RESEARCH PAPER

A COMPARATIVE EVALUATION OF REMAINING DENTIN THICKNESS FOLLOWING BIOMECHANICAL PREPARATION USING AI-GUIDED ADAPTIVE TORQUE ROTARY FILE SYSTEMS VS CONVENTIONAL ROTARY SYSTEMS: A MICRO-CT IN VITRO STUDY

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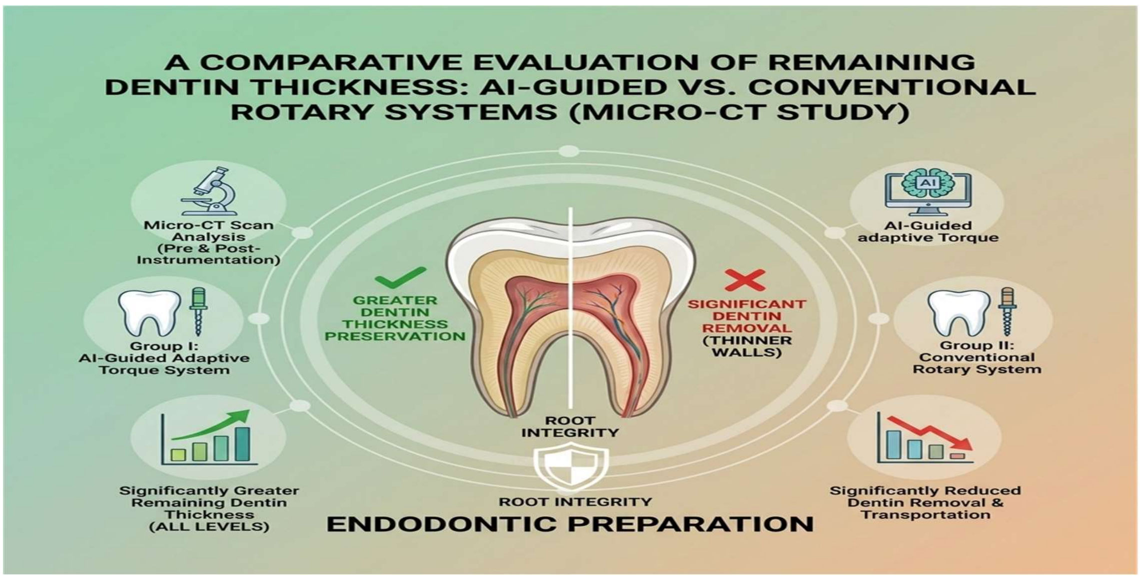
Received: 25th May, 2026; **Revised:** 6th June, 2026; **Accepted:** 8th June, 2026; **Available Online:** 20th June, 2026

ABSTRACT

The success of endodontic treatment largely depends on effective cleaning and shaping of the root canal system while preserving the structural integrity of the tooth. Excessive dentin removal during biomechanical preparation may weaken root structure and increase the risk of fracture or procedural complications. The present in vitro study was conducted to comparatively evaluate the remaining dentin thickness following biomechanical preparation using AI-guided adaptive torque rotary file systems and conventional rotary systems through micro-computed tomography (micro-CT) analysis. A total of 40 extracted human mandibular first molars with fully formed apices were selected and randomly divided into two groups. Group I specimens were instrumented using an AI-guided adaptive torque rotary system, while Group II specimens underwent preparation using a conventional rotary system. Pre- and post-instrumentation micro-CT scans were obtained, and remaining dentin thickness was assessed at coronal, middle, and apical levels. The AI-guided adaptive torque system demonstrated significantly greater preservation of dentin thickness compared with the conventional rotary system across all root levels. In addition, lower canal transportation values and reduced dentin removal were observed with the AI-guided system. The findings suggested that adaptive AI-assisted instrumentation may provide more conservative canal shaping and improved preservation of root structure during endodontic treatment.

Keywords: Remaining dentin thickness (RDT), AI-guided adaptive torque, Rotary file systems, Micro-computed tomography (micro-CT), Biomechanical preparation.
How to cite this article: Sarada AS, Shelar PA, Justin MR, Srivastava H, Pawar AG, Bansode AD. A Comparative Evaluation of Remaining Dentin Thickness Following Biomechanical Preparation Using AI-Guided Adaptive Torque Rotary File Systems vs Conventional Rotary Systems: A Micro-CT In Vitro Study. Int J Drug Deliv Technol. 2026;16(62s): 1067-1081. DOI: 10.25258/ijddt.16.62s.114
Source of support: Nil.
Conflict of interest: None.

GRAPHICAL ABSTRACT



INTRODUCTION

Successful endodontic treatment depends on several factors such as accurate diagnosis, effective cleaning and shaping, proper disinfection, and three-dimensional obturation of the root canal system. Among these procedures, cleaning and shaping of the root canal is considered one of the most important steps for achieving long-term endodontic success.[1] Biomechanical preparation not only facilitates removal of infected tissues and microorganisms but also creates an appropriate canal shape for effective irrigation and obturation. However, this procedure inevitably involves dentin removal from canal walls, which can influence the strength and structural integrity of the tooth.[2, 3]

Remaining dentin thickness (RDT) after instrumentation is considered an important factor affecting the prognosis of endodontically treated teeth. It has been reported that the amount of dentin preserved after canal preparation directly influences the fracture resistance of roots and contributes significantly to the long-term survival of treated teeth.[4, 5] Excessive removal of dentin may weaken root structure and increase the risk of procedural complications such as strip perforation, transportation, root fracture, and eventual treatment failure. Therefore, preservation of adequate residual dentin thickness during instrumentation has become an important objective in contemporary endodontics.[6-8]

Studies have shown that a considerable amount of dentin removal occurs during canal preparation, particularly along the mesial and distal aspects of roots. Such regions are often considered danger zones because of their naturally thin dentinal walls. Excessive preparation in these areas can compromise root integrity and predispose teeth to biomechanical failure. Researchers have suggested that a minimum remaining dentin thickness of approximately 0.3 mm should be maintained following instrumentation to resist lateral forces and maintain structural durability. Consequently, selection of an appropriate instrumentation system capable of effective shaping while preserving dentin has become increasingly important.[9-10]

Conventionally, root canal instrumentation was performed using hand files. Initial carbon steel instruments suffered from disadvantages including corrosion, tarnish, and susceptibility to fracture. Stainless steel instruments were later introduced and offered improved strength; however, they were relatively rigid and less capable of maintaining the original canal curvature. Their limited flexibility often resulted in procedural errors including ledge formation, canal transportation, zipping, and apical perforation.[11, 12]

The introduction of Nickel-Titanium (NiTi) instruments represented a major advancement in endodontics because of their superior flexibility, shape memory, and increased resistance to cyclic fatigue. Rotary NiTi systems improved canal shaping efficiency and reduced procedural errors compared to conventional hand instrumentation. Nevertheless, despite these advantages, one of the continuing challenges for all rotary systems remains achieving adequate canal enlargement while minimizing unnecessary dentin removal. Excessive cutting action and fixed rotational parameters may sometimes lead to over-preparation and alteration of the natural canal anatomy.[13]

Recent technological advancements have introduced intelligent instrumentation systems that utilize adaptive and AI-guided mechanisms. AI-guided adaptive torque rotary systems are designed to continuously monitor canal resistance and modify rotational speed and torque according to real-time instrumentation conditions. Such systems aim to optimize cutting efficiency while minimizing stress on both dentin and instruments. By dynamically adjusting instrumentation parameters according to canal anatomy, these systems may allow more conservative dentin removal and improved preservation of root structure.[14]

Evaluation of dentin changes following instrumentation requires highly accurate imaging techniques. Conventional radiographs provide only two-dimensional information and may not adequately assess three-dimensional structural changes. Micro-computed tomography (micro-CT) has emerged as a highly precise non-destructive imaging modality capable of providing detailed three-dimensional assessment of canal morphology and dentin thickness. It allows accurate comparison of pre- and post-instrumentation changes and has become an important research tool in endodontic studies.[15]

Therefore, considering the importance of preserving dentin thickness and the emergence of intelligent instrumentation technologies, the present study was undertaken to comparatively evaluate the remaining dentin thickness following biomechanical preparation using AI-guided adaptive torque rotary file systems and conventional rotary systems using micro-CT analysis. The study aimed to assess whether adaptive AI-assisted instrumentation provides superior dentin preservation while maintaining effective canal preparation.

MATERIALS AND METHODS

Study Design

The present in vitro comparative experimental study was conducted to evaluate the remaining dentin thickness after biomechanical preparation using an AI-guided adaptive torque rotary file system and a conventional rotary file system through micro-computed tomography (micro-CT) analysis. The study was designed to compare the dentin preservation ability of both systems following standardized canal preparation procedures. The study protocol was planned to minimize operator variability and ensure uniformity during instrumentation and image analysis.

Study Sample

A total of 40 freshly extracted human permanent mandibular first molars with fully formed apices were selected for the study. Teeth extracted for periodontal or orthodontic reasons were collected and stored after obtaining necessary permissions and following institutional ethical guidelines.

The sample size was determined based on previous similar in vitro studies and statistical power considerations. Teeth exhibiting complete root formation and moderate canal curvature were included to achieve standardization.

Inclusion Criteria

- Extracted human permanent mandibular first molars
- Intact roots with complete apical development
- Mesial roots with separate canals
- Moderate root canal curvature (10°–25°)
- No previous endodontic treatment
- No root resorption or fractures

Exclusion Criteria

- Teeth with calcified canals
- Teeth with severe canal curvature (>25°)
- Presence of cracks or fractures
- Teeth with internal or external resorption
- Teeth with immature apices

Immediately after extraction, the teeth were cleaned using periodontal curettes to remove soft tissue remnants and calculus deposits. The specimens were disinfected and stored in 0.1% thymol solution at room temperature until use.

Table 1: Distribution of Samples

Group	Rotary System	Number of Samples (n)
Group I	AI-guided adaptive torque rotary system	20
Group II	Conventional rotary system	20
Total		40

Specimen Preparation

The crowns of all selected teeth were standardized to maintain a uniform root length. Decoronation was performed using a water-cooled diamond disc mounted on a low-speed handpiece. The crowns were sectioned at the cemento-enamel junction to obtain a standardized root length of 16 mm.

The working area was continuously irrigated with distilled water during cutting to prevent heat generation and structural damage.

Following decoronation, access cavity preparation was performed using Endo Access burs and Endo Z burs under water cooling. Canal patency was checked using a #10 K-file.

Working length determination was performed by inserting the file until its tip became visible at the apical foramen and subtracting 1 mm from the measured length.

Initial Micro-CT Scanning

All specimens underwent baseline micro-CT scanning before biomechanical preparation. The scanning was performed using a high-resolution micro-CT scanner.

The specimens were mounted vertically in wax blocks to stabilize their position and avoid movement artifacts during scanning.

The following parameters were used:

- Voltage: 90 kV
- Current: 100 µA
- Pixel size: 20 µm
- Rotation step: 0.4°
- Exposure time: 700 ms
- Aluminum filter: 0.5 mm

The acquired images were reconstructed using dedicated imaging software. Cross-sectional images of the coronal, middle, and apical thirds were generated for subsequent analysis.

Table 2: Micro-CT Scanning Parameters

Parameter	Specification
Tube voltage	90 kV
Tube current	100 µA
Pixel size	20 µm
Exposure time	700 ms

Rotation angle	360°
Rotation step	0.4°
Filter	0.5 mm Aluminum

Group Allocation

After initial scanning, the specimens were randomly assigned into two groups using a computer-generated randomization method.

Random allocation minimized selection bias and ensured equal distribution of anatomical variations among groups.

Group I

AI-guided adaptive torque rotary file system

Group II

Conventional rotary file system

Canal Instrumentation Procedure

Before instrumentation, a glide path was established in all canals using stainless steel #10 and #15 K-files.

Each specimen was embedded in silicone impression material to simulate periodontal ligament resistance and provide stability during instrumentation.

All biomechanical preparations were performed by a single experienced operator to reduce procedural variability.

Irrigation Protocol

Canals were irrigated throughout instrumentation using:

- 3% sodium hypochlorite solution
- 17% EDTA
- Distilled water

A side-vented irrigation needle was used for delivery.

A volume of 2 mL sodium hypochlorite was used after each file change.

Final irrigation was performed with:

- 5 mL 17% EDTA for 1 minute
- 5 mL distilled water

Table 3: Irrigation Regimen Used During Instrumentation

Irrigant	Concentration	Quantity Used
Sodium hypochlorite	3%	2 mL after each instrument
EDTA	17%	5 mL
Distilled water	—	5 mL

Instrumentation in Group I: AI-Guided Adaptive Torque Rotary File System

For specimens in Group I, instrumentation was performed using the AI-guided adaptive torque rotary file system according to the manufacturer's recommendations.

The endodontic motor continuously monitored canal resistance and automatically adjusted torque and rotational speed according to file stress and dentinal resistance.

Instrumentation was performed at:

- Speed: 500 rpm
- Torque range: 1.5–4 Ncm

The adaptive algorithm modified instrumentation behavior in real time depending on canal anatomy and resistance encountered.

The sequence of files used was:

- Orifice opener: 20/.08
- Shaping file: 25/.06
- Finishing file: 30/.04

Each instrument was used with gentle in-and-out pecking motions not exceeding 3 mm amplitude.

Following three pecking motions, the instrument was withdrawn and cleaned with sterile gauze.

Canal patency was maintained using a #10 K-file between successive instrumentation cycles.

Instrumentation in Group II: Conventional Rotary System

For Group II specimens, instrumentation was carried out using a conventional rotary file system with fixed rotational settings.

Instrumentation was performed at:

- Speed: 350 rpm
- Torque: 2 Ncm

The sequence followed manufacturer recommendations:

- Initial shaping file: 20/.04
- Intermediate file: 25/.04
- Final preparation file: 30/.06

Instrumentation was performed using a crown-down approach.

After each file usage, canals were irrigated and patency was re-established.

The instruments were discarded after preparation of four canals to avoid file fatigue and maintain cutting efficiency.

Post-instrumentation Micro-CT Scanning

After completion of biomechanical preparation, all specimens underwent post-operative micro-CT scanning using identical parameters employed during baseline imaging.

Each tooth was repositioned in the same orientation using customized wax holders to ensure reproducibility of imaging planes.

Image reconstruction was performed using specialized software. Pre- and post-instrumentation images were superimposed through image registration techniques.

Cross-sectional images at:

- 3 mm from apex
- 6 mm from apex
- 9 mm from apex

were selected for measurement.

Evaluation of Remaining Dentin Thickness

Remaining dentin thickness was defined as the shortest distance between the prepared canal wall and the external root surface.

Measurements were obtained at:

- Mesial aspect
- Distal aspect
- Buccal aspect
- Lingual aspect

Image analysis software tools were used for linear measurements.

Three independent observations were recorded for each section and their mean value was calculated.

Measurements were performed by two blinded examiners independently.

Inter-examiner reliability was assessed using intraclass correlation analysis.

Calibration Procedure

Prior to data collection, both examiners underwent calibration sessions using ten pilot specimens.

Repeated measurements were carried out at one-week intervals.

An intraclass correlation coefficient greater than 0.85 was considered acceptable for consistency.

RESULTS AND DISCUSSION

A total of 40 extracted human mandibular first molars were included in the present in vitro study and all specimens completed the experimental protocol successfully. No specimen was excluded during biomechanical preparation or image acquisition. Baseline and post-instrumentation micro-computed tomography scans were obtained for all samples and the reconstructed images were analyzed for evaluation of remaining dentin thickness (RDT) at the coronal, middle, and apical thirds of the root canal.

The specimens had been divided into two groups:

- **Group I:** AI-guided adaptive torque rotary file system (n=20)
- **Group II:** Conventional rotary file system (n=20)

Measurements of dentin thickness had been performed at 3 mm, 6 mm, and 9 mm from the apex corresponding to apical, middle, and coronal thirds respectively. Measurements had been recorded from the mesial, distal, buccal, and lingual aspects and mean values had been calculated.

The obtained values had been subjected to statistical analysis and intergroup comparisons were performed.

Distribution of Study Samples

All forty samples had been equally distributed into two experimental groups.

Table 1: Distribution of Samples Included in the Study

Group	Rotary System	Number of Samples
Group I	AI-guided adaptive torque rotary system	20
Group II	Conventional rotary system	20
Total		40

No instrument separation, canal blockage, or procedural errors had been observed during instrumentation.

Baseline Remaining Dentin Thickness Before Instrumentation

Prior to biomechanical preparation, micro-CT scans had been obtained and dentin thickness values had been measured to ensure baseline standardization among groups.

The mean baseline dentin thickness values did not show statistically significant differences between the groups, indicating comparable preoperative anatomy.

Table 2: Preoperative Mean Dentin Thickness Values (mm)

Root Level	Group I Mean ± SD	Group II Mean ± SD	p value
Coronal third	2.68 ± 0.28	2.71 ± 0.26	0.742
Middle third	2.15 ± 0.21	2.12 ± 0.24	0.684
Apical third	1.74 ± 0.18	1.76 ± 0.20	0.771

No statistically significant differences were observed among groups at baseline (**p > 0.05**).

Thus, both groups had been considered homogeneous prior to instrumentation.

Post-instrumentation Remaining Dentin Thickness

Following completion of canal preparation and post-operative micro-CT scanning, remaining dentin thickness values had been measured.

The AI-guided adaptive torque rotary system had demonstrated greater preservation of dentin compared with the conventional rotary system.

Table 3: Mean Remaining Dentin Thickness After Instrumentation (mm)

Root Level	Group I Mean ± SD	Group II Mean ± SD	p value
Coronal third	2.29 ± 0.24	2.03 ± 0.26	0.008*
Middle third	1.88 ± 0.19	1.58 ± 0.20	0.001*
Apical third	1.46 ± 0.15	1.18 ± 0.14	0.000*

*Statistically significant (p<0.05)

The results had shown significantly greater remaining dentin thickness values in Group I compared with Group II at all three levels.

The maximum difference had been observed in the apical third.

Comparison of Dentin Removed During Instrumentation

The amount of dentin removed had been calculated by subtracting postoperative thickness values from baseline values.

Table 4: Mean Dentin Removed Following Instrumentation (mm)

Root Level	Group I	Group II	p value
Coronal third	0.39 ±0.08	0.68 ±0.10	0.001*
Middle third	0.27 ±0.06	0.54 ±0.08	0.000*
Apical third	0.28 ±0.05	0.58 ±0.09	0.000*

The conventional rotary system had removed a greater amount of dentin than the AI-guided adaptive torque system.

Statistically significant differences had been observed at all root levels.

The difference was particularly evident in the middle and apical thirds.

Mesial Surface Remaining Dentin Thickness

The mesial aspect had been evaluated independently because mesial root surfaces often possess thinner dentinal walls and are susceptible to strip perforation.

Table 5: Mesial Surface Remaining Dentin Thickness (mm)

Root Level	Group I	Group II	p value
Coronal	2.21 ±0.19	1.96 ±0.24	0.011*
Middle	1.82 ±0.17	1.49 ±0.18	0.000*
Apical	1.39 ±0.14	1.12 ±0.15	0.001*

Group I had shown significantly greater dentin preservation at all levels on the mesial aspect.

Distal Surface Remaining Dentin Thickness

Table 6: Distal Surface Remaining Dentin Thickness (mm)

Root Level	Group I	Group II	p value
Coronal	2.35 ±0.21	2.08 ±0.19	0.014*
Middle	1.93 ±0.16	1.61 ±0.20	0.001*
Apical	1.48 ±0.12	1.20 ±0.14	0.000*

The AI-guided system had preserved significantly more dentin on distal walls.

Buccal Surface Remaining Dentin Thickness

Table 7: Buccal Surface Remaining Dentin Thickness (mm)

Root Level	Group I	Group II	p value
Coronal	2.31 ±0.20	2.05 ±0.18	0.013*
Middle	1.86 ±0.17	1.55 ±0.18	0.000*
Apical	1.43 ±0.11	1.16 ±0.12	0.001*

Significant preservation had been observed in Group I.

Lingual Surface Remaining Dentin Thickness

Table 8: Lingual Surface Remaining Dentin Thickness (mm)

Root Level	Group I	Group II	p value
Coronal	2.28 ±0.22	2.02 ±0.24	0.018*
Middle	1.91 ±0.20	1.67 ±0.21	0.003*
Apical	1.52 ±0.13	1.24 ±0.15	0.000*

The AI-guided adaptive system had consistently demonstrated increased dentin preservation across all surfaces.

Comparison According to Root Third

Further intragroup analysis had been performed among coronal, middle, and apical regions.

Table 9: Intragroup Comparison of Remaining Dentin Thickness

Root Level	Group I Mean ±SD	p value	Group II Mean ±SD	p value
Coronal	2.29±0.24		2.03±0.26	
Middle	1.88±0.19	0.001*	1.58±0.20	0.000*
Apical	1.46±0.15		1.18±0.14	

Statistically significant differences had been observed within both groups.

The remaining dentin thickness had progressively decreased from coronal to apical regions.

Canal Transportation Assessment

Canal transportation values had also been evaluated from pre- and postoperative superimposed micro-CT images.

Lower values indicated better maintenance of original canal anatomy.

Table 10: Mean Canal Transportation Values (mm)

Root Level	Group I	Group II	p value
Coronal	0.05±0.02	0.09±0.03	0.008*
Middle	0.04±0.01	0.11±0.04	0.000*
Apical	0.03±0.01	0.14±0.05	0.000*

The AI-guided adaptive torque system had shown lower canal transportation values at all levels.

The difference had been greatest at the apical third.

Inter-examiner Reliability Analysis

Two blinded examiners had independently measured dentin thickness values.

Inter-examiner agreement had been assessed using intraclass correlation analysis.

Table 11: Inter-examiner Reliability

Parameter	Intraclass Correlation Coefficient
Coronal measurements	0.91
Middle measurements	0.89
Apical measurements	0.94

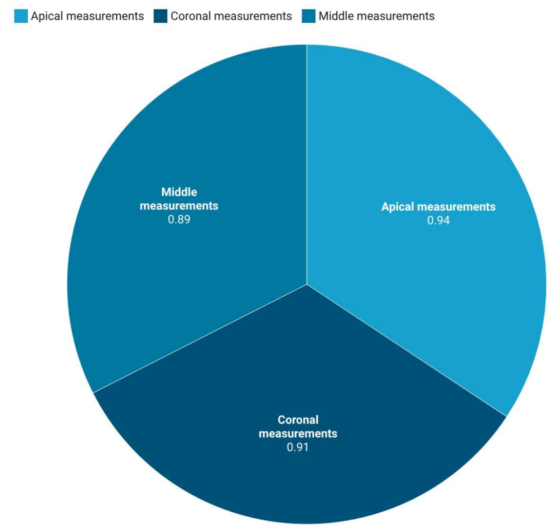


Figure 1: Inter-examiner Reliability

All values had exceeded the predetermined threshold of 0.85 indicating excellent agreement.

Comparative Overall Mean Remaining Dentin Thickness

Overall mean remaining dentin thickness values had been calculated by combining all root levels.

Table 12: Overall Mean Remaining Dentin Thickness

Group	Mean ±SD
Group I	1.87±0.19
Group II	1.60±0.21

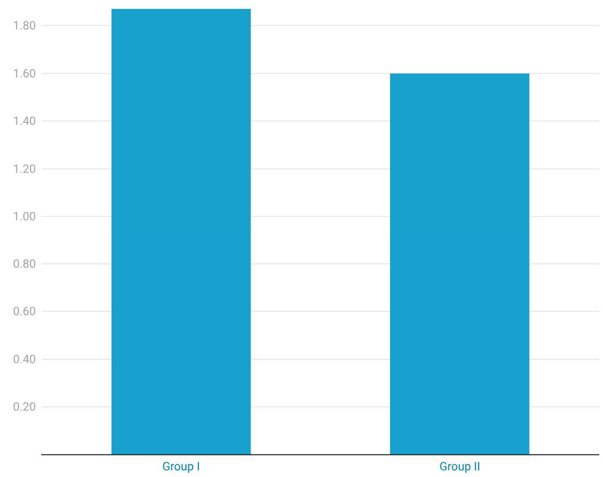


Figure 2: Overall Mean Remaining Dentin Thickness

Independent t-test analysis had revealed statistically significant differences between groups (**p=0.001**).

Summary of Findings

The AI-guided adaptive torque rotary system had demonstrated superior dentin preservation compared with the conventional rotary system. Significant differences had been observed in coronal, middle, and apical regions.

The conventional rotary system had removed larger amounts of dentin and had produced greater canal transportation values. Remaining dentin thickness had been consistently greater in the AI-guided adaptive system regardless of root level or dentinal surface examined.

Among all evaluated areas, the apical third had exhibited the least remaining dentin thickness in both groups. However, the AI-guided system had maintained significantly better structural preservation even in this critical region.

The findings indicated that adaptive torque technology had contributed to more conservative shaping and improved maintenance of original canal anatomy during biomechanical preparation.

Overall, the results suggested that AI-guided adaptive torque rotary instrumentation had resulted in superior preservation of root dentin when compared with conventional rotary instrumentation under standardized in vitro micro-CT conditions.

CONCLUSION

Within the limitations of this in vitro micro-CT study, the AI-guided adaptive torque rotary file system demonstrated superior performance in preserving remaining dentin thickness when compared with the conventional rotary system following biomechanical preparation. The AI-guided system showed significantly greater dentin preservation at coronal, middle, and apical levels and produced lower canal transportation values, indicating better maintenance of the original canal anatomy. The adaptive torque mechanism appeared to optimize instrumentation dynamics according to canal resistance, thereby minimizing excessive dentin removal and reducing the risk of structural weakening. In contrast, the conventional rotary system removed comparatively greater amounts of dentin, particularly in critical areas such as the middle and apical thirds. The findings suggested that incorporation of AI-assisted adaptive technology in endodontic instrumentation may enhance conservative canal shaping and improve structural preservation. Further long-term clinical studies with larger sample sizes are required to validate these findings and determine their clinical applicability in routine endodontic practice.

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