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Original Article

Efficacy of different calcium silicate materials as pulp-capping agents: Randomized clinical trial



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KEYWORDS

Calcium silicates;
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Abstract *Background/purpose:* Calcium hydroxide-based materials were the gold standard in vital pulp therapies for decades' despite of several shortcomings. However, calcium silicates have been discussed as an alternative to overcome these drawbacks. It was aimed to investigate the in-vivo effectiveness of different calcium silicates based materials in pulp capping in this study.

Materials and methods: A parallel-design, randomized controlled trial with 213 patients who has deep dentin caries, vital pulps and without spontaneous pain or history of swelling was designed. 525 M teeth were randomized, blinded and allocated to one of the five groups for pulp capping treatment (n = 105). All teeth were followed up clinically and radiographically (after 1st, 6th, 12th and 36th months) by blinded investigators. The clinical and radiographic success, and the effect of the pulp exposure to the success rate analyzed with Wald chi-square and Z tests.

Results: Clinical and radiographic success of MTA+ (86.3%, 85.4%) and Biodentine (79.4%, 80.1%) were found the highest. Although results of Theracal LC group (72.1%, 73.6%) were better than Dycal group (69.4%, 70.2%), the difference was nonsignificant ($p > 0.05$). Only in light-cured groups, (TheraCal LC & LC Calcihyd) pulpal exposure size effected the success of the materials ($p < 0.05$). MTA+ and Biodentine resulted better scores, when compared with TheraCal LC in large pulpal exposures ($p < 0.05$).

Conclusion: After 36-month follow-up, both MTA+ and Biodentine were found to be the appropriate material for direct pulp capping in permanent teeth. The filler ingredient of the Theracal-LC eases the usage of calcium silicates but decreases the success rate.

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Introduction

In many clinical studies, dental pulp can be exposed via either carious dentin removal or cavity preparation phases. Inflammation in the superficial layers of pulp is more likely to be restricted if the preservation of the vitality and function of pulp can be managed.^{1,2} Several investigators have demonstrated that a vital, well-vascularized, functioning pulp is capable of healing; however, the pulp can be exposed if microleakage and bacterial contamination are prevented.^{3–5} The optimal prognosis of vital pulp therapy is based on the elimination of etiologic factors with complete removal of diseased and contaminated tissues as well as the appropriate restoration of the tooth.⁶ Therefore, direct pulp capping is preferred to reduce the risk of infection and further damage to the pulp with a material that should be biocompatible, provide a biological seal, and prevent bacterial leakage.^{7–9}

Calcium hydroxide was once considered the gold-standard pulp-capping material.^{10–12} Recent studies have also confirmed that $\text{Ca}(\text{OH})_2$ is extremely toxic to cells in tissue culture and that it has some tissue-altering and dissolving effects that might be responsible for the variable and somewhat unpredictable results, such as reparative dentin bridges containing multiple tunnel defects and aseptic necrosis.^{12,13} Therefore, the search continues for procedures and materials that are more biocompatible while stimulating continued dentin bridge formation (DBF). As an alternative to calcium hydroxide, various materials have been tested for direct pulp capping, such as mineral trioxide aggregate (MTA), tricalcium silicates and bioceramics.^{5,7,10,14}

Bioceramics are ceramic compounds that act as multi-substituted hydroxyapatites and have the ability to induce a regenerative response in organisms as well as exhibit excellent biocompatibility due to their similarity with biological materials.¹⁴ Although *in vitro* studies have proven the biocompatibility, good nonmutagenic sealing ability and bioinductive properties of these materials,¹⁵ clinical trials have resulted in differences because of the lack of long-term follow-up and comparative clinical studies with bioceramics, MTA and calcium silicates as capping materials in direct pulp treatments in mature permanent teeth.

MTA+ (Bio MTA) is a similar material to conventional MTA but is modified with the insertion of nanoceramic particles (2%) and hydroxyapatite ingredients (2%) and by decreasing the size of the grains (33%).¹⁶ These particles are three times smaller than the smallest particles of conventional MTA, which provides penetration of calcium ions to the demineralized tissue; facilitates packing material in the application site; increases the sealing process, strength and homogeneity; and reduces the setting time.¹⁶

In this manner, this study was designed to evaluate the effectiveness of MTA+ (modified calcium silicate), Biodentine (conventional calcium silicate) and TheraCal LC (light-cured tricalcium silicate) as well as calcium hydroxide materials as direct pulp-capping agents in cariously exposed, finished apical formation, fully matured permanent teeth with completed root formation. The null hypothesis of this randomized clinical trial was that all of the calcium silicate materials would show similar success

rates when compared among each other and would present better clinical and radiographic findings compared to the calcium hydroxide materials.

Materials and methods

The study was conducted at the Department of Restorative Dentistry, Faculty of Dentistry, Ege University, Turkey. The study protocol was approved by the Ethical Committee of Ege University (ref no:2013018/09). The clinical procedure and associated risks and benefits were fully explained to the patients. Written informed consent forms were obtained from the participants prior to the investigation. All participants were screened by detailed dental and systemic examination as well as both clinical and radiographic examination.

Two hundreds and thirteen patients of the total 276 participants of age group 18–42 years, who had deep Class II carious lesions in 526 mandibular and maxillary molars were included into this study. 29 participants were excluded from the study prior to the group distribution phase according to the following exclusion criteria: history of systemic diseases; teeth showing clinical and radiographic evidence of pulp degeneration such as history of spontaneous or nocturnal pain, tenderness to percussion or palpation, necrosis of the pulp (negative to vitality tests), swelling or fistulous tract, pathological mobility due to aggressive periodontitis, periodontal ligament space widening (PDL), internal root resorption, external root resorption, furcal radiolucency/inter-radicular bone destruction and/or periapical bone destruction. 21 patients were excluded from the study because of excessive pulp exposure during operative phase. 13 patients were also excluded during follow-up phase according to the criteria below: occurrence of fracture/failure of the restoration (needs retreatment or prosthetic rehabilitation) and unable to contact for follow-ups. Five groups were randomly formed according to the selected materials (two calcium hydroxide materials and three calcium silicate materials), and each group consisted of one hundred and five teeth that were randomly assigned by a blind investigator ($n = 105$) (Table 1).

Gr-1 (CCH): Conventional Calcium Hydroxide (Dycal, Dentsply-Sirona, Charlotte, NC, USA).

Gr-2 (LCC): Light Cured Calcium Hydroxide (LC Calcihyd, Dr. Roberts', Istanbul, Turkey).

Gr-3 (TLC): Light Cured Calcium Silicate (Theracal LC, Bisco, Schaumburg, IL, USA).

Gr-4 (BD): Calcium Silicate (Biodentine, Septodont, Saint-Maur-des-Fossés France).

Gr-5 (MTA+): Modified Tricalcium Silicate (BioMTA+, Cerkamed, Stalowa Wola, Poland).

Clinical examination revealed class II profound caries with no signs of extraoral/intraoral symptoms or pulpal exposure while radiographic findings revealed caries in close proximity to the pulp [Fig. 1]. Teeth were negative to percussion and palpation tests and the mobility was within normal limits. Pulp vitality tests using vitalometer (Parkell, Edgewood, NY, USA) and cold spray test (Polodent spray, Amsterdam, Netherlands) showed positive response. Based

Table 1 Materials used in this study.

Group	Material	Composition	Manufacturer & Batch No.	Instructions for Use
CCH	Dycal	Calcium Hydroxide	Dentsply, USA 150308	Extrude equal volumes of the base and catalyst paste. Stir immediately using an applicator until a uniform color is achieved. Quickly apply the mixed material into the cavity with a ball-pointed instrument.
LCC	LC Calcihyd	Calcium Hydroxide	Dr. Roberts' TURKEY 1400001252	Dispense the formula on the parchment paper pad and mix it using the ball-pointed instrument, place it directly on the exposed pulp and cavity dentin. Finally light-cure the material with a light-curing unit for 20 s.
TLC	Theracal LC	Calcium Silicate Portland Cement PEG-DMA	Bisco, USA 1400007511	Apply the syringe directly to the cavity floor in incremental layers. Layer is not to exceed 1 mm in depth. Manipulate into a smooth surface and light cure for 20 s.
BD	Biodentine	Bioceramic Tricalcium Silicate Calcium Carbonate	Septodont, FRANCE B11446	Compose 5 drops from the single-dose liquid container with the powder. Close and mix for 30 s with a mixing device. Apply the composition regarding the setting time (12 min).
MTA+	MTA Plus	Tricalcium Silicate Tricalcium Aluminate Bismuth Oxide	Cerkamed, POLAND 38653	Mix the content of 1 sachet of powder with 1 drop of distilled water for 30 s. Place the cement on the pulp with a sterilized amalgam carrier regarding the setting time (15 min).

on the results of clinical and radiographic examinations, the pulp was diagnosed with reversible pulpitis. The initial treatment plan was removal of the carious lesion followed by clinical evaluation of the pulp exposure. Direct pulp capping with the materials mentioned above was planned for the anticipated pulp exposure.

Following the administration of local anesthesia, teeth were isolated with rubber dams. Caries removal was performed using a round polymer bur on a low-speed hand-piece with continuous water irrigation. During or after the removal of caries, exposure of the pulp and bleeding were observed [Fig. 2a–e]. A sterile cotton pellet moistened

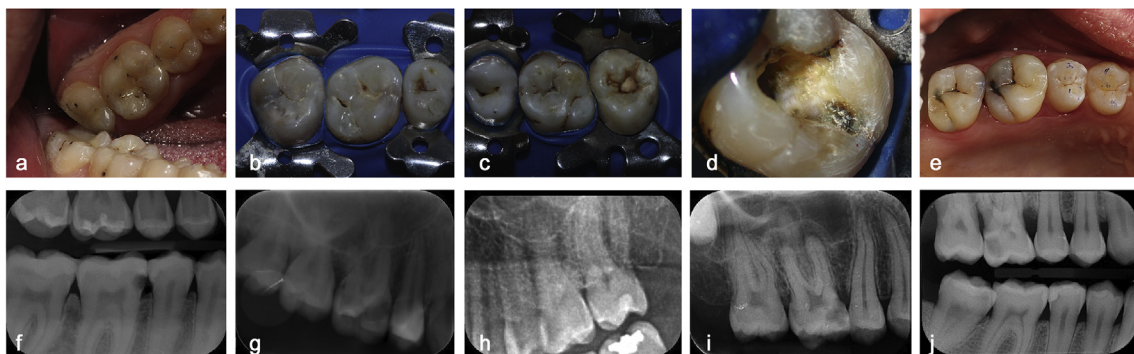


Figure 1 Preoperative clinical and radiographic images of the molar teeth with profound caries reaching pulp tissue in each group: (a–f) CCH, (b–g) LCC, (c–h) TLC, (d,i) BD and (e,j) MTA+.

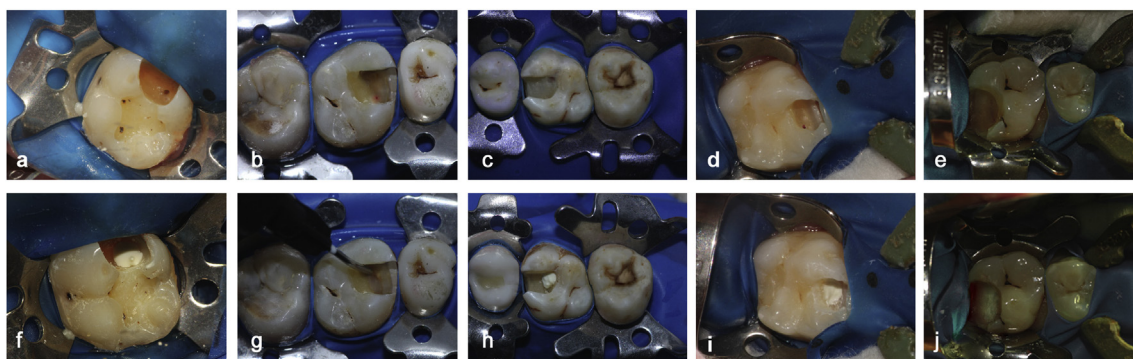


Figure 2 Photograph showing exposed pulp tissue (a–e), and direct pulp capping with the relevant material; (f) CCH, (g) LCC, (h) TLC, (i) BD and (j) MTA+.

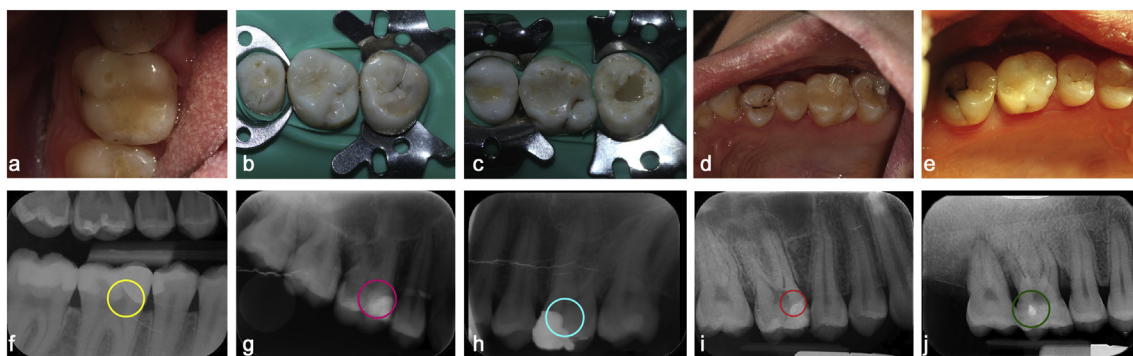


Figure 3 Postoperative clinical and radiographic images of the molar teeth restored with nanohybrid composite resin: (a–f) CCH, (b–g) LCC, (c–h) TLC, (d,i) BD and (e,j) MTA+.

with saline was used to apply moderate pressure to the exposed pulp for 5 min, and hemostasis was achieved. Sodium hypochlorite (2.5%) was used to disinfect the exposed pulp and the dentin as well as to remove the superficial clot and debris. The cavity was lightly dabbed with a moist pellet to remove the excess moisture. Pulp-capping material was applied according to the manufacturers' instructions and the group distribution (Table 1) [Fig. 2f–j]. Teeth were permanently restored with a universal self-etching adhesive system (Beauti Bond, Shofu Corp, Tokyo, Japan) and nanohybrid composite resin (NCR) (Beautifil II, Shofu Corp) (Fig. 3).

Patients were scheduled for a 1-month follow-up to monitor for any signs or symptoms according to the clinical and radiographic scores based on the criteria for clinical and radiographic scoring adapted from Zurn & Seale (Table 2).¹⁷ Patients were asked to call and acknowledge if any pain or discomfort occurred. In addition, a clinical examination was performed to evaluate an intact restoration and the absence of any abnormal signs or symptoms. Teeth were tested for vitality (EPT), and periapical radiographs were taken to evaluate any periapical changes.

At 6 months, one year and three years interventions, teeth were examined again for any abnormal findings, pulp testing was done to check the vitality of the pulp and radiographs were also taken [Fig. 4]. Patients were scheduled for routine recall visits every 6 months. Patients were informed about the potential need for root canal therapy in case of abnormal signs and symptoms.

The patients were divided into two different subgroups for evaluation of the results.

- Subgroup I: Follow-up period (short term: 1 year and long term: 3 years).
- Subgroup II: Diameter of pulp exposure (up to 0.5 mm and 0.5–1 mm wide).

Statistical analyses were performed using SPSS 22.0 (IBM, Chicago, IL, USA) software. The clinical and radiographic data for the groups were compared using the chi-square test ($p = 0.05$), the long and short-term success rates amongst the groups were compared using Mann Whitney U test and Z test was chosen to compare the effect of size of the pulp exposure to the success rate ($p = 0.05$).

Results

Twenty-one patients were excluded from the study during operative phase due to excessive exposure of the pulpal chamber that could not possible to seal and restore. Out of the remaining 213 patients who returned for regular follow-ups, 30 cases presented symptoms of irreversible pulpitis or periapical disease such as, spontaneous pain, excessive PDL widening, percussion sensitivity, etc. during the first month of the treatment (Table 3). End of the first year, 132 teeth showed signs of irreversible pulpitis or chronic apical diseases, while this number raised to 139 at the end of the

Table 2 Modified clinical and radiographic scoring criteria.^{17,38}

Clinical Scoring Criteria		
Clinical Score		Description
1	Asymptomatic	Pathology: Absent Functioning: Normal Percussion and Sensitivity: Asymptomatic Mobility: (∅)
2	Slight Discomfort	Pathology: Questionable Functioning: Chewing sensitivity, short-lasting Percussion and Sensitivity: (-) and only on cold Mobility: (Grade I)
3	Minor Discomfort	Pathology: Initial changes present Functioning: Chewing sensitivity, long-lasting Percussion and Sensitivity: (+) and only on cold Mobility: (Grade I or II)
4	Major Discomfort	Pathology: Late changes present Functioning: Spontaneous pain Percussion and Sensitivity: (+) and on cold & hot Mobility: (Grade II or III)
Radiographic Scoring Criteria		
Radiographic Score		Description
1	No changes present	PDL: Normal Width Periapical Region: Normal Root & Alveolar Bone Status: Normal Complete dentine bridge formation (>1 mm thickness)
2	Questionable pathological changes present	PDL: Slightly Widened PDL Periapical Region: Normal Root & Alveolar Bone Status: Abnormal Partial dentine bridge formation (0.5–1 mm thickness)
3	Minor Pathological changes present	PDL: Widened PDL Periapical Region: Minor external root resorption Root & Alveolar Bone Status: External changes Initial dentine bridge formation (<0.5 mm thickness)
4	Major Pathological changes present	PDL: Widened PDL Periapical Region: Radiolucency present Root & Alveolar Bone Status: Radiolucency present (No dentin bridge formation)

third year. One hundred twenty one teeth of the 139 received root canal treatment while in 18 teeth extraction was needed (Table 3).

In this study, to compare the present results with previous literature, scores 1 and 2 were estimated as success

and scores 3 and 4 as failure in both clinical and radiographic criteria.

The clinical success rate with MTA+ as the direct pulp-capping agent was found to be 84.75% in our study with a follow-up period of 36 months (5–3). At the first month, the recall success rates of the five groups did not differ from each other ($p = 0.363$). However, both MTA+ and BD demonstrated better success rates at the 1st and 3rd years of follow-up, and LCC had the lowest success rate ($p = 0.025$). The differences between the success rates of TLC and CCH were statistically insignificant ($p = 0.741$).

Radiographic success was determined with the periapical changes as well as the PDL status and DBF (Table 4). Although periapical changes (resorption, apical radiolucency) were observed after 6 months, the PDL status was evaluated at all stages of the 36-month follow-up period. The absence of any periradicular changes along with the questionable PDL changes was considered as success (score 2) in the rest of the cases. In 6 months recall scores 3 and 4 were significantly higher in LCC groups while score 3 was only significant in CCH group ($p = 0.028$). At 12 months scores 3 and 4 were significantly higher in CCH, LCC and TLC groups ($p = 0.001$).

The formation and quality of the DBF were assessed radiographically and the relationship with the success rate was also evaluated (Fig. 4). There was no statistically significant difference amongst all groups in terms of DBF and dentin bridge thickness at the 1st month follow-up ($p = 0.991$). Only 6.7% of the BD group and 4.8% of LCC group specimens showed initial dentin bridge formation (score 3). Although DBF has been observed in all groups after 6th months follow-ups, statistical differences between the groups were insignificant ($p = 0.576$). Complete dentin bridge formation (score 1) were observed in 86.7% of MT+ group, 85.7% of BD group and 85.0% of TLC group specimens. As regard to dentin bridge thickness, after 36th month interval there was a statistical significant difference between calcium silicate groups (MTA+, TLC & BD) and calcium hydroxide groups (CCH & LCC) ($p = 0.004$).

The overall success rate of group with pulp exposure size up to 0.5 mm was 79.1% and 0.6–1 mm was 63.5% (Table 5). According to the Z test results MTA+ presented higher success rates in both pulpal exposure situations while LCC failed to seal and maintain vitality of the pulp even in exposures smaller than 0.5 mm. This shows there is a significant difference in the success rate of pulp capping and diameter of pulp exposure up to 1 mm ($z = 2.51$).

Discussion

The primary aim of pulp-capping materials is to induce specifically hard tissue formation by pulp cells that seal the exposure site and ultimately contribute to continued pulp vitality.¹⁰ A liner must act as a barrier to protect the dental pulpal complex and induce the formation of a new dentine bridge or dentine-like bridge between the pulp and restorative material.^{9,18} The success of direct pulp capping depends on several factors: the type of biomaterial selected and the inductive effect on pulp cells, the quality of the seal that prevents microbial ingress, the

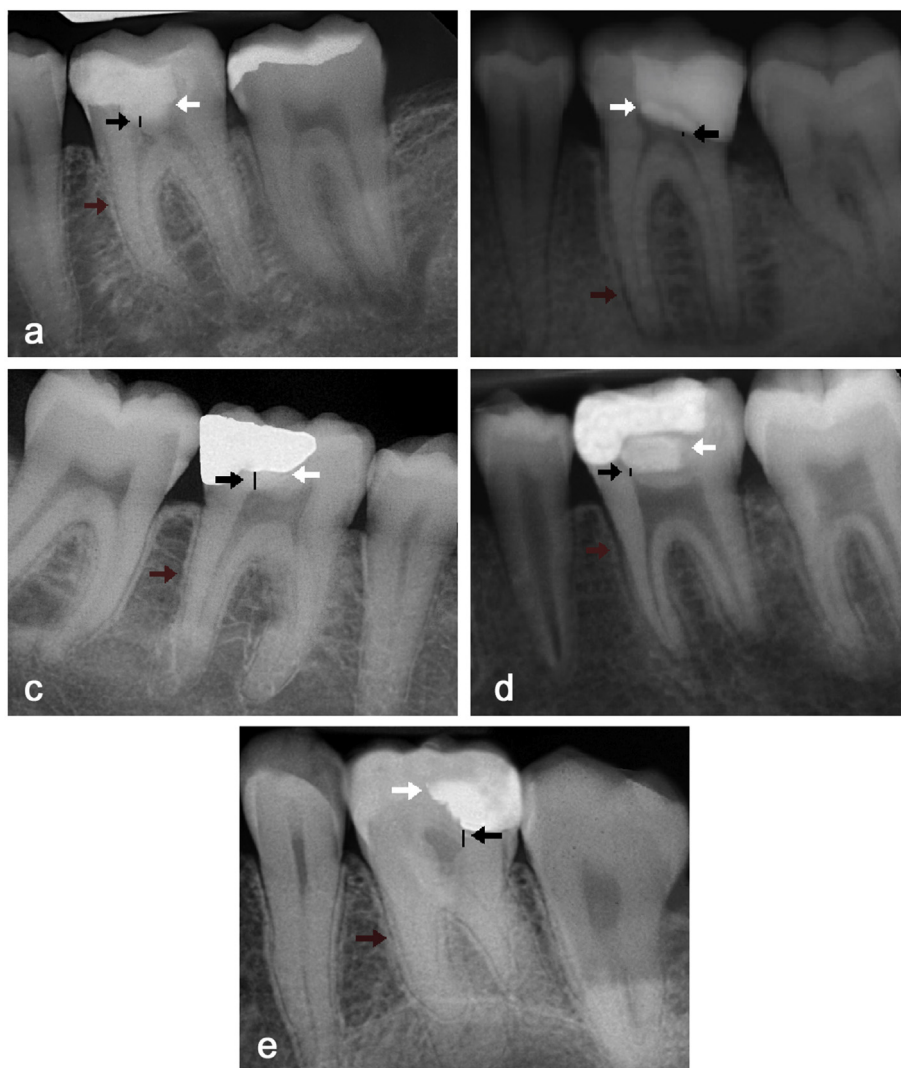


Figure 4 36th month radiograph of a molar tooth in each group, to evaluate the capping materials' adaptation (white arrow), DBF (black arrow) and PDL widening (red arrow): (f) CCH, (g) LCC, (h) TLC, (i) BD and (j) MTA+.

contamination and isolation of the cavity as well as careful case selection and treatment planning.

An increasing number of studies have proven that MTA has now almost replaced the gold standard of pulp-capping agents: calcium hydroxide. Most of clinical studies have suggested that the reparative and inductive effects of MTA on pulp are relatively higher than those of conventional $\text{Ca}(\text{OH})_2$.^{7,18–20} On the other hand, even MTA has certain drawbacks, such as difficulties with handling, high cost-effectiveness and a very long setting time, which might contribute to leakage, surface disintegration, marginal adaptation loss and material continuity.²¹ In this manner, bioceramics have been produced, necessitating the revision and/or modification of traditional MTA.^{14,16,22} Nanoparticle insertion to the base of conventional MTA facilitates preparation and increases the sealing process, strength, elasticity and homogeneity of the material. In this study, two novel modified calcium silicate materials as well as calcium hydroxide materials were used as pulp-capping agents and were evaluated in terms of sealing, restoring the vitality of the pulp and inducing the DBF. Consistent with the study

conducted by Linu et al. after 36 months of follow-up, clinical success rates of 85.4% and 79.6% were observed in the Biodentine and white MTA+ groups, respectively.¹⁴ Although our rates are low compared to many other studies, most of these previous studies were conducted on primary and immature teeth with conventional MTA material.^{21,23,24} On the other hand, when compared with those of studies that included permanent molars, the results of this study are in accordance with both the short- and long-term follow-up results.^{14,22,25–27} It should be noted that young, vital primary tooth pulp with uncompleted apical formation has the DBF ability to preserve vitality at a much higher rate than mature permanent teeth.²⁸

In the absence of contamination and chronic inflammation, undifferentiated mesenchymal cells in young pulp differentiate into odontoblasts, leading to reparation of the exposure area by tertiary dentin formation. In addition to the high vascularization and blood flow rate of the pulp in primary and immature permanent teeth, the pulp is more likely to preserve its vitality and remain asymptomatic.⁹ In the present study, light-cured calcium hydroxide (LCC) and calcium silicate (TLC)

Table 3 Clinical (C) and Radiographical (Rx) successful cases (rates %).

INTERVALS	Dycal(CCH)		LC Calcihyd(LCC)		TheraCal(TLC)		Biodentine(BD)		Bio MTA (MTA+)	
	C	Rx	C	Rx	C	Rx	C	Rx	C	Rx
1 Month	102 (97%)	104 (98%)	98 (93%)	99 (94%)	100 (96%)	101 (96%)	97 (92%)	96 (91%)	98 (93%)	104 (99%)
6 Months	81 (76%)	83 (78%)	74 (70%)	69 (66%) [#]	87 (83%)	85 (81%)	88 (84%)	90 (86%)	90 (86%)	92 (88%)
1 Year	76 (72%)	76 (72%)	68 (65%)*	67 (64%) [#]	77 (73%)	77 (73%)	84 (80%)*	86 (82%) [#]	90 (86%)*	90 (86%) [#]
3 Years	73 (69%)	74 (70%)	64 (61%)*	64 (61%) [#]	76 (72%)	77 (73%)	83 (79%)*	84 (80%) [#]	89 (85%)*	90 (86%) [#]

* and [#] indicates the statistically significant differences amongst the groups.

showed the best vital responses to larger pulpal exposure at the 1-month follow-up. This could be explained by the fast setting via light polymerization and the fact that better mechanical sealing was achieved during the procedures. In addition, the alkaline pH of Biodentine just after the setting time, which was lower than expected, would probably cause pulpal inflammation at the 1-month interval. However, throughout the evaluation period, the success of light-cured materials decreased due to the rapid reduction in the release rate of hydroxyl and calcium ions after a short time. Additionally, it is assumed that unpolymerized monomers in light-cured pulp-capping materials would leach out of the material into the surrounding cell area and interrupt the healing process, which is similar to the literature.^{29,30}

The use of MTA over carious exposure in a mature permanent tooth is commonly considered the appropriate and reasonable alternate treatment to root canal therapy or extraction. Various studies on pulpotomy with MTA in exposed teeth or teeth with irreversible pulpitis have even shown good results.³¹ Marques et al. found that pulps remained vital after direct capping of cariously exposed permanent molar pulp with MTA.¹ In addition, Ainehchi

et al. reported less inflammation and thicker DBF with MTA than calcium hydroxide when used as a pulp-capping material in human teeth with mechanical pulp exposure.²⁴ However, only a few studies have investigated the clinical efficacy of this MTA+. ¹⁶ In this study, MTA+ demonstrated a success rate of 86% after 36 months, which was similar to most studies performed with conventional MTA. In addition, all of the calcium silicate derivatives were found to be better than the calcium hydroxide preparations in both clinical and radiographic examinations. This finding is consistent with many other *in vivo* and *in vitro* studies; however, the difference between the light-cured calcium silicate TheraCal LC and DyCal was nonsignificant. Although the main constituent of TheraCal LC is tricalcium silicate (Portland cement) when compared with calcium hydroxide-based materials, it also showed dramatic declines in the percentage of cell viability in *in vitro* studies.^{32,33} One of the possible explanations for this situation could be that the filler ingredient of TheraCal LC could possibly affect pulp cells, inhibit cellular growth and induce cell cycle deregulation.³⁴⁻³⁶ Additionally, this could be the main reason for the failure of the light-cured calcium hydroxide

Table 4 Clinical (C) & Radiographic (Rx) scores at 1st, 6th 12th and 36th month follow-up.

		Clinical Score (% of teeth)					Score (% of teeth)				
		1	2	3	4	TOTAL	1	2	3	4	TOTAL
1 Month	CCH	79.3	17.9	0.9	1.9	100	89.6	8.5	1.9	—	100
	LCC	80	13.3	2.9	3.8	100	86.7	7.6	4.8	1.0	100
	TLC	81	15.2	—	3.8	100	87.6	8.6	3.8	—	100
	BD	73.3	19.0	3.8	3.8	100	87.6	3.8	6.7	1.9	100
	MTA+	76.2	17.1	—	6.7	100	91.4	7.6	1.0	—	100
6 months	CCH	72.6	3.8	8.5	14.2	100	75.5	2.8	15.1	6.6	100
	LCC	62.9	7.6	16.2	13.3	100	61.9	3.8	18.1	16.2	100
	TLC	77.1	5.7	4.8	12.4	100	85.0	1.9	11.4	7.6	100
	BD	79.0	4.8	7.6	8.6	100	85.7	—	8.6	5.7	100
	MTA+	82.9	2.9	5.7	8.6	100	86.7	1.0	7.6	4.8	100
1 year	CCH	68.9	2.8	12.3	16.0	100	70.8	0.9	10.4	17.9	100
	LCC	61.9	2.7	20.0	15.2	100	61.9	1.9	14.3	21.9	100
	TLC	72.4	1.0	8.6	18.1	100	72.4	1.0	11.4	15.2	100
	BD	78.1	1.9	8.6	11.4	100	81.9	—	7.6	10.5	100
	MTA+	85.7	—	3.8	10.5	100	84.8	1.0	6.7	7.6	100
3 years	CCH	68.9	0.9	11.3	18.9	100	66.0	3.8	8.5	20.8	100
	LCC	59.0	1.9	20.0	19.0	100	59.0	1.9	13.3	25.7	100
	TLC	72.4	—	8.6	19.1	100	72.4	1.0	10.5	16.2	100
	BD	79.0	—	8.6	12.4	100	80.0	—	8.6	11.4	100
	MTA+	84.8	—	4.8	10.5	100	84.8	1.0	1.9	12.4	100

* and [#] indicates the statistically significant differences amongst the groups.

Table 5 Effect of the pulpal exposure area on the success rates of the materials.

Groups	Baseline	1 month	6 months	1 year	3 years
<u>DYCAL (CCH)</u>					
<0.5 mm	66	65 (98%)	55 (83%)*	51 (77%)	49 (74%)*
0.5–1 mm	40	37 (93%)	26 (65%)	25 (63%)	25 (63%)
<u>LC CALCIHYD (LCC)</u>					
<0.5 mm	68	61 (90%)*	51 (75%)*	46 (68%)*	43 (63%)*
0.5–1 mm	37	36 (97%)	23 (62%)	22 (60%)	21 (57%)
<u>THERACAL LC (TLC)</u>					
<0.5 mm	62	61 (98%)	57 (92%)	50 (81%)	50 (81%)
0.5–1 mm	43	40 (93%)	30 (70%)	27 (63%)	26 (60%)
<u>BIODENTINE (BD)</u>					
<0.5 mm	72	71 (99%)	65 (90%)	62 (86%)	61 (85%)
0.5–1 mm	33	26 (79%)**	23 (70%)	22 (67%)	22 (67%)
<u>Bio MTA (MTA+)</u>					
<0.5 mm	66	63 (95%)	61 (92%)	61 (92%)	61 (92%)
0.5–1 mm	39	35 (90%)	29 (75%)**	29 (72%)**	28 (72%)**

* indicates the statistically significant differences in comparison with the other materials.

LC Calcihyd in this study. Less likely, the superficial necrotic area negatively affected the pulp cells and caused an inflammatory response in some cases.³⁷

The current study included factors that are believed to give indications of the health and healing capacity of pulpal tissue prior to treatment, such as the degree of symptoms and the radiographic progression of the treatment process. Each of these factors has been cited in the literature as having some relevance in the ability of pulp to recover from pulp exposure (cariou or otherwise), but none have been shown to be reliably predictive.^{14,35,37} In this study, the DBF and widening of the PDL in the calcium silicate materials were undeniably higher than those of the calcium hydroxide materials, which indicates that inflammation in pulpal tissues is also associated with periodontal health. On the other hand, DBF was also observed in almost 85% of all groups (98% of successful cases), and the final success rates depend on multiple factors, such as the dimensions of the exposed area, pulp-capping material consistency and thickness, which affect the sealing ability, and operational differences.

Based on the results of this randomized clinical trial, it may be concluded that tricalcium silicate materials (MTA+ and Biodentine) are the most appropriate materials in vital pulp treatments. Calcium hydroxide was once the gold standard and suitable material in pulp capping and sealing, and the clinical outcomes of (CaOH₂) are not predictive or reliable due to factors such as patient age, exposure size and bleeding amount. Although the short-term results of TheraCal LC are promising, the long-term efficacy remains limited. Considering the comparatively similar success rate of TheraCal LC with that of (CaOH₂) and the potential of making major contributions to maintaining pulp vitality, TheraCal LC can be used as an alternative calcium hydroxide material.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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References

1. Marques MS, Wesselink P, Shemesh H. Outcome of direct pulp capping with mineral trioxide aggregate: prospective study. *J Endod* 2015;41:1026–31.
2. Asgary S, Eghbal MJ, Ghodduji J. Two-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter randomized clinical trial. *Clin Oral Invest* 2014;18:635–41.
3. Tran XV, Gorin C, Willig C, et al. Effect of a calcium-silicate-based restorative cement on pulp repair. *J Dent Res* 2012;91:1166–71.
4. Petrou MA, Alhamoui FA, Welk A, Altarabulsi MB, Alkilzy M, Splieth HC. A randomized clinical trial on the use of medical portland cement, MTA and calcium hydroxide indirect pulp treatment. *Clin Oral Invest* 2014;18:1383–9.
5. Schwendicke F, Brouwer F, Stolpe M. Calcium hydroxide versus mineral trioxide aggregate for direct pulp capping: a cost-effectiveness analysis. *J Endod* 2015;41:1969–74.
6. Bogen G, Kim JS, Bakland LK. Direct pulp capping with mineral trioxide aggregate: an observational study. *J Am Dent Assoc* 2008;139:305–15.
7. Komabayashi T, Zhu Q, Eberhart R, Imai Y. Current status of direct pulp-capping materials for permanent teeth. *Dent Mater* 2016;35:1–12.
8. Goldberg M. *The dental pulp: biology, pathology, and regenerative therapies*. Berlin Heidelberg: Springer-Verlag Publishing, 2014.
9. Makkar S, Kaur H, Aggarwal A. A confocal laser scanning microscopic study evaluating the sealing ability of mineral trioxide aggregate, biodentine and anew pulp capping agent-theracal. *Dent J Adv Stud* 2015;3:20–5.
10. Schröder U. Effects of calcium hydroxide-containing pulp-capping agents on pulp cell migration, proliferation, differentiation. *J Dent Res* 1985;64:541–8.
11. El-Meligy OA, Avery DR. Comparison of mineral trioxide aggregate and calcium hydroxide as pulpotomy agents in young

- permanent teeth (apexogenesis). *Pediatr Dent* 2006;28:399–404.
12. Silva GA, Lanza LD, Lopes-Júnior N, Moreira A, Alves JB. Direct pulp capping with a dentin bonding system in human teeth: a clinical and histological evaluation. *Operat Dent* 2006;31:297–307.
 13. Koike T, Polan MA, Izumikawa M, Saito T. Induction of reparative dentin formation on exposed dental pulp by dentin phosphophoryn/collagen composite. *BioMed Res Int* 2014;2014:41–9.
 14. Linu S, Lekshmi MS, Varunkumar VS, Sam Joseph VG. Treatment outcome following direct pulp capping using bioceramic materials in mature permanent teeth with carious exposure: a retrospective study. *J Endod* 2017;43:1635–9.
 15. Camilleri J, Laurent P, About I. Hydration of biodentine, theracal LC, and a prototype tricalcium silicate-based dentin replacement material after pulp capping in entire tooth cultures. *J Endod* 2014;40:1846–54.
 16. Chalas R, Mielko E, Zubrzycka-Wrobel J, Nowak J. A chemical activity evaluation of two dental calcium silicate-based materials. *Curr Issues Pharm Med Sci* 2015;28:89–91.
 17. Zurn D, Seale NS. Light-cured calcium hydroxide vs formocresol in human primary molar pulpotomies: a randomized controlled trial. *Pediatr Dent* 2008;30:34–41.
 18. Torabinejad M, Parirokh M. Mineral trioxide aggregate: a comprehensive literature review-part II: leakage and biocompatibility investigations. *J Endod* 2010;36:190–202.
 19. Cuadros-Fernández C, Lorente Rodríguez AI, Sáez-Martínez S, García-Binimelis J, About I, Mercadé M. Short-term treatment outcome of pulpotomies in primary molars using mineral trioxide aggregate and Biodentine: a randomized clinical trial. *Clin Oral Invest* 2016;20:1639–45.
 20. Alqaderi H, Lee CT, Borzangy S, Pagonis TC. Coronal pulpotomy for cariously exposed permanent posterior teeth with closed apices: a systematic review and meta-analysis. *J Dent* 2016;44:1–7.
 21. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review-part III: clinical applications, drawbacks, and mechanism of action. *J Endod* 2010;36:400–13.
 22. Azimi S, Fazlyab M, Sadri D, Saghiri MA, Khosravanifard B, Asgary S. Comparison of pulp response to mineral trioxide aggregate and a bioceramic paste in partial pulpotomy of sound human premolars: a randomized controlled trial. *Int Endod J* 2014;47:873–81.
 23. Aeinehchi M, Dadvand S, Fayazi S, Bayat-Movahed S. Randomized controlled trial of mineral trioxide aggregate and formocresol for pulpotomy in primary molar teeth. *Int Endod J* 2007;40:261–7.
 24. Moretti AB, Sakai VT, Oliveira TM, Fornetti AP, Santos CF, Machado MA. The effectiveness of mineral trioxide aggregate, calcium hydroxide and formocresol for pulpotomies in primary teeth. *Int Endod J* 2008;41:547–55.
 25. Rajasekharan S, Martens LC, Vandenbulcke J, Jacquet W, Bottenberg P, Cauwels RGE. Efficacy of three different pulpotomy agents in primary molars: a randomized control trial. *Int Endod J* 2017;50:215–28.
 26. Barrieshi-Nusair KM, Qudeimat MA. A prospective clinical study of mineral trioxide aggregate for partial pulpotomy in cariously exposed permanent teeth. *J Endod* 2006;32:731–5.
 27. Mente J, Leo M, Panagidis D, Saure D, Pfefferle T. Treatment outcome of mineral trioxide aggregate: repair of root perforations-long-term results. *J Endod* 2014;40:790–6.
 28. Parisay I, Ghoddusi J, Forghani M. A review on vital pulp therapy in primary teeth. *Iran Endod J* 2015;10:6–15.
 29. Chaudhari WA, Jain RJ, Jadhav SK, Hegde VS, Dixit MV. Calcium ion release from four different light-cured calcium hydroxide cements. *J Endod* 2016;28:114–8.
 30. Boland EJ, MacDougall M, Carnes DL, Dickens SH. In vitro cytotoxicity of a remineralizing resin-based calcium phosphate cement. *Dent Mater* 2006;22:338–45.
 31. Qudeimat MA, Alyahya A, Hasan AA, Barrieshi-Nusair KM. MTA pulpotomy for permanent molars with clinical signs indicative of irreversible pulpitis: a preliminary study. *Int Endod J* 2017;50:126–34.
 32. Poggio C, Ceci M, Dagna A, Beltrami R, Colombo M, Chiesa M. In vitro cytotoxicity evaluation of different pulp capping materials: a comparative study. *Arh Hig Rada Toksikol* 2015;66:181–8.
 33. Bortoluzzi EA, Niu LN, Palani CD, et al. Cytotoxicity and osteogenic potential of silicate calcium cements as potential protective materials for pulpal revascularization. *Dent Mater* 2015;31:1510–22.
 34. Chang HH, Chang MC, Huang GF, et al. Effect of triethylene glycol dimethacrylate on the cytotoxicity, cyclooxygenase-2 expression and prostanooids production in human dental pulp cells. *Int Endod J* 2012;45:848–58.
 35. Cooper PR, Takahashi Y, Graham LW, Simon S, Imazato S, Smith AJ. Inflammation-regeneration interplay in the dentine-pulp complex. *J Dent* 2010;38:687–97.
 36. Simon S, Perard M, Zanini M, et al. Should pulp chamber pulpotomy be seen as a permanent treatment? some preliminary thoughts. *Int Endod J* 2013;46:79–87.
 37. Silva FB, Almeida JM. Natural medicaments in endodontics: a comparative study of the anti-inflammatory action. *Braz Oral Res* 2004;18:174–9.
 38. Al-Saudi KW, Nabih SM, Farghaly AM, AboHager EA. Pulpal repair after direct pulp capping with new bioceramic materials: a comparative histological study. *Saudi Dent J* 2019;31:469–75.