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Original Article

Dentistry Section

Comparative Evaluation of Apically Extruded Debris using an Integrated Endomotor and a Conventional Endomotor with Two Different Nickel-Titanium File Systems: An In-vitro Study

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ABSTRACT

Introduction: Apical extrusion of debris during root canal instrumentation is an unavoidable phenomenon that may contribute to postoperative pain, inflammation and delayed periapical healing. The design of endodontic file systems and the type of endomotor used can significantly influence the amount of debris extruded beyond the apex. Accurate working length determination and controlled instrumentation are important factors in minimising apical extrusion during biomechanical preparation. The rationale for the present study stems from the lack of direct comparative evidence on the effect of integrated versus conventional endomotors used with matched file systems on apical debris extrusion under standardised in-vitro conditions.

Aim: To assess the apically extruded debris with an Integrated Endomotor (Canal Pro CL2i) and conventional endomotor (Endo-Mate TC2) using two different file systems (HyFlex CM and NT Gold Pro).

Materials and Methods: This in-vitro study was conducted at Department of Conservative Dentistry and Endodontics, Vokkaligara Sangha Dental College and Hospital, Bengaluru, Karnataka, India from January 2024 to September 2024. Total 40 extracted human permanent single-rooted premolars were categorised into two groups: Group 1 (Canal Pro CL2i integrated endomotor) and Group 2 (Endo-Mate TC2 conventional endomotor), each subdivided into: Group 1A (Canal Pro CL2i+HyFlex CM), Group 1B (Canal Pro CL2i+NT Gold Pro), Group 2A (Endo-Mate TC2+HyFlex CM), and Group 2B (Endo-Mate TC2+NT Gold Pro). Teeth were prepared to a standardised working length up to file size 30/0.04, and the amount of debris extruded was measured using the laboratory model described by Myers GL and Montgomery S. Statistical analysis was performed using One-way Analysis of Variance (ANOVA) with Tukey's post-hoc test ($p<0.05$).

Results: The mean weight of extruded debris for canal Pro CL2i integrated endomotor HyFlex CM rotary files was 0.1244±0.0395 g, Canal ProCL2i integrated endomotor with NT Gold Pro rotary files was 0.2126±0.0528 g, Endo-Mate TC2 endomotor with HyFlex CM rotary files was 0.2457±0.0424 g and Endo-Mate TC2 endomotor with NT Gold Pro rotary files was 0.4240±0.0405 g. The difference in mean weight of extruded debris between four subgroups was statistically significant at $p<0.001$.

Conclusion: Canal Pro CL2i produced significantly less apical debris extrusion than the Endo-Mate TC2 across both file systems tested. File system selection also independently influenced extrusion levels; HyFlex CM consistently generated lower debris extrusion values than NT Gold Pro.

Keywords: Apical debris extrusion, Electronic apex locator, Endodontic motors, Nickel-titanium rotary instruments, Working length determination

INTRODUCTION

Thorough disinfection and three-dimensional shaping of the root canal system are the primary objectives of endodontic treatment, with chemo-mechanical preparation serving as the principal means of achieving them [1]. A well-recognised adverse consequence of instrumentation is the apical displacement of canal contents including pulp remnants, bacterial elements, dentinal particles, and irrigating fluids which may provoke periapical inflammation and postoperative pain [2]. The apical constriction, situated roughly 0.5-1 mm coronal to the major foramen, represents the canal's narrowest cross-sectional diameter and demarcates the interface between pulpal and periradicular structures. Most clinicians and researchers concur that preparation and filling should terminate at this constriction to avoid periapical damage [3]. Working length determination has been transformed by Electronic Apex Locators (EALs), which offer reproducible, radiation-free measurement. The scientific basis for these devices was laid by Custer in 1918, and later expanded upon by Suzuki in 1942 [4]. Sunada I (1962) subsequently formalised this principle, showing that a constant impedance ratio exists between the periodontal ligament and oral mucous membrane, which underpins the functioning of modern EALs [5].

HyFlex CM (Coltene) is a controlled memory nickel-titanium rotary file system manufactured using proprietary CM-wire thermomechanical processing, which imparts superior flexibility and enhanced cyclic fatigue resistance compared with conventional NiTi instruments [6,7]. NT Gold Pro (Nine Ten) is a gold heat-treated nickel-titanium rotary system designed to improve flexibility and cyclic fatigue resistance through thermomechanical processing while maintaining adequate cutting efficiency [7,8]. Both systems used in the present study possessed a constant 4% taper and a passive non cutting safety tip design [9]. These two file systems were selected for comparison because they represent different thermomechanical treatment philosophies while maintaining comparable taper, tip size, and instrumentation sequence. This minimises geometric variables and allows the influence of motor kinematics to be evaluated more reliably.

To further optimise endodontic workflow, device manufacturers combined the functions of rotary motors and apex locators into unified systems [10,11]. These integrated systems operate in real time to monitor file depth and employ an Auto Apical Reverse (AAR) mechanism combined with adjustable torque and speed settings, substantially reducing the probability of preparation beyond the established working length [11].

In the Canal Pro CL2i, this mechanism activates automatically when the preset working length is detected, reversing the file to prevent apical breach and contain extruded debris [12]. In contrast, the Endo-Mate TC2 relies solely on torque-sensitive feedback to modulate rotation in response to intracanal resistance and is not equipped with any apex-sensing capability [13].

Insufficient working length leads to incomplete debridement, while excessive length estimation drives file tips and irrigants beyond the apex, traumatising periapical tissues and provoking an inflammatory cascade that impairs healing [14]. Consistent working length control throughout the procedure is therefore essential for preserving periapical health and minimising postoperative sequelae [15]. No prior published study has directly contrasted these two specific motor systems (Canal Pro CL2i and Endo-Mate TC2) for apical debris extrusion. The two file systems were matched in taper, sequence, and metallurgical treatment so that any observed difference in debris extrusion between groups could be attributable specifically to the motor type rather than to the files.

Against this background, the present study set out to compare the volume of apically extruded material generated during root canal preparation by an integrated endomotor versus a conventional motor, using two matched file systems.

The aim of the present study was to comparatively evaluate apically extruded debris between an integrated endomotor (Canal Pro CL2i) and a conventional endomotor (Endo-Mate TC2) when used with HyFlex CM and NT Gold Pro file systems. The null hypothesis that there was no statistically significant difference in the mean weight of apically extruded debris among the four experimental groups. The alternate hypothesis that there was statistically significant difference in the mean weight of apically extruded debris among the four experimental groups.

MATERIALS AND METHODS

This was an in-vitro experimental study conducted at Department of Conservative Dentistry and Endodontics, Vokkaligara Sangha Dental College and Hospital, Bengaluru, Karnataka, India from January 2024 to September 2024. The research protocol was reviewed and approved by the Institutional Ethics Committee (IEC No: KIMS/IEC/A213/D/2024).

Sample size calculation: The sample size for present study was determined using GPower software (ver. 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Germany). The sample size estimation was performed at 5% alpha error (α=0.05), with an effect size of 0.58 based on the study by Madhusudhana K et al., (2010) [16], which evaluated the mean difference in the weight of apically extruded debris among the groups, and a power of 80%. This revealed that a minimum of 40 samples would be required, with 10 samples per group. No specimens were excluded or lost during the course of the study. Therefore, the attrition rate was 0%, and all 40 specimens were included in the final analysis.

Specimens consisted of 40 extracted single-rooted permanent premolars (both maxillary and mandibular) with fully developed root apices.

Group allocation: Specimens were randomly allocated to four groups (n=10 each) using a computer-generated randomisation sequence. [Table/Fig-1] below summarises the group allocation:

Inclusion criteria: Single-rooted premolars with closed apices, undisturbed root anatomy, and an initial apical binding file of #25.

Group	Endomotor	File system	n
Group 1A	Canal Pro CL2i (Integrated)	HyFlex CM	10
Group 1B	Canal Pro CL2i (Integrated)	NT Gold Pro	10
Group 2A	Endo-Mate TC2 (Conventional)	HyFlex CM	10
Group 2B	Endo-Mate TC2 (Conventional)	NT Gold Pro	10

[Table/Fig-1]: Group allocation summary (N=40).

Exclusion criteria: Teeth exhibiting open apices, canal calcification, resorptive defects, perforations, root curvature >5° (assessed by Schneider's method), fractures, or morphological anomalies were excluded.

Study Procedure

Radiographic screening and canal morphology: All teeth were screened with periapical radiographs in two projections (bucco-lingual and mesio-distal) to confirm single canal morphology (Vertucci Type I), absence of calcifications, normal root length, and closed apices prior to inclusion.

Access preparations were made with an Endo access bur (Dentsply), after which each tooth's initial apical binding file size was verified; only size #15 cases proceeded to the experimental phase. A fixed reference point was marked at the cusp tip. After initial K-file (Mani) exploration and saline flush, the pulp was removed with H-files (Mani), followed by coronal flaring using Gates Glidden drills (Mani).

Specimen storage and sterilisation: All specimens were ultrasonically scaled to remove calculus and soft tissue. Teeth were then autoclaved (134°C, 18 minutes) for sterilisation and stored in saline at 4°C until use. All specimens were used within four weeks of extraction. The study was conducted at a room temperature of 23±2°C and relative humidity of 45±5%.

Working length determination: In Group 1 (Canal Pro CL2i), the working length was determined electronically using the integrated apex locator and subsequently confirmed with a periapical radiograph. The AAR function of the Canal Pro CL2i was then set to activate 0.5 mm short of the established working length during instrumentation [Table/Fig-2]. In Group 2 (Endo-Mate TC2), the working length was determined electronically using the Root ZX Mini apex locator and subsequently confirmed with a periapical radiograph. A reference point 0.5 mm short of the established working length was maintained manually throughout instrumentation.



[Table/Fig-2]: Integrated endomotor (Canal Pro CL2i) showing the real-time apical reference display during instrumentation.

File system specifications and root canal preparation: HyFlex CM (Coltene) rotary files are manufactured from controlled-memory (CM-wire) nickel-titanium alloy and comprise a three-bladed triangular cross-section in the 15/0.04 and 30/0.04 instruments and a four-bladed quadrangular cross-section in the 20/0.04 and 25/0.04 instruments. The files were operated at 500 rpm with a torque setting of 2.5 Ncm. NT Gold Pro (Nine Ten) rotary files are manufactured from gold heat-treated nickel-titanium alloy and possess a convex triangular cross-section throughout the sequence. These files were operated at 300 rpm with a torque setting of 2.5 Ncm. Both systems featured a uniform 4% taper, a non

cutting safety tip, and were used according to the manufacturer's recommended sequence (15/.04, 20/.04, 25/.04, and 30/0.04) following coronal enlargement [9,17]. Root canal preparation was performed using the assigned rotary system according to the respective manufacturer's instructions until the established working length was reached. In Group 1, the AAR function of the Canal Pro CL2i was activated to automatically reverse the instrument when it reached 0.5 mm short of the established working length. In Group 2, instrumentation was performed conventionally with the Endo-Mate TC2 endomotor, and biomechanical preparation was manually terminated at 0.5 mm short of the established working length. A new set of rotary instruments was used for each specimen to eliminate the influence of instrument fatigue.

Irrigation was delivered through a side-vented 30-gauge needle placed 2 mm short of the working length, with distilled water used throughout to prevent confounding from Sodium hypochlorite (NaOCl) crystals. Each file change was preceded by 2 mL of distilled water, totalling 10 mL per root. After preparation, collection tubes were incubated at 70°C for five days until the irrigant had fully evaporated, leaving dry debris for gravimetric analysis. The dried samples were weighed using a Shimadzu LIBROR AEG-120 analytical balance (Shimadzu Corporation, Kyoto, Japan; readability 0.0001 g) [Table/Fig-3]. Each tube was weighed three times and the mean weight recorded to reduce measurement error. The evaporation protocol (70°C for 5 days) was validated in a pilot run of five samples, confirming complete moisture elimination before the main study. Debris weights were recorded and statistically evaluated.



[Table/Fig-3]: Analytical balance (Shimadzu LIBROR AEG-120) used for gravimetric measurement of apically extruded debris.

Debris collection: The debris collection apparatus was assembled according to the model described by Myers GL and Montgomery S [18]. The assembly consisted of a 1.5 mL Eppendorf tube, a rubber stopper with a standardised perforation to secure the tooth, a 27-gauge needle for pressure equalisation, and an empty Local Anaesthetic (LA) glass vial to support and stabilise the Eppendorf tube during instrumentation. [Table/Fig-4]. Each experimental tooth was inserted through a rubber stopper into an empty LA glass vial supporting a pre-weighed 1.5 mL Eppendorf tube for collection of apically extruded debris. Following instrumentation, the entire external root surface was rinsed with 1 mL of distilled water into the Eppendorf tube to recover any adherent debris. Root canal preparation was performed by a single trained operator according to the speed and torque parameters specified by the respective file manufacturer. The operator was experienced with both systems and was calibrated through a 10-sample pilot run prior to the study. Debris weight measurements were performed by a blinded investigator using a Shimadzu LIBROR AEG-120 analytical balance (Shimadzu Corporation, Kyoto, Japan; readability 0.0001 g) to eliminate examiner bias.

STATISTICAL ANALYSIS

Statistical analysis was performed using Statistical Package of the Social Sciences (SPSS) version 22.0 software. Data normality



[Table/Fig-4]: Modified Myers and Montgomery debris collection apparatus assembled using a pre-weighed 1.5 mL Eppendorf tube supported within an empty Local Anaesthetic (LA) glass vial. Apically extruded debris was collected in the Eppendorf tube during root canal instrumentation.

was assessed using the Shapiro-Wilk test ($p>0.05$ for all groups, confirming normal distribution). Homogeneity of variance was confirmed using Levene's test. Comparison of mean weight of extruded debris (in grams) among the four groups was performed using one-way ANOVA, followed by Tukey's post-hoc test for multiple pair-wise comparisons. Effect size was calculated as eta squared (η^2) and omega squared (ω^2). The level of significance was set at $p<0.05$. All p-values were two-tailed.

RESULTS

The comparison of mean weight of extruded debris (in grams) among the four groups has been depicted in [Table/Fig-5]. The mean weight of extruded debris was: Group 1A: 0.1244±0.0395 g; Group 1B: 0.2126±0.0528 g; Group 2A: 0.2457±0.0424 g; Group 2B: 0.4240±0.0405 g. The difference in mean weight of extruded debris among the four groups was statistically significant ($p<0.001$). The F-value was 81.273 with degrees of freedom df (between)=3 and df (within)=36. The eta squared effect size was $\eta^2=0.871$ and omega squared $\omega^2=0.857$, indicating that more than 85% of the variance in extruded debris weight is explained by group differences a very large effect size.

Groups	N	Mean±SD	Min	Max	F-value	df	p-value
Group 1A Canal Pro CL2i+HyFlex CM	10	0.1244±0.0395	0.069	0.198	81.273	3, 36	<0.001*
Group 1B Canal Pro CL2i+NT Gold Pro	10	0.2126±0.0528	0.123	0.298			
Group 2A Endo-Mate TC2+HyFlex CM	10	0.2457±0.0424	0.197	0.318			
Group 2B Endo-Mate TC2+NT Gold Pro	10	0.4240±0.0405	0.372	0.497			

[Table/Fig-5]: Comparison of mean weight of extruded debris (in grams) among four groups using one-way ANOVA.
*Statistically significant ($p<0.001$). Group 1A=Canal Pro CL2i+HyFlex CM; Group 1B=Canal Pro CL2i+NT Gold Pro; Group 2A=Endo-Mate TC2+HyFlex CM; Group 2B=Endo-Mate TC2+NT Gold Pro; SD: Standard deviation; df: Degrees of freedom

The multiple pair-wise comparisons using Tukey's post-hoc test has been depicted in [Table/Fig-6]. Group 2B showed the highest mean weight of extruded debris, significantly greater than Groups-1A, 1B, and 2A ($p<0.001$ for all comparisons). Group 2B showed the highest debris extrusion, Group 1A the lowest, while Groups 1B and 2A demonstrated comparable values ($p=0.35$). Groups 2A and 1B both showed significantly greater extrusion than Group 1A ($p<0.001$ for both). However, no statistically significant difference was found between Groups 1B and 2A ($p=0.35$); this should be interpreted with caution as it indicates that the integrated motor with

NT Gold Pro and the conventional motor with HyFlex CM produced comparable debris quantities suggesting both motor type and file system independently contribute to extrusion outcomes.

(I) Group	(J) Group	Mean Diff. (I-J)	95% CI lower	95% CI upper	p-value
Group 1A	Group 1B	-0.0882	-0.1413	-0.0351	<0.001*
Group 1A	Group 2A	-0.1213	-0.1744	-0.0682	<0.001*
Group 1A	Group 2B	-0.2996	-0.3527	-0.2465	<0.001*
Group 1B	Group 2A	-0.0331	-0.0862	0.0200	0.35
Group 1B	Group 2B	-0.2114	-0.2645	-0.1583	<0.001*
Group 2A	Group 2B	-0.1783	-0.2314	-0.1252	<0.001*

[Table/Fig-6]: Multiple pair-wise comparison of mean differences in extruded debris weight using Tukey's post-hoc test.
*Statistically significant (p<0.001)
Note: Mean differences are expressed as (I) – (J); negative values indicate Group I extruded less than Group J. Group 1A=Canal Pro CL2i+HyFlex CM; Group 1B=Canal Pro CL2i+NT Gold Pro; Group 2A=Endo-Mate TC2+HyFlex CM; Group 2B=Endo-Mate TC2+NT Gold Pro

DISCUSSION

Among the recognised causes of discomfort after root canal treatment, the extrusion of infected debris into periradicular tissues occupies a prominent position [19]. The extent of apical debris extrusion is influenced by multiple tooth-specific and patient-related factors: the class of tooth involved, root canal curvature, the diameter of the apical foramen, and patient age all contribute to the degree of extrusion observed [20]. In addition to tooth-related variables, procedural factors exert considerable influence on extrusion volumes. These include the instrumentation technique, choice of motor, file cross-sectional design, alloy composition, rotational kinematics, number of instruments used, and irrigation strategy [21].

Accurate working length measurement underpins every aspect of safe canal preparation. Across a large body of published literature, the apical constriction has consistently been identified as the preferred apical terminus [22]. Where working length is poorly controlled, the apical constriction may be iatrogenically destroyed, facilitating extrusion of dentinal debris, irrigants, and obturating materials beyond the foramen. Each of these events elevates the risk of periapical reaction and delayed tissue recovery [23]. Serial verification of working length at every step of procedure is therefore non negotiable. Inadequate adjustment predisposes to a range of clinical complications, and under such circumstances, coupling an endodontic motor with an integrated apex locator may substantially improve treatment outcomes [24].

Next-generation endodontic motors have been specifically developed to address two persistent challenges: preventing accidental over-preparation and protecting NiTi instruments against cyclic fatigue failure. Central to their design is a rapid autoreverse function that engages in milliseconds. Once motor detects that torque has exceeded its set limit or that the file has reached the minimum apical safety distance, it immediately reverses the rotational direction and retracts the instrument from the canal [24].

In the present study, the Canal Pro CL2i integrated endomotor produced significantly less apical debris extrusion than the Endo-Mate TC2 across both file systems (Group 1A: 0.1244 g<Group 2A: 0.2457 g with HyFlex CM; Group 1B: 0.2126 g <Group 2B: 0.4240 g with NT Gold Pro) therefore rejecting the null hypothesis. This may be attributed to the onboard apex locator's Automatic Apical Stop feature, which enforces continuous working length compliance during preparation and activates auto-reversal at 0.5 mm from the apex, thereby preventing over-instrumentation and limiting debris propulsion beyond the foramen. These findings are consistent with those of Swarupa C et al., who demonstrated that a combined apex locator–motor device maintained working length reliably in autoreverse mode with ProTaper F3 instruments and reported lower debris extrusion compared to a conventional motor [24]. Similarly, Dweedar AM et al., confirmed that the auto-reverse function of an integrated motor was comparable in accuracy to a standard Electronic Apex Locator (EAL) for working length determination, supporting the reliability of the integrated system used in the present study [14]. In contrast, Kılıç Y et al., found no statistically significant difference among continuous rotation, apical slowdown, and apex setting auto-reverse modes of a single integrated endomotor, suggesting that the specific apical action protocol may matter less when the same motor is used throughout [25]. The present study extends this by demonstrating a significant advantage of an integrated system over a non-integrated motor when all other variables are controlled.

Regarding file system performance, HyFlex CM consistently generated less extruded debris than NT Gold Pro across both motor groups (Group 1A vs 1B; Group 2A vs 2B). This difference may be attributed to the distinct cross-sectional geometry and metallurgical properties of the two systems. HyFlex CM's controlled-memory wire technology confers superior file flexibility, which is associated with lower apical transportation and reduced axial apical force during instrumentation both of which minimise debris propulsion beyond the apex. This is supported by Peters OA et al., who demonstrated that HyFlex CM's instrument design confers superior flexibility and reduced apical force, and by Shen Y et al., who confirmed its favourable metallurgical properties [26,27]. NT Gold Pro's gold heat treatment, while improving cyclic fatigue resistance, does not impart the same degree of controlled memory and canal-following flexibility as CM-wire. The different rotational speeds used (HyFlex CM at 500 RPM vs NT Gold Pro at 300 RPM) represent a limitation of this study, as the differential speed may independently affect apical force and debris extrusion; this confounding factor is acknowledged. Khalil W and Abu-Haimed T demonstrated that higher rotational speed may reduce axial apical force, which could contribute to the lower extrusion seen with HyFlex CM a factor that cannot be fully separated from the file geometry effect in the present design [28].

The non significant difference between Groups 1B (Canal Pro CL2i+NT Gold Pro) and 2A (Endo-Mate TC2+HyFlex CM) is a noteworthy finding. It suggests that the advantages conferred by the integrated motor can be partially offset by a less favourable file system, and conversely, that a superior file system (HyFlex CM) can partially compensate for the absence of integrated apex locator function. This underscores the importance of considering both motor type and file system design as independent yet interacting contributors to apical extrusion outcomes.

Clinical significance: While the absolute values are small, the biological relevance of even minute amounts of debris in the periapical space is well established: contaminated debris containing bacterial Lipopolysaccharides (LPS), dentinal particles, and necrotic pulp remnants can trigger an acute inflammatory cascade, causing postoperative pain and delaying periapical healing. The use of an integrated endomotor with HyFlex CM therefore offers a clinically meaningful reduction in the risk of post-treatment flare-up, particularly in cases with necrotic pulp and existing periapical pathology. The cost-effectiveness of integrated systems should also be considered in clinical decision-making; while their initial cost is higher than conventional motors, the potential for fewer postoperative complications may justify the investment in high-risk cases.

Being an in-vitro study, the full physiological complexity of periapical tissues was not replicated; laboratory conditions still enabled reproducible comparisons between groups. Distilled water was substituted for sodium hypochlorite to prevent chemical dissolution of collected debris. The gravimetric method of Myers GL and Montgomery S was selected for debris quantification given its established validity [18]. One recognised limitation of laboratory extrusion models is the absence of physiological back pressure from periapical tissues, which clinically would resist apical displacement of material [29]. Although Altundasar E et al., attempted to address this by employing floral foam as a periapical tissue surrogate, this approach is limited by the foam's tendency to absorb both irrigant and extruded debris [30].

Limitation(s)

Despite the strengths of the present study, certain limitations should be acknowledged. The statistical analysis was performed using One-way ANOVA to compare differences among the four groups; however, this approach did not separately examine the effects of the endomotor system, file system, or the interaction between these two variables. Future studies employing a two-way ANOVA would provide a more comprehensive evaluation of these factors. The assessment of apically extruded debris was limited to gravimetric measurement, and no attempt was made to determine the particle size distribution or microbiological composition of the extruded material. In addition, the investigation was confined to two endomotor systems, which limits the generalisability of the findings to other commercially available integrated and conventional endomotors. Since, the study was conducted under in-vitro conditions, the experimental setup could not accurately reproduce the biological environment or the resistance offered by periapical tissues during clinical treatment. Consequently, caution should be exercised when applying these findings to clinical practice. Furthermore, to reduce anatomical variability, only extracted human permanent single-rooted premolars with a single canal were included, and therefore the results may not be directly applicable to teeth with multiple roots or more complex canal anatomies.

CONCLUSION(S)

Under the conditions of present investigation, use of the Canal Pro CL2i integrated endomotor resulted in significantly lower apical debris extrusion compared to the Endo-Mate TC2 conventional motor. Irrespective of the motor employed, HyFlex CM files consistently generated less extruded debris than NT Gold Pro files, confirming an independent contribution of file design to extrusion outcomes. The combination of an integrated endomotor with HyFlex CM files produced the least apical debris extrusion among all groups tested.

REFERENCES

[1] Hülsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: Shaping goals, techniques and means. Endod Topics. 2005;10(1):30-76.
[2] Predin Djuric N, Van der Vyver PJ, Vorster M, Vally ZI. Factors influencing apical debris extrusion during endodontic treatment - A review of the literature. SADJ. 2021;76(1):28-36.
[3] Elayouti A, Hülber JM, Judenhofer MS, Connert T, Mannheim JG, Löst C, et al. Apical constriction: Location and dimensions in molars-a micro-computed tomography study. J Endod. 2014;40(8):1095-99.
[4] Kim E, Lee SJ. Electronic apex locator. Dent Clin North Am. 2004;48:35-54.
[5] Sunada I. New method for measuring the length of the root canal. J Dent Res. 1962;41(2):375-87.
[6] Shim KS, Oh S, Kum KY, Kim YC, Jee KK, Chang SW. Mechanical and metallurgical properties of various nickel-titanium rotary instruments. Biomed Res Int. 2017;2017:4528601.
[7] Oh S, Kim TH, Chang SW. Mechanical properties of niti rotary files fabricated through gold-wire, CM-wire, T-wire, and R-phase heat treatment. Appl Sci (Basel). 2023;13(6):3604.
[8] Hieawy A, Haapasalo M, Zhou H, Wang ZJ, Shen Y. Phase transformation behavior and resistance to bending and cyclic fatigue of protaper Gold and protaper Universal instruments. J Endod. 2015;41(7):1134-38.
[9] Nine Ten. NT Gold Pro rotary files [Internet]. India: Nine Ten; [cited 2026 Jul 21]. Available from: https://nineten.in/product/nt-gold-pro-file/.
[10] Nekoofar MH, Ghandi MM, Hayes SJ, Dummer PMH. The fundamental operating principles of electronic root canal length measurement devices. Int Endod J. 2006;39(8):595-609.
[11] Fadel G, Piasecki L, Westphalen VPD, Silva Neto UX, Fariniuk LF, Carneiro E. An in vivo evaluation of the auto apical reverse function of the Root ZX II: Evaluation of the Root ZX II. Int Endod J. 2012;45(10):950-54.
[12] Klemz AA, Cruz ATG, Piasecki L, Carneiro E, Westphalen VPD, da Silva Neto UX. Accuracy of electronic apical functions of a new integrated motor compared to the visual control of the working length: An ex vivo study. Clin Oral Investig. 2021;25(1):231-36.
[13] NSK Nakanishi Inc. ENDO-MATE TC2 operation manual [Internet]. Kanuma, Tochigi, Japan: NSK Nakanishi Inc.; 2013. Available from: https://www.nsk-dental.com/admin/wp-content/uploads/ENDO-MATE-TC2_OM-E0390E-001_OPERATION-MANUAL_EN_DE_FR_ES_IT.pdf.
[14] Dweedar AM, Genena SM, Sherif RA, Moussa SM. Accuracy of auto reverse function in integrated motor compared to a standard electronic apex locator in maintaining the working length (in-vitro study). Alex Dent J. 2022;47(1):109-14.
[15] Gordon MPJ, Chandler NP. Electronic apex locators. Int Endod J. 2004;37(7):425-37.
[16] Koppolu Madhusudhana, Rosaline Misquith A, Bhaskara Rao N. Evaluation of apically extruded debris and irrigants using protaper, Hero Shaper, and Mtwo rotary systems: An in-vitro study. J Conserv Dent. 2010;13(1):30-33.
[17] COLTENE. HyFlex CM NiTi root canal instruments: Instructions for use [Internet]. Altstätten, Switzerland: COLTENE; 2025. Available from: https://media.coltene.com/EN/GB/media/DOC_IFU_30001992-03-25-HyFlex-CM-A4_IND.pdf?sprache=EN.
[18] Myers GL, Montgomery S. A comparison of weights of debris extruded apically by conventional filing and Canal Master techniques. J Endod. 1991;17(6):275-79.
[19] Seltzer S, Naidorf IJ. Flare-ups in endodontics: I. Etiological factors. J Endod. 1985;11(11):472-78.
[20] Tanalp J, Güngör T. Apical extrusion of debris: A literature review of an inherent occurrence during root canal treatment. Int Endod J. 2014;47(3):211-21.
[21] Western JS, Dicksit DD. Apical extrusion of debris in four different endodontic instrumentation systems: A meta-analysis. J Conserv Dent. 2017;20(1):30-36.
[22] Ricucci D, Langeland K. Apical limit of root canal instrumentation and obturation, part 2. A histological study. Int Endod J. 1998;31(6):394-409.
[23] Cemaltinaz A, Alacam T, Uzun O, Maden M, Kayaoglu G. The effect of disruption of apical constriction on periapical extrusion. J Endod. 2005;31(7):533-35.
[24] Swarupa C, Sajjan GS, Sashi Kanth Y. An in-vitro stereomicroscopic comparative evaluation of a combination of apex locator and endodontic motor with an integrated endodontic motor. J Conserv Dent. 2013;16(5):458-61.
[25] Kılıç Y, Tulgar MM, Karataşlıoğlu E. Effect of different apical actions of new integrated endodontic motors on apical debris extrusion: An in-vitro study. Aust Endod J. 2024;50(1):110-14.
[26] Peters OA, Gluskin AK, Weiss RA, Han JT. An in-vitro assessment of the physical properties of novel HyFlex nickel-titanium rotary instruments. Int Endod J. 2012;45(11):1027-34.
[27] Shen Y, Coil JM, Zhou H, Zheng Y, Haapasalo M. HyFlex nickel-titanium rotary instruments after clinical use: Metallurgical properties. Int Endod J. 2013;46(8):720-29.
[28] Khalil W, Abu-Haimed T. Evaluation of the defects in reciprocating and rotating nickel-titanium files used as a single file to prepare molar teeth. Egypt Dent J. 2017;63(4):2639-49.
[29] Verma M, Meena N, Kumari RA, Mallandur S, Vikram R, Gowda V. Comparison of apical debris extrusion during root canal preparation using instrumentation techniques with two operating principles: An in-vitro study. J Conserv Dent. 2017;20(2):96-99.
[30] Altundasar E, Nagas E, Uyanik O, Serper A. Debris and irrigant extrusion potential of 2 rotary systems and irrigation needles. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;112(4):e31-e35.

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