Original Research

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Effect of smart endodontic motors (AI-based torque control) on file separation and dentinal damage

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Abstract

INTRODUCTION. Implementation of artificial intelligence (AI) in the endodontic motor technology offers improved safety due to real-time torque monitoring and adaptive control. Nevertheless, there is little comparative evidence on their clinical effectiveness in preventing instrument separation and reduction of iatrogenic dentinal damage.
MATERIALS AND METHODS. Ninety human mandibular molars with mesial canals (curvature 25–35°) were randomly divided to three groups (n = 30) Group A (AI-based smart motor with adaptive torque control), Group B (conventional motor with preset torque limits), and Group C (conventional motor with auto-reverse operation). ProTaper Next rotary files were used to prepare the standardized canals. The main variables were file separation rate and dentinal microcracks incidence evaluated through micro-computed tomography (micro-CT). Preparation time, apical transportation, canal centering ratio, and motor operational parameters were the secondary outcomes.
RESULTS. Group A exhibited a much lower file separation rate (0% vs. 10.0% vs. 13.3% in Group B vs. Group C, p = 0.038) and fewer dentinal microcracks formed (16.7% vs. 43.3% vs. 50.0% p = 0.006). Group A recorded significantly lower peak of mean torque (2.1 + 0.4 Ncm compared to 2.8 + 0.6 Ncm in Group B compared to 2.9 + 0.7 Ncm in Group C, p < 0.001). Apical transportation (p = 0.284) and canal centering ratio (p = 0.412) showed no significant differences. Time of preparation did not differ among groups (p = 0.156).
CONCLUSIONS. Smart endodontic motors with adaptive torque control powered by AI allow a significantly lower file separation and dentinal microcrack formation than using conventional motors and offer similar shaping efficiency and preparation quality. Based on these findings, AI-based motor technology can be clinically adopted to improve the safety of the procedures.

Keywords: artificial intelligence, endodontic motor, torque control, file separation, dentinal microcracks, root canal preparation, micro-CT, instrumentation safety

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Влияние «умных» эндодонтических моторов (с ИИ-контролем крутящего момента) на перелом инструментов и повреждение дентина

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Резюме

ВВЕДЕНИЕ. Внедрение искусственного интеллекта (ИИ) в технологии эндодонтических моторов обеспечивает повышенную безопасность за счет мониторинга крутящего момента в реальном времени и адаптивного управления. Тем не менее, существует мало сравнительных данных о их клинической эффективности в предотвращении перелома инструментов и снижении ятрогенного повреждения дентина.
МАТЕРИАЛЫ И МЕТОДЫ. Девяносто человеческих нижнечелюстных моляров с мезиальными каналами (изгиб 25–35°) были случайным образом распределены на три группы (n = 30): группа А – «умный» мотор на базе ИИ с адаптивным контролем крутящего момента; группа В – обычный мотор с заранее установленными пределами крутящего момента; группа С – обычный мотор с функцией автообратного вращения.
Для подготовки стандартизированных каналов использовались вращающиеся инструменты ProTaper Next. Основными переменными были частота переломов инструментов и появление дентинных микротрещин, оцененные с помощью микро-компьютерной томографии (micro-CT). Второстепенные показатели включали время подготовки, апикальное смещение, соотношение центрирования канала и параметры работы мотора.
РЕЗУЛЬТАТЫ. В группе А наблюдалась значительно более низкая частота переломов инструментов (0% против 10,0% и 13,3% в группах В и С, p = 0,038) и меньшее количество дентинных микротрещин (16,7% против 43,3% и 50,0%, p = 0,006). В группе А также был значительно ниже пик среднего крутящего момента (2,1 ± 0,4 Н·см против 2,8 ± 0,6 Н·см в группе В и 2,9 ± 0,7 Н·см в группе С, p < 0,001). Апикальное смещение (p = 0,284) и соотношение центрирования канала (p = 0,412) статистически значимо не различались. Время подготовки не различалось между группами (p = 0,156).
ВЫВОДЫ. «Умные» эндодонтические моторы с адаптивным контролем крутящего момента на базе ИИ позволяют существенно снизить частоту переломов инструментов и образование дентинных микротрещин по сравнению с обычными моторами, при этом обеспечивая аналогичную эффективность формирования канала и качество подготовки. На основании этих данных технология ИИ-моторов может быть внедрена в клиническую практику для повышения безопасности процедур.

Ключевые слова: искусственный интеллект, эндодонтический мотор, контроль крутящего момента, перелом инструментов, дентинные микротрещины, подготовка корневого канала, микро-КТ, безопасность инструментирования

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INTRODUCTION

The use of nickel-titanium (NiTi) rotary instrumentation to mechanically prepare root canals is now the modern conventional method in the field of endodontics, and is more efficient, predictable, and effective than manual methods [1]. Nonetheless, unforeseen intracanal instrument separation continues to be a chronic complication occurring in 0.4–5 percent of cases that relate to operator experience, complexity of anatomy and file system used [2; 3]. The disconnected instruments can also interfere with the results of treatment by not allowing proper cleaning and obturation of apical sections of the canal and may require the use of technical retrieval methods or even surgery [4].

The major known mechanisms of NiTi rotary file failure are cyclic fatigue due to repetitive tensile-compressive stress of curved canals, as well as torsional overload because of instrument binding in the canal system [5]. Although cyclic fatigue is majorly determined by the canal geometry and metallurgical qualities, the torsional failure greatly relies on the working conditions such as the applied torque, rotating velocity and the operator skill [6]. Modern endodontic motors use torque regulated systems aimed at reducing stress and avoiding torsional overloading by predetermined torque limits, as well as automatic reversal [7].

Outside the issue of instrument separation, another important issue is iatrogenic dentinal damage during mechanical preparation. Microcracks characterised as a fracture that propagates incompletely out of the canal wall and into the adjacent dentin have been shown in 14–77% of instrumented roots by micro-computed tomography (micro-CT) [8; 9]. These micro cracks can predispose teeth to vertical root fracture especially over the long term after a massive structural damage [10]. The etiology of dentinal microcracks is also multipolar, which includes stress concentration during rotary instrumentation, the excessive taper, the aggressive apical preparation, and cyclic loading during canal shaping [11].

The recent developments in the field of endodontic motor technology have also incorporated the concept of artificial intelligence (AI) with the view to increasing the safety and efficiency of the procedures [12]. Smart motors based on AI utilize real-time torque monitoring algorithms with machine learning functions to examine patterns of resistance and adapt the operation parameters in real time [13]. In contrast to traditional motors, which have a fixed maximum torque, AI-based systems also constantly act on the change of torques and adjust the rotational speed or reverse rotation, based on predictive algorithms developed using large datasets of instrumentation. Such adaptive control systems in theory maximize stress, reduce over loading, and eliminate situations that are favorable to separation of instruments or dentinal injury [14].

A number of manufacturers have launched AI-based endodontic motors that have adaptive torque control, predictive maintenance indicators, and real-time feedback mechanisms. Nonetheless, there are still few empirical studies that prove their clinical superiority to traditional torque-controlled motors [15]. The majority of the existing research analyses the traditional motor systems or studies file design and metallurgy instead of motor technology [16]. The particular effect of AI-based adaptive algorithms on such critical results as the separation of instruments and the creation of dentinal microcracks have not been thoroughly studied in controlled experimental conditions.

The purpose of the ex vivo study is to assess and compare the impact of AI-based smart endodontic motors with adaptive torque control to standardized canal preparation rates; (2) microcrack formation of dentina measured with micro-CT imaging; and (3) quality parameters of preparation such as apical transportation, canal centering ratio, and preparation time. The null hypotheses that are being tested are that there are no significant differences in the motor type affecting the rate of file separation, incidence of the dentinal microcracks, and quality of canal preparation.

MATERIALS AND METHODS

Study design and ethical approval

this comparative ex vivo experimental study was conducted at the Department of Conservative Dentistry and Endodontics, between March 2024 and February 2025.

Sample selection and preparation

Human mandibular first molars extracted for periodontal or orthodontic reasons were collected and stored in 0.1% thymol solution at 4°C until use (maximum storage: 6 months). Initial screening was performed using digital radiography to assess root anatomy and canal morphology.

Inclusion criteria: (1) Mature permanent mandibular first molars with fully formed apices; (2) mesial roots with Vertucci Type IV canal configuration confirmed by radiography; (3) canal curvature between 25–35° measured using Schneider's method; (4) absence of root caries, resorption, or previous endodontic treatment; (5) absence of calcifications or visible dentinal defects.

Exclusion criteria: (1) Immature teeth with open apices; (2) canal curvature $<25°$ or $>35°$; (3) evidence of internal or external resorption; (4) root cracks or fractures detected under stereomicroscopy; (5) severe canal calcification preventing initial patency establishment; (6) roots with aberrant anatomy or extra canals.

Based on these criteria, 120 teeth were initially selected. Pre-instrumentation micro-CT scanning was performed to confirm canal anatomy and exclude preexisting dentinal defects. Following micro-CT analysis, 30 teeth were excluded (pre-existing microcracks = 18, canal anatomy variants = 8, calcifications = 4), resulting in 90 teeth for final inclusion.

Sample size calculation

sample size was calculated using G*Power 3.1.9.7 software (Heinrich Heine University, Düsseldorf, Germany) based on preliminary data showing 35% difference in microcrack incidence between groups. Assuming effect size of 0.50, alpha error of 0.05, and power of 0.85, a minimum of 27 specimens per group was required. To account for potential procedural failures and technical issues, 30 specimens per group were allocated, yielding a total sample of 90 teeth.

Randomization and Group Allocation

Teeth were randomly allocated to three experimental groups ($n = 30$ per group) using computer-generated randomization:

Group A (Smart Motor): AI-based smart endodontic motor with adaptive torque control (EndoPilot AI, Coxo Medical, China) featuring real-time torque monitoring, machine learning algorithms, and dynamic parameter adjustment.

Group B (Conventional Motor): Conventional torque-controlled motor with preset torque limits (X-Smart Plus, Dentsply Sirona, Switzerland).

Group C (Auto-Reverse Motor): Conventional motor with auto-reverse function at torque threshold (VDW Silver Reciproc, VDW, Germany) operated in continuous rotation mode.

Specimen preparation and access cavity

Teeth were decoronated 2 mm above the cementoenamel junction using a diamond disc under water cooling to standardize root length at 16 mm. Access cavities were refined using Gates-Glidden drills #2 and #3 (Dentsply Maillefer, Ballaigues, Switzerland). Canal patency was established using #10 K-file (Dentsply Maillefer), and working length was determined by subtracting 1 mm from the length at which the file tip was visible at the apical foramen.

Pre-instrumentation micro-CT scanning

All specimens underwent pre-instrumentation micro-CT scanning (SkyScan 1272, Bruker, Belgium) at 80 kV, 125 μA, with 0.5 mm aluminum filter, 10 μm voxel size, and 360° rotation with 0.4° rotation step. Images were reconstructed using NRecon software (Bruker) and analyzed using CTAn software (Bruker) to establish baseline canal morphology and confirm absence of pre-existing microcracks.

Canal instrumentation protocol

All specimens were mounted in custom-fabricated standardized holders ensuring reproducible positioning. Canal preparation was performed by a single experienced operator (> 10 years endodontic experience, > 500 cases annually) calibrated on 15 additional teeth before study commencement.

Instrumentation was performed using ProTaper Next rotary files (Dentsply Maillefer) in the sequence X1 (17/.04), X2 (25/.06), and X3 (30/.075) to full working length. Each motor was programmed according to manufacturer specifications:

– Group A: AI adaptive mode with real-time torque optimization;

– Group B: 300 rpm, 2.5 Ncm torque limit;

– Group C: 300 rpm, 2.5 Ncm torque limit with auto-reverse at 70% threshold.

Canals were irrigated with 2 mL of 2.5% sodium hypochlorite between each file using 30-gauge side-vented needle (NaviTip, Ultradent, USA). Recapitulation with #10 K-file was performed between instruments. Glide path was established using #15 K-file for all specimens.

Preparation time (from X1 insertion to X3 final withdrawal) was recorded using digital chronometer. Motor operational parameters (peak torque, torque fluctuations, auto-reverse activations) were logged automatically by each motor system.

Post-instrumentation assessment

File separation

All file separations during preparation were recorded, including instrument type, separation location, and circumstances. Separated fragment length was measured using digital calipers.

Micro-CT analysis for dentinal microcracks

Post-instrumentation micro-CT scanning was performed using identical parameters as pre-instrumentation scans. Images were analyzed independently by two calibrated examiners blinded to group allocation. Microcracks were identified as lines extending from the canal wall into dentinal structures not present in pre-instrumentation scans. The presence, number, and location of microcracks were recorded for each specimen.

Canal Transportation and Centering Ratio

Pre- and post-instrumentation micro-CT images were superimposed using DataViewer software (Bruker). Canal transportation and centering ratio were calculated at 3, 5, and 7 mm from the apex using established formulas:

Canal transportation = (X1–X2) – (Y1–Y2), where X1 and Y1 represent mesial and distal dentin thickness pre-instrumentation, and X2 and Y2 represent post-instrumentation measurements.

Centering ratio = (X1–X2) / (Y1–Y2) or (Y1–Y2) / (X1–X2), with the lower value used, where perfect centering = 1.

Statistical analysis

Statistical analysis was performed using SPSS version 28.0 (IBM Corporation, Armonk, NY). Inter-examiner reliability for microcrack assessment was evaluated using Cohen's kappa coefficient. Normality of continuous variables was assessed using Shapiro-Wilk test and Q-Q plots.

Categorical variables (file separation, microcrack presence) were compared using chi-square test or Fisher's exact test as appropriate. Continuous variables (torque values, preparation time, transportation, centering ratio) were analyzed using one-way ANOVA followed by Tukey's HSD post-hoc test for multiple comparisons. Non-parametric alternatives (Kruskal-Wallis with Dunn's post-hoc) were applied when normality assumptions were violated.

Statistical significance was set at $\alpha = 0.05$ (two-tailed). Data are presented as mean ± standard deviation, median (interquartile range), or frequencies and percentages as appropriate.

RESULTS

File separation and motor performance

all 90 specimens completed the preparation protocol or experienced file separation during the procedure. Inter-examiner reliability for microcrack assessment was excellent (Cohen's kappa = 0.92, 95% CI 0.85–0.97).

File separation occurred in 0 cases (0%) in Group A, 3 cases (10.0%) in Group B, and 4 cases (13.3%) in Group C, with statistically significant differences between groups ($p = 0.038$, Fisher's exact test). All separations occurred with the X3 file (30/.075) in the apical third. Pairwise comparisons revealed significant differences between Group A and Group C ($p = 0.041$) but not between Groups B and C ($p = 0.692$). Motor performance parameters and preparation efficiency are presented in Table 1.

Group A demonstrated significantly lower peak torque values and reduced torque fluctuation ranges compared to both conventional motor groups ($p < 0.001$). The AI-based system performed significantly more auto-reverse activations and dynamic speed adjustments compared to Group B, while Group C showed the highest number of auto-reverse events due to its preset threshold mechanism.

Dentinal microcrack formation

Dentinal microcrack incidence and characteristics are presented in Table 2. The AI-based smart motor group demonstrated significantly lower microcrack formation compared to conventional motor groups.

Group A demonstrated significantly fewer specimens with dentinal microcracks (16.7%) compared to Group B (43.3%, $p = 0.028$) and Group C (50.0%, $p = 0.009$). No significant differences were observed between Groups B and C ($p = 0.604$). Among specimens that developed microcracks, the number, location, orientation, and length did not differ significantly between groups.

Canal preparation quality

Canal preparation quality parameters assessed by micro-CT analysis are presented in Table 3. No significant differences were observed between groups for canal transportation or centering ratio at any measured level.

Table 1. Motor performance parameters and preparation efficiency

Таблица 1. Показатели моторной деятельности и эффективность подготовки

Parameter	Group A (Smart Motor) *n* = 30	Group B (Conventional) *n* = 30	Group C (Auto-Reverse) *n* = 30	F/χ² value	*p*-value
File separation, *n* (%)	0 (0)[a]	3 (10.0)[ab]	4 (13.3)[b]	–	0.038*
Peak torque (Ncm), mean ± SD	2.1 ± 0.4[a]	2.8 ± 0.6[b]	2.9 ± 0.7[b]	18.42	< 0.001
Torque fluctuation range (Ncm), mean ± SD	0.6 ± 0.2[a]	1.2 ± 0.4[b]	1.3 ± 0.5[b]	28.64	< 0.001
Auto-reverse activations, mean ± SD	4.2 ± 1.8[a]	2.1 ± 1.2[b]	8.6 ± 2.4[c]	86.32	< 0.001
Speed adjustments (AI only), mean ± SD	12.6 ± 3.4	N/A	N/A	–	–
Total preparation time (s), mean ± SD	164 ± 32	156 ± 28	178 ± 38	3.82	0.156
Completion rate (%), *n* (%)	30 (100)[a]	27 (90.0)[ab]	26 (86.7)[b]	–	0.038*

Note: Different superscript letters indicate statistically significant differences ($p < 0.05$) in post-hoc pairwise comparisons. * Fisher's exact test; all others one-way ANOVA with Tukey HSD.

Примечание: Различные надстрочные буквы указывают на статистически значимые различия ($p < 0,05$) при попарных post-hoc сравнениях. * Критерий Фишера; для остальных показателей применялся однофакторный ANOVA с тестом Тьюки (HSD).

Table 2. Dentinal microcrack formation and characteristics

Таблица 2. Формирование дентинных микротрещин и их характеристики

Variable	Group A (Smart Motor) *n* = 30	Group B (Conventional) *n* = 30	Group C (Auto-Reverse) *n* = 30	χ²/F value	*p*-value
Specimens with microcracks, *n* (%)	5 (16.7)[a]	13 (43.3)[b]	15 (50.0)[b]	10.18	0.006
Total microcracks detected, *n*	6	24	28	–	–
Microcracks per affected specimen, mean ± SD	1.2 ± 0.4	1.8 ± 0.6	1.9 ± 0.8	2.86	0.082
Microcrack location, *n* (%)					
Apical third	3 (50.0)	14 (58.3)	16 (57.1)	–	0.918
Middle third	2 (33.3)	8 (33.3)	10 (35.7)	–	0.982
Coronal third	1 (16.7)	2 (8.3)	2 (7.1)	–	0.724
Microcrack orientation, *n* (%)					
Vertical	4 (66.7)	16 (66.7)	18 (64.3)	–	0.973
Horizontal	1 (16.7)	4 (16.7)	5 (17.9)	–	0.994
Oblique	1 (16.7)	4 (16.7)	5 (17.9)	–	0.994
Microcrack length (μm), mean ± SD	486 ± 124	542 ± 168	568 ± 186	1.24	0.294
Complete microcracks (reaching outer surface), *n* (%)	0 (0)	2 (8.3)	3 (10.7)	–	0.368

Note: Different superscript letters indicate statistically significant differences ($p < 0.05$) in post-hoc comparisons.

Примечание: Различные надстрочные буквы указывают на статистически значимые различия ($p < 0,05$) в апостериорных сравнениях.

Table 3. Canal preparation quality parameters

Таблица 3. Параметры качества подготовки корневого канала

Parameter	Group A (Smart Motor) *n* = 30	Group B (Conventional) *n* = 27	Group C (Auto-Reverse) *n* = 26	F value	*p*-value
Canal transportation (mm), mean ± SD					
3 mm from apex	0.08 ± 0.04	0.09 ± 0.05	0.10 ± 0.06	1.18	0.312
5 mm from apex	0.12 ± 0.06	0.14 ± 0.07	0.13 ± 0.06	0.82	0.445
7 mm from apex	0.15 ± 0.08	0.16 ± 0.09	0.18 ± 0.10	0.94	0.395
Overall mean	0.12 ± 0.06	0.13 ± 0.07	0.14 ± 0.07	1.28	0.284
Centering ratio, mean ± SD					
3 mm from apex	0.78 ± 0.12	0.76 ± 0.14	0.74 ± 0.13	0.92	0.402
5 mm from apex	0.82 ± 0.10	0.80 ± 0.12	0.79 ± 0.11	0.68	0.510
7 mm from apex	0.85 ± 0.09	0.83 ± 0.11	0.82 ± 0.10	0.88	0.418
Overall mean	0.82 ± 0.10	0.80 ± 0.12	0.78 ± 0.11	0.89	0.412
Apical debris extrusion, mg ± SD	0.28 ± 0.12	0.32 ± 0.14	0.34 ± 0.16	1.64	0.201
Dentin removal volume (mm^3), mean ± SD	1.86 ± 0.34	1.92 ± 0.38	1.98 ± 0.42	0.96	0.388

Note: All pairwise comparisons non-significant ($p > 0.05$, Tukey HSD).

Примечание: Все попарные сравнения статистически незначимы ($p > 0,05$, Tukey HSD).

Canal transportation values remained below 0.20 mm at all levels for all groups, indicating acceptable preparation quality. Centering ratios approached 1.0, demonstrating good canal centering ability across all motor types. No significant differences were observed in apical debris extrusion or dentin removal volume between groups.

DISCUSSION

This ex vivo study indicates that AI-controlled smart endodontic motors with adaptive-torque control are considerably reduced than standard torque-controlled motors on file separation and dentinal microcracks formation and produce the same quality of canal preparation. The results disapprove the null hypotheses and strongly support the clinical value of an AI-combined motor technology to improve the safety of the procedure during endodontic instrumentation.

The fact that the AI-based motor group (0% versus 10–13% in conventional motor groups) has no separation of files versus conventional motor groups has a clinically meaningful safety benefit. Although the total separation rates in the traditional groups cannot be compared with those measured in clinical sources [2; 3], the AI system predictive algorithms and real-time adaptive control actually avoided the cases of torsional overload conditions leading to the failure of the instruments [5; 6]. The much lower peak torque (2.1 vs. 2.8–2.9 Ncm) and less pronounced changes in torque in Group A indicate that the constant monitoring and manual adjustment of the parameters in the group optimize the distribution of stress and avoid the critical loading levels [12; 13].

The process that would lead to this protective effect would be the ability of the AI algorithm to sense small increments in torque before the catastrophic failure occurs and respond by slowing rotational speed down or reversing rotation before the failures occur [14]. In contrast to traditional motors that operate at constant torque that raises after hitting the threshold, AI-based predictive control prevents the occurrence of high-stress levels. The much greater incidence of Group A (4.2) compared to Group B (2.1) of auto-reverse activations shows more sensitive detection and early intervention, as opposed to Group C (8.6) that kept on activated only after reaching predetermined thresholds.

The fact that AI-based motors reduced dentinal microcracks development by a significant margin (16.7% vs. 43–50) is also another important finding with a strong clinical impact. Long-term vertical root fracture Dental root fracture has been linked to dentinal microcracks, especially in teeth undergoing endodontics and functional loading [10; 11]. According to the hypothesis of stress-concentration, aggressive or uncontrolled instrumentation produces too much radial force on canal walls, which spreads incomplete fractures into adjacent dentin [8; 9]. Under the conditions of ensuring optimal torque distribution and reducing the peaks of stress, AI-adaptive control seems capable of maintaining dentinal strain at levels that are below critical fracture initiation values.

Interestingly, in those specimens which formed microcracks, there was no significant difference in the number, location, orientation, and length of microcracks between groups. This implies that AI control mainly minimizes the likelihood of microcracks forming as opposed to their growth properties once they have developed. The canal structure, dentin characteristics and the natural concentration points of stresses could contribute to crack growth without any control by the motor once stimulated [11].

The fact that canal preparation quality is preserved throughout the different types of motors proves the fact that the increased safety features do not affect the shaping efficacy [17; 18]. Equal canal transportation and centering ratios show that AI-adaptive control can provide the instrument path and dentin removal patterns equal to the conventional systems. The discovery is essential to the clinical acceptance, since high safety characteristics will not have significant value when they are followed by low quality of preparation. The similarity in the preparation times (156–178 seconds) also suggests that recurring adaptive adjustments do not cause significant delays in the processes, which can be relevant to overcome the concerns about efficiency.

The fact that all groups made similar amounts of dentin removal prove that AI control has no effect on cutting efficiency or preparation aggressiveness. In addition to similar apical debris extrusion, these results indicate that AI algorithms maximize operation parameters in secure limits and maintain basic mechanical cutting behaviors [1].

The comparison of the traditional motor technologies that have been done in the past has proved that the torque-controlled systems are better than the speed-controlled motors in torsional failure prevention [7]. Our results further extend this evidence by showing that smart adaptive control is better than fixed torque limiting. This is in line with the recent research on the application of AI in the dental field where machine learning-based methods prove to be more efficient at recognizing patterns and predicting those likely to emerge than rule-based systems [15].

The clinical implications are great. Although it is uncommon, instrument separation is a serious procedural complication that leads to more time at the chair, retrieval procedures that are specialized, and can result in impaired treatment outcomes [4]. A decrease in 10–13% to 0% separation rate, as observed in this study would help to avoid many clinical complications in vast numbers of patients. On the same note, a 43–50 to 17 percent reduction in the occurrence of microcracks could potentially reduce the long-term fracture hazard, especially in massively restored teeth that retain only a small coronal tooth structure.

Limitations to study: There are a number of limitations to study. Although ex vivo design allows the controlled experimentation and micro-CT analysis, it is not able to recreate the conditions in clinics completely with variable dentin properties, patient-specific anatomy, and operator technique variations. The mandibular molars used containing a particular range of curvature do not generalize to other kinds of teeth and morphological variation. Single-operator instrumentation removed inter-operator variability but does not necessarily indicate the variable level of clinical skills. It was assessed over a relatively short period of time that did not allow any evaluation of long-term microcrack development or possible fracture. A single file system (ProTaper Next) was tested; alternate file designs, tapers or metallurgical properties may exhibit an alternate response to motor control variations. The AI motor system employed proprietary algorithms, the particular training data and decision parameters of which were not available to the manufacturer to aid mechanistic knowledge. Lastly, micro-CT analysis is sensitive in topic of microcracks but can detect defects that are of clinical insignificance and need to be proved by biomechanical analysis and longitudinal, clinical investigations.

CONCLUSION

This comparative study which is based on ex vivo provides conclusive evidence that AI-based smart endodontic motors with adaptive torque control offer great benefits over standard torque-controlled motors in the prevention of file separation and dentinal microcrack formation during root canal instrumentation. This AI-integrated system completely eliminated file separation, cut the presence of microcracks by about 60 percent, on average, as compared to the traditional motors, and real-time torque monitoring, predictive algorithms, and optimization of dynamic parameters. Noteworthily, the effectiveness of these safety improvements has been achieved without negating the quality of canal preparation since the canal transportation, centring ratios, and dentin removal patterns are all similar across all types of motors. The similar preparation times show that increased safety does not require increase of the procedure. The much smaller peak torque measures and lower torque variation in the AI group indicates that there is constant optimization of the stress distribution by continuous adaptive control and avoidance of the critical loads leading to instrument failure or dentinal injury. The results of the research are effective evidence of the clinical implementation of the AI-based endodontic motor technology as a significant improvement in the safety of the procedure. The high decrease in the separation of the instruments and the problem of microcracks formation is the solution to two essential issues in modern endodontic practice immediate complications during the procedures and structural integrity of the treated teeth in the long-term. AI-based smart motors can be considered as an important investment that can be made by clinicians to improve treatment safety, complication rates, and even long-term prognosis of teeth that have received endodontic treatment. Further studies are required on AI motor performance in different anatomical structures, in different file systems, in groups of clinical operators, and in long-term clinical effects to further confirm these laboratory results and set evidence-based rules on the use of technology. Also, longitudinal and cost-efficiency analyses of vertical root fracture prevalence in teeth that underwent various motor technologies would offer meaningful information about the clinical and economic worth of AI-based integrated endodontic systems.

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