INTERNATIONAL
ENDODONTIC JOURNAL

doi:10.1111/iej.13071

Partial pulpotomy with two bioactive cements in permanent teeth of 6- to 18-year-old patients with signs and symptoms indicative of irreversible pulpitis: a noninferiority randomized controlled trial

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Abstract

Uesrichai N, Nirunsittirat A, Chuveera P, Srisuwan T, Sastraruji T, Chompu-inwai P. Partial pulpotomy with two bioactive cements in permanent teeth of 6- to 18-year-old patients with signs and symptoms indicative of irreversible pulpitis: a noninferiority randomized controlled trial. *International Endodontic Journal*, **52**, 749–759, 2019.

Aim To compare the outcome of partial pulpotomy using two cements, ProRoot MTA (Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) and Biodentine (Septodont, Saint-Maur-des-Fossés, France), in permanent teeth of 6- to 18-year-old patients with signs and symptoms indicative of irreversible pulpitis. Furthermore, the frequencies of perceptible grey discoloration caused by the cements were compared.

Methodology Sixty-nine permanent first molars with signs and symptoms indicative of irreversible pulpitis, from 69 patients, were included. All operators performed partial pulpotomy under a standardized protocol. Teeth were allocated, using a website-generated number of simple randomization, to partial pulpotomy with either ProRoot MTA (37 teeth) or Biodentine (32 teeth) and were restored with composite resin or stainless steel crowns. Patients were recalled every 6 months. To be categorized as having success, the evaluated tooth must have had both clinical and radiographic success. In addition, photographs of treated teeth were evaluated for frequency of perceptible grey discoloration. Success rates between the two cements were compared using the Fisher exact test. The frequencies of perceptible grey discoloration were compared using the chi-square test. The percentage difference was estimated by 95% confidence interval, and the level of significant difference was $P < 0.05$.

Results At a mean follow-up of 32.2 ± 17.9 months, a total of 67 teeth, 37 with ProRoot MTA and 30 with Biodentine, were available for evaluation. The mean age of participants was 10 ± 2.1 years and, there were no differences in the baseline variables (gender, age, tooth type, periapical status, stage of root development, final restoration and follow-up period) between the groups. The overall success in both groups was 90%, with 92% for ProRoot MTA and 87% for Biodentine (difference, 5%; 95% confidence interval, −9% to 19%, $P = 0.487$), suggesting that Biodentine was noninferior to ProRoot MTA. Perceptible grey discoloration was observed in both groups, 80% for teeth treated with ProRoot MTA and 27% for teeth treated with Biodentine, with a significant difference between the materials ($P < 0.001$).

Conclusions Permanent teeth with signs and symptoms indicative of irreversible pulpitis in 6- to 18-year-old patients were successfully treated with partial pulpotomy using both cements. Biodentine exhibited significantly less frequency of discoloration than did ProRoot MTA.

Keywords: bioactive cement, irreversible pulpitis, partial pulpotomy.

Received 24 October 2018; accepted 1 January 2019

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Introduction

Pain caused by pulpitis is one of the most common reasons for emergency dental visits in 7-year-old patients (Shqair *et al.* 2012), and root canal treatment has traditionally been recommended as a treatment of choice (AAE 2013). However, evidence has shown that in 6- to 18-year-old patients, root canal treatment was performed completely in approximately only 20% of teeth with signs and symptoms indicative of irreversible pulpitis, whereas 24% and 59% of teeth were extracted or received temporary restorative treatments, respectively (Al-Madi *et al.* 2018). This low number of root canal treatments may result from the fact that it is a time-consuming, expensive, and complicated procedure (Asgary *et al.* 2015). Moreover, children's cooperation and the unique characteristics of young permanent teeth, such as thin dentine walls and open apices, may increase the difficulty of root canal treatment, leading to a poorer outcome. Only 36% of root canal treatment performed in children aged 8–16 years was associated with complete healing after long-term follow-up (Peretz *et al.* 1997). In contrast, root canal treatments performed in patients aged 19–86 years followed over a period up to 4.5 years had a 76% success rate (Peters & Wesselink 2002).

Compared to root canal treatment, vital pulp therapy is a simpler and less expensive treatment (Asgary *et al.* 2015). A 5-year randomized clinical trial reported that coronal pulpotomy, one form of vital pulp therapy, had comparable success and can be an acceptable alternative to root canal treatment in teeth with signs and symptoms indicative of irreversible pulpitis (Asgary *et al.* 2015). However, total removal of coronal pulp tissue in young permanent teeth of children may cease dentine apposition on the coronal dentine wall, thus resulting in the risk of cervical fracture of the treated tooth (Camp 2008). To preserve coronal pulp tissue as much as possible, partial pulpotomy, a more conservative form of vital pulp therapy, is an alternative treatment modality. Mineral trioxide aggregate (MTA), a type of bioactive cement, has been shown to improve the success of partial pulpotomy over calcium hydroxide in teeth with signs and symptoms indicative of irreversible pulpitis in patients older than 20 years (Taha & Khazali 2017). Moreover, 100% success of coronal pulpotomy with MTA in teeth with signs and symptoms indicative of irreversible pulpitis has been reported (Qudeimat *et al.* 2017).

Mineral trioxide aggregate is one of the most-evidenced bioactive cements studied with high biocompatibility, sealing ability, and antibacterial effect (Bhavana *et al.* 2015). Moreover, MTA can also induce tertiary dentine or dentine bridge formation; however, its disadvantages include tooth discoloration, prolonged setting time, and handling difficulty (Parirokh *et al.* 2018). Biodentine is bioactive cement with improved properties, such as easier handling, shorter setting time, higher level of calcium ion release, better sealing ability, and better colour stability (Rajasekharan *et al.* 2018).

The aim of this study was to compare the outcome of partial pulpotomy using two bioactive cements, ProRoot MTA and Biodentine, in permanent teeth of 6- to 18-year-old patients with signs and symptoms indicative of irreversible pulpitis. The null hypothesis was that the outcome of partial pulpotomy with Biodentine in teeth with signs and symptoms indicative of irreversible pulpitis was noninferior to that with ProRoot MTA. Furthermore, perceptible grey discoloration between the two cements was compared.

Materials and methods

Ethics

This study was approved by the Human Experimentation Committee of the Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand, and registered in the Thai Clinical Trials Registry (TCTR20180612004). The patients and their legal guardians signed assent and informed consent forms after they agreed to participate in the study.

Study design

The study was a single-blind, noninferiority, randomized, controlled trial comparing the success of, and discoloration caused by, partial pulpotomy using two bioactive cements: Biodentine (Septodont, Saint-Maur-des-Fossés, France) and ProRoot MTA (Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) in permanent teeth of 6- to 18-year-old patients with signs and symptoms indicative of irreversible pulpitis. The teeth were allocated into two material groups by the simple random sampling method, using a website-generated number of simple randomization (Dallal 2008).

Sample size calculation

Sample size was calculated using the automatic programme for binary outcome of a noninferiority trial (Sealed Envelope 2012). Based on the study of Taha & Khazali (2017), the success of partial pulpotomy using ProRoot MTA in mature permanent teeth with signs and symptoms indicative of irreversible pulpitis was 85%. With the lack of evidence for partial pulpotomy using Biodentine, the authors inferred a 96.4% success rate of direct pulp capping using Biodentine in young permanent teeth (Parinyaprom *et al.* 2018). With a 10% noninferiority limit, 80% power and 5% significance level, the required sample size per group was 22. The minimum of 10% of the required sample size was added to compensate for follow-up loss, resulting in a minimum of 25 teeth in each group.

Participants

Paediatric patients, the American Society of Anesthesiologists I or II, aged from 6 to 18 years, attending the Paediatric Dentistry Clinic, Faculty of Dentistry, Chiang Mai University, were recruited. Only one permanent tooth with a deep carious lesion per patient was included.

Inclusion criteria

Clinical inclusion criteria were teeth that: (i) had deep caries, with signs and symptoms indicative of irreversible pulpitis (patient reported spontaneous pain together with sharp and lingering pain with cold testing using Endo-Ice (Coltene/Whaledent; Cuyahoga Falls, OH, USA); (ii) were restorable with resin composite or stainless steel crown (SSC); (iii) had no abnormal tooth mobility, clinical swelling and pus exudate/fistula; (iv) had pulp exposure larger than 1 mm, but not larger than 5 mm in diameter, as measured using a sterilized preformed wire; and (v) had vital pulp, judged by its appearance, bright red colour and amount of bleeding was overflowing from the pulp exposure site but can be controlled within 10 min.

Radiographic inclusion criteria were the following: (i) the radiolucent caries penetrated into at least three-quarters of the inner dentine thickness; (ii) no prominent radiolucency at the periapical or furcation regions; however, the presence of early periapical changes, such as widened periodontal ligament space or condensing osteitis was not considered an exclusion criterion for this study; and (iii) the absence of calcification, pulp canal obliteration, internal root resorption, and pathologic external root resorption.

Exclusion criteria

Clinical exclusion criteria were teeth that: (i) had no pulp exposure or the size of pulp exposure was smaller than 1 mm and larger than 5 mm in diameter, as measured by a sterilized preformed wire, (ii) bleeding from pulp exposure site could not be controlled within 10 min and (iii) pulp tissue appeared necrotic, judged by the absence of bleeding or the presence of pale necrotic pulp tissue.

Radiographic exclusion criteria were the following: (i) prominent radiolucency at the furcation or periapical regions and (ii) the presence of internal or pathologic external root resorption, calcification or pulp canal obliteration.

Interventions

Patients were blind to the pulp dressing material received. Ten unblinded paediatric dentistry postgraduate students performed all treatments, under the same protocol and supervision of one experienced instructor. First, topical anaesthesia (One touch; Hager Worldwide, Ontario, Canada) was applied, followed by the administration of 4% articaine with 1 : 100 000 epinephrine (Septanest SP; Septodont, Saint-Maur-des-Fossés, France). Then, the tooth was isolated with rubber dam. The cavity was prepared using a high-speed round diamond bur, whereas carious removal was performed using a slow-speed round steel bur and an excavator. When the size of pulp exposure met the inclusion criteria, approximately 2–3 mm or more of pulpal tissue underneath the exposure site was removed, using a sterile high-speed round carbide bur. The pulp tissue was removed until only healthy pulp tissue, judged by its appearance along with colour and amount of bleeding, remained. The pulpal tissue was irrigated with 10 mL of 2.5% sodium hypochlorite, and the bleeding was controlled with 2.5% sodium hypochlorite-moistened cotton pellets. If the bleeding was not controlled within 10 min, the treated tooth was excluded from the study and further treated with either coronal pulpotomy or root canal treatment.

Teeth that met the inclusion criteria were randomly allocated to be treated with either ProRoot MTA or Biodentine. Both materials were mixed according to

the manufacturers' instructions. In the ProRoot MTA group, 1.5–3 mm thickness of ProRoot MTA was applied on the pulp exposure site and thin surrounding dentine. Then, resin-modified glass ionomer (Vitrebond, 3M, ESPE, St Paul, MN, USA) was mixed according to the manufacturer's instructions and placed immediately over the MTA layer as a protective base. In the Biodentine group, Biodentine served as a pulp dressing material and a protective base, leaving 2 mm for the restorative material. Biodentine was allowed to set for 12 min. Then, the tooth was restored with resin composite or stainless steel crown depending on the amount of tooth structure left. After the restoration was completed, a periapical radiograph was recorded immediately to serve as a baseline for future evaluation. Patients were called back every 6 months, for up to 6 years. Photographs of each tooth were recorded using the same camera with the same setting at the treatment and follow-up visits for the later evaluation of perceptible grey discoloration.

Outcomes

Every 6 months, clinical (visual inspection, mobility testing and cold testing) and radiographic evaluations of the treated tooth were performed by 10 unblinded paediatric dentistry postgraduate students under the supervision of one experienced instructor. To be categorized as having overall success, the evaluated tooth must have had both clinical and radiographic success. Clinical success criteria consisted of the absence of signs and symptoms of pulpitis (pain on stimulation or spontaneous pain), absence of abnormal mobility and fistula, and positive response to cold testing, leading to a diagnosis of uninflamed pulp. Radiographic success criteria consisted of continued root formation of the previously incomplete root, improvement of early periapical changes, and absence of prominent periapical lesion and internal and/or external root resorption. The material used was concealed from the two blinded postgraduate students, who were previously calibrated with an oral radiologist, before they assessed the radiographs. The calibration resulted in 95% and 100% agreement. Then, 20 sets of radiographs were independently evaluated by two calibrated examiners twice, 1 month apart. The intra-examiner reliabilities of both were 100%, and the inter-examiner reliability was 95%.

In addition, photographs of teeth restored with resin composite were evaluated for perceptible grey discoloration. Photographs at the treatment and the latest follow-up visits were compared by an operative dentist who was not associated with this study and who was also blind to the material used. One month later, 20 sets of photographs were evaluated again by the same operative dentist, and the intra-examiner reliability was 95%.

Statistical analysis

The baseline variables between the two cements were compared using the chi-square test for categorical outcomes and independent *t*-test for continuous outcomes. Success rates between the two cements were compared using the Fisher exact test. The frequencies of perceptible grey discoloration were compared using the chi-square test. The percentage difference was estimated by 95% confidence interval, and the level of significant difference was $P < 0.05$. The statistical analyses were performed using the SPSS 24.0 software (SPSS Science, Chicago, IL, USA).

Results

The CONSORT flow diagram of this study (Fig. 1) shows that 386 teeth were initially recruited, and 317 teeth were excluded because they did not meet the inclusion criteria. Reasons for exclusion are shown in Fig. 1. Sixty-nine teeth (from 69 patients) were randomly allocated to be treated with ProRoot MTA (37 teeth) and Biodentine (32 teeth). Two patients could not be contacted for follow-up, resulting in an overall recall rate of 97% (67/69). At a mean follow-up period of 32.2 ± 17.9 months, a total of 67 teeth, 37 with ProRoot MTA and 30 with Biodentine, were analysed. The participants consisted of 22 males and 45 females, aged 6.4–16.9 years (mean 10 ± 2.1 years). Thirty-one of 67 teeth (46%) exhibited early periapical changes on periapical radiographs. The baseline variables between the two cements were not different (Table 1).

Clinical success was 92% (34/37) for ProRoot MTA and 87% (26/30) for Biodentine. Radiographic success was 95% (35/37) and 97% (29/30) for ProRoot MTA and Biodentine, respectively. Examples of radiographic success of both cements are shown in Fig. 2. Overall success for both cements was 90% (60/67), with 92% (34/37) for ProRoot MTA and 87% (26/30) for Biodentine (difference, 5%; 95% confidence interval, −9% to 19%, $P = 0.487$). As the lower limit

of the 95% confidence interval for the difference between the two cements was above the inferiority limit of −10%, Biodentine was considered to be non-inferior to ProRoot MTA when used as a pulp dressing material in partial pulpotomy of teeth with signs and symptoms indicative of irreversible pulpitis in 6- to 18-year-old patients. Failures were detected in seven teeth at various follow-up periods, ranging from 11 to 35 months. In seven failures, four had normal periapical tissue and three had early apical changes before treatment.

Of a total of 67 teeth, six were restored with SSCs, thus were excluded from discoloration evaluation. Sixty-one teeth restored with resin composite were available for evaluation. Perceptible grey discoloration was observed with both cements (Fig. 3), 80% (28/35) in teeth treated with ProRoot MTA and 27% (7/26) in teeth treated with Biodentine, with a significant difference between the materials ($P < 0.001$; Table 2).

Discussion

The overall success of partial pulpotomy with two cements, ProRoot MTA and Biodentine, in this study was not different because both are bioactive hydraulic calcium silicate-based cements and it is the main reason why the study was designed as a noninferiority trial. This result is consistent with those of previous direct pulp capping clinical studies comparing these two cements (Brizuela *et al.* 2017, Parinyaprom *et al.* 2018). Both bioactive cements have similar biological properties for vital pulp therapy, including high biocompatibility, odontogenic effect, low inflammatory response, angiogenesis (Emara *et al.* 2018) and antibacterial effects (Prati & Gandolfi 2015).

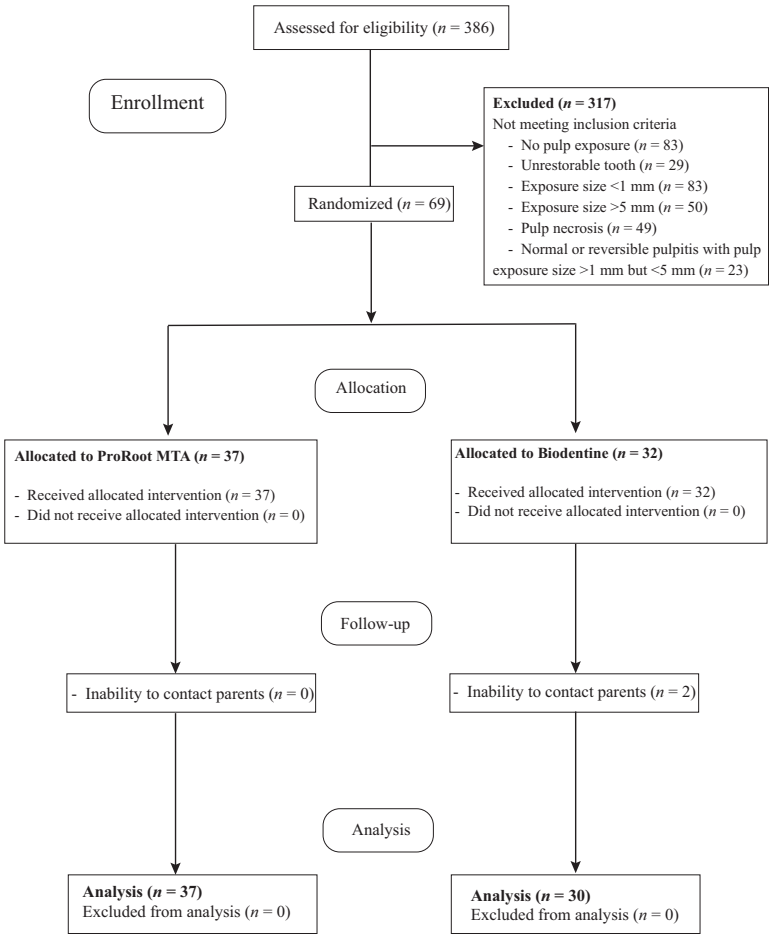

Figure 1 CONSORT flow diagram.

Table 1 Baseline variables of ProRoot MTA and Biodentine groups

	Total	ProRoot MTA	Biodentine	*P* value
Number of teeth	67	37	30	–
Gender, % (*n*/*N*)				
Male	33 (22/67)	12/37)	33 (10/30)	0.938[a]
Female	67 (45/67)	68 (25/37)	67 (20/30)	
Age (year)				
Range	6.4–16.9	6.4–16.4	6.4–16.9	0.434[b]
Mean ± SD	10 ± 2.1	9.8 ± 2.2	10.2 ± 1.9	
Tooth type, % (*n*/*N*)				
Maxillary	34 (23/67)	35 (13/37)	33 (10/30)	0.877[a]
Mandibular	66 (44/67)	65 (24/37)	67 (20/30)	
Periapical status, % (*n*/*N*)				
Normal	54 (36/67)	57 (21/37)	50 (15/30)	0.581[a]
Early periapical changes	46 (31/67)	43 (16/37)	50 (15/30)	
Stage of root development, % (*n*/*N*)				
Open apex	60 (40/67)	62 (23/37)	57 (17/30)	0.648[a]
Closed apex	40 (27/67)	38 (14/37)	43 (13/30)	
Final restoration, % (*n*/*N*)				
Composite resin				
One surface	57 (38/67)	60 (22/37)	53 (16/30)	0.525[a]
Two surfaces	34 (23/67)	35 (13/37)	33 (10/30)	
Stainless steel crown	9 (6/67)	5 (2/37)	13 (4/30)	
Follow-up period (month)				
Range	7–69	7–55	7–69	0.826[b]
Mean ± SD	32.2 ± 17.9	31.8 ± 14.4	32.7 ± 21.8	

SD, standard deviation.
[a]Chi-square test.
[b]Independent *t*-test.

Although both cements share similar biologic effects, they differ in terms of physical properties, such as handling and setting time (Rajasekharan *et al.* 2018). Difficulty of handling is a drawback of MTA. Freshly mixed MTA is grainy or sandy in texture, thus causing difficulty when carried to the operative site (Camilleri 2015a). In contrast, freshly mixed Biodentine adheres well to dentine, resulting in ease of handling (Wang 2015). Another drawback of MTA is its long setting time. The setting time of MTA is approximately 2 h and 45 min (Torabinejad *et al.* 1995), whereas Biodentine requires a shorter setting time of 10–12 min (Wang 2015). This shorter setting time is the result of calcium chloride in the liquid component of Biodentine, which accelerates the setting time (Bortoluzzi *et al.* 2009). However, the long setting time of MTA does not seem to be a major problem for several clinicians. Although placing a moistened cotton pellet over MTA to aid in its setting is recommended by the manufacturer, this practice was not followed in this study nor in several other studies (Barrieshi-Nusair & Qudeimat 2006, Qudeimat *et al.* 2007, Mente *et al.* 2010, 2014, Parinyaprom *et al.* 2018) but a base material (resin-modified glass ionomer cement) was placed immediately over the MTA. Similarly, Marques *et al.* (2015) reported that MTA, without a moistened cotton pellet, was completely set at the 4–12 weeks follow-up visit; they further concluded that moisture from the pulpal tissue and dentine can assist the cement in its complete setting.

Another major improvement of Biodentine over MTA that may have clinical significance is its better colour stability (Rajasekharan *et al.* 2018). As expected, perceptible grey discoloration was observed significantly less with Biodentine than with MTA in this study. The main reason for MTA discoloration is the oxidative reaction of radiopacifier bismuth oxide, forming the dark precipitation (Camilleri 2015a). In addition, other causes of discoloration are the interaction between bismuth oxide and sodium hypochlorite or collagen in dentine (Camilleri 2015a). In Biodentine, bismuth oxide is replaced with zirconium oxide to reduce discoloration. Several laboratory and *ex vivo* studies (Camilleri 2015b, Kohli *et al.* 2015, Marconyak *et al.* 2016) and one randomized clinical trial on direct pulp capping (Parinyaprom *et al.* 2018) similarly reported no discoloration in Biodentine treated

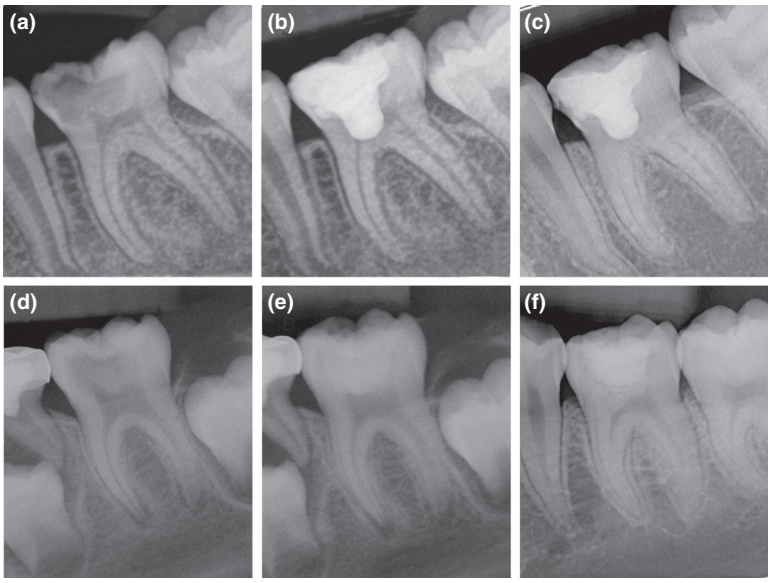

Figure 2 Radiographic success of teeth treated with partial pulpotomy. (a) preoperative radiograph revealing early periapical changes around the mesial and distal root of tooth 36 (b) immediately postoperative radiograph after partial pulpotomy with ProRoot MTA. (c) 38 months postoperative radiograph showing normal periapical tissue. (d) Preoperative radiograph showing early periapical changes around mesial and distal root of tooth 36. (e) Immediately postoperative radiograph after partial pulpotomy with Biodentine. (f) 59 months postoperative radiograph showing normal periapical tissue.

teeth. Surprisingly, the present study demonstrated 27%, of discoloration with Biodentine, a higher rate than that of Parinyaprom *et al.* (2018). The differences in discoloration rates between a previous clinical study (Parinyaprom *et al.* 2018) and the present one may derive from the fact that partial pulpotomy performed in this study had a larger exposure size. Moreover, the pulp tissue was removed, resulting in a larger amount of material and greater surface contact with the pulp tissue, both of which have been shown to worsen discoloration (Felman & Parashos 2013). Moreover, a longer follow-up period in the present study (32 vs. 19 months) may also affect this result. A previous laboratory study demonstrated that discoloration of teeth treated with Biodentine increased over time (Shokouhinejad *et al.* 2016). The result of the present study needs to be confirmed by future clinical studies with different types of vital pulp therapy and longer follow-up.

In general, treatment planning is based mainly on clinical diagnosis; however, confusion exists between different diagnostic systems. In this study, the classification of Wolters *et al.* (2017) was followed, teeth included in this study can be categorized as having mild-to-moderate pulpitis, and partial pulpotomy can be one of the recommended treatments. However, if the clinical diagnosis of the teeth, with spontaneous pain together with sharp and lingering pain on cold testing, is defined in this study using the recommendation of the American Association of Endodontists (AAE), the teeth would be diagnosed with irreversible pulpitis and root canal treatment has been traditionally recommended for these teeth (AAE 2013). However, this study had a high success (90%) of partial pulpotomy in the teeth with signs and symptoms indicative of irreversible pulpitis.

Currently, histological examination is the only method that can determine exactly the pulpal condition; unfortunately, it is impractical in the clinical situation. In addition, the correlation between clinical and histological pulpal status does not have a definite conclusion and symptoms alone cannot reflect the actual inflammatory stage of the pulp (Giuroiu *et al.* 2015). Ricucci *et al.* (2014) reported a 96.6% correlation of clinical and histological status in teeth with normal pulp or reversible pulpitis, whereas only 84.4% correlation was found in teeth with signs and symptoms indicative of irreversible pulpitis.

Because histologic evaluation of pulp tissue is not possible in clinical situations, the appearance of pulp tissue and the time used to control bleeding have

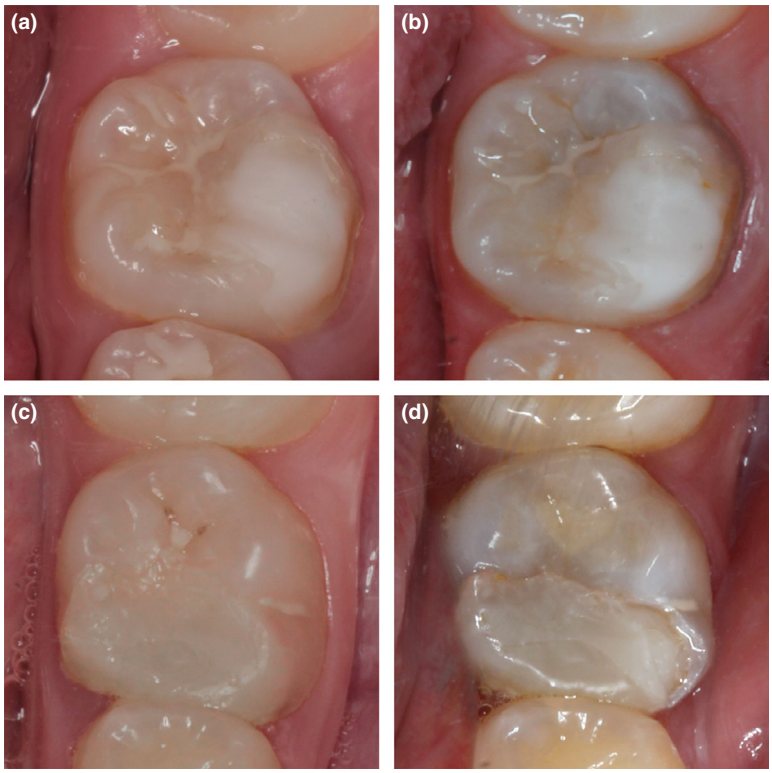

Figure 3 Perceptible grey discoloration of teeth treated with partial pulpotomy. (a) Immediately postoperative photograph of a tooth with partial pulpotomy with ProRoot MTA. (b) 50-month follow-up photograph showing perceptible grey discoloration. (c) Immediately postoperative photograph of a tooth with partial pulpotomy with Biodentine. (d) 36-month follow-up photograph showing perceptible grey discoloration.

Table 2 Outcomes of partial pulpotomy with ProRoot MTA and Biodentine

Criterion measured	Overall, % (*n*/*N*)	ProRoot MTA, % (*n*/*N*)	Biodentine, % (*n*/*N*)	*P* value	% Difference (95% confidence interval)
Overall success	90 (60/67)	92 (34/37)	87 (26/30)	0.487[a]	5% (−9%, 19%)
Perceptible grey discoloration	57 (35/61)	80 (28/35)	27 (7/26)	<0.001[b]	–

[a]Fisher's exact test.
[b]Chi-square test.

been used as indicators of pulp status (Chailertvanitkul *et al.* 2014, Özgür *et al.* 2017, Taha & Khazali 2017, Parinyaprom *et al.* 2018). In this study, the same criteria were also used to differentiate inflamed from healthy pulp tissue. However, the specific amount of time required to control pulpal bleeding is inconclusive and previous studies have suggested that the time varies from 30 s to 25 min (Matsuo *et al.* 1996, Qudeimat *et al.* 2017). Moreover, the correlation between bleeding and inflammation of pulp is unclear. Several authors suggest that pulpal bleeding can be used as a clinical indicator of pulpal inflammation (Matsuo *et al.* 1996, Bogen & Chandler 2010, Aminabadi *et al.* 2017). In primary teeth, Aminabadi *et al.* (2017) demonstrated a positive correlation between the colour of pulpal bleeding and the level of pulpal inflammation; on the other hand, Mutluay *et al.* (2018) suggested that the evaluation of pulpal bleeding is subjective and may not reflect the actual pulpal status. Currently, evidence to support the correlation between bleeding and inflammation of pulp in permanent teeth is limited. A more accurate

molecular analysis is currently under investigation (Elsalhy *et al.* 2013).

Approximately 46% of the treated teeth in this study had early periapical changes preoperatively and most of them had favourable outcomes following partial pulpotomy with bioactive cements. The occurrence of periapical involvement might not always be associated with pulp necrosis, and some part of the pulp tissue might still be vital (Ricucci *et al.* 2006). The development of a periapical changes associated with a vital pulp may be the result of the response to inflammation of the nerve fibres supplying pulp and periapical tissues (Khayat *et al.* 1988). Previous clinical studies have reported favourable outcomes of partial pulpotomy in teeth with periapical changes (Asgary *et al.* 2016, Parinyaprom *et al.* 2018). Therefore, the presence of periapical changes should not be an absolute contraindication for partial pulpotomy.

In this study, all operators performed treatment under the same strict protocol and supervision of only one instructor, thus increasing the validity of the treatment performed. However, the limitations of this study are the fact that several postgraduate students in Paediatric Dentistry performed the treatment and could not be blinded to the pulp dressing materials because they have different characteristics. Moreover, the treatment groups were disclosed to the clinical examiners. However, the clinical criteria were explicit and depended entirely on the patients' report of their symptoms, thus reducing the effect of bias of the clinical examiners. Another limitation may be in the evaluation of discoloration by comparison of the photographs of the treated teeth. Although previous clinical studies also used this technique for assessment of discoloration (Belobrov & Parashos 2011, Parinyaprom *et al.* 2018), it may result in underestimation because of human eye limitations. Evaluations of discoloration with more sophisticated methods, such as spectrophotometry and colourimetry, have been reported in laboratory and *ex vivo* studies (Camilleri 2015b, Kohli *et al.* 2015, Marconyak *et al.* 2016, Ramos *et al.* 2016), and thus may be recommended for future clinical studies. Additionally, this study did not plan to radiographically evaluate dentine bridge formation or pulp canal obliteration because of concerns over the accuracy of the results. Evaluating dentine bridge formation and pulp canal obliteration from overlapping two-dimensional radiographs is difficult (Özgür *et al.* 2017), especially in teeth with buccal or lingual restorations. Furthermore, one study reported that radiographs were unable to detect thin dentine bridge of less than 0.5 mm (De Rossi *et al.* 2014). Pulpal canal obliteration can make root canal treatment more difficult if such treatment is needed in the future; however, evidence regarding this issue is limited, and previous studies were mostly performed subjectively by investigators and the reported percentage of pulp canal obliteration varied between 0% and 30% (Mass & Zilberman 2011, Alqaderi *et al.* 2014). Moreover, factors influencing pulp canal obliteration, such as age, exposure size, pulp dressing materials and type of vital pulp therapy should also be further investigated, and the development of more accurate methods to evaluate pulp canal obliteration and dentine bridge formation is recommended.

Conclusions

Permanent teeth with signs and symptoms indicative of irreversible pulpitis in 6- to 18-year-old patients were successfully treated with partial pulpotomy using ProRoot MTA and Biodentine. Biodentine was found to be noninferior to ProRoot MTA when used as a pulp dressing material. In addition, the frequency of perceptible grey discoloration was significantly less with Biodentine.

Acknowledgements

This research was supported by the Research Fund for Postgraduate Students of the Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand. The authors also thank the paediatric dentistry postgraduate students, Sakarat Na Lampang, oral radiologist and Watcharaphong Ariyakriangkai, operative dentist, of the Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand, for their assistance in conducting this study. The authors thank Dr. M. Kevin O Carroll, Professor Emeritus of the School of Dentistry, University of Mississippi, and faculty consultant with the Faculty of Dentistry, Chiang Mai University, Thailand, for his assistance in the preparation of the manuscript. The authors deny any conflicts of interest related to this study.

Conflict of interest

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

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