revision of the criteria distinguishing reversible from irreversible pulpitis (Glickman 2009).

Conventionally CH has been the material of choice for VPT, showing favourable outcomes particularly in young teeth (Aguilar & Linsuwanont 2011). However, its physical limitations such as dissolution in tissue fluids, degradation upon tooth flexure and poor quality of the proximal hard tissue barriers are drawbacks (Cox *et al.* 1996). On the other hand, MTA is currently the most commonly used material in VPT. It has excellent marginal adaptation and induces cell proliferation and formation of a high-quality hard tissue barrier (Torabinejad *et al.* 1995, Aeinehchi *et al.* 2003).

Vital pulp therapy in general has been reported to have a high success rate (91%–93%) in young permanent molars and is recommended as an alternative option in asymptomatic cariously exposed teeth (Mejare & Cvek 1993, Barrieshi-Nusair & Qudeimat 2006, Qudeimat *et al.* 2007). However, few studies have examined direct pulp capping and partial pulpotomy in symptomatic permanent teeth. The majority of previous investigations have sampled only asymptomatic teeth or teeth that exhibited pain of short duration (Aguilar & Linsuwanont 2011). Furthermore, most of the studies that included teeth with signs and symptoms clinically suggestive of irreversible pulpitis have used CH as the capping material (Mejare & Cvek 1993, Caliskan 1995, Matsuo *et al.* 1996, Teixeira *et al.* 2001). A recent multicentre randomized clinical trial reported a success rate of 78% for complete pulpotomy using calcium-enriched mixture cement (CEM) in mature molars with signs and symptoms clinically suggestive of irreversible pulpitis over 5-year follow-up (Asgary *et al.* 2015). Therefore, the aim of this study was to assess the outcome of complete pulpotomy in mature teeth with carious exposures demonstrating variable pulpal conditions using MTA Angelus over a 3-year period.

Materials and methods

Fifty-two permanent molar teeth meeting the inclusion criteria with the fully developed roots (in terms

of length and apical closure) and vital pulps in 43 patients who were referred to the endodontic postgraduate clinic for the management of symptomatic deep carious lesions were included (Tables 1 and 2). Ethical approval was obtained from the institutional ethics and human research committee, and informed consent was obtained from all patients prior to the treatment. Patients were offered root canal treatment in case of treatment failure.

Patients who had a molar tooth with a vital pulp (detected by clinical signs/symptoms) with a history of pain indicative of reversible pulpitis or signs and symptoms classically suggestive of irreversible pulpitis, in the absence of sinus tracts or swelling, were included (Mejare *et al.* 2012). Pain indicative of reversible pulpitis was defined as provoked short-duration pain that lasted for a few seconds and disappeared after removal of the stimulus. Pain suggestive of irreversible pulpitis was defined as spontaneous pain or pain exacerbated by cold stimuli and lasting for a few seconds to several hours (interpreted as lingering pain) compared to control teeth, and which could be reproduced using cold testing.

Preoperative pulpal and periapical diagnosis was established after clinical examination and cold testing (Endo-Ice, Hygenic Corp, Akron, OH, USA), and periapical radiographs were taken (Table 1). The periapical index was used to score cases with periapical rarefaction (Ørstavik *et al.* 1986) during diagnosis and follow-up periods. Subsequently, the following pulpotomy technique was followed: after local anaesthesia and dental dam application, the crown was disinfected with 5% NaOCl before caries excavation; after exposure, the pulp was amputated to the level of the canal orifices (full pulpotomy) using a sterile high-speed round bur under water coolant; pulp vitality was confirmed by the presence of bleeding pulp tissue from all canals. Haemostasis was achieved by the application of a pellet moistened with 2.5% NaOCl for 2 min and repeated as needed; bleeding time was recorded. After haemostasis, Grey MTA (MTA reparative cement, Angelus, Londrina, Brazil) was mixed according to the manufacturer's instructions and gently placed over the pulp to a thickness of 2–3 mm; a wet cotton pellet was placed over the MTA, and the tooth was temporized using the intermediate restorative material (IRM, Dentsply, Caulk, Milford, DE, USA). Patients were reviewed after 1 week, and if the tooth was asymptomatic, the set MTA was then covered with resin-modified glass–ionomer cement (Vitrebond, 3M, ESPE, St. Paul, MN, USA) and restored using resin composite or amalgam. A postoperative periapical radiograph was taken.

Table 1 Characteristics of the study participants

Variable	*N*
Age	
10–19	8
20–29	18
30–39	11
40–49	4
50–59	2
Total	43
Gender	
Female	26
Male	17
Pulpal Diagnosis[a]	
Reversible Pulpitis	8
Irreversible Pulpitis	44
Periapical Diagnosis	
Apical periodontitis present	14
Apical periodontitis absent	38

[a]Many authors consider that a carious exposure in a permanent tooth of an adult always indicates irreversible pulpitis. The pulpal diagnosis here was based on history of pain, response to thermal testing and clinical findings.

Table 2 Inclusion and outcome criteria

Inclusion Criteria
Permanent molar tooth with deep caries and subsequent pulp exposure
Tooth should be vital on cold testing
Vital bleeding pulp tissue should be present in all canals after complete pulpotomy
Diagnosis is either reversible or irreversible pulpitis with/without periapical rarefaction
The tooth is restorable and free from advanced periodontal disease
Soft tissues around the tooth are normal with no swelling or sinus tract
Haemostatis should be achieved after complete pulpotomy
The patient has noncontributory medical history
Success Criteria
Clinical criteria
No history of spontaneous pain or discomfort except for the first day after treatment
No tenderness to palpation or percussion and the tooth is functional
Normal mobility and probing pocket depth
Soft tissues around the tooth are normal with no swelling or sinus tract
Radiographic criteria
No pathosis evident on the radiograph such as root resorption, furcal pathosis or new periapical pathosis
Complete radiographic healing (PAI score 1 or 2) or reduction in the PAI score if periapical rarefaction was present preoperatively

Clinical and radiographic evaluation was completed 3 months, 6 months, 1 year and 3 years postoperatively, and the outcome was determined according to clinical and radiographic criteria as described in Table 2. The outcome was considered successful if the following situation occurs:

1. the absence of clinical signs and symptoms of pulpal pathosis (pain, tenderness to percussion, sinus tract, swelling),
2. no pathosis evident on the recall radiograph such as root resorption, new furcal or periapical rarefaction,
3. complete radiographic healing (PAI score 1 or 2) or reduction in the PAI score if periapical rarefaction was present preoperatively.

The quality of the coronal restoration was checked, and the restoration was repaired if deemed necessary. The clinical procedure was performed by one operator; all recall radiographs were examined by an experienced endodontist twice on two different occasions, without referring back to previous readings. Intraobserver reliability was assessed by Cohen's kappa coefficient of agreement index.

Data analysis: Because only one treatment procedure was performed, statistical analysis was limited to chi-square analysis of the outcome in relation to age, gender, pulpal and periapical diagnosis. Significance was set at $P < 0.05$.

Results

After 1 week, the preoperative symptoms had disappeared in all cases except one (female, age group 20–29 years) who continued to have pain, and root canal treatment was initiated. Five cases encountered postoperative discomfort, but only one patient (male, age group 30–39 year) reported intake of analgesics. The permanent restoration was placed at the 1-week recall: 9 amalgam and 43 resin composites. The patients were advised to proceed with coronal coverage restorations after the 1-year recall, but the compliance rate was low (2/43 patients).

A summary of the results at the recall periods is presented in Table 3. The success rate of the procedure was generally high, ranging from 97.5% at 1 year to 92.7% at 3 years (Figs 1, 2 and 3). Because of the high success rate, there was no difference between the different age groups or different diagnostic categories using chi-square test ($P > 0.05$), and therefore, no advanced statistical analysis was performed. Intraexaminer Cohen's kappa scores ranged from 1.00 for outcome to 0.875 for radiographic signs of hard tissue barrier formation and 0.755 for narrowing of canals.

During the pulpotomy procedure, 7 cases had prolonged bleeding (>5 min), and 2/7 did not attend the 3-year recall; 1/7 failed. This case experienced loss of the permanent restoration and a portion of the MTA during subsequent crown preparation. The remaining 4/7 were successful. Hard tissue barrier formation subjacent to the capping material was evident in 2 cases at 1-year recall, and another 3 were evident at the 3-year recall. Seven cases had narrowing of canals, but none had complete obliteration. No evidence of internal resorption was noted in any of the reviewed cases. Four cases had discoloration of the gingival third of the crown.

Table 3 Summary of results at recall periods

Recall Period	Number of cases Attending recall	Outcome
3 months	48/51; 13/48 with periapical rarefaction	One case had persistent symptoms for a week after pulpotomy and RCT were performed 100% Clinical success of cases attending 3-month recall 89.5 Radiographic success (rarefaction has not improved in 5 cases) (same PAI score)
6 months	47/51; 13/47 with periapical rarefaction	100% Clinical success 97.8 Radiographic success: rarefaction has not improved in 1 case (same PAI score)
12 months[a]	40/51; 12/40 with periapical rarefaction	100% Clinical success 97.5 Radiographic success: rarefaction has not improved in 1 case (same PAI score) (this case did not attend 3-year recall)
3 years and (1–7) months	41/51; 12/41 with periapical rarefaction	92.7% Clinical and radiographic success 2/3 failed cases developed new periapical lesion following the loss of the restoration and capping material

[a]Six patients who did not attend 1-year recall did attend the 3-year recall, and 5/6 cases were successful.

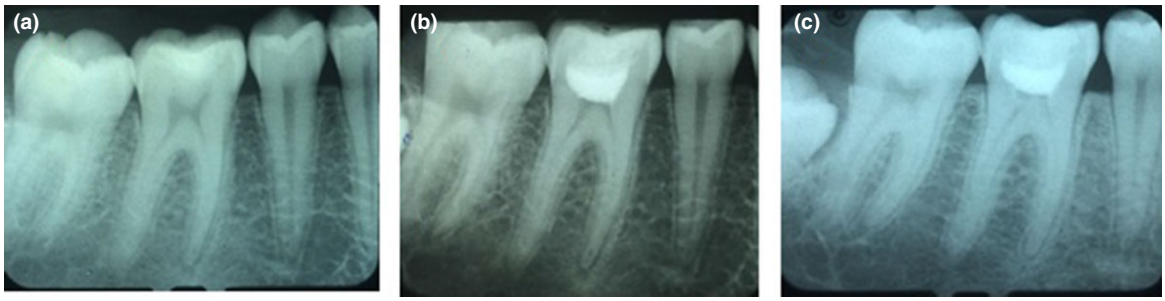

Figure 1 Radiographs of 15-year-old female patient with signs and symptoms clinically suggestive of irreversible pulpitis and apical periodontitis in tooth 46. (a) preoperative radiograph, (b) Immediate postoperative radiograph with resin composite restoration. (c) 3-year recall showing advanced healing of apical periodontitis (PAI 1) and hard tissue barrier formation in the distal canal below the MTA with concomitant narrowing and calcification of the mesial canals.

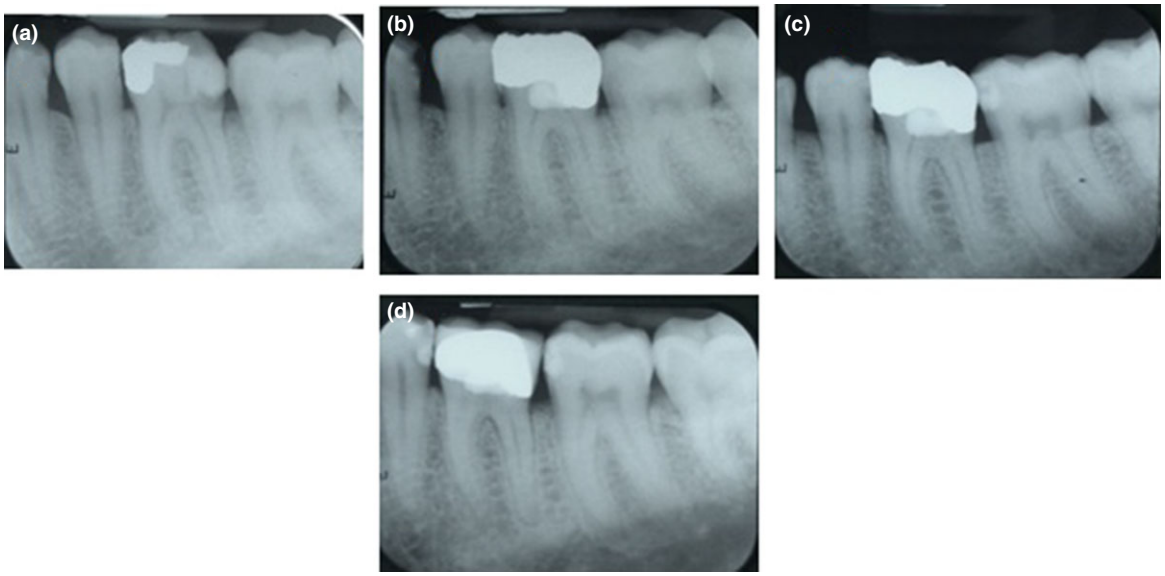

Figure 2 Radiographs of 36-year-old male patient with signs and symptoms clinically suggestive of irreversible pulpitis and widening of the periodontal ligament space in tooth 36. (a) preoperative radiograph, (b) Immediate postoperative radiograph, (c) 3-year recall, (d) 4-year recall: the tooth is asymptomatic with normal periapex and hard tissue barrier formation in the distal canal below the MTA with concomitant narrowing and calcification of the mesial canals. The tooth has a metal ceramic crown restoration.

The coronal restoration was amalgam in 9 cases; 2 cases did not attend any follow-up, whilst the rest were intact at follow-ups. In 43 cases, resin composite was placed, 2 were completely dislodged from the tooth and both cases failed, 3 had recurrent caries and 9 required repair of a fractured margin.

Discussion

Clinical decision-making should be based on the best available evidence, and currently, there are no conclusive guidelines regarding the management of cariously exposed mature permanent teeth. The necessity to reach accurate assessment of the state of the pulp is obvious to prescribe the correct treatment (Dummer *et al.* 1980). Despite the high number of cases that histologically match the clinical diagnosis of irreversible pulpitis, a small number of teeth would be treated unnecessarily using the currently accepted parameters of pulp diagnosis (Ricucci *et al.* 2014a). With the advantage of greater technical ease over root canal treatment, the recent development of

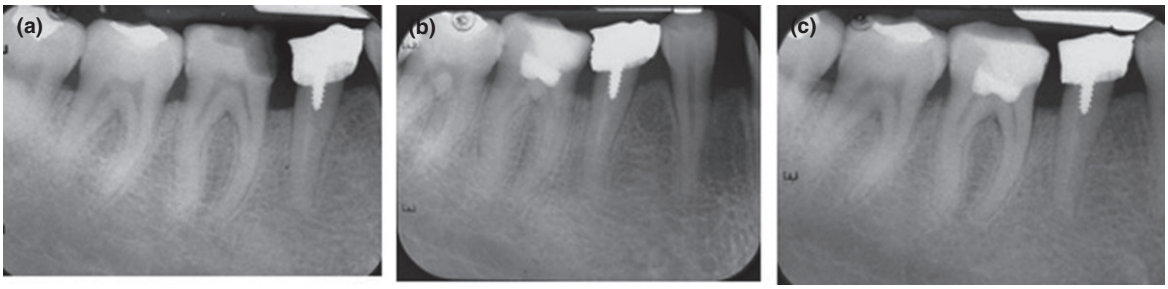

Figure 3 Radiographs of 30-year-old female patient with signs and symptoms clinically suggestive of irreversible pulpitis and normal periapex in tooth 46. (a) preoperative radiograph, (b) Immediate postoperative radiograph, (c) 3-year recall showing normal periapex.

newer materials and our improved understanding of pulp biology and reparative processes (Simon *et al.* 2013), the clinical application of adult pulpotomy may provide an alternative future treatment option.

This study is an extended case series and is the first to investigate the outcome of complete pulpotomy in cariously exposed mature permanent teeth with inflamed symptomatic pulps using MTA Angelus with reasonable sample size and high recall rate. The incidence of unfavourable outcomes was low, and the survival rate was high; therefore, survival statistics were not relevant. The overall success rate at 3 years was 92.7%, which coincides with the pooled success rate estimated by Aguilar & Linsuwanont (2011) for (mostly immature) teeth with irreversible pulpitis and apical periodontitis. This result was superior to the outcome reported by Asgary *et al.* (2015) using CEM over a 5-year follow-up.

In immature teeth, partial pulpotomy is favoured over complete pulpotomy to avoid the destruction of the cell-rich coronal pulp, which could arrest cervical dentine formation and result in obliteration of the canals (Fong & Davis 2002). However, in this study only 7 cases had narrowing of root canals with no obliteration, similar to the findings of Simon *et al.* (2013) for pulpotomy on 17 teeth with reversible pulpitis over 1- to 2-year recall. Therefore, subsequent pulpectomy of these cases (if required) is much less challenging than in the past. Cervical discoloration was rare and has been previously reported with the use of grey MTA (Karabucak *et al.* 2005).

The dental pulp in mature teeth retains the ability to form dentine, but at a lower rate than the young dental pulp cells (Matsuzaka *et al.* 2008). Wear, caries and restorative procedures may impair the ability of odontoblasts to form additional dentine. The pulp environment and inflammation are critical to the signalling events associated with the induction of cell differentiation and subsequent regulatory control of the secretory activity of these cells (Schmalz & Smith 2014). After loss of the primary odontoblasts in response to severe noxious irritation, the main evidence-based observation in the literature supports that reparative dentine is formed by specific cells undergoing cyto-differentiation (odontoblast-like cells) (Smith & Lesot 2001, Goldberg & Smith 2004, Simon *et al.* 2012). A recent study found that pulpal fibroblasts or fibroblast-like cells produced a calcific material that resembles pulp stones rather than tubular dentine under CH as a direct pulp capping procedure; this hard tissue barrier was considered to represent a repair response rather than a regenerative process (Ricucci *et al.* 2014b). Hard tissue barrier formation as detected radiographically has been reported in 10/26 young permanent teeth (Alqaderi *et al.* 2014) compared to 5/43 in this study; similarly, hard tissue barrier formation and pulp horn obliteration were found in 70% of 49 young permanent teeth treated with CH partial pulpotomy over 1- to 11-year follow-up (Mass & Zilberman 2011).

Generally there is a little evidence regarding the effect of age or status of root development on the outcome of VPT (Aguilar & Linsuwanont 2011). In a randomized clinical trial, age was not found to be a significant factor in the outcome of complete pulpotomy using CEM in three age groups (<20, 20–29, and ≥30 years) (Asgary *et al.* 2015). Similar to the findings of this study, several investigations have reported successful VPT in patients with age ranging from 6 to 70 years (Matsuo *et al.* 1996, Barthel *et al.* 2000, Mente *et al.* 2010). Long-term adverse responses of VPT are not evident yet. However, this study indicates these effects to be minimal.

The ability to control bleeding after amputation of the inflamed portion of the pulp has been suggested as an important prognostic factor (Matsuo *et al.* 1996), being a stronger indicator of the degree of pulp inflammation than preoperative symptoms. Amongst the cases that had prolonged bleeding in this study 4/7 were successful, one of these cases had bleeding up to 10 min and another for 15 min; however, it is not reasonable to draw conclusions based on these isolated cases. The ability to control bleeding eventually, the use of MTA and adequate coronal seal may have contributed to the high success rate.

The treated teeth in this study had large restorations replacing 2–3 surfaces. However, the survival rate was high over 3 years, and the repairs required were minimal, which is consistent with the reports on the durability of resin composite posterior restorations (Astvaldsdottir *et al.* 2015). Patients were nevertheless advised to receive full-coverage restorations to maximize longevity of the treated teeth, as secondary caries often occurs after 3 or more years (Astvaldsdottir *et al.* 2015). Few patients followed this recommendation.

Evaluation of outcomes followed strict clinical and radiographic criteria. Cases showing a reduction in the PAI score at the 1-year follow-up were considered successful, whilst the one case that demonstrated no change in the PAI score was considered failure at the 1-year period despite the fact that it was asymptomatic. However, no intervention was performed, and the tooth was scheduled for further follow-up based on the evidence that periapical lesions may continue to heal up to 4 years (Ørstavik 1996). The time course and risk analysis for the development of apical periodontitis in teeth with the complete pulpotomy have not yet been studied, unlike that for root-filled teeth (Ørstavik 1996), and there is no consensus on the length of time necessary for follow-up. However, none of the cases that were considered healed at the 1-year interval showed reversal of healing at the 3-year recall, and the case that developed a new lesion at the 3-year recall was subjected to contamination by loss of the coronal restoration.

Whilst Matsuo *et al.* (1996) recommended 3-month follow-up for a tentative assessment of the outcome, long-term follow-up is still required to reveal late failures or long-term adverse responses to VPT, particularly for cases with signs and symptoms suggestive of irreversible pulpitis in adolescents and adult patients. According to the systematic review by Aguilar & Linsuwanont (2011) unlike direct pulp capping, partial and complete pulpotomy tends to sustain a high success rate after 3 years or more. Complete pulpotomy had 99.3% success rate in >3-year follow-up; the results of this study are promising considering the sample size and the characteristics of included teeth.

In the absence of clinical signs and symptoms with normal radiographic features and evidence of apical healing during recall, the clinical procedure can be considered successful (Ricucci *et al.* 2014a). However, this assumes that pulpal healing has occurred, as histological assessment and confirmation of the pulpal status using cold testing procedures cannot be reliably performed in teeth receiving complete pulpotomies. Furthermore, if it is assumed that the entire coronal pulp was totally inflamed with the areas of partial necrosis as identified by histological studies in the majority of cases with clinical signs and symptoms suggestive of irreversible pulpitis, its entire removal will leave a healthy radicular pulp or even allow the chance for a reversibly inflamed radicular pulp to heal following the removal of the microbial load. On the other hand, if the radicular pulp is inflamed beyond repair, the pulpotomy will eventually fail. Histological success of MTA pulpotomy in human permanent molars with clinical signs and symptoms of irreversible pulpitis has been reported (Eghbal *et al.* 2009, Chueh & Chiang 2010); in these teeth, the radicular pulp was free from inflammation although one case showed mild hyperaemia.

The high success rate of MTA full pulpotomy and the survival of direct restoration over a 3-year period favour the potential advantages of full pulpotomy as a permanent treatment modality in certain circumstances.

Conclusion

1. Over a 3-year follow-up, MTA full pulpotomy was highly successful both clinically and radiographically in symptomatic permanent teeth with carious exposures.
2. Teeth with signs and symptoms clinically suggestive of irreversible pulpitis may still have the potential to heal following full pulpotomy as it is likely that the radicular pulp is at worse reversibly inflamed. Longer-term observation may confirm the future benefits of this treatment option.

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Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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