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Radiographic Dentinal Bridge Formation and Clinical Outcome Discordance after Calcium Silicate Pulpotomy in Primary Molars: A 12-Month Secondary Analysis

Tanzila Ferdous,[1] Md. Masud Rana,[2] Tanjiba Manjur,[3] Saosun Binta Rob,[4] Shammi Akter,[5] Shoma Saha[6]

[1]*Assistant Professor, Department of Children and Preventive Dentistry, Shaheed Suhrawardy Medical College & Hospital, Dhaka, Bangladesh.*
[2]*Assistant Professor, Department of Ophthalmology, National Institute of Ophthalmology and Hospital, Dhaka, Bangladesh.*
[3]*Associate Professor, Department of Dental Public Health, Sir Salimullah Medical College & Mitford Hospital, Dhaka, Bangladesh.*
[4]*Assistant Professor & Head, Department of Pediatric Dentistry, Dhaka Community Medical College , Dhaka, Bangladesh.*
[5]*Assistant Professor, Department of Pediatric Dentistry, Dhaka Dental College & Hospital, Dhaka, Bangladesh.*
[6]*Junior Consultant, Department of Pediatric Dentistry, Dhaka Dental College & Hospital, Dhaka, Bangladesh.*
Corresponding Author: *Dr. Tanzila Ferdous, Assistant Professor, Department of Pediatric Dentistry, Shaheed Suhrawardy Medical College & Hospital, Dhaka, Bangladesh*

Abstract
Introduction: *Dentinal bridge formation is commonly used as a radiographic marker of pulpal repair after vital pulp therapy. However, its relationship with clinical outcome after Calcium Silicate pulpotomy in primary molars remains unclear.*
Aim of the study: *This study aimed to evaluate 12-month radiographic dentinal bridge formation and its aggregate relationship with clinical outcome after Mineral Trioxide Aggregate (MTA), and Biodentine pulpotomy in primary molars.*
Methods: *This secondary analysis used data from a quasi-randomized comparative clinical study conducted in the Department of* Pediatric Dentistry*, Bangladesh Medical University (BMU), Dhaka, Bangladesh. A total of 44 primary molars from children aged 4 to 8 years were included, with 22 teeth treated using MTA and 22 teeth treated using Biodentine. Clinical outcomes included pain and tenderness to percussion. Radiographic outcomes included dentinal bridge formation and pathological root resorption. The main endpoint was the 12-month relationship between clinical success and visible radiographic dentinal bridge formation. Data were summarized as frequency, percentage, mean, and standard deviation. Between-group comparisons were performed using the independent-samples t-test and Pearson's chi-square test, with $p<0.05$ considered statistically significant.*
Results: *At 12 months, clinical success was observed in 39 of 44 teeth, 88.6%, while visible radiographic dentinal bridge formation was observed in 20 of 44 teeth, 45.5%, giving an aggregate difference of 43.1 percentage points. Clinical success was 18 of 22 teeth, 81.8%, in the MTA group and 21 of 22 teeth, 95.5%, in the Biodentine group, $p=0.154$. Dentinal bridge formation was present in 8 of 22 MTA-treated teeth, 36.4%, and 12 of 22 Biodentine-treated teeth, 54.5%, $p=0.226$. Pathological root resorption was uncommon, occurring in 1 of 44 teeth, 2.3%.*
Conclusion: *Clinical success was substantially more frequent than visible radiographic dentinal bridge formation at 12 months. Dentinal bridge formation should be interpreted as a supportive healing marker, not as a standalone indicator of clinical success.*
Keywords: *Pulpotomy; Dentinal bridge; Primary molars; Mineral Trioxide Aggregate; Biodentine*

I. INTRODUCTION

Pulpotomy remains a central vital pulp therapy in pediatric dentistry because it preserves cariously exposed primary molars until their physiological exfoliation, maintaining arch integrity, mastication, speech, and esthetics. The biological goal is not only symptom control, but preservation of radicular pulp vitality after removal of the inflamed coronal pulp. Traditional medicaments such as formocresol were widely used for decades, but concerns about tissue toxicity and systemic safety shifted clinical interest toward biocompatible and bioactive materials. Contemporary evidence now favors calcium silicate-based materials because they provide an alkaline environment, acceptable sealing ability, bioactivity, and potential stimulation of reparative hard-tissue formation. Systematic reviews have repeatedly identified Mineral Trioxide Aggregate (MTA), as a high-performing

pulpotomy medicament in primary teeth, while newer materials such as Biodentine have been developed to improve handling, property setting time, color stability, and mechanical performance (1,2).

Clinical trials comparing MTA, Biodentine, and related calcium silicate materials generally report high clinical success in primary molar pulpotomy. Kusum et al. evaluated MTA, Biodentine, and propolis, and reported favorable clinical and radiographic outcomes for both calcium silicate materials (3). Guven et al. compared several calcium silicate-based agents and found high success rates across groups during follow-up (4). El Meligy et al. reported 100% clinical success for Biodentine and formocresol pulpotomy at 12 months, with similarly high radiographic success (5). Ahuja et al. reported better outcomes for Biodentine and MTA than formocresol over a 9-month period, while Eshghi et al. found comparable clinical and radiographic performance between MTA and Biodentine in primary mandibular second molars (6,7). More recent evidence remains consistent. Koruyucu et al. compared calcium silicate-based materials in primary molar pulpotomies, and Gisour et al. reported 100% clinical success at 6 and 12 months with formocresol, Portland cement, and NeoMTA Plus, while radiographic success rates were slightly lower (8,9). These findings show that clinical symptom control after pulpotomy is often high, but radiographic findings may not follow the same frequency pattern.

Dentinal bridge formation is commonly used as a radiographic marker of pulpal repair after vital pulp therapy. Biologically, bridge formation suggests mineralized tissue deposition near the pulpotomy site; clinically, however, its meaning is less straightforward in primary teeth. Grewal et al. directly evaluated reactive dentin bridge formation after Biodentine pulpotomy, supporting its dentinogenic potential (10). The 2018 study by Nasrallah et al. and the 2022 study by Nasrallah and El Noueiri emphasized radiographic hard-tissue responses after Biodentine pulpotomy, including pulp canal obliteration and root-related changes (11,12). Such findings indicate that radiographic healing after pulpotomy is multidimensional, and a visible dentinal bridge is only one part of that response. Caruso et al. observed that clinical and radiographic outcomes after Biodentine and calcium hydroxide pulpotomies were not always equivalent, reinforcing the need to interpret radiographs alongside clinical signs rather than as isolated proof of success or failure (13).

Outcome assessment itself has become an important methodological issue in pulpotomy research. A recent scoping review by Elhamouly et al. found that pulpotomy trials using bioactive and biodegradable materials rely predominantly on clinical and radiographic criteria, while biological, inflammatory, histological, and microbiological endpoints are much less frequently assessed (14). Gerihan et al. extended this concern by incorporating matrix metalloproteinase assessment into a clinical trial of calcium silicate pulpotomy, illustrating that routine clinical and radiographic endpoints may not fully reflect underlying pulpal inflammation (15). Therefore, the relationship between visible radiographic dentinal bridge formation and clinical status deserves focused evaluation. The present secondary analysis examined 12-month radiographic dentinal bridge formation and clinical outcome after calcium silicate pulpotomy in primary molars, with attention to aggregate clinical-radiographic mismatch rather than material efficacy alone.

II. METHODS

This secondary analysis used data from a quasi-randomized comparative clinical study conducted in the Department of Pediatric Dentistry, Bangladesh Medical University(BMU), Dhaka, Bangladesh. The analysis focused on radiographic dentinal bridge formation and its relationship with clinical outcome after calcium silicate-based pulpotomy in primary molars. Children aged 4 to 8 years were included if they had a restorable primary molar with exposed vital pulp due to caries and clinical features consistent with reversible pulpitis. Teeth with features suggestive of irreversible pulp inflammation were excluded. Medically compromised children, uncooperative patients, and unrestorable teeth were also excluded. A total of 44 primary molars were analyzed, with 22 teeth treated using mineral Trioxide Aggregate(MTA), and 22 teeth treated using Biodentine. Participants were selected by purposive consecutive sampling. Treatment allocation was performed according to patient serial number, with odd-numbered cases assigned to the MTA group and even-numbered cases assigned to the Biodentine group. The baseline variables included age, gender, dental arch, tooth number, and location.

All procedures were performed under standard aseptic conditions. Local anesthesia was administered, and the operative field was isolated. Dental caries was removed using a sterile round bur with water spray. After complete caries removal, the pulp chamber was unroofed, and the coronal pulp was removed using a sterile excavator or round bur until the canal orifices were visible. The pulp chamber was irrigated with normal saline. Hemostasis was achieved by applying gentle pressure with a sterile cotton pellet moistened with normal saline. In the MTA group, MTA was mixed and placed over the radicular pulp stumps in an approximately 2 to 3 mm thick layer. In the Biodentine group, Biodentine was mixed according to the manufacturer's instructions and placed over the radicular pulp stumps in a similar 2 to 3 mm thickness. In both groups, the cavity was restored with glass ionomer cement, occlusion was checked, and a postoperative radiograph was taken as the baseline radiograph. Clinical and radiographic follow-up assessments were performed postoperatively, with the present manuscript focusing mainly on baseline and 12-month endpoint findings. Interim 3- and 6-month clinical findings were not used as main endpoint tables because no pain or tenderness to percussion was recorded in either group at those

scheduled assessments. However, 3- and 6-month radiographic dentinal bridge formation findings were retained descriptively to show the temporal pattern of bridge formation.

The clinical outcome variables were pain and tenderness to percussion. Clinical success at 12 months was defined as absence of both pain and tenderness to percussion. The radiographic outcome variables were dentinal bridge formation and pathological root resorption. Dentinal bridge formation was defined as the presence of a visible hard-tissue barrier at the pulpotomy site on follow-up radiograph. Pathological root resorption was recorded when abnormal root resorption was detected radiographically. The primary endpoint of this secondary analysis was the 12-month relationship between clinical success and radiographic dentinal bridge formation. Because several variables were available only as aggregate categorical counts, and not as tooth-level linked observations, the analysis emphasized group-level endpoint frequencies and between-group comparisons. Direct tooth-level agreement between individual clinical status and individual dentinal bridge status was therefore not treated as confirmatory. The clinical-radiographic relationship was interpreted as an aggregate mismatch between the frequency of clinical success and the frequency of visible dentinal bridge formation at 12 months.

Data were analyzed using SPSS version 26. Continuous variables were summarized as mean and standard deviation. Categorical variables were summarized as frequency and percentage. Mean age was compared between groups using the independent-samples t-test. Categorical variables were compared using Pearson's chi-square test. Rows with zero events in both groups were not statistically tested. A p-value of less than 0.05 was considered statistically significant. No multivariable model, time-to-event analysis, or tooth-level diagnostic agreement analysis was performed because the available dataset for some variables consisted of aggregate categorical counts rather than linked individual observations. Ethical approval was obtained from the Institutional Review Board of Bangladesh Medical University, BMU. The study procedure, expected benefits, possible risks, and follow-up requirements were explained to the legal guardians in understandable language. Written informed consent was obtained before treatment. Confidentiality was maintained by using study identification numbers, and data were used only for research purposes.

RESULTS

A total of 44 primary molars were included in the analysis, with 22 teeth treated with Mineral Trioxide Aggregate (MTA), and 22 teeth treated with Biodentine. The primary endpoint for this secondary analysis was radiographic dentinal bridge formation at 12 months, interpreted alongside clinical status at the same endpoint.

Table 1. Baseline demographic and tooth-related characteristics of the study sample

Variable	Overall, N=44	MTA, n=22	Biodentine, n=22	p-value
Age group, years				
4 years	12, 27.3%	5, 22.7%	7, 31.8%	0.210
5 years	17, 38.6%	10, 45.5%	7, 31.8%	
6 years	10, 22.7%	5, 22.7%	5, 22.7%	
7 years	3, 6.8%	0, 0.0%	3, 13.6%	
8 years	2, 4.5%	2, 9.1%	0, 0.0%	
Age, years, mean ± SD	5.23 ± 1.08	5.27 ± 1.12	5.18 ± 1.05	0.783
Gender				
Male	23, 52.3%	11, 50.0%	12, 54.5%	0.763
Female	21, 47.7%	11, 50.0%	10, 45.5%	
Dental arch				
Maxillary molars	8, 18.2%	3, 13.6%	5, 22.7%	0.434
Mandibular molars	36, 81.8%	19, 86.4%	17, 77.3%	
Tooth location				
Right side	20, 45.5%	15, 68.2%	5, 22.7%	**0.002**
Left side	24, 54.5%	7, 31.8%	17, 77.3%	
Tooth number				
Primary first molar, D	26, 59.1%	12, 54.5%	14, 63.6%	0.540
Primary second molar, E	18, 40.9%	10, 45.5%	8, 36.4%	

Footnote: Values are presented as n, %, unless otherwise stated. Percentages are calculated within the relevant column. MTA, Mineral Trioxide Aggregate; SD, standard deviation. The p-value for mean age was calculated using an independent-samples t-test. P-values for categorical variables were calculated using Pearson's chi-square test. Tooth number was categorized as primary first molar, D, and primary second molar, E.

The mean age was comparable between the MTA and Biodentine groups, 5.27 ± 1.12 years versus 5.18 ± 1.05 years, p=0.783. Sex distribution was also similar between groups. Mandibular molars represented most treated teeth, 36 of 44, 81.8%, and arch distribution did not differ significantly between groups, p=0.434. Tooth side distribution differed significantly, with right-sided teeth more frequent in the MTA group and left-sided teeth more frequent in the Biodentine group, p=0.002. The distribution of primary first and second molars was not significantly different between groups, p=0.540.

Table 2. Baseline and 12-month clinical status

Clinical parameter	Time point	Overall, N=44	MTA, n=22	Biodentine, n=22	p-value
Pain present	Baseline	13, 29.5%	6, 27.3%	7, 31.8%	0.741
Pain present	12 months	5, 11.4%	4, 18.2%	1, 4.5%	0.154
Tenderness to percussion present	Baseline	7, 15.9%	0, 0.0%	7, 31.8%	**0.004**
Tenderness to percussion present	12 months	5, 11.4%	4, 18.2%	1, 4.5%	0.154
Clinical success	12 months	39, 88.6%	18, 81.8%	21, 95.5%	0.154

Footnote: Values are presented as n, %. Percentages are calculated within each treatment group, except for the overall column. Clinical success was defined as absence of both pain and tenderness to percussion at the 12-month assessment. P-values were calculated using Pearson's chi-square test.

At baseline, pain was present in 13 teeth, 29.5%, with similar distribution between the MTA and Biodentine groups, p=0.741. Baseline tenderness to percussion differed significantly between groups, being absent in all MTA-treated teeth and present in 7 Biodentine-treated teeth, 31.8%, p=0.004. At the scheduled 12-month assessment, pain and tenderness to percussion were each recorded in 5 teeth overall, 11.4%. Clinical success at 12 months was observed in 39 of 44 teeth, 88.6%, including 18 MTA-treated teeth, 81.8%, and 21 Biodentine-treated teeth, 95.5%, p=0.154. Interim 3- and 6-month clinical data were not included in the main endpoint table because no pain or tenderness to percussion was recorded in either group at those scheduled assessments.

Table 3. Twelve-month radiographic outcomes

Radiographic parameter	Outcome definition	Overall, N=44	MTA, n=22	Biodentine, n=22	p-value
Dentinal bridge formation	Present	20, 45.5%	8, 36.4%	12, 54.5%	0.226
	Absent	24, 54.5%	14, 63.6%	10, 45.5%	
Pathological root resorption	Present	1, 2.3%	1, 4.5%	0, 0.0%	0.312
	Absent	43, 97.7%	21, 95.5%	22, 100.0%	

Footnote: Values are presented as n, %. Percentages are calculated within each treatment group, except for the overall column. P-values were calculated using Pearson's chi-square test.

At 12 months, radiographic dentinal bridge formation was observed in 20 of 44 teeth, 45.5%. Bridge formation was numerically higher in the Biodentine group, 12 of 22 teeth, 54.5%, than in the MTA group, 8 of 22 teeth, 36.4%, but the difference was not statistically significant, p=0.226. Pathological root resorption was uncommon, being observed in only one MTA-treated tooth, 4.5%, and in no Biodentine-treated teeth, p=0.312.

Table 4. Aggregate clinical-radiographic endpoint profile at 12 months

Endpoint indicator	Overall, N=44	Interpretation
Clinical success	39, 88.6%	Absence of both pain and tenderness to percussion
Clinical symptoms present	5, 11.4%	Pain and/or tenderness to percussion present
Presence of Dentinal bridge formation	20, 45.5%	Visible radiographic dentinal bridge formation
Absence of Dentinal bridge formation	24, 54.5%	No visible radiographic dentinal bridge formation
Pathological root resorption absent	43, 97.7%	No radiographic evidence of pathological root resorption
Pathological root resorption present	1, 2.3%	Radiographic pathological root resorption detected

Footnote: Values are presented as n, %. This table compares aggregate endpoint frequencies at 12 months. It does not represent a paired tooth-level cross-tabulation between clinical success and dentinal bridge status.

At the 12-month endpoint, the frequency of clinical success was substantially higher than the frequency of radiographic dentinal bridge formation. Clinical success was observed in 39 teeth, 88.6%, whereas visible dentinal bridge formation was observed in 20 teeth, 45.5%. Thus, the absolute difference between clinical success and visible radiographic dentinal bridge formation was 43.1 percentage points. This finding indicates that radiographic dentinal bridge formation was less frequently observed than favorable clinical status at the same follow-up point. Pathological root resorption was rare, supporting that absence of a visible radiographic dentinal bridge formation should be interpreted cautiously and not equated with treatment failure in isolation.

Table 5. Dentinal bridge formation during radiographic follow-up

Follow-up time	Overall, N=44	MTA, n=22	Biodentine, n=22	p-value
3 months	9, 20.5%	3, 13.6%	6, 27.3%	0.262
6 months	13, 29.5%	5, 22.7%	8, 36.4%	0.322
12 months	20, 45.5%	8, 36.4%	12, 54.5%	0.226

Footnote: Values are presented as n, %. Percentages are calculated within each treatment group, except for the overall column. P-values were calculated using Pearson's chi-square test.

Dentinal bridge formation increased progressively across follow-up. Overall dentinal bridge formation was 20.5% at 3 months, 29.5% at 6 months, and 45.5% at 12 months. Biodentine showed numerically higher dentinal bridge formation than MTA at each follow-up point, although none of the between-group differences reached statistical significance.

III. DISCUSSION

The present secondary analysis examined whether radiographic dentinal bridge formation paralleled clinical outcome after Calcium Silicate pulpotomy in primary molars. The main finding was an aggregate mismatch at the 12-month endpoint: clinical success was observed in 39 of 44 teeth, 88.6%, whereas visible radiographic dentinal bridge formation was observed in 20 of 44 teeth, 45.5%. The absolute difference between these two endpoint frequencies was 43.1 percentage points. This suggests that visible dentinal bridge formation, although biologically meaningful, should not be interpreted as a direct substitute for clinical success. In this study, the frequency of symptom-free teeth was nearly twice the frequency of teeth showing visible dentinal bridge formation, indicating that absence of a visible dentinal bridge on radiograph may not necessarily represent clinical failure.

The overall 12-month clinical success rate of 88.6% is consistent with the broader literature showing favorable clinical outcomes after Calcium Silicate-based pulpotomy in primary teeth, although it is slightly lower than some reports. Kusum et al. reported 100% clinical success for both MTA and Biodentine at 9 months, while El Meligy et al. reported 100% clinical success for Biodentine pulpotomy at 12 months (3,5). Similarly, Eshghi et al. found high clinical and radiographic success for both MTA and Biodentine, with no significant difference between the materials (7). More recent pooled evidence also supports high success rates for bioceramic pulpotomy materials. Neves et al. included 14 studies, 1128 primary molars, and 637 children, and found no statistically significant difference in clinical or radiographic success between first- and second-generation bioceramics across follow-up periods up to 24 months (16). This supports the present finding that both MTA and Biodentine produced generally favorable outcomes, without a statistically significant difference in clinical success.

The distinct contribution of this analysis is not the comparison between MTA and Biodentine, but the observation that clinical and radiographic endpoints behaved differently. Similar clinical-radiographic divergence has been reported by Kusum et al., who observed 100% clinical success in MTA and Biodentine groups, while radiographic success was lower, 92% for MTA and 80% for Biodentine (3). Caruso et al. also emphasized that radiographic failures may be detected even when clinical signs are absent, supporting the need to interpret radiographs together with clinical findings (13). Yucel and Sengul reported a comparable pattern in a randomized clinical trial of Calcium Silicate cements, with 12-month clinical success exceeding radiographic success for NeoPutty MTA, ProRoot MTA, and TheraCal PT (17). For ProRoot MTA, clinical success was 97.4%, while radiographic success was 84.2%; for TheraCal PT, clinical success was 91.9%, while radiographic success was 67.6%. These findings support the present interpretation that clinical and radiographic outcomes should be reported separately and not treated as interchangeable.

However, the magnitude of mismatch in this study was larger than in many previous reports. A likely explanation is the outcome definition. Many studies define radiographic success broadly as absence of internal resorption, external resorption, furcation radiolucency, periapical pathology, pathological mobility, or widening of the periodontal ligament space. In contrast, this analysis focused specifically on visible dentinal bridge formation. Dentinal bridge formation is a narrower and more demanding radiographic marker than general radiographic success. Bastos et al. found high clinical and radiographic success for Biodentine across vital pulp therapy procedures, but their radiographic endpoint reflected overall treatment success rather than isolated dentinal bridge formation (18). Laser et al. similarly reported very high pooled clinical and radiographic success for Biodentine compared with Calcium Hydroxide, but again, radiographic success was measured as a composite outcome (19). Therefore, the lower dentinal bridge formation frequency in the present study should not be read as poor treatment performance; rather, it reflects the specific radiographic marker selected for this secondary analysis.

Dentinal bridge formation increased progressively during follow-up, from 20.5% at 3 months to 29.5% at 6 months and 45.5% at 12 months. This temporal pattern is biologically plausible, because reparative hard-tissue deposition is expected to develop gradually rather than immediately after pulpotomy. Grewal et al. directly evaluated reactive dentin bridge formation after Biodentine pulpotomy and supported the dentinogenic potential of Biodentine (10). In the present analysis, Biodentine showed numerically higher dentinal bridge formation than MTA at all follow-up points: 27.3% versus 13.6% at 3 months, 36.4% versus 22.7% at 6 months, and 54.5% versus 36.4% at 12 months. None of these differences reached statistical significance. This pattern is compatible with the meta-analysis by Neves et al., which found comparable outcomes between MTA and Biodentine despite practical advantages of newer bioceramics, such as improved handling property and setting characteristics (16).

The present Biodentine group also showed numerically higher 12-month clinical success than the MTA group, 95.5% versus 81.8%, but this difference was not statistically significant. This is in line with Eshghi et al.,

who found similar long-term performance for MTA and Biodentine in primary mandibular second molars (7). It also aligns with the broader evidence that material superiority is not always consistent across trials. Ahuja et al. reported a clearer radiographic advantage for Biodentine over MTA and formocresol, whereas Kusum et al. reported higher radiographic success for MTA than Biodentine (3,6). Such variation may reflect differences in case selection, diagnostic criteria, restorative protocol, radiographic scoring, follow-up duration, operator technique, and definitions of failure. Therefore, the present numerical advantage for Biodentine should be interpreted cautiously, especially given the modest sample size and the absence of statistical significance.

Pathological root resorption was uncommon, occurring in only 1 of 44 teeth, 2.3%, at 12 months. This supports the favorable safety profile of both calcium silicate materials. Guagnano et al. evaluated Biodentine pulpotomy using a composite clinical-radiographic outcome score and reported high success at 6 and 12 months, with assessment of pain to percussion, mobility, radiolucency, and pathological root resorption (20). El Meligy et al. also reported very high radiographic success after Biodentine pulpotomy and did not treat pulp canal obliteration as failure (5). In the present study, the low rate of pathological root resorption strengthens the interpretation that absent visible dentinal bridge formation should not be equated with radiographic failure in isolation.

Limitations of The Study

This study had a small sample size, with 22 teeth in each treatment group, which limited statistical power for detecting between-group differences. Some variables were available only as aggregate categorical counts rather than tooth-level linked observations, so direct clinical-radiographic agreement analysis could not be performed. Radiographic assessment of dentinal bridge formation may also have been influenced by image quality, angulation, material radiopacity, and observer interpretation.

IV. CONCLUSION

Clinical success after Calcium Silicate pulpotomy in primary molars was high at 12 months, while visible radiographic dentinal bridge formation was observed in fewer than half of the treated teeth. Biodentine showed numerically higher clinical success and dentinal bridge formation than MTA, but the differences were not statistically significant. The findings suggest that dentinal bridge formation should be interpreted as a supportive radiographic healing marker rather than a standalone indicator of clinical success or failure.

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