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Comparative Evaluation Of Apical Debris Extrusion During Root Canal Preparation Using Four Different Single-File Systems: An In-Vitro Study

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Abstract

Background: *Effective cleaning and shaping of the root canal system are essential for successful endodontic therapy. However, extrusion of debris beyond the apical foramen during biomechanical preparation may result in postoperative pain, inflammation, and delayed healing. Contemporary nickel–titanium (NiTi) single-file systems have simplified instrumentation and claim to minimize apical extrusion through improved design and metallurgy.*

Aim: *To evaluate and compare the amount of apically extruded debris produced by four single-file systems—WaveOne Gold (WOG), Hyflex EDM (HEDM), One Curve (OC), and XP-Endo Shaper (XPS).*

Materials and Methods: *Sixty extracted human mandibular premolars were randomly divided into four groups (n = 15) and instrumented with one of the above systems. The Myers and Montgomery apparatus was used for debris collection. Tubes were incubated at 70 °C for 5 days and weighed on a digital analytical balance. Data were analyzed using one-way ANOVA and Tukey's post hoc test ($\alpha = 0.05$).*

Results: *All groups showed measurable apical extrusion. Mean extrusion (g): OC 0.0382 > HEDM 0.0370 > WOG 0.0286 > XPS 0.0214. ANOVA showed a significant difference ($p = 0.001$).*

Conclusion: *Apical extrusion of debris is unavoidable, but the XP-Endo Shaper produced the least extrusion, followed by WOG, HEDM, and OC. File design, taper, alloy, and motion kinematics play critical roles in reducing apical extrusion.*

Keywords: *Apical debris extrusion; nickel-titanium files; single-file systems; WaveOne Gold; Hyflex EDM; One Curve; XP-Endo Shaper.*

INTRODUCTION

Successful endodontic therapy depends on efficient cleaning and shaping of the root canal system while preventing damage to periapical tissues. During canal preparation, dentinal chips, microorganisms, and irrigants may be extruded apically, provoking inflammation, postoperative pain, or delayed periapical healing. The amount of extrusion depends on the canal anatomy, irrigation protocol, and instrument design.[1-3]

NiTi instrumentation has revolutionized endodontics because of its superior flexibility and cyclic-fatigue resistance. The development of *single-file systems* using advanced alloys and motion kinematics has further simplified canal shaping. These files operate either in continuous rotary or reciprocating motions, and their geometry directly affects debris transportation and extrusion.[2-5]

WaveOne Gold (WOG) employs a reciprocating motion and M-wire alloy. Hyflex EDM (HEDM) is manufactured via electrical-discharge machining, producing a rough surface and controlled memory.[6-7] One Curve (OC) uses C-wire heat-treated NiTi and continuous rotary motion. XP-Endo Shaper (XPS) utilizes MaxWire alloy, whose adaptive snake-like design contacts canal walls dynamically, minimizing apical compaction.[8-10]

Because previous studies show inconsistent results on apical extrusion between these newer single-file systems, this study aimed to compare and quantify the apical debris extrusion among WOG, HEDM, OC, and XPS systems under standardized in-vitro conditions.

MATERIALS AND METHODS

Sample Selection and Preparation

Sixty freshly extracted single-rooted mandibular premolars were selected and stored in 0.9% saline. Teeth with caries, fractures, restorations, or resorption were excluded. Radiographs confirmed single canals. Cusp tips were flattened to standardize the length to 16 mm. Working length was determined 0.5 mm short of the apex using a #10 K-file.

Grouping and Instrumentation

Samples were divided into four groups (n = 15):

- **Group I (WOG):** Reciprocating #25/.07, 300 rpm, 2.5 N·cm torque.
- **Group II (HEDM):** Rotary #25/.08, 500 rpm, 2.5 N·cm torque.
- **Group III (OC):** Rotary #25/.06, 300 rpm, 2.5 N·cm torque.
- **Group IV (XPS):** Rotary #30/.01, 800 rpm, 1 N·cm torque.

Instrumentation was performed using an X-Smart Plus endomotor (Dentsply Maillefer, Switzerland). Two mL of distilled water was used as irrigant per tooth, delivered with a 27-gauge needle. Each file prepared four canals.

Debris Collection

Apical debris was collected using the Myers & Montgomery model[7]. Teeth were inserted into pre-weighed Eppendorf tubes sealed with cyanoacrylate, with a 27-gauge needle to equalize pressure. After instrumentation, debris adhered to the root was flushed into the tube with 1 mL distilled water. Tubes were incubated at 70 °C for five days and re-weighed. The difference between final and initial weights gave the amount of extruded debris.

Statistical Analysis

Data were analyzed using SPSS v22. Means ± SD were calculated. One-way ANOVA tested overall differences, followed by Tukey's post hoc test ($p \leq 0.05$).

RESULTS

A total of 60 extracted teeth were randomly distributed into four groups (n = 15) according to the single-file system used for root canal instrumentation. The amount of apically extruded debris was measured for each sample using a digital analytical balance with an accuracy of 0.0001 g.

The four experimental groups were as follows:

- Group I: WaveOne Gold Primary (Reciprocating file system)
- Group II: Hyflex EDM One File (Rotary file system)
- Group III: One Curve (Rotary file system)
- Group IV: XP-Endo Shaper (Rotary file system)

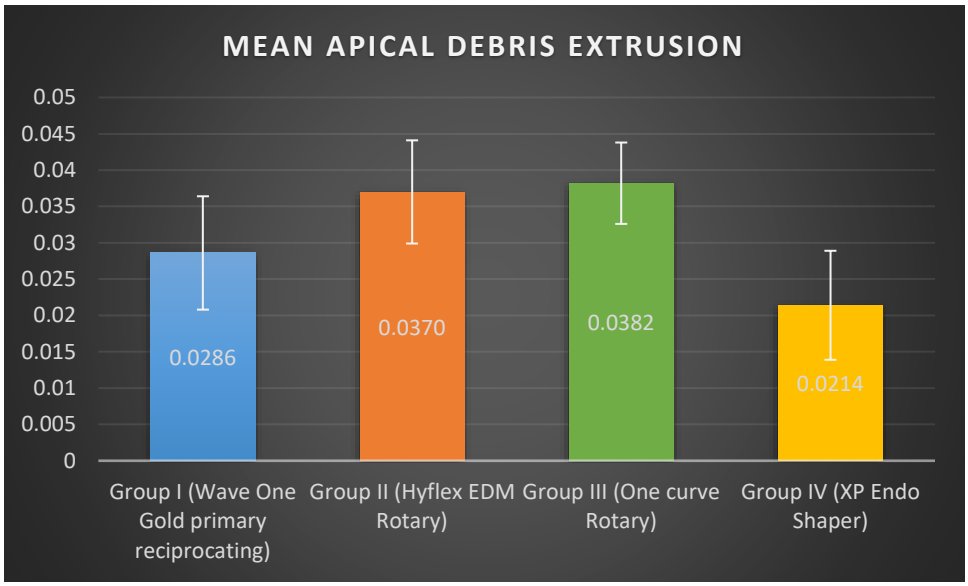
The recorded mean values of apically extruded debris for each group are presented in Table 1 and illustrated in Graph 1.

Table 1: Description of amount of apically extruded debris using four different single file systems (Group Ⅰ: WaveOne Gold primary reciprocating file, Group Ⅱ: HyflexEDM One file, Group Ⅲ: One Curve rotary file, Group Ⅳ: XP-endo Shaper rotary file) respectively.

Sample No.	Group Ⅰ (WaveOne Gold)	Group Ⅱ (HyflexEDM)	Group Ⅲ (One Curve)	Group Ⅳ (XP-Endo Shaper)
1	0.0249	0.0349	0.0394	0.0144
2	0.0210	0.0310	0.0336	0.0291
3	0.0273	0.0373	0.0361	0.0156
4	0.0260	0.0360	0.0394	0.0265

5	0.0245	0.0345	0.0390	0.0321
6	0.0231	0.0331	0.0351	0.0221
7	0.0192	0.0392	0.0361	0.0281
8	0.0290	0.0490	0.0497	0.0225
9	0.0276	0.0476	0.0321	0.0101
10	0.0229	0.0329	0.0339	0.0114
11	0.0385	0.0385	0.0473	0.0264
12	0.0285	0.0245	0.0327	0.0149
13	0.0291	0.0291	0.0329	0.0282
14	0.0373	0.0373	0.0393	0.0274
15	0.0494	0.0494	0.0470	0.0122
Mean	**0.0286**	**0.0370**	**0.0382**	**0.0214**

Graph 1: Comparison of mean value of apical debris extrusion.



Descriptive Analysis

The mean apical debris extrusion of each group was as follows:

- Group I (WaveOne Gold): 0.0286 g
- Group II (Hyflex EDM): 0.0370 g
- Group III (One Curve): 0.0382 g
- Group IV (XP-Endo Shaper): 0.0214 g

The order of mean apical debris extrusion was:
Group III > Group II > Group I > Group IV
(0.0382 g > 0.0370 g > 0.0286 g > 0.0214 g)

This indicates that One Curve produced the maximum amount of apically extruded debris, whereas XP-Endo Shaper exhibited the least amount of debris extrusion.

Statistical Analysis

All data were entered into Microsoft Excel 2010 and analyzed using SPSS version 22 (SPSS Inc., Chicago, IL).

Normality of the data was verified using the Shapiro–Wilk test, confirming that the data followed a normal distribution.

The level of significance (α) was set at 5% ($p \leq 0.05$).

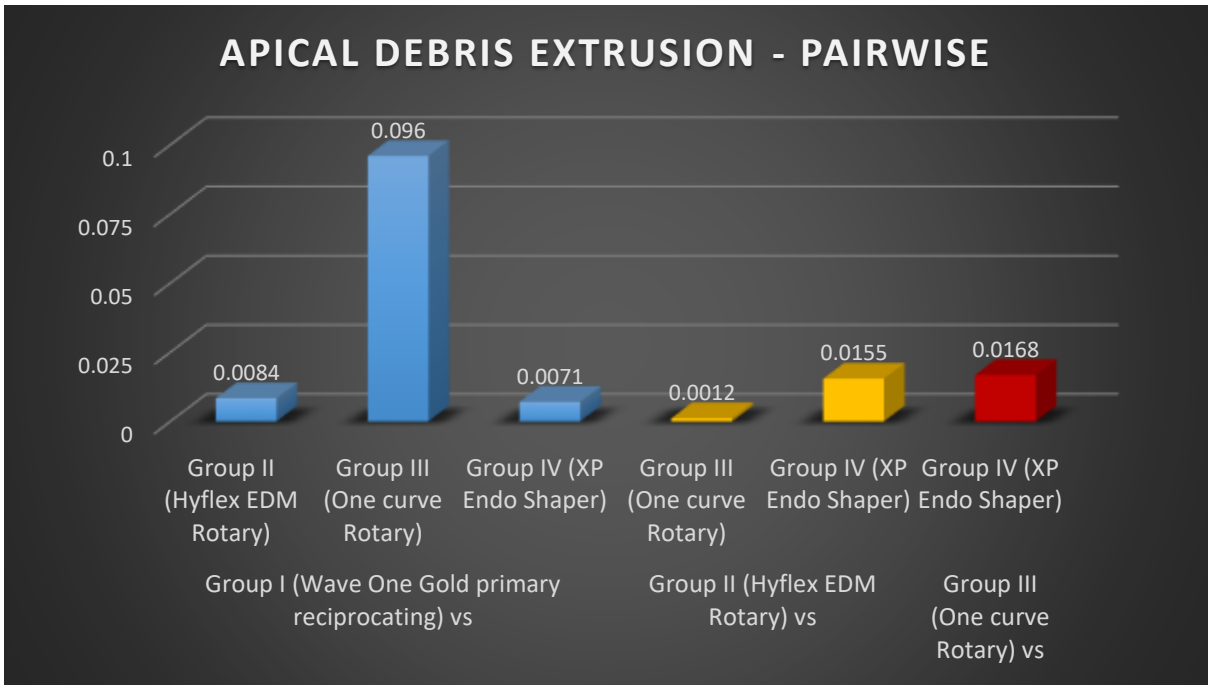
A one-way ANOVA (F-test) was applied to compare the mean amount of apically extruded debris among the four groups.

Table 2: Comparison of amount of apically extruded debris during root canal preparation using four different single file systems.

Groups	Mean	Sd	One way anova f test	P value, significance
Group I (Wave One Gold)	0.0286	0.0078	F = 18.483	p = 0.001* (Significant overall difference)
Group II (Hyflex EDM)	0.0370	0.0071		
Group III (One Curve)	0.0382	0.0056		
Group IV (XP Endo Shaper)	0.0214	0.0075		

*The mean difference is significant at the 0.05 level of significance

Graph 2: Multiple individual pairwise comparison of apically extruded debris among each of the four groups.



As presented in Table 2, a statistically significant difference was found among the groups (F = 18.483, p = 0.001), indicating that the amount of debris extrusion significantly varied depending on the file system used.

Intergroup Comparison (Tukey's Post Hoc Test)

To determine the specific differences between individual groups, Tukey's post hoc test was applied.

Table 3: Pairwise comparison of apical debris extrusion during root canal preparation using four different single file systems using Tukey's post hoc test**.**

Group	Comparison Group	Mean Difference	P value	Significance
Group I (Wave One Gold)	Group II (Hyflex EDM)	0.0084	p =0.01*	Significant
	Group III (One Curve)	0.096	p =0.002*	Significant
	Group IV (XP Endo Shaper)	0.0071	p =0.038*	Significant
Group II (Hyflex EDM)	Group III (One Curve)	0.0012	p=0.959	Non-Significant
	Group IV (XP Endo Shaper)	0.0155	p =0.000*	Significant
Group III (One Curve)	Group IV (XP Endo Shaper)	0.0168	p= 0.000*	Significant

*The mean difference is significant at the 0.05 level of significance

The results are summarized in Table 3 and Graph 2, revealing the following findings:

1. Group II (Hyflex EDM) extruded more debris compared to Group I (WaveOne Gold) — this difference was statistically significant (p = 0.01).
2. Group III (One Curve) produced a significantly higher amount of debris compared to Group I (WaveOne Gold) (p = 0.002).
3. Group IV (XP-Endo Shaper) showed significantly less debris extrusion than Group I (WaveOne Gold) (p = 0.038).
4. When comparing Group III (One Curve) with Group II (Hyflex EDM), the difference was not statistically significant (p = 0.959), indicating similar extrusion behavior.
5. Group IV (XP-Endo Shaper) extruded significantly less debris than Group II (Hyflex EDM) (p = 0.000).
6. Group IV (XP-Endo Shaper) also exhibited significantly less debris extrusion than Group III (One Curve) (p = 0.000).

Overall Interpretation

The results demonstrated a statistically significant difference in the mean values of apical debris extrusion among all file systems tested.

The One Curve rotary file system (Group III) extruded the highest amount of apical debris, followed by Hyflex EDM (Group II), WaveOne Gold (Group I), and the XP-Endo Shaper (Group IV), which produced the least amount of apical debris extrusion.

This suggests that the design, metallurgy, and motion kinematics of the files have a direct influence on the extent of debris extrusion.

The XP-Endo Shaper, with its adaptive design and snake-like flexibility, minimized apical extrusion effectively compared to other systems.

Based on the present study, all tested single-file systems extruded apical debris to varying degrees. However, XP-Endo Shaper showed the least apical debris extrusion, whereas One Curve exhibited the maximum extrusion, indicating that file design, cross-sectional geometry, and motion kinematics play a crucial role in the amount of debris extruded apically during root canal instrumentation.

DISCUSSION

Apical extrusion of debris during canal preparation remains inevitable despite technological advancements.[11-12] The phenomenon can lead to postoperative pain, flare-ups, and delayed

healing.[13] This study's results confirmed that although all systems extruded debris, XP-Endo Shaper (XPS) produced the least, while One Curve (OC) produced the most.

Influence of Instrument Design and Motion

File design and motion kinematics profoundly affect debris transportation. Reciprocating systems such as WOG alternate clockwise and counter-clockwise rotations, mimicking the balanced-force concept and minimizing continuous apical pressure. Rotary systems, conversely, create a "screw-in" effect that tends to direct debris apically. XPS exhibited minimal extrusion owing to its smaller taper (0.01) and adaptive design that allows effective coronal evacuation.

The OC file, made of C-wire NiTi and operated in continuous rotation, has variable cross-section and positive rake angle, which increases cutting efficiency but may push debris toward the apex[29]. HEDM, despite its improved flexibility from EDM processing, possesses an 0.08 taper at the apical 4 mm and hence generated larger chip volumes.[14-15]

Comparison with Previous Literature

The present findings correspond with Uslu et al. who found the least extrusion with XPS compared to Hyflex EDM and Reciproc Blue. Muhaibes and Alwakeel also reported similar trends. Haridas et al. observed that reciprocating and adaptive systems produced significantly less extrusion than conventional rotary ones.

Earlier studies by Bürklein and Schäfer and Üstün et al. showed that full-sequence rotary systems extrude more debris than reciprocating single-file systems.[17] Patel et al. and Koçak et al. further confirmed that larger apical tapers are associated with increased extrusion.[18-20]

Biomechanical Explanation

The difference in debris extrusion is likely due to canal fluid dynamics and chip-load behavior. Reciprocating files disengage from canal walls periodically, permitting debris backflow coronally, whereas continuous rotation maintains constant engagement, pushing chips apically. The thermal-treated alloys (M-wire, C-wire, MaxWire) affect flexibility and fatigue resistance, indirectly influencing debris compaction.[21-23]

Clinical Significance

Clinically, the reduction of apical extrusion correlates with fewer postoperative flare-ups and improved patient comfort. XPS, with its low extrusion and efficient shaping, may be ideal in teeth with periapical pathology. However, periapical tissues in vivo provide resistance not replicated in vitro. Therefore, although quantitative values differ clinically, comparative trends remain relevant.[24-26]

Future studies incorporating simulated periapical barriers, dynamic irrigation, or micro-CT imaging could provide deeper insight into three-dimensional debris movement.[27-30]

CONCLUSION

All four single-file systems tested caused apical extrusion of debris. XP-Endo Shaper produced the least extrusion, followed by WaveOne Gold, Hyflex EDM, and One Curve. The variation arises primarily from differences in file geometry, taper, alloy treatment, and motion kinematics. Using instruments with adaptive or reciprocating motion and smaller taper can help minimize postoperative discomfort in clinical practice.

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