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Clinical and radiographic outcomes of indirect pulp treatment and direct pulp capping using MTA in deeply carious primary second molars: a 12-month prospective study

Seren Kaya[1,3], Özlem Beren Satılmış[1*], Ayşe Işıl Cihan[2] and Firdevs Tulga Öz[1]

Abstract

Background Vital pulp therapies are treatment approaches that preserve the health and function of the primary tooth pulp. This study aimed to evaluate the clinical and radiographic outcomes of indirect pulp treatment (IPT) and direct pulp capping (DPC) performed with MTA in deeply carious primary second molars.

Methods This clinical outcome study evaluated IPT ($n=30$) and DPC ($n=30$) treatments using MTA in 60 deeply carious second primary molars. Clinical and radiographic assessments were conducted at 6 and 12 months to determine treatment success based on predefined criteria**.** Categorical variables for both treatment groups were analyzed using Fisher's exact test. A p-value <0.05 was considered statistically significant.

Results The overall success rate of the IPT group was 96.55%, with clinical and radiographic success rates of 96.67% at 6 months and 100% at 12 months. In the DPC group, the overall success rate was 86.21%, showing clinical success of 96.67% and radiographic success of 90% at the 6-month follow-up, and both clinical and radiographic success rates of 96.15% at the 12-month follow-up. Despite these numerical differences, no statistically significant difference was found between the treatment outcomes ($p=0.352$).

Conclusions IPT and DPC treatments using MTA demonstrated high clinical and radiographic success in primary molars over the 12-month follow-up period. Under appropriate clinical conditions, including proper case selection, appropriate material selection, and meticulous technique, IPT and DPC can be considered successful conservative treatments.

Trial registration ClinicalTrials.gov Identifier: NCT07382115, registered on 26 January 2026, retrospectively registered.

Keywords Indirect pulp treatment, Direct pulp capping, Mineral trioxide aggregate, Deep dentin caries, Primary teeth

*Correspondence:
Özlem Beren Satılmış
ozlemberensa@gmail.com
[1]Department of Pediatric Dentistry, Faculty of Dentistry, Ankara University, Ankara 06560, Turkey
[2]Department of Pediatric Dentistry, Faculty of Dentistry, Ankara Yildirim Beyazit University, Ankara 06010, Turkey
[3]Present Address: Private Pediatric Dental Clinic. Fabrikalar Street. Küpeli Apartment, Block B, No: 12/3, Eskişehir 26170, Türkiye

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Background

Deep dentin caries require careful treatment planning due to their proximity to the pulp tissue. Vital pulp therapy (VPT) approaches, such as indirect pulp treatment (IPT) and direct pulp capping (DPC), are conservative endodontic procedures used to maintain pulpal health [1]. The biological basis of pulp capping treatments involves the activation of cellular mechanisms responsible for pulp healing and dentin bridge formation. These processes create a microenvironment that supports hard tissue deposition by surviving pulp cells, effectively sealing the exposure site and helping to maintain pulp vitality. When the pulp is exposed, bacterial invasion can trigger an immune response, leading to the recruitment and differentiation of progenitor cells from the dentin–pulp complex. These cells contribute to the formation of reparative dentin, which serves as a natural barrier protecting the pulp from further insult [2].

In IPT, the affected dentin adjacent to the pulp is left in place to avoid pulp exposure, and a biocompatible liner is applied following controlled caries excavation. This approach reduces the likelihood of pulp exposure and supports the natural healing capacity of the dentin–pulp complex [3, 4]. To minimize bacterial infiltration at the restoration–dentin interface, treatment should be completed with a hermetic restoration. In cases where the pulp is exposed as a caries-free pinpoint (< 1 mm) during cavity preparation or after traumatic injury, a biocompatible material such as mineral trioxide aggregate (MTA) or calcium hydroxide is placed in direct contact with the exposed pulp tissue, and the tooth is restored with a material that prevents microleakage [5].

The success of DPC in primary teeth has historically been limited, making careful case selection, accurate pulpal diagnosis, and appropriate material selection essential [6]. Treatment failure has been attributed to the high cellular content of the pulp tissue. It has been suggested that undifferentiated mesenchymal cells may differentiate into odontoclasts, leading to internal resorption, a key finding of DPC failure in primary teeth [7, 8]. However, in recent years, calcium silicate–based bioceramics used in VPT have gained increasing prominence. Recent studies have reported high success rates for DPC performed with biocompatible materials [9–11]. MTA and similar cements are notable for their high alkalinity, excellent biocompatibility, and their ability to stimulate hard tissue formation, including dentin bridge development [2].

This study evaluates clinical outcomes under routine practice conditions, where treatment decisions are based on intraoperative findings. This approach provides clinically relevant insights into the management of deep carious lesions. Although several studies have investigated vital pulp therapies in primary teeth, clinical data evaluating IPT and DPC using calcium silicate–based materials in deeply carious primary molars remain limited. This study aimed to evaluate the clinical and radiographic outcomes of IPT and DPC using MTA in deeply carious primary molars. The null hypothesis was that there would be no significant difference in long-term success rates between the two treatment protocols (IPT and DPC) applied according to clinical findings.

Methods

Ethical approval and informed consent

Ethics committee approval was obtained from the Ankara University Faculty of Dentistry Research Ethics Committee (No: 07/07; approval date: 17.04.2019). The study included children whose parents provided written informed consent for participation. All procedures were conducted in accordance with the Declaration of Helsinki. The study was registered at ClinicalTrials.gov (Identifier: NCT07382115).

Study design and eligibility criteria

This study was designed as a clinical outcome study evaluating indirect pulp treatment and direct pulp capping performed under routine clinical conditions over a 12-month follow-up period. It was reported in accordance with the STROBE guidelines [12]. Treatment allocation was based on intraoperative clinical findings, specifically the presence or absence of pulpal exposure during caries excavation. The study was conducted at the Department of Pediatric Dentistry, Faculty of Dentistry, Ankara University, where patient recruitment and treatment took place between April 2019 and April 2020 among children attending the clinic for routine dental care. The study included systemically healthy children aged 7–9 years who were diagnosed with deep dentin caries in their primary second molars according to the International Caries Detection and Evaluation System (ICDAS codes 5 and 6) [13]. Initially, 305 s primary molars were screened for eligibility.

In addition to this primary selection criterion, the following clinical conditions were required prior to treatment:

- Absence of symptoms associated with irreversible pulpitis, such as spontaneous pain or prolonged pain in response to thermal or chemical stimuli;
- No tenderness to percussion or palpation;
- No signs of pathological or physiological tooth mobility;
- No evidence of swelling, fistula, or discoloration.

Radiographic inclusion criteria were as follows:

- A deep carious lesion in close proximity to the pulp without direct pulpal communication;
- Intact lamina dura and a normal periodontal ligament (PDL) space;
- No signs of bone loss surrounding the roots;
- No evidence of internal or external root resorption, either physiological or pathological;
- Absence of pulpal calcifications or pulp stones within the pulp chamber.

Of these, 60 teeth that fulfilled the inclusion criteria were enrolled and allocated to the study groups (IPT group, n = 30; DPC group, n = 30). Treatment allocation was based on intraoperative clinical findings, specifically the presence or absence of pulpal exposure during caries excavation, reflecting routine clinical decision-making. The sample size was determined by the number of eligible teeth meeting the strict clinical and radiographic inclusion criteria during the study period, representing all available cases within the defined timeframe.

Treatment procedures

Treatment allocation was based on clinical findings at the time of the operative procedure. All procedures were performed under standardized clinical protocols. Although pulp sensibility tests have limited reliability in primary teeth, a cold test (Endo-Frost, Roeko, Langenau, Germany) was used as an adjunct to support clinical diagnosis. Topical anesthesia (Xylocaine topical gel, Astra, Södertälje, Sweden) was applied to the dried mucosa for 1–2 min, followed by local anesthesia using Ultracain DS Forte (articaine hydrochloride with epinephrine 1:200,000; Sanofi Aventis, Istanbul, Türkiye). Each treated tooth was isolated with a rubber dam to ensure a dry and contamination-free working field. Access to the lesion was gained, and initial caries excavation was performed using a sharp spoon excavator or a low-speed round bur, removing the necrotic, demineralized superficial dentin while avoiding unnecessary trauma near the pulp. The cavity was then irrigated with sterile physiological saline (0.9% NaCl) using a cotton pellet and gently dried. A calcium silicate–based capping material, MTA Angelus (Angelus, Londrina, Brazil), was then placed over the remaining dentin close to the pulp in accordance with the manufacturer's instructions (Fig. 1). In cases where pulpal perforation occurred within an area surrounded by sound dentin, the cavity was gently cleansed with sterile physiological saline (0.9% NaCl) using a cotton pellet to remove debris and reduce contamination. This procedure was performed in primary teeth with a clinically normal pulp following a small pulp exposure of less than 1 mm in diameter. Following careful drying of the cavity, a calcium silicate–based capping material, MTA Angelus (Angelus, Londrina, Brazil), was directly applied to the exposure site (Fig. 2). The cavity was then restored with a conventional glass ionomer cement (Riva Self Cure Capsule, SDI Limited, Australia), and the tooth was restored in the same session with a prefabricated stainless steel crown (3 M ESPE, St. Paul, MN, USA), cemented using a conventional glass ionomer luting cement (Meron, VOCO GmbH, Germany). All procedures were performed by the same experienced pediatric dentist.

Follow-up and outcome assessment

Clinical and radiographic evaluations were performed at 6 and 12 months post-treatment. During follow-up visits, patients were assessed using standardized clinical forms, and any reported postoperative symptoms were recorded. Clinical and radiographic outcomes were evaluated independently. During anamnesis, the following symptomatic parameters were recorded: post-treatment pain, as well as provoked pain, spontaneous pain, and night pain. In the clinical examination, the following findings were assessed:

- Tenderness to percussion or palpation and abnormal mobility (luxation);
- Presence of swelling or edema;
- Presence of a sinus tract or fistula.

In the radiographic evaluation, the following criteria were examined:

- Continuity of the lamina dura;
- Presence of periapical radiolucency;
- Furcal radiolucency (suggestive of interradicular pathology);
- Evidence of physiological root resorption (age-appropriate);
- Signs of pathological root resorption (internal or external).

Radiographic evaluations were conducted using a standardized imaging protocol, and all follow-up assessments were performed by the same calibrated examiner, thereby reducing measurement and observer bias.

Statistical analysis

The data obtained in this study were analyzed using SPSS software (version 11.5; SPSS Inc., Chicago, IL, USA). Descriptive statistics were presented as frequencies and percentages (n, %). Fisher's exact test was used to evaluate associations between categorical variables and to compare the two treatment groups, given the sample size and expected frequency distribution. A p-value < 0.05 was considered statistically significant.



Fig. 1 **a** Preoperative clinical image of the second primary molar treated with IPT; **b** clinical image showing removal of infected dentin; **c** clinical image after MTA application; **d** clinical image after restoration of the tooth with GIC; **e** clinical image after placement of a SSC

Results

The study included 45 patients: 18 females (21 teeth) and 27 males (39 teeth). The patients were aged 7 to 9 years, with a mean age of 7.8 years.

Of the 60 treated teeth, 34 were mandibular second primary molars (18 on the right side, 16 on the left), and 26 were maxillary second primary molars (13 on the right and 13 on the left).

In the IPT group, both clinical and radiographic failures were observed at the 6-month follow-up in one tooth that was subsequently extracted. Clinically, abscess formation, mobility, and percussion sensitivity were noted; radiographically, periapical lesions, furcation involvement, and loss of the lamina dura were observed (Fig. 3).

In the DPC group, four teeth showed radiographic failure, of which only two also exhibited clinical failure. The remaining two teeth, which showed radiographic failure without clinical signs or symptoms, were also classified as failures, as they were extracted at the 6-month follow-up due to advanced radiographic findings. Failures in the DPC group included cases with spontaneous pain,



Fig. 2 **a** Preoperative clinical image of the second primary molar treated with DPC; **b** clinical image of pulp exposure (indicated by a red line) following complete caries removal; **c** clinical image after MTA application to the site of pulp exposure; **d** clinical image after placement of a SSC

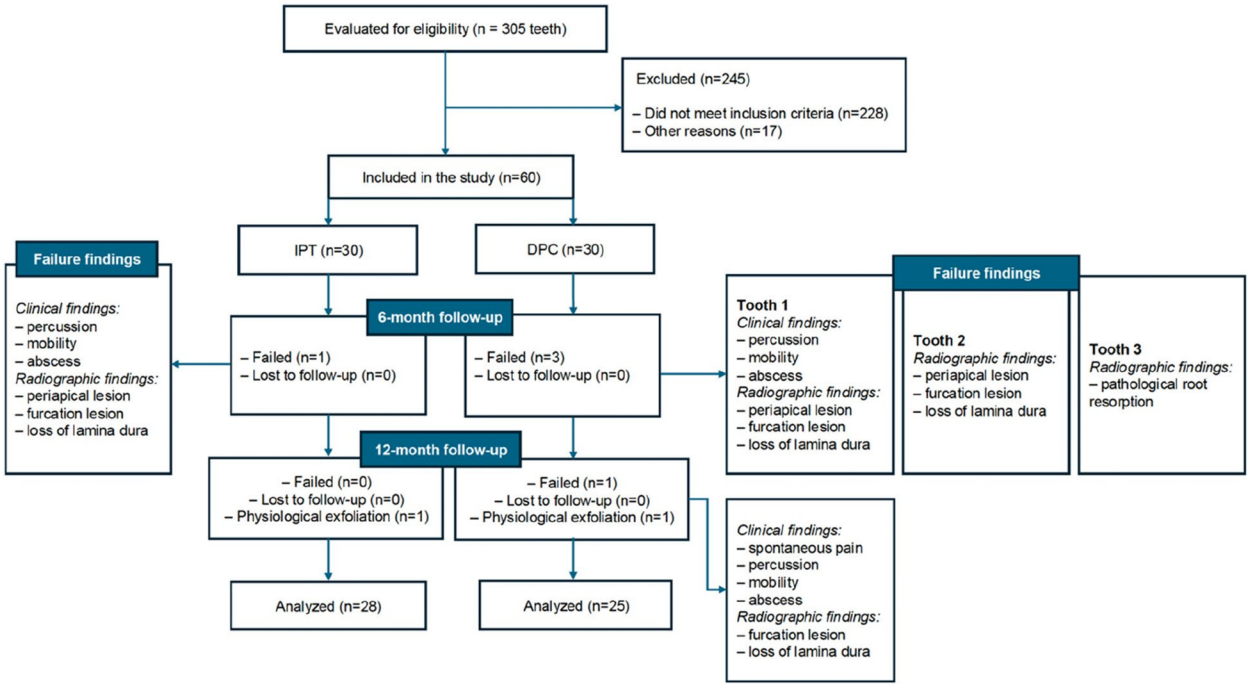


Fig. 3 Flow chart of study design, eligibility screening, IPT/DPC allocation, follow-up, and outcome analysis

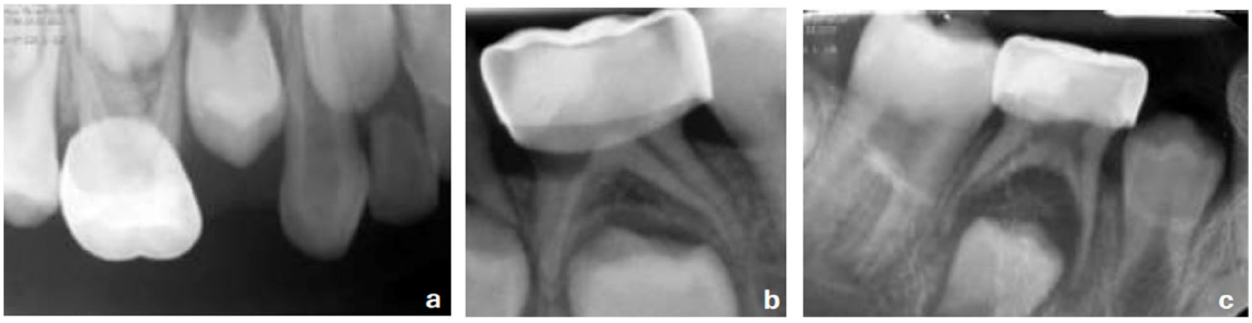


Fig. 4 **a** Radiographic image of a tooth treated with DPC, showing loss of the lamina dura and a periapical lesion at 3 weeks; **b** radiographic image of a tooth treated with DPC, showing internal resorption at 6 months; **c** radiographic image of a tooth treated with IPT, showing furcal and periapical lesions at 6 months

Table 1 Overall success rates of teeth in the study groups

Group	Follow-up period	IPT	DPC	p value
		n/%	n/%	
Clinical Success	6-month	29 (96.67%)	29 (96.67%)	1.000
	12-month	28 (100%)	25 (96.15%)	0.481
Radiographic Success	6-month	29 (96.67%)	27 (90%)	0.612
	12-month	28 (100%)	25 (96.15%)	0.481
General Success	Total	28 (96.55%)	25 (86.21%)	0.352

IPT Indirect pulp treatment, *DPC* Direct pulp capping, *n* number, *%* Percentage *p* p-value (significance level set at 0.05)

p-values were calculated using Fisher's exact test

internal resorption, tenderness to percussion, mobility, and radiographic findings such as furcation involvement and loss of the lamina dura (Fig. 3).

Representative radiographic images of failed cases for which patient consent was obtained are presented in Fig. 4.

Two teeth underwent physiological exfoliation during the follow-up period. At the 6-month follow-up, both teeth were clinically and radiographically healthy. By the 12-month follow-up, parents reported that these teeth had recently become mobile and exfoliated. Although exfoliation occurred slightly earlier than the expected physiological timeframe compared with contralateral teeth, root resorption in the affected teeth was observed to occur concurrently with that of the ipsilateral first primary molar. Therefore, these cases were not considered treatment failures; however, they were excluded from the 12-month follow-up and overall success analyses.

The overall success rate was 96.55% in the IPT group and 86.21% in the DPC group; however, no statistically significant difference was observed between the groups ($p = 0.352$) (Table 1).

At the 6-month follow-up, clinical success rates were identical at 96.67% in both the IPT and DPC groups ($p = 1.000$). At 12 months, clinical success was 100% in the IPT group and 96.15% in the DPC group; however, this difference was not statistically significant ($p = 0.481$) (Table 1).

At the 6-month follow-up, radiographic success was 96.67% in the IPT group and 90% in the DPC group. At 12 months, radiographic success rates were 100% and 96.15%, respectively. No statistically significant difference was observed between the groups at either 6 months ($p = 0.612$) or 12 months ($p = 0.481$) (Table 1).

These findings should be interpreted as outcome evaluations under different clinical conditions rather than direct group comparisons.

Discussion

MTA is a capping material characterized by high impermeability, biocompatibility, and antibacterial properties. It consists of a hydrophilic powder composed primarily of tricalcium silicate, tricalcium aluminate, and silicate oxides. Upon contact with moisture, MTA forms a colloidal gel, and calcium hydroxide is the main reaction product generated during this process [14]. It has been used as an alternative to calcium hydroxide in IPT and DPC treatments, particularly in recent years. Previous studies have reported significant reparative dentin formation following IPT [15–17]. In primary teeth, the biological mechanism of MTA in DPC is similar to that of calcium hydroxide, as both materials release calcium ions and create a high-pH environment that promotes pulp healing [18, 19].

In the present study, IPT demonstrated high clinical and radiographic success at both 6 and 12 months. Comparable success rates have been reported in previous

clinical studies evaluating IPT in primary molars, ranging from approximately 80% to over 95%, depending on follow-up duration, restorative materials, and case selection [15]. A systematic review and meta-analysis on VPT in primary teeth also reported that IPT achieved one of the highest success rates among vital pulp therapies and was at least comparable, if not superior, to more invasive treatment approaches such as pulpotomy [20]. The high success observed in this study is consistent with these findings. The favorable outcomes in the IPT group may be explained by the biological advantages of preserving a thin layer of affected but uninfected dentin over the pulp. This affected dentin acts as a protective barrier, reducing inflammatory damage and allowing the pulp to respond with reparative dentinogenesis under a well-sealed restoration [21]. The findings of this study support the growing body of evidence suggesting that IPT should be considered a first-line VPT for deeply carious primary molars without signs of irreversible pulpitis, owing to its high success rate, conservative nature, and low risk of complications [22].

In this study, the DPC group demonstrated a numerically lower overall success rate due to radiographic failures and the need for extractions in a subset of cases. However, the 12-month clinical and radiographic success rates observed are comparable to previous reports of DPC in primary molars using calcium hydroxide or calcium silicate–based materials. Several randomized controlled trials and cohort studies have reported that 12-month clinical success rates for DPC in primary molars range from approximately 70% to 90%, with radiographic success often being slightly lower than clinical success [6, 23, 24]. Success rates in recent studies using MTA and other calcium silicate–based materials, although more variable than those reported for IPT and pulpotomy, support the potential of DPC as a viable treatment option. An important finding of this study was the discrepancy between clinical and radiographic outcomes in the DPC group, with more teeth showing radiographic failure (3/30) than clinical failure (1/30) at the 6-month follow-up. These findings suggest that teeth may remain asymptomatic despite early radiographic signs of periapical or furcation pathology, lamina dura disruption, or internal resorption. The slightly lower success rate of DPC, despite the enhanced sealing ability and biocompatibility of MTA compared with traditional materials, underscores the need for appropriate case selection and careful radiographic monitoring when performing DPC in primary molars.

Two teeth (one in each group) underwent exfoliation during the 12-month follow-up after being clinically and radiographically healthy at 6 months. Exfoliation occurred slightly earlier than in the contralateral teeth; however, root resorption progressed synchronously with that of other primary molars in the same quadrant. Previous studies have reported that primary molars treated with VPT tend to exfoliate on time or slightly earlier, without adversely affecting the development or eruption of the permanent successor. Treatment failure is defined by pathological findings such as pain, apical or furcation radiolucency, and pathological root resorption [25], whereas physiological exfoliation is considered the intended natural endpoint of therapy rather than a sign of failure [26]. Therefore, these cases were not classified as failures and were excluded from the 12-month follow-up and overall success analyses.

In vital pulp treatments, achieving a hermetic coronal seal is considered one of the most critical determinants of long-term success. The healing capacity of the pulp largely depends on preventing bacterial contamination. Even when a biocompatible material such as MTA is placed over the exposure site, microleakage resulting from an inadequate restoration may allow bacterial infiltration, leading to persistent inflammation, internal resorption, or ultimately pulp necrosis. For this reason, all teeth included in the study were restored with stainless steel crowns.

The study has some limitations, including a relatively small sample size and the absence of an a priori sample size calculation, as the sample size was determined by the number of eligible patients treated during the study period. This may have resulted in limited statistical power and an increased risk of Type II error; therefore, the absence of statistically significant differences should be interpreted with caution. Furthermore, clinical procedures were performed at a single center, which may limit the generalizability of the findings. The results may have been influenced by variability in operator experience, patient cooperation, and caries spread; these factors were controlled for as much as possible but not eliminated. Although all procedures were performed by the same experienced operator to ensure treatment standardization, this may have introduced operator-related bias. Finally, the relatively short follow-up period (12 months) may also limit the ability to evaluate long-term outcomes. Longer follow-up periods may provide more robust information regarding the long-term prognosis of IPT and DPC in primary molars. More clinical studies with larger sample sizes and longer follow-up periods are needed to better elucidate the long-term prognosis of these treatment methods.

As no statistically significant difference was observed between IPT and DPC, the null hypothesis was not rejected. Maintaining the health and function of the primary pulp is essential for preserving arch integrity, ensuring normal exfoliation, and supporting the proper eruption of permanent successors. The high clinical and radiographic success rates observed for both IPT and

DPC with MTA support the use of minimally invasive treatment strategies in pediatric dentistry. Furthermore, the prospective design and combined clinical and radiographic follow-up strengthen the reliability of the findings. These results provide valuable clinical evidence to support decision-making in the management of deep carious lesions in primary molars.

Future research should focus on well-designed prospective studies with larger sample sizes to better evaluate the comparative effectiveness of vital pulp therapy approaches in primary teeth. In addition, studies incorporating standardized clinical protocols and longer follow-up periods would provide more robust evidence on long-term outcomes. Further research may also explore the influence of clinical variables, such as lesion characteristics and patient-related factors, on treatment success.

Conclusions

Within the limitations of this study, IPT and DPC using MTA demonstrated high success rates. IPT should be considered the first-line treatment for deep carious primary molars, while DPC may serve as a viable alternative in cases of controlled pulp exposure with proper case selection.

Abbreviations

VPT	Vital pulp therapy
IPT	Indirect pulp treatment
DPC	Direct pulp capping
MTA	Mineral Trioxide Aggregate
ICDAS	International Caries Detection and Evaluation System
PDL	Periodontal ligament

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None.

Authors' contributions

Author Contributions: SK: conception and design of the study, literature search, experimental development, data acquisition, data analysis and interpretation, manuscript drafting. ÖBS: literature search, data analysis and interpretation, manuscript drafting, writing/editing the manuscript. AIC and FTÖ: conception and design of the study, experimental development, data analysis and interpretation, manuscript drafting, writing/editing the manuscript. All authors approved the final manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethics committee approval was received from the Ankara University Faculty of Dentistry Research Ethics Committee (Number: 07/07, Approval date: 17.04.2019). Written informed consent to participate was obtained from the parents or legal guardians of all participants prior to inclusion in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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