

RADIOGRAPHIC EVALUATION OF RADICULAR DENTIN THICKNESS AND FURCATION DENTIN DENSITY OF IMMATURE FIRST PERMANENT MOLARS AFTER APEXOGENESIS

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Abstract

Background: Vital pulp therapy (VPT) via apexogenesis preserves pulpal vitality and promotes root maturation in immature permanent teeth. While Mineral Trioxide Aggregate (MTA) remains the benchmark medicament, novel bioactive agents such as melatonin offer anti-inflammatory, antioxidant, and dentinogenic benefits. This randomized clinical trial radiographically evaluated radicular dentin thickness and furcation dentin density in immature mandibular first permanent molars following apexogenesis using MTA, melatonin, or a combination of both. **Methods:** Forty-five young mandibular first permanent molars in children aged 6–8 years were randomly allocated (1:1:1) into three equal groups ($n = 15$ each): Group A (MTA), Group B (Melatonin), and Group C (MTA + Melatonin). Standardized apexogenesis procedures were performed under rubber dam isolation. Standardized digital periapical radiographs were obtained at baseline and at 1-, 3-, 6-, 9-, and 12-month recalls. Using ImageJ software, radicular dentin thickness (5 mm apical to the CEJ) and furcation dentin density (calibrated 256 grey-scale level) were measured. Data were analyzed using repeated-measures ANOVA and non-parametric tests ($p < 0.05$). **Results:** All groups exhibited progressive, statistically significant increases in radicular dentin thickness ($p < 0.01$) and furcation dentin density ($p < 0.001$) over 12 months. At 12 months, distal root dentin thickness increased by 18.9% (MTA), 15.1% (Melatonin), and 22.3% (Mixed), and mesial root dentin thickness increased by 20.0% (MTA), 21.7% (Melatonin), and 27.4% (Mixed), while furcation dentin density increased by 27.5%, 27.3%, and 25.1%, respectively. Intergroup comparisons revealed no statistically significant differences in the percentage change of dentin thickness or furcation density across all three groups. **Conclusion:** Melatonin demonstrates comparable bio-inductive efficacy to MTA in promoting root edification and furcation dentin deposition, making it a viable alternative or additive for apexogenesis in immature permanent teeth.

Keywords: Apexogenesis, Dentin Density, Melatonin, Mineral Trioxide Aggregate, Vital Pulp Therapy.

INTRODUCTION

Maintaining pulp vitality in immature permanent teeth affected by deep caries or trauma is a major clinical challenge in pediatric endodontics. When pulpal damage occurs before

complete root formation, conventional root canal treatment diminishes pulp vitality, proprioception, and structural integrity, predisposing the tooth to fracture. Vital pulp therapy (VPT) specifically full pulpotomy (apexogenesis) aims to preserve residual radicular pulp tissue to promote physiological root development, apical closure, and an optimal crown-root ratio (**Chen et al., 2019; Sabeti et al., 2021; AlShareef, 2023**). Successful apexogenesis relies on maintaining healthy hard-tissue edification, which can be evaluated radiographically by measuring the thickness of radicular dentin and the density of dentin at the furcation area over time. Mineral Trioxide Aggregate (MTA) is considered a benchmark bio-inductive material for VPT due to its biocompatibility, superior sealing ability, high compressive strength, and capacity to stimulate dentine bridge formation and hard tissue regeneration (**Torabinejad et al., 1995; Moretti et al., 2008; Chandak et al., 2021**). However, traditional MTA has inherent limitations, such as prolonged setting time, handling difficulties, potential tooth discoloration, and high cost (**Schwendicke et al., 2015; Pushpalatha et al., 2022**).

Recently, melatonin (N-acetyl-5-methoxy-tryptamine) has emerged as a promising alternative capping agent. Recognized for its potent anti-inflammatory, antioxidant, and cytoprotective properties, melatonin modulates pulpal inflammation by suppressing the TLR4/NF- κ B signaling pathway (**Li et al., 2015**). Furthermore, melatonin plays a key physiological role in hard-tissue regulation; it promotes osteoblast and odontoblast proliferation and differentiation, enhances dentin sialoprotein (DSP) expression, and regulates bone mineral density while inhibiting osteoclastogenesis (**Liu et al., 2017; Chan et al., 2022; Gupta et al., 2024**). In vitro and animal studies demonstrate that melatonin facilitates odontogenic differentiation of human dental pulp cells, promoting mineralized matrix formation comparable to MTA (**Guerrero-Gironés et al., 2020; Li et al., 2020**).

Despite these favorable biological characteristics, there is a lack of clinical research evaluating melatonin's regenerative performance in human teeth. Therefore, this study aims to clinically and radiographically evaluate and compare the pulpal response specifically focusing on the thickness of radicular dentin and the density of dentin at the furcation area in immature permanent first molars following apexogenesis using melatonin versus MTA.

MATERIALS AND METHODS

Study Design and Ethical Approval

This randomized clinical trial (RCT) evaluated 45 young mandibular permanent first molars in children attending the Pediatric Dentistry Outpatient Clinic, Suez Canal University. The protocol was approved by the Institutional Research Ethical Committee (REC No. 569/2022) and registered on ClinicalTrials.gov (NCT06372561). Written informed consent was obtained from parents or legal guardians prior to enrollment.

Sample Size Calculation

Sample size was calculated using G*Power software (version 3.1.9.6); (**Guerrero-Gironés et al., 2020**). For a two-way repeated-measures ANOVA across three treatment

groups and six follow-up timepoints, a minimum of 36 molars was required to achieve 95% power ($1 - \beta = 0.95$), an effect size of 0.25 ($\alpha = 0.05$), and a partial η^2 of 0.06. Factoring in an anticipated 25% dropout rate, 45 molars were enrolled.

Randomization and Group Allocation

Eligible molars were randomly assigned in a 1:1:1 ratio into three treatment groups ($n = 15$ each) using computer-generated random numbers (www.randomizer.org) and a paper lottery (Kahan et al., 2015):

- **Group A (MTA):** Treated with Mineral Trioxide Aggregate mixed with saline (setting time: 15 min).
- **Group B (Melatonin):** Treated with 20 mg melatonin powder mixed with 0.1 mL saline to a paste consistency (setting time: 5 min) (Rostom et al., 2020).
- **Group C (Mixed):** Treated with a combination of MTA powder and 10 mg melatonin powder mixed with 0.1 mL saline (setting time: 15 min).

Clinical Apexogenesis Procedure

Following pulp vitality confirmation via cold pulp testing, inferior alveolar nerve block was administered using 2% lidocaine with 1:80,000 adrenaline, positioned slightly lower and more posteriorly for pediatric anatomy (Khalil, 2014). Under rubber dam isolation, coronal pulp tissue was amputated using a No. 3 round bur and a high-speed non-end-cutting Endo-Z bur with water cooling (El-Khodary et al., 2014; AAPD, 2023). Hemostasis was achieved using 5% NaOCl-drenched cotton pellets applied in 30-second increments up to 10 minutes (AAE, 2021). The assigned dressing material was applied over pulp stumps as a sub-base (0.5–2 mm thickness) and condensed with moist cotton pellets (Daniele, 2017). Cavities were sealed with glass ionomer cement (Fuji IX) and restored with composite resin.

Follow-Up and Radiographic Assessments

Radiographic evaluations occurred at baseline, 1, 3, 6, 9, and 12 months to monitor changes in radicular dentin thickness and furcation dentin density. Standardized periapical radiographs were acquired at each recall using the parallel technique (Rinn XCP holder, size 2 imaging plates, 70 kV, 7 mA, 0.125 s (Smail et al., 2018). ImageJ software (v1.44p; Mahfouz et al., 2021) was used by a blinded examiner at two-week intervals to evaluate:

- **Thickness of Radicular Dentin:** A vertical reference line was drawn 5 mm apical to the CEJ on mesial and distal roots (Line A). Radicular dentin thickness (Line B) was measured horizontally from the terminal point of Line A to the lateral root canal wall (Fig. 1).
- **Density of Dentin at Furcation Area:** Densitometric analysis of mid-furcation dentin adjacent to the material was performed by measuring a 2 cm × 2 cm region of interest calibrated on a 256 grey-scale level (0 = completely radiolucent, 256 = completely radiopaque) (Fig. 2).

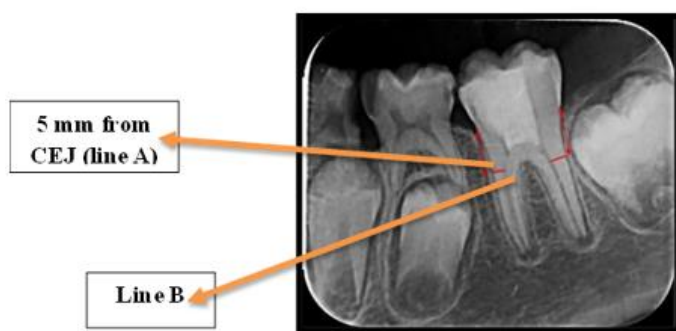


Figure (1): Radiometric analysis of radicular dentin thickness (5mm from CEJ) in both mesial and distal roots



Figure (2): Densitometric analysis of furcation dentin density through 2*2 cm square from the base of radiopaque material

Statistical Analysis

Data were analyzed using SPSS v26.0 (IBM Corp.). Normality was confirmed using the Shapiro-Wilk test. Continuous parametric variables were analyzed using two-way repeated-measures ANOVA, one-way ANOVA, and paired t-tests, followed by Duncan's multiple range tests (DMRTs). Nonparametric data were evaluated using Kruskal-Wallis tests. Cumulative material survival was determined via Kaplan-Meier analysis. Pearson's correlation coefficients were visualized using a red-blue correlation heatmap ($p < 0.05$).

RESULTS

Demographic data:

- Age and Gender distribution of the patients

- The age of patients in the study was 6-8 years old, with mean age almost 7 years.
- Regarding gender, the study included 45 patients (26 females and 19 males).

There was no statistically significant difference between the gender or the number of females and males in the total study sample or within each group as seen in Table (1) and Fig (3).

Table (1): Age and gender distribution in the three study groups

Gender and Age per groups						
	Gender		Chi square P value	Mean Age		T test P value
	Male	Female		Male	Female	
MTA	6 (40%)	9 (60%)	0.438ns	7.3 (0.7)	7.1(0.69)	0.831ns
Melatonin	5 (33.3%)	10 (66.7%)	0.196ns	7.0 (0.65)	7.2(0.55)	0.874ns
Mixed	8(53.7%)	7(46.7%)	0.796ns	7.2(0.48)	7.1(0.53)	0.953ns
Total	19 (42.2%)	26(57.8%)	0.296ns			
Chi square P value	0.688	0.760				

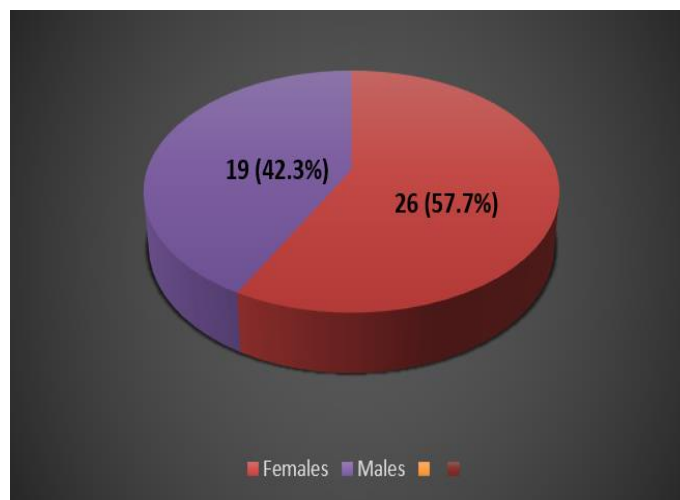


Fig (3): Pie chart representing gender distribution among the patients

Thickness of radicular dentin

Changes of thickness of radicular dentin in MTA, Melatonin and Mixed groups and comparison between the 3 groups regarding thickness of radicular dentin in distal and mesial roots:

MTA group:

The Thickness of radicular dentin of MTA group in lateral surface of distal root (5 mm from CEJ) at different times of investigation (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded an average ($\pm$ SD) of $1.3\pm0.11\text{mm.}$, $1.3\pm0.12\text{mm.}$, $1.4\pm0.13\text{mm.}$, $1.4\pm0.14\text{mm.}$, $1.5\pm0.12\text{mm.}$, and $1.5\pm0.12\text{mm.}$; respectively and are presented in Table (2).

The least thickness of radicular dentin in MTA group in distal root was recorded at immediate post-operatively with value 1.3mm, and the highest value was at 12 M. follow-up with value 1.5 mm, The difference between immediate post-operative and 12 M. follow-up in distal root was highly significant ($P<0.001$) with percentage of change 18.9% at the last follow-up (12 M.).

Furthermore, the thickness of radicular dentin of MTA group in lateral surface of mesial root (5 mm from CEJ) at different time of investigation (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded an average ($\pm$ SD) of $1.3\pm0.20\text{mm.}$, $1.3\pm0.19\text{mm.}$, $1.4\pm0.18\text{mm.}$, $1.4\pm0.16\text{mm.}$, $1.5\pm0.15\text{mm.}$, and $1.5\pm0.14\text{mm.}$; respectively are presented in Table (2).

The least thickness of radicular dentin of MTA group value in Mesial root was recorded at immediate post-operatively with value 1.3mm. and the highest was at 12 M. with value 1.5mm., The difference between immediate post-operative and 12 M. in Mesial was significant ($P=0.002$) with percentage of change 20.0% at the last follow-up (12 M.).

Melatonin group:

The Thickness of radicular dentin of Melatonin group in lateral surface of distal root (5 mm from CEJ) at different times of investigation (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded a mean ($\pm$ SD) of 1.3 ± 0.19 , 1.3 ± 0.22 mm., 1.4 ± 0.21 mm., 1.4 ± 0.24 mm., 1.4 ± 0.25 mm., and 1.5 ± 0.24 mm.; respectively and are presented in Table (2).

The least thickness of radicular dentin in Melatonin group in distal root was recorded at immediate post-operatively with value 1.3mm, and the highest value was at 12 M. follow-up with value 1.5 mm, The difference between immediate post-operative and 12 M. follow-up in distal root was non-significant ($P=0.250$) with percentage of change 15.1% at the last follow-up (12 M.).

Furthermore, the thickness of radicular dentin of Melatonin group in lateral surface of mesial root (5 mm from CEJ) at different time of investigation (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded an average ($\pm$ SD) of 1.2 ± 0.34 mm., 1.3 ± 0.30 mm., 1.3 ± 0.30 mm., 1.3 ± 0.29 mm., 1.4 ± 0.28 mm., and 1.4 ± 0.27 mm. ; respectively are presented in Table (2).

The least thickness of radicular dentin of Melatonin group value in Mesial root was recorded at immediate post-operatively with value 1.2mm. and the highest was at 12 M. with value 1.4mm., The difference between immediate post-operative and 12 M. in Mesial was non-significant ($P=0.256$) with percentage of change 21.7% at the last follow-up (12 M.).

Mixed group (MTA+Melatonin):

The Thickness of radicular dentin of Mixed group in lateral surface of distal root (5 mm from CEJ) at different times of investigations (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded a mean ($\pm$ SD) of 1.4 ± 0.15 mm, 1.4 ± 0.23 mm, 1.4 ± 0.19 mm, 1.5 ± 0.21 mm, 1.6 ± 0.18 mm, and 1.7 ± 0.17 mm.; respectively and are presented in Table (2)

The least thickness of radicular dentin in Mixed group in distal root was recorded at immediate post-operatively with value 1.4mm, and the highest value was at 12 M. follow-up with value 1.7mm, the difference between immediate post-operative and 12 M. follow-up in distal root was a highly significant difference ($P<0.001$) with percentage of change 22.3% at the last follow-up (12 M.).

Furthermore, the thickness of radicular dentin of Mixed group in lateral surface of mesial root (5 mm from CEJ) at different time of investigations (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded an average ($\pm$ SD) of 1.3 ± 0.20 mm, 1.4 ± 0.20 mm, 1.5 ± 0.24 mm, 1.5 ± 0.29 mm, 1.6 ± 0.12 mm, and 1.7 ± 0.09 mm; respectively are presented in Table.

The least thickness of radicular dentin of Mixed group value in Mesial root was recorded at immediate post-operatively with value 1.4 mm. and the highest was at 12 M. with value 1.7mm., The difference between immediate post-operative and 12 M. in Mesial was a

highly significant ($P=0.001$) with percentage of change 27.4% at the last follow-up (12 M.).

At immediate post-operative, 1-month, 3-months, 6-months, 9-months and 12-months follow-ups, there was a highly significant difference between the thickness of radicular dentin of distal roots' averages of the 3 groups ($P<0.001^{***}$). There was a highly significant difference between the thickness of radicular dentin of mesial roots' averages of the 3 groups at these follow-ups ($P<0.001^{***}$).

Table (2): Comparison between thickness of radicular dentin in the three study groups in both distal and mesial roots

Group	Group-1 MTA								%	Paired t-test
	Follow up	Distal			%	Mesial				
		Mean	SD	DMRT		Mean	SD	DMRT		
Group-1 MTA	Immediate	1.3	0.11	e	0.0	1.3	0.20	de	0.0	0.604 ns
	F1	1.3	0.12	cde	6.3	1.3	0.19	cde	5.5	
	F2	1.4	0.13	bcd	10.2	1.4	0.18	bc	9.6	
	F3	1.4	0.14	abc	12.6	1.4	0.16	abc	12.4	
	F4	1.5	0.12	ab	16.9	1.5	0.15	ab	16.0	
	F5	1.5	0.12	ab	18.9	1.5	0.14	a	20.0	
	ANOVA RM	<0.001***				0.002**				
Group	Group-2 Melatonin								%	Paired t-test
	Follow up	Distal			%	Mesial				
		Mean	SD	DMRT		Mean	SD	DMRT		
Group-2 Melatonin	Immediate	1.3	0.19	ab	0.0	1.2	0.34	b	0.0	0.148 ns
	F1	1.3	0.22	ab	4.5	1.3	0.30	ab	9.5	
	F2	1.4	0.21	ab	5.8	1.3	0.30	ab	12.2	
	F3	1.4	0.24	ab	8.6	1.3	0.29	ab	14.5	
	F4	1.4	0.25	a	10.8	1.4	0.28	ab	18.5	
	F5	1.5	0.24	a	15.1	1.4	0.27	a	21.7	
	ANOVA RM	0.250 ns				0.256 ns				
Group	Group-3 Mixed								%	Paired t-test
	Follow up	Distal			%	Mesial				
		Mean	SD	DMRT		Mean	SD	DMRT		
Group-3 Mixed	Immediate	1.4	0.15	f	0.0	1.3	0.20	bcd	0.0	0.044*
	F1	1.4	0.23	ef	1.2	1.4	0.20	def	9.9	
	F2	1.4	0.19	def	5.0	1.5	0.24	bcde	14.3	
	F3	1.5	0.21	cde	9.1	1.5	0.29	bcd	18.3	
	F4	1.6	0.18	abc	15.1	1.6	0.12	ab	22.9	
	F5	1.7	0.17	a	22.3	1.7	0.09	a	27.4	
	ANOVA RM	<0.001***				0.001***				
Two-way repeated measure ANOVA										
Group	<0.001***									
Time	<0.001***									
Group*Time	0.758 ns									

*, **, *** significant at $p<0.05$, $p<0.01$, $p<0.001$; ns, nonsignificant

The Density of furcation dentin:

The density of furcation dentin in MTA, Melatonin and Mixed groups and comparison between the three study groups regarding the furcation dentin:

MTA group:

The Density of furcation dentin MTA group at different times of investigation (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded an average ($\pm$ SD) of 145.3 $\pm$ 26.11mm., 168.5 $\pm$ 23.40mm., 169.9 $\pm$ 20.66mm., 174.5 $\pm$ 14.85mm., 179.8 $\pm$ 17.2mm., and 185.3 $\pm$ 24.76mm.; respectively and is presented in Table (3).

The lowest Density of furcation dentin value in MTA group was recorded at immediate post-operatively with value 145.3 mm. and the highest was at 12 M. with value 185.3mm. The difference between immediate post-operative and 12 M. was highly significant ($P<0.001$) with percentage of change 27.5% at the last follow-up (12M.).

Melatonin group:

The Density of furcation dentin Melatonin group at different times of investigation (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded an average ($\pm$ SD) of 132.9 $\pm$ 25.65mm., 150.8 $\pm$ 25.95mm., 168.1 $\pm$ 19.87mm., 175.5 $\pm$ 19.14mm., 180.8 $\pm$ 21.35mm., and 185.0 $\pm$ 22.04mm; respectively and is presented in Table (3).

The lowest Density of furcation dentin value in Melatonin group was recorded at immediate post-operatively with value 132.9 mm. and the highest was at 12 M. with value 185.0 mm., The difference between immediate post-operative and 12 M. follow-up intervals was highly significant ($P<0.001$) with percentage of change 27.3% at the last follow-up (12M.).

Mixed group (MTA+Melatonin):

The of Density of furcation dentin in Mixed group at different times of investigation (immediate post-operative, 1 M., 3 M., 6 M., 9 M., 12 M.) recorded an average ($\pm$ SD) of 135.8 $\pm$ 38.60mm., 150.5 $\pm$ 41.71mm., 159.2 $\pm$ 43.83mm., 174.3 $\pm$ 50.55mm., 178.3 $\pm$ 51.95mm., and 181.8 $\pm$ 53.00mm.; respectively and is presented in Table (3).

The lowest density of furcation dentin value in Mixed group was recorded in immediate post-operative with a value of 135.8 mm. and the highest was at 12 M. with a value of 181.8 mm. The difference between immediate post-operative and 12 M. follow-up intervals was highly significant ($p<0.001$) with percentage of change 25.1% at the last follow-up (12M.).

At immediate post-operative, 1-month, 3-months, 6-months, 9-months and 12-months follow-ups, there was a highly significant difference in density of furcation dentin between the 3 study groups ($p<0.001^{***}$).

Table (3): The changes in density of furcation dentin between the 3 groups

Group	Follow up	Density of furcation dentin			ANOVA RM
		Mean	SD	% of change	
Group-I MTA	Immediate-post	145.3	26.11	0.0	<0.001***
	F1	168.5	23.40	16.0	
	F2	169.9	20.66	16.9	
	F3	174.5	14.85	20.1	
	F4	179.8	17.20	23.7	
	F5	185.3	24.76	27.5	
Group-II Melatonin	Immediate-post	132.9	25.65	0.0	<0.001***
	F1	150.8	25.95	3.8	
	F2	168.1	19.87	15.7	
	F3	175.5	19.14	20.8	
	F4	180.8	21.35	24.4	
	F5	185.0	22.04	27.3	
Group-III Mixed	Immediate-post	135.8	38.60	0.0	<0.001***
	F1	150.5	41.71	3.6	
	F2	159.2	43.83	9.6	
	F3	174.3	50.55	20.0	
	F4	178.3	51.95	22.7	
	F5	181.8	53.00	25.1	
	Two-way Repeated ANOVA				
Group	0.015*				
Time	<0.001***				
Group X Time	0.632 ns				

*, **, *** significant at $p < 0.05$, $p < 0.01$, $p < 0.001$; ns, nonsignificant at $p > 0.05$

DISCUSSION

Preservation of the first permanent molar is critical for mandibular and maxillary growth and establishing proper occlusion in children (**Abuelniel et al., 2019**). Vital pulp therapy (VPT) aims to maintain pulp vitality, functionality, and render the tooth asymptomatic (**Abuelniel et al., 2019**). Selecting an ideal pulpotomy dressing agent in immature permanent teeth supports continuous root development (apexogenesis), provides tissue regeneration, and minimizes cytotoxicity (**Chen et al., 2019; AAPD, 2023**). Melatonin has recently emerged as a promising agent due to its anti-inflammatory, immunomodulatory, and antioxidant properties, promoting human dental pulp stem cell (HDPSC) migration and proliferation (**Naeimi et al., 2024; Sanidhya et al., 2025**).

In the present study, melatonin was investigated as a novel VPT agent and compared against Mineral Trioxide Aggregate (MTA), the gold standard reference material (**Guerrero-Girones et al., 2020; Kermeoglu et al., 2021; Patil et al., 2022; Lall, 2025; Pusa et al., 2025**). The clinical trial selected healthy children aged 6–8 years presenting with vital carious exposed mandibular first permanent molars with incompletely formed roots (**El-Khodary et al., 2014; Taha et al., 2017; Elchaghaby et al., 2020; Murray, 2022**). Mandibular molars were chosen to avoid anatomical superimpositions and allow accurate radiographic interpretations (**Aminabadi et al., 2008; Şendişçi et al., 2025**).

Cold vitality testing confirmed pulp vitality (Igna et al., 2022; Afkhami et al., 2024). Standardized rubber dam isolation, 5% NaOCl hemostasis within a 5-minute limit, a 0.5–2 mm dressing thickness, a Fuji IX base, and a definitive composite resin restoration were utilized across treatment groups: Group I (MTA), Group II (Melatonin), and Group III (Mixed MTA + Melatonin) (Yahya et al., 2024).

Standardized direct digital periapical radiographs and ImageJ photometric analysis were employed to quantify structural pulp response (AAE, 2021; Kurylo et al., 2024). Focus was directed toward assessing hard tissue deposition, specifically the **thickness of radicular dentin** and the **density of dentin at the furcation area**.

Regarding the **thickness of radicular dentin**, all successful cases across the three study groups exhibited a consistent increase over the 12-month follow-up period (ESE, 2019). Percentage increases in radicular dentin thickness were almost similar across groups, showing no statistically significant differences. This dentin thickens reflects continued root wall development and dentinogenesis after pulpotomy.

Similarly, evaluation of the **density of dentin at the furcation area** demonstrated an overall increase in furcation dentin density in all successful cases across the three groups, reflecting overall treatment success and mineralized tissue deposition. The percentage increases in furcation dentin density were comparable among the groups, with no statistically significant differences observed.

Concerning the thickness of radicular dentin and density of furcation dentin, all cases in the three study groups demonstrated an increase in radicular dentin thickness and enhancement in density of furcation dentin, except for two the failed cases, which were excluded due to clinical failure and stoppage of changes in the affected root radiographically. The percentages of changes were similar across groups, with no statistically significant differences observed. These radiographic findings may be attributed to its high alkalinity, facilitates the release of growth factors from the surrounding dentin (Kermeoglu F. et al., 2021).

These structural outcomes in radicular dentin thickness and furcation dentin density—alongside root length increase and apical width reduction—are attributed to synergistic mechanisms of tissue mineralized matrix **deposition** (Daniele et al., 2017; Sanidhya et al., 2025). MTA promotes dentin bridge formation via its high alkalinity, bioactivity, release of calcium ions, and formation of a hydroxyapatite layer upon contact with tissue **fluids** (Abuhashema et al., 2025; Karunakaran et al., 2025). Concurrently, melatonin facilitates mineralized tissue formation by upregulating TLR4/NF- κ B pathways, suppressing pro-inflammatory cytokines such as IL-1 β , regulating epigenetic histone modifications/DNA methylation in dental stem cells, and interacting with M1a melatonin receptors on odontogenic cells (Liu et al., 2012; Ma et al., 2013; Lin et al., 2015; Wang et al., 2016; Guerrero-Girones et al., 2020; Li et al., 2020; Chang et al., 2022).

Overall, melatonin achieved a 93.3% success rate, yielding results comparable to MTA, while the mixed group exhibited superior outcomes due to complementary bioactivity and anti-inflammatory action.

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