Survival After 3-Year of Partial Pulpotomy Using Bioactive Cements as Pulp Capping Materials in Adult's Permanent Teeth with Carious Pulp Exposure

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Abstract

Objective: The present study aimed to explore the survival rate after 3 years of partial pulpotomy in adult permanent teeth with carious pulp exposure, using ProRoot MTA® and Biodentine™.

Materials and Methods: This study is a follow-up to a previously reported 1-year outcome of a randomized clinical trial investigating the non-inferiority of Biodentine compared to MTA for partial pulpotomy in adults' permanent teeth with carious pulp exposure (Thai Clinical Trials Registry: TCTR20171228003). All 58 participants whose teeth were treated for at least 3 years were contacted for follow-up, which included clinical examinations, radiographic evaluations, and a patient satisfaction survey.

Results: Forty-eight patients (82.8% recall rate) were followed up for an average of 40.95 ± 4.24 months. The overall cumulative pulp survival rate was 78.7%, with 87.4% for ProRoot MTA® and 70.7% for Biodentine™, showing no significant difference between the materials. The highest frequency of failure occurred between 24 and 35 months. Discoloration of teeth was observed in both groups, 42.1% (8/19) in teeth treated with ProRoot MTA® and 10% (2/20) in teeth treated with Biodentine™, showing a statistically significant difference ($p = 0.031$). Acceptable restorations were present in 74.4% of patients, and most patients were very satisfied with the treatment.

Conclusion: The cumulative pulp survival rate for adult permanent teeth with carious pulp exposure was 78.7% after at least 3 years of partial pulpotomy, with no significant difference between ProRoot MTA® and Biodentine™. Since treatment failures were most frequent between 24 and 35 months, clinical and radiographic follow-ups are recommended for at least 3 years. For patients with significant tooth structure loss who have not received full coverage restoration, annual follow-ups are advised to assess restoration quality.

Keywords: Biodentine™, Cohort study, Mineral trioxide aggregates, Partial pulpotomy, Survival analysis

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Introduction

Currently, vital pulp therapy has gained interest and support due to increasing empirical evidence (1,2). Partial pulpotomy, a method of vital pulp therapy, involves the removal of a small portion of the vital coronal pulp as a means of preserving the remaining coronal and radicular pulp tissues (3). This is coupled with the application of biocompatible materials over the pulp tissue to promote healing and coronal seal.

Biological rationales for partial pulpotomy procedure in treating carious pulp exposure have been underpinned by histo-bacteriological studies (4,5) that pulp tissue affected by caries is usually limited in the area close to exposure site and removing the inflamed portion appeared to sufficiently encourage self-healing.

Calcium silicate cements (CSCs) are increasingly used in vital pulp therapy (VPT) procedures. CSCs include materials like tricalcium silicates, dicalcium silicates, hydraulic calcium silicate cements, and “bioceramics” or “bioactive” cements. Mineral trioxide aggregate (MTA) is the first and well-established CSCs that is widely used and extensively studied. Systematic reviews and meta-analyses have shown that MTA as a capping material in partial pulpotomy has overall higher clinical success than calcium hydroxide (6). However, MTA has some clinical limitations, such as a long setting time, tooth discoloration, and high cost (7,8). Biodentine™ is a second-generation calcium silicate cement which compensates for some of the limitations of MTA by having a shorter setting time and a lower incidence of tooth discoloration (9,10). Nevertheless, studies comparing the success rates of partial pulpotomy using Biodentine™ versus MTA are still limited.

A recent systematic review (11) suggested that partial pulpotomy resulted in high success rates in treating cariously exposed permanent posterior teeth for up to 2 years, with limited studies on success rates over 2 years. Various factors have been proposed as potential prognostic factors on success rate of pulpotomy in permanent teeth. However a comprehensive review supported by best available evidence concluded that only caries depth, inflammatory status of the pulp, capping material, level of inflammatory pulpal-biomarkers and the final restoration integrity were influential factors while other factors such as age and gender did not impact significantly on pulpotomy outcome (12).

This study aimed to evaluate survival rate over 3 years of partial pulpotomy treatment in mature permanent teeth with carious pulp exposure, comparing the use of two bioactive cements: Biodentine™ and ProRoot MTA® as capping materials. This study was a follow-up analysis of patients from the previously reported clinical trial (Thai Clinical Trials Registry: TCTR20171228003) by Suwannaphrom et al (13) which reported 1-year treatment outcomes. Additional objective was to evaluate patient satisfaction with the partial pulpotomy treatment, providing insights into patient perspectives and overall acceptance of the procedure.

Survival analysis was advantageous for dealing with incomplete data where the event of interest has not occurred for some subjects during the study period (censored data). Moreover, it focuses on the time until the occurrence of an event (Time-to-Event analysis), providing insights into the timing and risk factors associated with the event. The findings from this study were

expected to provide valuable insights into the survival rates of partial pulpotomy treatments, guiding the appropriate follow-up intervals and care.

Materials and methods

Study design

The present study was designed as a follow-up to the previously reported 1-year outcome of a randomized clinical trial investigating the non-inferiority of Biodentine™ compared to MTA for partial pulpotomy in adult's permanent teeth with carious pulp exposure (Thai Clinical Trials Registry: TCTR20171228003)(13). All 58 trial participants (ProRoot MTA® = 29, Biodentine™ = 29) whose teeth had received treatment for at least 3 years were contacted for recall. These participants had premolars or molars with deep caries extending more than two-thirds of the dentin thickness, both with and without clinical symptoms, and responded to pulp sensibility tests. After completed caries removal under the rubber dam isolation, the caries had reached the pulp, which was still vital. The tissue was excised from the superficial level of the pulp to the remaining pulp tissue, which appeared relatively dense. The pulp chamber was irrigated with 2.5% sodium hypochlorite. A cotton pellet soaked in sodium hypochlorite was applied to achieve hemostasis and hemostasis could be achieved within 10 minutes (13). The follow-up included clinical examinations, radiographic evaluations, and a patient satisfaction survey. The present study has received ethical approval from the Human Research Ethics Committee of the Faculty of Dentistry, Chiang Mai University (Approval No. 25/2564, dated May 24, 2021).

Inclusion Criteria

1. Participants of the trial "Partial Pulpotomy Treatment in Permanent Teeth with Cariously Exposed Pulp in Adult Patients: A Non-inferiority Randomized Controlled Trial Comparing Two Calcium Silicate-based Cements" (Study ID: TCTR20171228003) who received treatment at the Comprehensive Dental Clinic, Faculty of Dentistry, Chiang Mai University, from May 2017 to October 2018.

2. Patient consent to participate in the follow-up research.

Exclusion Criteria

1. Patients who cannot be contacted.
2. Patients who refuse to participate in the follow up.

Follow-up Procedures

Patients who attended the follow-up received an information sheet detailing the study and an informed consent form. The follow-up included clinical examinations, radiographic examination, and a patient satisfaction survey.

Clinical examination procedures

First, the presence of the treated tooth in the oral cavity was verified. In cases where the tooth was missing, the reasons for extraction and any associated symptoms were reviewed and documented. Patients were asked about any current symptoms and the functionality of the treated tooth. Pulp sensibility was evaluated using cold tests (Endo-Ice®, Coltene/Whaledent, USA) and electric pulp tests (EPT) (Vitality Scanner™, Kerr, USA). Percussion and palpation

tests were performed to detect any tenderness or abnormal responses. Tooth mobility and periodontal status were examined. Tooth discoloration was evaluated visually by comparing it with the adjacent normal teeth. The condition of the restorative material was assessed using the Modified USPHS criteria(14). Intraoral photographs were taken with a digital camera (EOS 700D, Canon Inc., Japan) to document the condition of the restorative material and any observed tooth discoloration. If any tooth exhibited signs of pulp inflammation or necrosis, patients were informed about the available treatment options and referred for appropriate care. Additionally, if the restorative material was found to be defective, patients received a new dental filling.

Radiographic examination and assessment procedures

The parallel periapical radiographs of the treated teeth were taken using digital imaging plate no.2 (Durr Dental Imaging, Germany) with a film holder (XCP®, Densply, USA). Assessments focused on: Periapical Index (PAI) score (15), widening of the periodontal ligament space, presence or absence of the lamina dura, presence of apical radiolucencies, root resorption, pulp chamber and canal calcification, pulp canal obliterations, and formation of dentine bridges. A certified endodontist (Diplomate, Thai Board of Endodontics) who was blinded to the treatment information performed radiographic evaluations. The intra-examiner calibration process involved the assessing a set of 20 periapical radiographs twice, with a two-week interval of readings. At least 0.8 Cohen Kappa statistic was required.

Patient satisfaction survey

The survey questionnaire employed a 7-point scale ranging from “very satisfied” to “strongly dissatisfied” responses on: the symptoms of the treated tooth, the functionality of the treated tooth, the satisfaction on the condition of the restorative material, the aesthetics, and the treatment and follow-up care procedure.

Data for Survival Analysis

To perform a survival analysis using Kaplan-Meier statistic, first the event and censor date of each treated tooth must be defined. Then the survival time were calculated from the treatment date to the event or censoring date, measured in months. The characteristic of event and censor were that:

1. Event date: the date when clinical failure was documented in dental records or when the patient reported receiving treatment elsewhere. An event occurred in cases where:

1.1 The treated tooth had clinical failures, which determined by presence of pain, no response to sensibility tests, swelling, or sinus tract opening, or

1.2 The treated tooth underwent tooth extraction or root canal treatment.

2. Censor date: the last follow-up date of patient who did not experience the event. Censoring occurred in cases where:

2.1 The treated tooth remained in the oral cavity, responded to vitality tests, and functioned normally upon follow-up date, or

2.2 The patient was lost to follow-up and could not be tracked.

Statistical Analysis

Kaplan-Meier survival analysis was used to evaluate the pulp survival probability at the end of the study. The pulp survival probabilities of the ProRoot MTA® group and Biodentine™ group were compared using the log-rank test. Tooth discoloration rates and the success rates of restoration of each group were compared using the Chi-square test. Patient satisfactions were analyzed using descriptive statistics. The significance level was set at 5%, and the analyses were conducted using SPSS 20.0 statistical software (SPSS Inc., 2011, Chicago, IL).

Results

The intra-examiner's Cohen Kappa reliability of the radiographic evaluator was 0.90. Demographic and preoperative characteristics of the participants who attended the present follow-up was shown in Table 1. No significant differences were observed among these variables.

Out of the 58 patients, 48 patients (82.8%) attended the follow-up. Among these, 39 patients showed pulp survival of the treated teeth (19 with ProRoot MTA® and 20 with Biodentine™). Nine patients underwent tooth extraction or root canal treatment (3 with ProRoot MTA® and 6 with Biodentine™). Ten patients (17.2%) were lost to follow-up (7with ProRoot MTA® and 3 with Biodentine™) (Fig. 1).

Table 1. Demographic, preoperative and intra-operative characteristics of the samples who attended the present follow-up (tooth is unit of analysis).

Factors	Total	ProRoot MTA®	Biodentine™	p-value
n	48	22	26	-
Sex, % (n/N)				
Male	52.1 (25/48)	54.5 (12/22)	50.0 (13/26)	0.753a
Female	47.9 (23/48)	45.5 (10/22)	50.0 (13/26)	
Age (year)				
Range	18–56	19-56	18-42	0.959¥
Mean ± SD	26.77 ± 9.60	28.18 ± 11.76	25.58 ± 7.33	
Pre-operative symptoms, % (n/N)				
Initial pulpitis	8.3 (4/48)	13.6 (3/22)	3.8 (1/26)	0.540§
Mild pulpitis	64.6 (31/48)	59.1 (13/22)	69.2 (18/26)	
Moderate pulpitis	27.1 (13/48)	27.3 (6/22)	26.9 (7/26)	
Pre-operative PAI score, % (n/N)				
PAI score of 1	27.1 (13/48)	27.3 (6/22)	26.9 (7/26)	0.555a
PAI score of 2	56.2 (27/48)	50.0 (11/22)	61.5 (16/26)	
PAI score of 3	16.7 (8/48)	22.7 (5/22)	11.5 (3/26)	
Caries site, % (n/N)				
Occlusal/buccal/lingual	14.6 (7/48)	13.6 (3/22)	15.4 (4/26)	1.000§
Proximal	85.4 (41/48)	86.4 (19/22)	84.6 (22/26)	
Time to control bleeding (mins), % (n/N)				
0 - 5	83.3 (40/48)	95.5 (21/22)	73.1 (19/26)	0.055§
> 5 - 10	16.7 (8/48)	4.5 (1/22)	26.9 (7/26)	
Exposure size (mm.), % (n/N)				
< 2	72.9 (35/48)	77.3 (17/22)	69.2 (18/26)	0.532a
=, > 2	27.1 (13/48)	22.7 (5/22)	30.8 (8/26)	

SD, standard deviation; a Chi-square test; § Fisher's exact Test; ¥ Mann-Whitney Test.

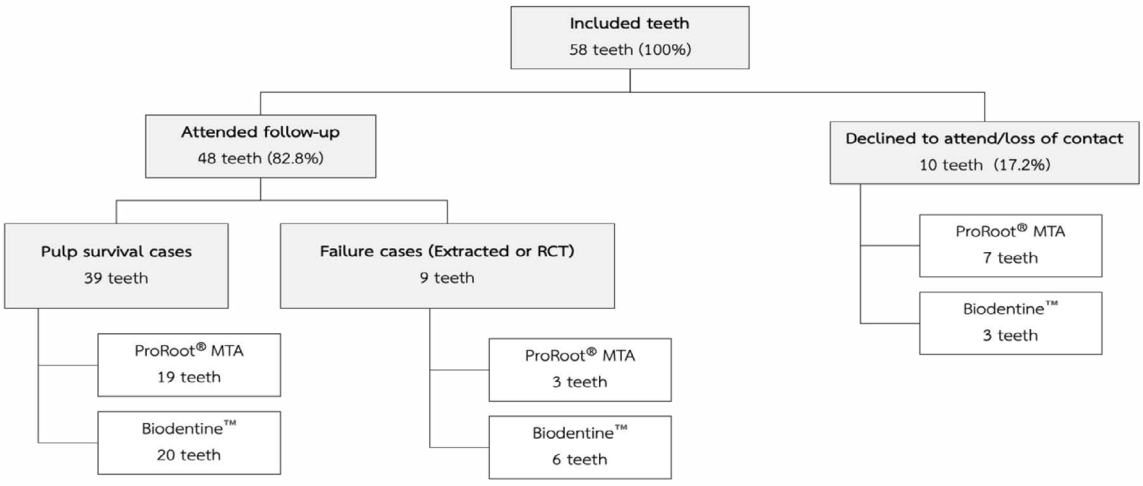

Fig.1 Flow chart showing patient follow-up.

The average follow-up period was 40.95 ± 4.24 months. The estimated cumulative pulp survival rate in the first 12 months was 98.2% and decreased to 78.7% at the end of the study. The highest frequency of failures occurred between 24 and 35 months (4 teeth) (Table 2). The overall mean survival time is 46.52 ± 1.43 months. The median survival time cannot be determined because the cumulative survival throughout the study period was greater than 50% (Table 3).

Table 2. Survival table.

Follow-up time (months)	Number of teeth at beginning	Number of survival teeth	Number of teeth that had failure	Number of teeth withdrawing (censor/loss of follow-up)	Estimated cumulative survival probability % (Standard error)
0-11	58	57	1	4	98.2 (1.76)
12-23	53	51	2	5	94.3 (3.18)
24-35	46	42	4	1	86.0 (4.91)
36-47	41	39	2	35	78.7 (6.68)
48-51	4	4	0	4	78.7 (6.68)

Table 3. Mean and median survival time.

Group	Mean			Median		
	Estimate	Std.Error	95% CI	Estimate	Std.Error	95% CI
ProRoot MTA®	45.38	2.117	41.232–49.530	-	-	-
Biodentine™	46.03	1.880	42.347–49.716	-	-	-
Overall	46.52	1.434	43.710–49.331	-	-	-

From the Kaplan-Meier survival curve (Fig. 2), a cumulative pulp survival rate at the end of the study (51 months) was 87.4% for ProRoot MTA® group and 70.7% for Biodentine™ group. The log-rank test showed no significant difference between the groups (p = 0.416).

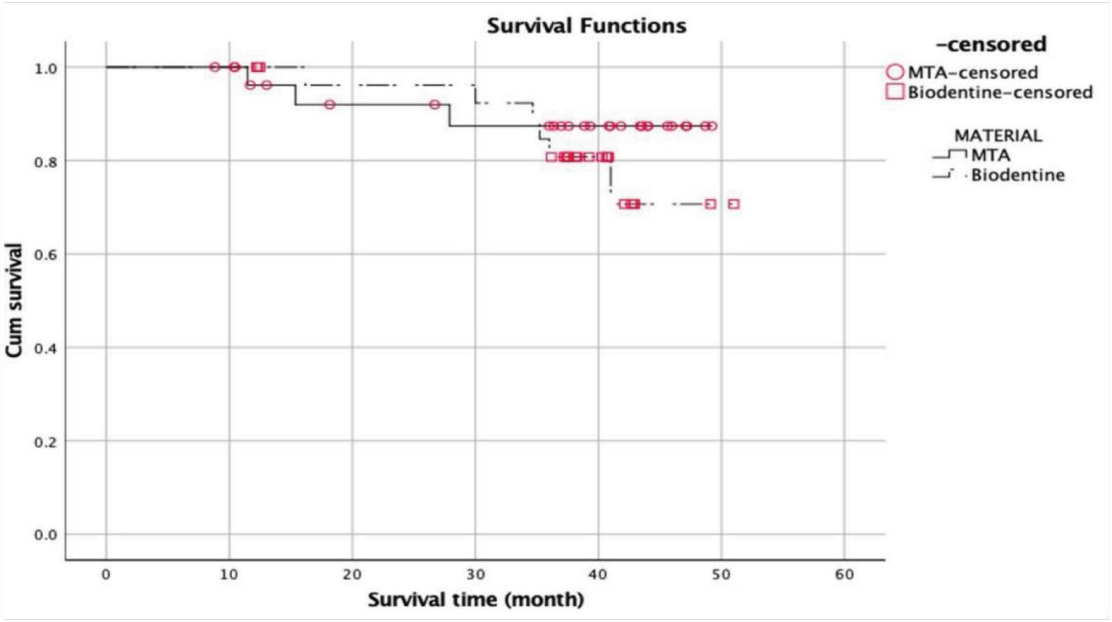

Fig.2 Kaplan-Meier survival curve shown the cumulative pulp survival probabilities of ProRoot MTA® and Biodentine™ group.

The descriptive radiographic results showed that, among the 39 patients, no internal or external root resorption was observed. Diffusion calcification in pulp chamber was found in 26 teeth (10 with ProRoot MTA® and 16 with Biodentine™). Diffusion calcification in root canal was found in 11 teeth (3 with ProRoot MTA® and 8 with Biodentine™). Pulp canal obliteration after treatment was found in 8 teeth (3 with ProRoot MTA® and 5 with Biodentine™). Reparative dentin formation was detected in 31 teeth (14 with ProRoot MTA® and 17 with Biodentine™). PAI score of 1 was observed in 33 teeth (15 with ProRoot MTA® and 18 with Biodentine™). PAI score of 2 was observed in 5 teeth (4 with ProRoot MTA® and 1 with Biodentine™). PAI score of 3 was observed in 1 tooth with a positive pulp sensibility test (Biodentine™ group) (table 4).

Table 4. Radiographic appearance of the treated teeth according to pulp capping material group.

Radiographic aspects	ProRoot MTA® (teeth, N = 19)	Biodentine™ (teeth, N = 20)
Internal root resorption	0	0
External root resorption	0	0
Diffusion calcification in pulp chamber	10	16
Diffusion calcification in root canal	3	8
Pulp canal obliterations	3	5
Detectable dentine bridge formation	14	17
PAI score of 1	15	18
PAI score of 2	4	1
PAI score of 3	0	1

Discoloration of teeth was observed in both groups, 42.1% (8/19) in teeth treated with ProRoot MTA® and 10% (2/20) in teeth treated with Biodentine™, with a statistically significant difference between the group ($p = 0.031$) (Fig. 3).

The acceptable restorations rate was 74.4%. Losing of anatomical form and the recurrence of caries were found as the main reasons of unacceptable condition. Of the 10 teeth with unacceptable restorations, 5 with ProRoot MTA® and 5 with Biodentine™, showing no significant difference between the groups ($p = 0.925$). Reparative dentin formation was observed during the replacement of unacceptable restorations in all cases.

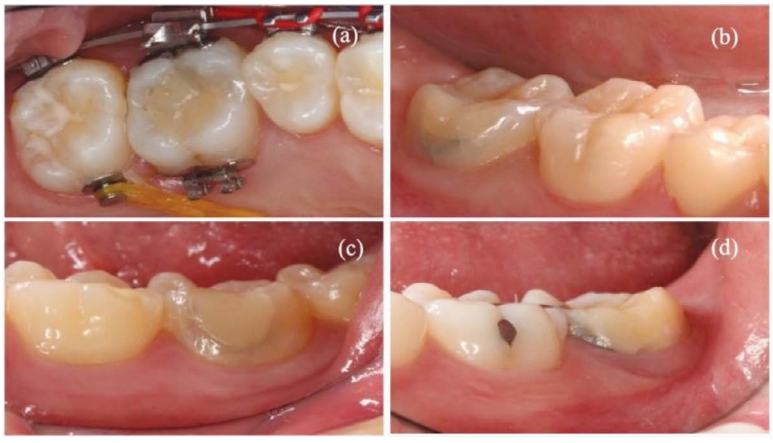

Fig.3 Representative cases of tooth discoloration after partial pulpotomy. (a) Tooth 16 with ProRoot MTA® at 36-months follow-up. (b) Tooth 47 with ProRoot MTA® at 41 months-months follow-up. (c) Tooth 37 with Biodentine™ at 40-months follow-up. (d) Tooth 37 with Biodentine™ at 36-months follow-up.

Cumulatively, 9 teeth failed after treatment, 3 were treated with ProRoot MTA® and 6 were treated with Biodentine™. The earliest failure (ProRoot MTA® group) occurred at 11.5 months post-treatment, the patient exhibited an abscess and non-responsive sensibility test, resulting in tooth extraction. The latest failure (Biodentine™ group) occurred at 41 months post-treatment, the patient reported the dislodgement of restoration, followed by spontaneous pain, resulting in tooth extraction. Details of all failed teeth are shown in Table 5 (Table 5).

The results of satisfaction survey were favorable as presented in Table 6 (Table 6).

Table 5. Characteristic of the failed cases.

ID	Tooth	Pulp dressing material	Age	Pre-op PAI score	Preoperative symptom	Time at failure (month)	Conditions	Treatment
3	46	Biodentine™	31	2	moderate pulpitis	36	crown-root fracture	extraction
6	17	Biodentine™	36	2	initial pulpitis	16.2	spontaneous pain	RCT
10	47	Biodentine™	28	2	moderate pulpitis	35.2	crown fracture	RCT, post and core with crown
28	16	Biodentine™	21	2	moderate pulpitis	41	dislodgement of restoration and spontaneous pain	extraction
38	37	Biodentine™	22	2	mild pulpitis	30	dislodgement of restoration and spontaneous pain	RCT
40	36	ProRoot MTA®	35	2	moderate pulpitis	27.9	spontaneous pain	extraction
43	36	Biodentine™	21	2	mild pulpitis	34.7	spontaneous pain	RCT
45	36	ProRoot MTA®	20	3	mild pulpitis	15.4	secondary caries causing asymptomatic apical periodontitis	RCT
55	48	ProRoot MTA®	51	2	mild pulpitis	11.5	negative to sensibility test, sinus tract	extraction

Table 6. Patient's satisfaction level on various aspects of treatment.

Satisfaction level	Very satisfied %(n/N)	Satisfied %(n/N)	Somewhat satisfied %(n/N)	Neutral %(n/N)	Somewhat dissatisfied %(n/N)	Dissatisfied %(n/N)	Strongly dissatisfied %(n/N)
Post-operative symptoms	46.1 (18/39)	46.1 (18/39)	7.7 (3/39)	0	0	0	0
Functionality of the tooth after treatment	71.8 (28/39)	17.9 (7/39)	10.2 (4/39)	0	0	0	0
Restoration on the tooth	64.1 (25/39)	17.9 (7/39)	7.7 (3/39)	10.2 (4/39)	0	0	0
Aesthetic of the tooth	48.7 (19/39)	33.3 (13/39)	10.2 (4/39)	7.7 (3/39)	0	0	0
Treatment procedure	71.8 (28/39)	17.9 (7/39)	10.2 (4/39)	0	0	0	0
Follow-up care	71.8 (28/39)	12.8 (5/39)	10.2 (4/39)	5.1 (2/39)	0	0	0

Discussion

This study found a cumulative pulp survival rate of 70.7% in the Biodentine™ group, similar to the prospective study by Tan et al. (16), which reported a success rate of 72.7% in adult permanent teeth with mild or no symptoms treated with partial pulpotomy using Biodentine™ over an average follow-up period of 3 years. For the ProRoot MTA® group, a cumulative pulp survival rate of 87.4% was observed, aligning closely with the findings of Taha and Khazali (17), who reported a success rates of 85% of ProRoot MTA®, and Tzanetakis et al (18), who reported a success rates of 89.2% of MTA Angelus. Both studies were randomized clinical trials on permanent teeth with closed apices and carious pulp exposure, with an average follow-up period of 2 years. The survival criteria used in the present study was focused on the retain of tooth with pulp response as indicated by pulp sensibility testing, showing "procedural survival", regardless of radiographic outcome. However, trials reported success rate usually determined success using both success on clinical and radiographic outcome(17,19,20).

The present study found no statistically significant difference in pulp survival between the ProRoot MTA® and Biodentine™ group. This aligned with Uesrichai et al (19), who also found no significant difference in the success rates of partial pulpotomy in young cariously exposed permanent teeth with either ProRoot MTA® or Biodentine™ at average 32-month follow-up period. Similarly, a systematic review and meta-analysis by Sabeti et al (21) reported no significant

difference in the success rates of various vital pulp therapies using MTA or calcium silicate-based materials such as Biodentine™. This lack of significant difference is likely due to the ability of calcium silicate-based cements to induce reparative dentin formation at the site of pulp exposure (22).

Although no significant difference was observed between Biodentine™ and ProRoot MTA®, it is notable that the success rates for Biodentine™ treated teeth were slightly lower than those for MTA treated teeth in some studies (19,23,24). The possible explanation could be related to the procedure and material itself, for instance, Nekoofar et al (25) investigated the shear bond strength of Biodentine™ and various resin materials at different setting times. They found that the shear bond strength of RMGIC (resin-modified glass ionomer cement) to Biodentine™ increased when RMGIC was placed 1 week after setting compared to its placement after 12 minutes. In this single-visit treatment study, RMGIC was applied over Biodentine™ after a 12-minute setting time, which might have resulted in reduced adhesion between the two materials, potentially affecting the overall success rate.

Treated teeth in both groups exhibited tooth discoloration, with a significantly higher incidence in the ProRoot MTA® group. This discoloration was believed to result from the oxidation of bismuth oxide, a radiopacifier in MTA, which contributes to tooth discoloration (26). This observation aligned with the study by Uesrichai et al. (19) which reported a perceptible grey discoloration for 80% in ProRoot MTA® treated teeth and 27% in Biodentine™ treated teeth at average 32 months follow-up period. However, the discoloration rate observed in this study was lower. In contrast, the initial study by Suwannaphrom et al (13) found no tooth discoloration in the Biodentine™ group after a 1-year follow-up. However, in this study, which followed up for at least 3 years, tooth discoloration was observed in the Biodentine™group, suggesting that Biodentine™ may cause discoloration over longer periods. This was supported by the study by Shokouhinejad et al (27), which indicated that the incidence of tooth discoloration increased with time in an in vitro setting comparing various calcium silicate-based materials. Taha et al (28) also reported an increased discoloration over time in clinical trials of full pulpotomy in adult permanent teeth using MTA, TotalFill, and Biodentine™ as capping materials, the highest rate of discoloration was observed in MTA group. In addition to the oxidation process of bismuth oxide, which was believed to cause tooth discoloration, laboratory studies have identified blood contamination as another factor contributing to tooth discoloration (27,29,30). Therefore, it was possible that the discoloration observed in the Biodentine™ group might have cause by blood contamination from the pulp tissue during the treatment.

Pulp inflammation, secondary caries, and fractures of the restorative material or the tooth itself were reasons of failures in this study, leading to tooth extraction or root canal treatment. Due to the limitations in identifying the causes of failure, which mostly reported by patients, it was difficult to diagnose the true condition of the pulp before failure. This aligned with other studies (17,20,31) that classified teeth requiring further treatment, such as root canal therapy or tooth extraction, as failures.

Failure of the coronal seal led to bacterial infiltration into the dentinal tubules, potentially causing recurrent pulp inflammation. Studies have shown that a good coronal seal significantly enhances the success of root canal treatments (32,33). In this study, teeth with fractured restorations or recurrent caries, whose pulp still survived for more than 3 years, exhibited reparative dentin formation. This was observed during the replacement of the old restorations (Fig.4). A study found that the presence of reparative dentin on radiographs significantly increased the success rate (34). From the radiographic analysis in this study, reparative dentine formation was observed in 31 (14 in the ProRoot MTA® group and 17 in the Biodentine™ group) out of 39 surviving teeth, which was considered a high level. Therefore, the detection of reparative dentine formation after treatment may serve as an indicator of a favorable prognosis.

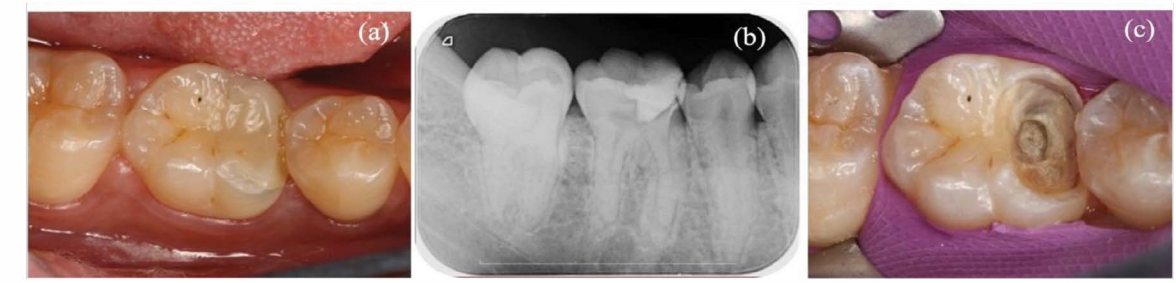

Fig.4 Representative case of the reparative dentine formation in a tooth with restorative failure but pulp survival. (a) Tooth 46 with marginal leakage and secondary caries (ProRoot MTA® group). (b) A 36-month follow-up radiograph. (c) The reparative dentine was seen after removal of defective restoration and caries.

Currently, there are no definitive guidelines for the optimal duration to assess the success of partial pulpotomy. Nosrat and Nosrat (35) suggested that reparative dentin formation occurred within 3 months post-treatment in all samples, supporting a 3-month post-treatment as a suitable timeframe for initial success evaluation. Elmsmari et al (11) found no significant difference in success rates at 6 months, 1 year, and 2 years post-treatment, suggesting 6 months as a reasonable assessment period. Matsuo et al (36) reported no difference in success rates at 3 months and 18 months following direct pulp capping, supporting a 3-month evaluation period. However, for a longer term follow-up, Awawdeh et al (37) suggested that 3 years might insufficient for fully assess the success rates of vital pulp therapy with MTA and Biodentine™ as success rates tend to decrease over time. This finding aligned with the present study, which failure frequency increased continuously at 2-3 years.

The survival rate of teeth restored with composite resin after root canal treatment were reported to be significantly decreased around 2 years (38), particularly when multiple tooth walls were lost, which further reduced the survival rate against fractures (39). The present study, most of teeth had lost occlusal and proximal surfaces

due to caries and were restored with composite resin. Survival analysis indicated that failures increased after 12 months, with the highest frequency of failures occurring between 24 and 35 months. Therefore, it is recommended to provide full-coverage restorations as soon as possible or after a 1-year follow-up to minimize the risk of fractures and ensure a good coronal seal.

Conclusion

The pulp survival of adult permanent teeth with carious pulp exposure after at least 3 years of partial pulpotomy was relatively high, with the overall pulp survival rate of 78.7%. There was no significant difference in survival between the use of ProRoot MTA® and Biodentine™ as pulp capping materials. Tooth discoloration was more prevalent in ProRoot MTA® group compared to Biodentine™ group, with a statistically significant difference. The majority of patients were very satisfied with the treatment. Full - coverage restorations should be provided as soon as possible, or no later than a 1-year follow-up, since the highest frequency of treatment failures occurred between 24 and 35 months.

Study Limitations

Radiographic Evaluation: This study assessed the radiographic outcome using periapical radiographs, which are two-dimensional images. These images often show overlapping of the tooth and root structures from the buccal and lingual sides, as well as the restorative materials, which are typically large. Consequently, it was sometimes challenging to assess internal root canal features such as dentin bridge formation or canal obliteration accurately.

Tooth Discoloration Assessment: Tooth discoloration was evaluated visually by comparing the treated tooth with adjacent teeth. Human visual assessment is inherently limited and may underestimate the extent of discoloration. Standardized measurement tools should be employed for more accurate and reliable assessments of tooth color changes.

Patient Follow-Up: Some patients were lost to follow-up due to relocation or inability to contact them. In long-term follow-up studies, the rate of patient retention may decrease, affecting the overall evaluation of treatment outcomes.

Identifying the causes of failure: Some failures were tracked by dental record or reported by patients, making it difficult to diagnose the true condition of the pulp survival before failure.

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Ethics declarations

Ethics approval and consent to participate Ethical approval was taken from the Human Research Ethics Committee of the Faculty of Dentistry, Chiang Mai University (Approval No. 25/2564, dated May 24, 2021).

Competing interests

The authors declare no competing interests.

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