

Effect of Gamma Radiation on Adaptability of Mineral Trioxide Aggregate (MTA) and Nano Mineral Trioxide Aggregate (Nano-MTA) as Root-End Filling Materials (An In vitro study)

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Abstract

This study aimed to assess and compare the effect of gamma irradiation on the marginal adaptability of mineral trioxide aggregate (MTA) and Nano-MTA to root-end cavity walls using scanning electron microscopy (SEM). Twenty-eight extracted human single-rooted teeth were divided into two groups (n=14 each): Non-irradiated, irradiated group, then each group was subdivided according to the material used MTA and Nano-MTA. Irradiated groups were exposed to a fractionated dose of 60 Gy to simulate clinical radiotherapy. Root-end resections and standardized retrograde cavity preparations were performed, followed by root-end filling with either MTA or Nano-MTA. Samples were stored in physiologic saline at 37°C. Transverse sections were prepared and examined using scanning electron microscope. Data were statistically analyzed using ANOVA and Tukey's post-hoc tests. Irradiated samples showed wider marginal gaps than non-irradiated groups with no statistically significant difference. Among all groups, Nano-MTA exhibited superior marginal adaptation with less size of gaps than conventional MTA, particularly in the non-irradiated group. Nano-MTA showed better marginal adaptation over conventional MTA, even after exposure to gamma irradiation suggesting its potential as a more effective root-end filling material.

Keywords: Radiotherapy, Marginal adaptation, MTA, Nano-MTA, Scanning electron microscope.

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1. Introduction

Successful endodontic treatment depends on the effective eradication of infection and the prevention of reinfection within the root canal system. In cases of failure of conventional orthograde root canal therapy's, surgical intervention such as peri-apical surgery including excision of lesion, apicectomy and preparing retrograde cavity combined with retrograde filling is often employed as a last resort to preserve the natural tooth [1]. The choice of root-end filling material plays a critical role in success of such procedures, as it must provide an effective seal, biocompatibility, and long-term stability. Mineral trioxide aggregate (MTA) has been regarded as the gold standard for root-end filling due to its superior sealing ability, biocompatibility, and regenerative potential. However, MTA showed some drawbacks. It exhibits poor handling properties, a prolonged setting time, and can cause tooth discoloration, which may compromise its clinical performance [2]. Nanotechnology has recently been

used in dentistry to introduce materials with improved properties. The reduction of particle size to nanoscale has been shown to enhance material properties by increasing surface area and reactivity [1].

A novel material known as nano-mineral trioxide aggregate (nano-WMTA) has been introduced with improved handling and setting characteristics through reduced particle size. Two essential properties for the long-term success of root-end filling materials are marginal adaptation and bond strength to dentin. Proper marginal adaptation minimizes microleakage, while strong adhesion to dentin resists dislodgement under functional forces. The push-out bond strength test is commonly used to evaluate the adhesion of endodontic materials to root canal dentin [3] referring to the clinical importance of these factors will provide valuable insight into potential advantages of nanomodified materials in endodontic surgery. Radiotherapy is a primary modality for treating head and neck cancers, but it negatively affects

oral tissues, including radicular dentin. These changes may influence the sealing ability and marginal adaptation of root-end filling materials, which are critical for the long-term success of endodontic surgery. Accordingly, this study aimed to assess and compare the effect of gamma irradiation on the marginal adaptability of mineral trioxide aggregate (MTA) and nano- MTA (nano-MTA) to root-end cavity walls using scanning electron microscopy (SEM).

2. Materials and Methods

28 extracted single rooted teeth were collected from the Faculty of Dentistry, Ain Shams University. The study was conducted according to the ethical committee protocol of the Faculty of Dentistry, Ain-Shams University, Egypt. (FDASU – RecID 06191). Eligibility Criteria for Tooth Selection including single rooted teeth containing a single canal (Vertucci Type I). With intact, broad roots and fully developed apices. Teeth with adequate root length to permit proper instrumentation and sectioning. Excluding Teeth with structural defects, cracks, any developmental anomalies, including internal or external resorption or canal calcification. Teeth with an open apex. All selected teeth were thoroughly cleaned using an ultrasonic scaler to eliminate calculus deposits, surface stains, and organic debris. The cleaned specimens were then stored in sterile glass containers filled with physiologic saline at room temperature until they were used in the experiment. The teeth were randomly assigned into 2 groups according to their exposure to gamma irradiation (n=14 teeth/ group), then each group was subdivided into 2 subgroups according to the material used (n=7teeth /subgroup) as shown in Figure 1.

- Group A (MTA Group): Root-end cavities filled with MTA Angelus according to manufacturer's instructions.
- Group B (Irradiated MTA Group): Root-end cavities were filled with MTA Angelus then exposed to gamma irradiation.
- SubGroup C (Nano MTA): Root-end cavities were filled with Nano MTA.
- SubGroup D (Irradiated Nano MTA): Root-end cavities were filled with Nano MTA then exposed to gamma irradiation.

2.1. Root Canal Preparation

Teeth were decoronated at the cemento-enamel junction with a high-speed diamond disc using coolant. Root canals were measured using size 15 K-file* extending beyond the apical foramen, then subtracting the working length by 1 mm. Root canals were prepared using Root canal instrumentation and canals were dried with paper points and a 2% standard gutta-percha master cone (ISO #50) were selected based on the size of the prepared canal restored with gutta-percha cone coated with AH Plus sealer [4].

2.2. Root-End Cavity Preparation

A 3 mm apical resection was performed at a 90° angle to the long axis of the root using a diamond bur under copious irrigation. Root-end cavities were prepared using ultrasonic retrograde tips attached to ultrasonic device operating at a low power setting. Samples were stored in 100% humidity at 37°C to allow complete setting for 4 hours, after which they were transferred into physiologic saline for long-term storage. All specimens were individually placed in

sterile, tightly sealed, and labeled glass tubes containing normal saline solution and incubated at 37°C.

2.3. Specimens Preparation

After setting, specimens were sectioned transversely at 1 mm and 3 mm from the apex as shown in figure 2. The cross-sections were examined using SEM to evaluate the marginal adaptation between the material and dentin. Seven specimens from each experimental group were selected for SEM examination in transverse section.

2.4. Irradiation exposure

Teeth were subjected to a total dose of 60 Gy of irradiation in fractions of two Gy/day (conventional fractionation schedule) 5 days a week for six weeks. Gamma irradiation carried out at 137 Cesium Gamma Cell 40 with a dose rate 0.59 Rad/s. at the National Centre for Radiation Research and Technology (NCRRT), Cairo at Scanning were performed using a Zeiss Scanning Electron Microscope. Each specimen examined at seven predetermined points along material-dentin interface. Width of marginal gaps measured linearly at each point using Image J Analysis Software.

2.5. Statistical Analysis

Data were statistically analyzed using SPSS version 25 (IBM, USA). The mean and standard deviation were calculated. One-way ANOVA was used to assess the effect of material type and radiotherapy on marginal adaptation. Post-hoc comparisons were performed using Tukey's test. Significance was set at $p < 0.05$.

3. Results and discussion

3.1. Results

3.1.1. Adaptation using SEM

Descriptive analysis of marginal adaptation assessed by scanning electron microscope by measuring mean gap size exhibited by different groups presented in Table 1,2. Comparison between groups using the One-Way ANOVA test showed statistically significant difference overall ($P = 0.0001$). However, subsequent multiple comparisons with Tukey's Post Hoc test revealed important pairwise differences. The highest mean gap size was recorded in the Irradiated MTA group (2.18 ± 0.54), followed closely by the MTA Angelus group (2.10 ± 0.45), with no significant difference between them ($P = 0.99$). Conversely, the Nano-MTA (1.05 ± 0.53) and Irradiated Nano-MTA (1.29 ± 0.30) groups exhibited lower mean values, also with no significant difference between them ($P = 0.77$). Both MTA Angelus and Irradiated MTA Angelus showed significantly increased gap size compared to Nano-MTA and Irradiated Nano-MTA groups (P -values ranging from 0.0001 to 0.02), indicating superior adaptability of the Nano-MTA-based materials regardless of irradiation status as shown in figure 3.

3.2. Discussion

Good marginal adaptation of biocompatible root-end filling materials is crucial for preventing microleakage [5]. Scanning electron microscopy (SEM) is commonly used to assess this property, as its high magnification allows precise evaluation of the gap at dentin-material interface [6].

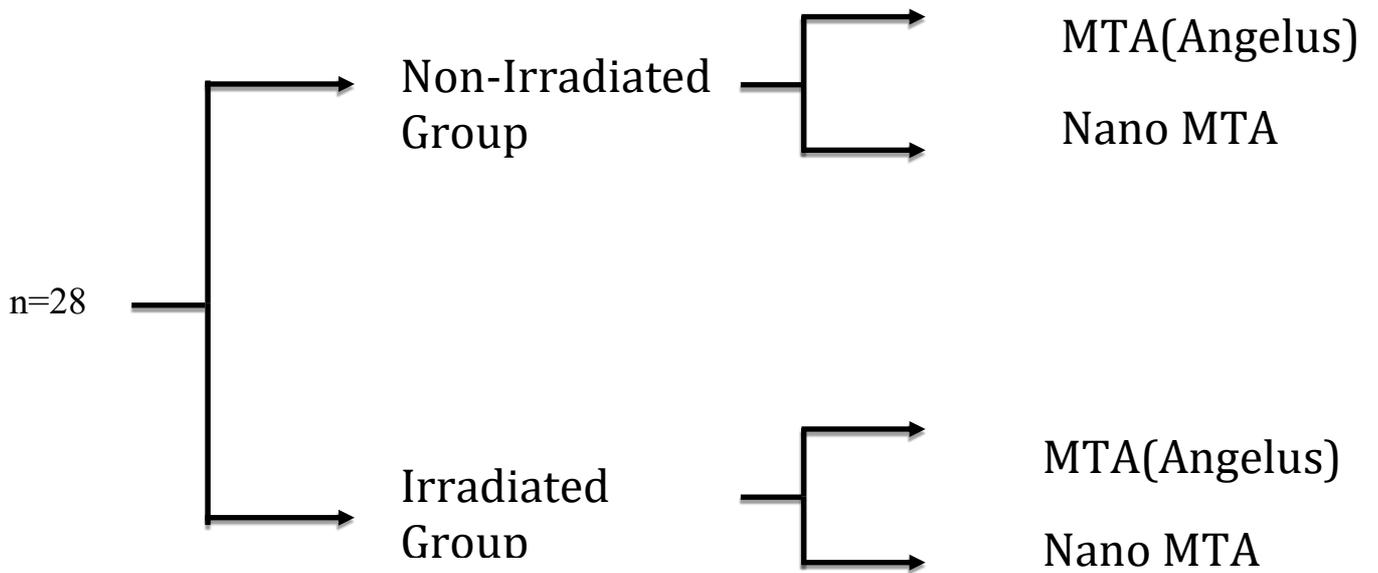


Figure 1: Classification of samples for adaptation evaluation



Figure 2: Stereomicroscope images of transverse cross-sectional views of root end-filled specimens. [2a]: Root filled with MTA; [2b]: Root filled nanoMTA

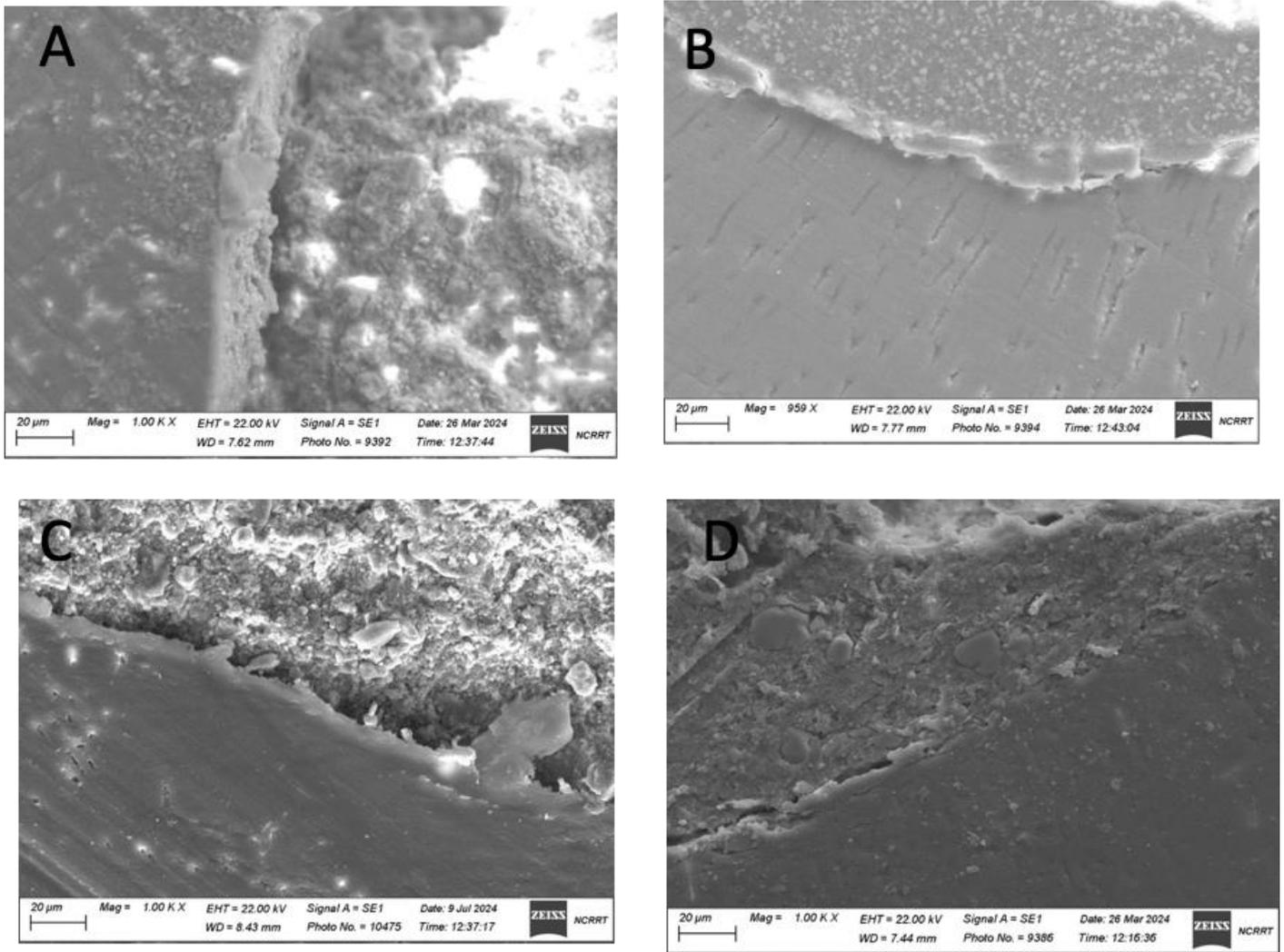


Figure 3: SEM images of: [A] non irradiated MTA(Angelus), [B] non irradiated Nano-MTA, [C] irradiated Nano-MTA, [D] irradiated MTA(Angelus).

Table 1. Descriptive results of scanning adaptation using electron microscope in all groups, comparison between groups using One Way ANOVA test

Adaptability	Gap size				P value
	Minimum	Maximum	Mean	Standard Deviation	
MTA (Angelus)	1.39	2.56	2.10 ^a	0.45	0.0001*
Nano-MTA	0.49	2.07	1.05 ^b	0.53	
Irradiated MTA	1.56	2.87	2.18 ^a	0.54	
Irradiated Nano-MTA	0.89	1.89	1.29 ^b	0.30	

*Significant difference as $P \leq 0.05$. Means with different superscript letters were significantly different as $P < 0.05$.

Table 2. Pairwise comparisons regarding marginal adaptation using SEM using Tukey's Post Hoc test

	Mean Difference	Std. Error	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
MTA(Angelus) Vs Nano-MTA	1.05	0.25	0.36	1.74	0.001*
MTA vs Irradiated MTA(Angelus)	-0.07	0.25	-0.76	0.62	0.99
MTA(Angelus) vs Irradiated Nano-MTA	0.81	0.25	0.12	1.49	0.02*
Nano- MTA vs Irradiated MTA(Angelus)	-1.12	0.25	-1.81	-0.43	0.0001*
Nano-MTA vs Irradiated Nano-MTA	-0.24	0.25	-0.93	0.44	0.77
Irradiated MTA(Angelus) vs Irradiated Nano-MTA	0.88	0.25	0.19	1.57	0.01*

*Significant difference as $P \leq 0.05$.

Studies have shown that retrograde cavities prepared with ultrasonic tips provide a better sealed than those made with burs, due to smoother cavity margins that improve material adaptation [7-9]. MTA remains most used root-end filling material, valued for its biological properties linked to release of calcium and hydroxyl ions during hydration [10]. Research also indicates that longer setting times enhance bond strength. Materials like MTA and Nano-MTA show improved adhesion to dentin when stored in humid conditions at 37°C for seven days, compared to shorter incubation periods [11-12]. According to the SEM analysis, Nano-MTA exhibited superior marginal adaptation compared to MTA Angelus, with the latter demonstrating significantly wider interfacial gaps. The variation in composition between the two materials may account for these observations. Nano-MTA's enhanced adaptation can be attributed to its reduced particle size and increased surface area which collectively promotes stronger mechanical interlocking with dentin [13]. These material characteristics likely explain the improved adaptation noted in the Nano-MTA samples compared to those of the MTA Angelus group. However, irradiation affect the marginal gap size in both MTA Angelus and Nano-MTA groups but with no significance difference this may be due to that exposure to gamma irradiation occurred after setting of the materials.

Radiotherapy reduces dentin organic matrix integrity and alters mineral-to-organic ratios, affecting material bonding. Despite its advantages, MTA is known for certain drawbacks, particularly its extended setting time and challenging handling characteristics. In response to these issues, a Nano-formulated version of MTA (nano-MTA) has been developed. Recently, Nano Mineral Trioxide Aggregate (nano-MTA) was prepared by Nano Gate Company in Egypt. Nano-MTA is a newly introduced root-end filling material. The manufacturers claim that it resemble MTA composition. This material shares the same base composition as traditional MTA, but its significantly reduced particle size increases the surface area of powder, which may facilitate more efficient hydration and potentially produce a denser and less porous set material. During mixing and setting phases, higher number of reactive particles is expected to result in improved

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physical properties. Previous studies highlighted that particle size of MTA influenced its ability to penetrate dentinal tubules [14].

This study aimed to assess the effect of gamma irradiation on adaptability of Nano-WMTA and conventional MTA(Angelus) by using Scanning Electron Microscope (SEM) and comparing marginal adaptation. According to the SEM analysis, Nano-WMTA exhibited superior marginal adaptation compared to MTA Angelus, with the latter demonstrating significantly wider interfacial gaps. The variation in composition between two materials may account for these observations. Nano-WMTA's enhanced adaptation can be attributed to its reduced particle size and increased surface area which collectively promote stronger mechanical interlocking with dentin [15]. These material characteristics likely explain the improved adaptation noted in the Nano-WMTA samples compared to those of the MTA Angelus group. However, irradiation affected the marginal gap size in both MTA Angelus and Nano-WMTA groups but with no significant difference this may be due to that exposure to gamma irradiation occurred after setting of materials.

4. Conclusions

In the highlight of the current study, it can be concluded that despite the promising results, it is important to recognize that marginal adaptation alone does not guarantee clinical success. Other factors, such as biocompatibility, setting time, radiopacity, and resistance to dislocation forces, must also be considered. Future investigations could explore long-term sealing ability of Nano-MTA under cyclic thermal and mechanical stress to further simulate intraoral conditions.

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Declaration of Conflicting Interest

The Authors declare that there is no conflict of interest. No funding was provided for this study.

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