

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Original Article

Influence of pecking frequency at working length on the volume of apically extruded debris: A micro-computed tomography analysis

Li-Xiao Wang^{a,b†}, Hui Chen^{a,b†}, Rui-Tian Lin^{a,b}, Li-Sha Gu^{a,b*}



^a Hospital of Stomatology, Sun Yat-sen University, Guangzhou, Guangdong, China

^b Guangdong Provincial Key Laboratory of Stomatology, Guanghua School of Stomatology, Sun Yat-sen University, Guangzhou, Guangdong, China

Received 3 November 2021; Final revision received 18 November 2021

Available online 6 December 2021

KEYWORDS

Dental instruments;
Endodontics;
Micro-computed
tomography;
Root canal
preparation

Abstract *Background/purpose:* There is no consensus to date on how many repetitive pecking motions at working length (WL) should be regarded as optimal during instrumentation. Therefore, this study aimed to evaluate the effect of pecking frequency at WL on the volume of apically extruded debris using three single-file systems in curved, oval-shaped canals.

Materials and methods: Forty-five single-rooted mandibular premolars with curved, oval-shaped canals were prescanned by micro-computed tomography, anatomically paired-matched, and randomly divided among three groups ($n = 15$ each): Reciproc Blue (RB), WaveOne Gold (WOG) and XP-endo Shaper (XPS). Samples were embedded in agarose gel to collect extruded debris. After preparation to the WL, each sample was rescanned after one, two, four, 10, and 20 pecking motions at WL, respectively. The debris volume was innovatively calculated by a modification of an existing method using micro-computed tomography. The apical preparation size was also measured. Data were compared using a two-way repeated-measures analysis of variance.

Results: All single-file systems extruded debris apically, irrespective of the pecking frequency at WL. The extruded debris volume correlated positively with the minor foramen size ($P < 0.05$); both increased with pecking frequency for each single-file system ($P < 0.05$). The minor foramen size corresponded to the instrument tip size when reaching the WL once.

* Corresponding author. Hospital of Stomatology, Sun Yat-sen University, No. 56, Lingyuan West Road, Guangzhou, Guangdong, 510055, China. Fax: +86 20 83822807.

E-mail address: gulisha@mail.sysu.edu.cn (L.-S. Gu).

† These two authors contributed equally to this work.

Conclusion: To produce less debris extrusion and obtain a predictable foramen size corresponding to the instrument tip size, a single pecking motion may be preferred when using single-file systems. Caution should be exercised when applying the current results to clinical situations.

© 2021 Association for Dental Sciences of the Republic of China. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Effective root canal preparation is fundamental for successful root canal therapy.^{1,2} During instrumentation, the smear layer containing toxin residuals, debris of dentin and pulp tissues, along with irrigation solutions may extrude into periapical tissues. Both the uncontaminated and contaminated hard tissue debris can trigger an inflammatory reaction when extruded periapically, and result in acute periapical tissue swelling, postoperative pain, and infection.^{3,4} Meanwhile, the inflammatory reactions may be exacerbated by an increase in the amount of debris extruded beyond the apex.^{3,5} Therefore, the lesser the apical debris extrusion caused by instrumentation, the lower the risk of postoperative pain and complications during root canal therapy.^{3–6}

In recent years, single-file nickel-titanium (NiTi) systems have become an important part of the armamentarium for root canal preparation; they are increasingly used by clinicians to facilitate the cleaning and shaping phases of instrumentation. Manufacturers claim that metallurgical improvements in NiTi alloys, such as blue (Reciproc Blue; VDW, Munich, Germany), gold (WaveOne Gold; Dentsply Maillefer, Ballaigues, Switzerland) and Maxwire (XP-endo Shaper; FKG Dentaire, La Chaux-de-Fonds, Switzerland) thermomechanical treatments, improve the elasticity and adaptation of endodontic files to the root canal anatomy with a reduction in the amount of debris extrusion.^{7–11} Reciproc Blue (RB) and WaveOne Gold (WOG) are two popular single-file systems working with reciprocating motion.⁷ Recently introduced XP-endo Shaper (XPS) is specifically designed to overcome the challenge of irregular root canals, including oval-shaped canals.^{12,13} To date, the debris extruded by them in oval-shaped and curved canals remains unclear.

Repetitive pecking motions, also known as repetitive in-and-out movements, have always been recommended for canal shaping with NiTi files. Such motions are especially useful for the shaping of the apical region of the root canal.¹⁴ Pecking is necessary for distributing the flexural stress of the files to reduce the risk of separation. These motions are also beneficial for minimizing screw-in forces that create high levels of torsional stresses as rotary instruments are inadvertently drawn into the canal space to produce torsional failure.¹⁴ The rational use of pecking motions results in better preparation quality during root canal preparation.¹⁴

Despite the broad range of applications, there is no consensus on how many repetitive pecking motions at

working length (WL) should be regarded as optimal during instrumentation. Previous studies reported that increasing the pecking frequency at WL leads to enlargement of the apical preparation,^{1,15} whereas other authors suggested that such motions did not remarkably increase the apical preparation size.¹⁶ A large apical size is beneficial for the sufficient removal of infected dentin and subsequent irrigation,¹ but also may increase the extrusion of debris from the apex and potentially result in a poor prognosis. Therefore, the objective of this study was to evaluate the effects of pecking frequency at WL on the extruded debris volume using RB, WOG and XPS single-file systems in curved, oval-shaped canals. The null hypothesis was that the pecking frequency at WL has no influence on the extruded debris volume and apical preparation size.

Materials and methods

Specimen selection

This study was in accordance with the Declaration of Helsinki and approved by the local ethics committee (KQEC-2020–02). Informed consent was obtained for experimentation with human subjects. Sample size calculation indicated that 15 teeth/group would be sufficient to show a 5% difference in tooth-related data with a power of 80%. Single-root mandibular premolars extracted because of orthodontics or periodontitis without open apices, caries, restoration or fractures were collected. The teeth were radiographed in buccolingual and mesiodistal projections to confirm the presence of a single canal. The canal orifices were located and confirmed with a #10 K-file (Dentsply Maillefer). In addition, teeth with an apical foramen wider than 0.15 mm, as determined using a #15 K-file (Dentsply Maillefer), were excluded for standardization.³

The specimens were prescanned by a CT scanner (Scanco μ 50; SCANCO Medical AG, Zurich, Switzerland) at 70 kV, 200 μ A and with an isotropic pixel size of 15 μ m. The image stacks were converted using Avizo software version 2019.1.0 (Thermo Fisher Scientific, Waltham, MA, USA) to obtain morphologic features of each canal. The maximal and minimal initial canal diameters at a 1-mm interval in the apical 5 mm of the canal cross-sections were measured respectively. Only teeth with a canal curvature angle of 15–25° at the middle-third of the canal according to Schneider's method,^{13,17} and root canals with a maximal:minimal canal diameter ratio of ≥ 2 in the apical 5 mm (i.e. oval-shaped canals), were included.^{12,13,18–21}

Subsequently, the samples were divided into anatomically paired-matched groups based on similar canal length, volume and surface area.^{19,22} These strict selection criteria were implemented to reduce the bias generated by anatomic variation and create a reliable baseline. Each tooth-pair was randomly allocated to one of three groups according to the instrument used as follows: RB R25, WOG primary (size 25, 0.07 taper) and XPS ($n = 15$).

Apparatus for the measurement of extruded debris

The apparatus design for debris collection was based on that used by Alves et al.⁸ Customized transparent plastic cylinders were made for evaluation. Two-thirds of the cylinders were filled with 1.5% sterile agarose gels to simulate periapical tissue and provide a matrix to collect extruded debris.⁸ During the semi-solidification periods, three specimens were vertically inserted into the agarose gels with the coronal portions out. After gel solidification, self-curing acrylic resins were used to fix the specimens during instrumentation and micro-CT scanning (Fig. 1).

Root canal preparation

The WL of each canal was set 0.5 mm short of the apex with a #10 K-file under a microscope (ZEISS, Jena, Germany). Glide path preparation was conducted using #15 K-files for all teeth, followed by irrigation.²³ Root canal preparation was performed by an experienced operator using a 6:1 contra-angle handpiece driven by an X-smart Plus endodontic motor (Dentsply Maillefer). The RB and WOG files were advanced toward the root apex in a slow pecking motion (3 mm in amplitude) using the 'Reciproc' and 'WaveOne' preset modes, respectively.²⁴ The XPS files were operated at a speed of 800 rpm and a torque value of 1 Ncm, using gentle, long strokes toward the apical stop.^{8,25}

Once the WL was reached, the canal was irrigated again and apical patency was confirmed. The debris accumulated on the flutes was cleaned off with an alcohol-soaked cotton pellet. The root canal was instrumented with one pecking motion at WL combined with brushing against the inner walls.¹ Thereafter, the instrument was withdrawn and

cleaned. The canal was irrigated and dried with absorbent paper points. The specimen then underwent a post-operative micro-CT scan. Morphological reconstruction was performed using the aforementioned parameters.

Each specimen was subjected to repeated pecking at WL for two, four, 10, and 20 times combined with brushing against the inner walls, according to previous studies^{1,15,16} and the manufacturer's recommendation for the XPS system.³ After finishing each designated number of pecking motions, the specimens were rinsed, dried, and scanned for the reconstruction of the instrumented canals.

Each irrigation was performed using 2 mL preheated physiological saline ($37 \pm 1^\circ\text{C}$) at a constant rate for 1 min. The irrigant was delivered using a 30-gauge side-vented irrigation needle inserted to 1 mm short of the WL without tightening in the canal. Root canal preparation was performed in a 37°C water bath to simulate clinical conditions. The files were observed under the microscope at $40\times$ magnification after each instrumentation. They were discarded after instrumenting one canal or after identification of cracks or file distortion.

Micro-CT analysis

Three-dimensional models of the same specimens before and after preparation were reconstructed using the Avizo software, rendered, co-registered and combined accordingly. The volumes of apically extruded debris were calculated according to the formula $V_B - V_A$ (Fig. 2), where V_A and V_B represent the parameter values of the dentin volume beyond the apical foramen acquired before and after instrumentation, respectively. The major and minor diameters of the oval-shaped canals at WL were also calculated.

Statistical analysis

The SPSS version 25.0 (SPSS Inc, Chicago, IL, USA) was used for analyses with α preset at 0.05. All data were distributed normally (Shapiro–Wilk test). A two-way repeated-measures analysis of variance (ANOVA) was subsequently used to analyze the effects of system-type

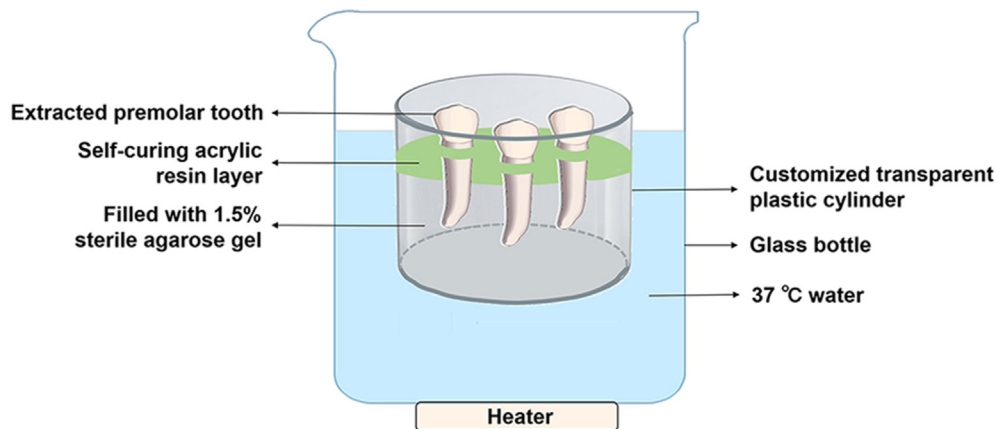


Figure 1 A schematic of the agar gel model. Teeth were positioned in a transparent plastic cylinder and immersed in 1.5% agar gel heated to a constant 37°C in a water bath.

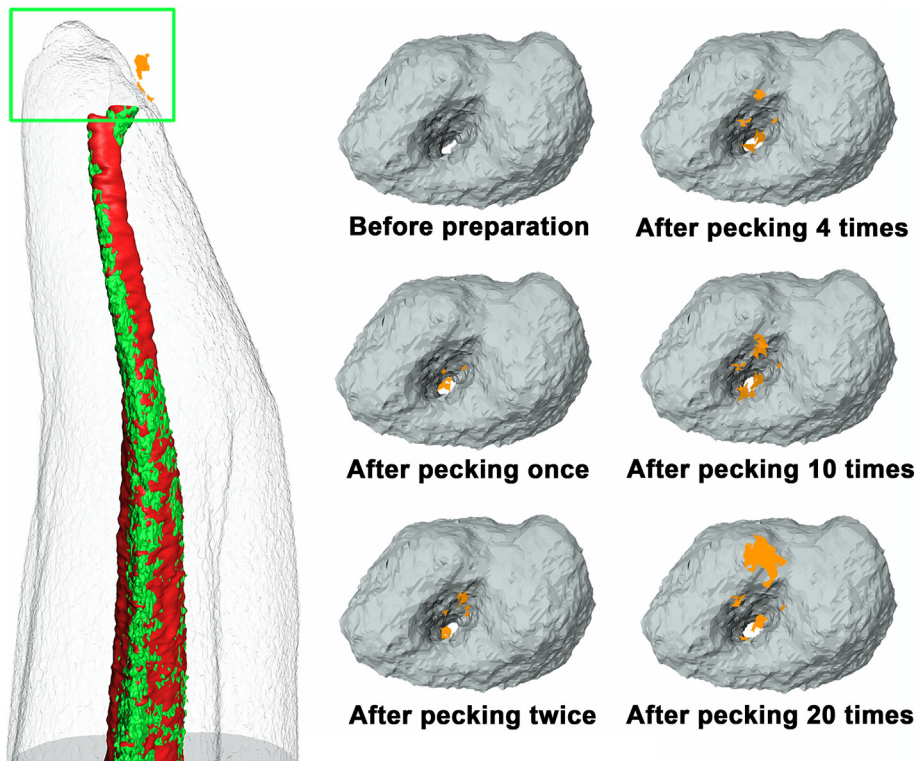


Figure 2 Micro-CT 3-dimensional reconstructions of a curved, oval-shaped root canal before and after root canal preparation showing apically extruded hard tissue debris resulting from different pecking frequencies at working length (orange). The green regions represent the canal portion before preparation. The red regions represent the increased canal portion after preparation.

and pecking frequency on the debris volume and apical minor diameter. The major diameter was also analyzed after Log_{10} transformation. The Pearson correlation analysis was used to verify the relationship between debris volumes and apical diameters.

Results

Apically extruded debris existed in all single-file systems irrespective of the pecking frequency used (Table 1). Both system-type and pecking frequency significantly affected

the debris volume and minor diameter ($P < 0.05$); the interaction between the two factors was also significant ($P < 0.05$; Table 2). Neither system-type nor pecking frequency significantly affected the major diameter; the interaction between the two factors was nonsignificant.

The extruded debris volume and minor foramen size increased with pecking frequency in each system ($P < 0.05$; Tables 1 and 2). When pecking was done once, the mean minor diameters (in mm) of RB, WOG and XPS systems were 0.255, 0.253 and 0.301, respectively. No significant differences in the debris volume among single-file systems were found. With two, four and 10 pecking motions, the debris volume was smaller for the XPS system than for the WOG system ($P < 0.05$) and slightly smaller than that for the RB system. The XPS system extruded the least debris volume when pecking was done 20 times ($P < 0.05$).

The extruded debris volume showed a positive correlation with the minor diameter ($P < 0.05$) but a nonsignificant correlation with the major diameter, irrespective of the pecking frequency or system used (Table 3).

Discussion

Due to their small ionic size, hypochlorite ions can diffuse into mineralized collagen fibrils of the intra-radicular dentin and dissolve the collagen components, leaving behind mineral ghosts that are more brittle than the original mineralized dentin.²⁶ The use of saline as an irrigant in the present study enabled direct comparison of the mechanical effects of single-file systems, avoiding influence attributed to the

Table 1 Mean values and standard deviations of the debris volumes ($\ast 10^6 \mu\text{m}^3$) beyond the apical foramen in curved and oval-shaped canals.

Pecking frequency	Reciproc Blue	WaveOne Gold	XP-endo Shaper
1	9.63 \pm 2.34 ^{Aa}	11.41 \pm 2.65 ^{Aa}	9.85 \pm 2.44 ^{Aa}
2	15.09 \pm 4.19 ^{Ba}	18.78 \pm 4.67 ^{Ba}	14.41 \pm 4.35 ^{Ba}
4	27.67 \pm 10.01 ^{Ca}	25.41 \pm 3.67 ^{Ca}	20.69 \pm 5.54 ^{Ca}
10	33.23 \pm 10.62 ^{Dab}	34.73 \pm 7.12 ^{Da}	25.19 \pm 7.03 ^{Db}
20	43.58 \pm 11.77 ^{Ea}	41.34 \pm 10.75 ^{Ea}	28.85 \pm 6.40 ^{Eb}

Different superscript capital letters indicate statistically significant differences among groups with different pecking frequencies at working length ($P < 0.05$).

Different superscript lowercase letters indicate statistically significant differences among single-file systems ($P < 0.05$).

Table 2 Mean values and standard deviations of the major and minor apical diameters (μm) at working length.

Pecking frequency	Major diameter at working length			Minor diameter at working length		
	Reciproc Blue	WaveOne Gold	XP-endo Shaper	Reciproc Blue	WaveOne Gold	XP-endo Shaper
1	391.27 \pm 60.43 ^{Aa}	395.87 \pm 73.62 ^{Aa}	403.00 \pm 84.18 ^{Aa}	255.00 \pm 15.30 ^{Aa}	252.53 \pm 10.58 ^{Aa}	301.33 \pm 18.32 ^{Ab}
2	393.07 \pm 62.40 ^{Aa}	396.53 \pm 72.91 ^{Aa}	402.67 \pm 87.62 ^{Aa}	273.67 \pm 22.08 ^{Ba}	271.67 \pm 13.23 ^{Ba}	322.87 \pm 27.61 ^{Bb}
4	393.73 \pm 65.93 ^{Aa}	397.80 \pm 72.52 ^{Aa}	403.73 \pm 85.84 ^{Aa}	294.67 \pm 29.87 ^{Ca}	296.47 \pm 18.01 ^{Ca}	340.93 \pm 31.13 ^{Cb}
10	394.00 \pm 63.17 ^{Aa}	399.73 \pm 69.99 ^{Aa}	399.87 \pm 89.64 ^{Aa}	317.93 \pm 26.44 ^{Da}	322.60 \pm 20.05 ^{Da}	351.53 \pm 28.62 ^{Db}
20	392.60 \pm 58.39 ^{Aa}	404.47 \pm 66.38 ^{Aa}	412.00 \pm 83.27 ^{Aa}	349.33 \pm 15.99 ^{Ea}	351.07 \pm 22.81 ^{Ea}	359.33 \pm 27.42 ^{Ea}

Different superscript capital letters in columns indicate statistically significant differences between groups with different pecking frequencies at working length (two-way repeated-measures analysis of variance and Bonferroni corrected post hoc test, P -value < 0.05). Different superscript lowercase letters in rows indicate statistically significant differences between single-file systems (two-way repeated-measures analysis of variance and Bonferroni corrected post hoc test, P -value < 0.05).

Table 3 Correlation of the extruded debris volume with the major and minor diameters at working length (WL) in groups with different pecking frequencies and systems.

Pecking frequency	Major diameter at WL			Minor diameter at WL		
	Reciproc Blue	WaveOne Gold	XP-endo Shaper	Reciproc Blue	WaveOne Gold	XP-endo Shaper
1	0.07	-0.42	0.04	0.88 ^{***}	0.55 [*]	0.91 ^{***}
2	-0.33	-0.00	0.07	0.84 ^{***}	0.55 [*]	0.61 [*]
4	-0.46	0.09	-0.12	0.57 [*]	0.54 [*]	0.53 [*]
10	-0.49	0.22	-0.09	0.61 [*]	0.52 [*]	0.74 ^{**}
20	-0.24	0.42	-0.09	0.56 [*]	0.68 ^{**}	0.51 [*]

Pearson correlation analysis. ^{*} $P < 0.05$, ^{**} $P < 0.01$, ^{***} $P < 0.001$.

use of sodium hypochlorite (NaOCl). In addition, the use of saline can avoid destabilization of the gel matrix caused by NaOCl.⁸

In clinical practice, it is difficult to calculate the specific amount of debris extrusion during instrumentation. Numerous studies have calculated the amount of collectable extruded debris in vitro by using a weighing device.^{3,7,8,27-35} Some studies modified the apparatus to simulate periapical tissues' resistance to apical extrusion for more clinical applications.^{3,5,7} Although these devices provide valuable information, advances in technology have led to even more promising devices. Micro-CT is innovatively applied by Alves et al.⁸ to calculate the volume of apically extruded debris. Micro-CT analysis permits visualization of the debris extrusion and avoids the influence of uncontrollable environmental conditions such as air humidity,¹⁴ in contrast to the other methods, which only weigh the debris.⁸

Alves et al.⁸ found that visualized extruded debris existed in 48% and 29% curved canals for the XPS and Reciproc systems, respectively. Nevertheless, in the current study, it was verified that apically extruded debris existed in all groups. These different results may be attributed to the sensitivity of the specific computation applied. Alves et al. used CTAn software to binarize, select and quantify dentinal debris extrusion.⁸ The computation appears to have measurement errors because of the binarization itself and since it is hard to select debris only, as the threshold values of the dentin and debris were approximate. In the present study, after completion of superimposition, the debris volume was calculated directly using the difference of the quantification of the dentin beyond the apical foramen before and after instrumentation (Fig. 2). The modified computation method

presented herein can accurately measure the volume of tiny extruded debris attached to dentin, consistent with previously reported methods involving the weighing of debris extrusion.^{3,7,10,29,31,33} The results reinforce the fact that it is impossible to prepare a root canal system chemomechanically without any debris extrusion.

Both the RB and WOG reciprocating single-file systems caused volumes of apically extruded debris similar to those of the XPS system when pecking was performed once. The results were compatible with previous studies without regard to the pecking frequency factor.^{7,27,32,36,37} Nevertheless, when pecking was performed more than once, XPS caused less debris than the other two reciprocating systems. The better performance of XPS is probably attributable to its unique snake-like rotation at high speed, smaller taper and adaptive core, which are conducive to avoiding debris accumulation in the apical region and providing more available space to remove debris coronally.^{3,9,12,13,29,33,38} Thereby, different preparation techniques can induce different results regarding debris extrusion.

Based on the results of this investigation, the volume of apically extruded debris increased with augmented pecking frequency (Fig. 3A). Since there was a positive correlation between the minor foramen size and extruded debris volume, this could be attributable to an increase in the size of the minor foramen diameter with an increase in the pecking frequency (Fig. 3B),³⁹ which is in agreement with Jeon et al.'s reports.¹ When pecking was performed once, the apical preparation sizes matched International Organization for Standardization (ISO) size 25 for the RB and WOG systems, and ISO size 30 for the XPS system. Thereby, the minor foramen size corresponds to the instrument tip size

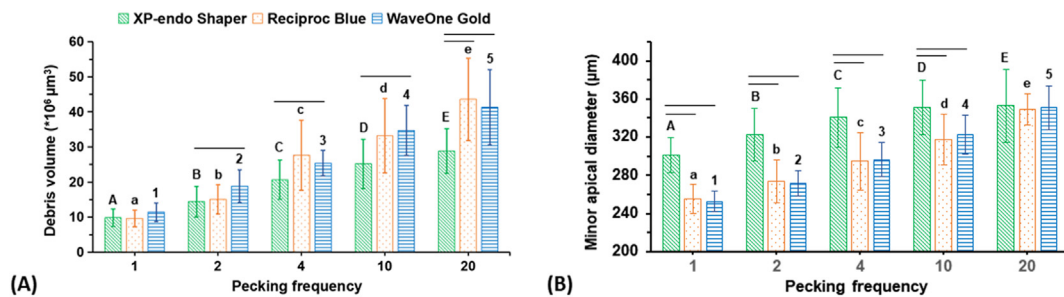


Figure 3 Effects of pecking frequency on the volume of apically extruded debris (A) and the minor apical diameter (B) when three single-file systems were used in curved, oval-shaped canals. Data represent means \pm standard deviations. For XP-endo Shaper, different capital letter superscripts indicate significant differences ($P < 0.05$). For Reciproc Blue, different lowercase letter superscripts indicate significant differences ($P < 0.05$). For WaveOne Gold, different numeral superscripts indicate significant differences ($P < 0.05$). For comparison among different file systems, columns linked by horizontal bars are significantly different ($P < 0.05$).

when reaching the WL once. In addition, frequent pecking may result in excessively prepared canal walls, especially in the apical part of curved canals. The curvature of the root canal is thus slightly straightened,¹⁵ making the endpoint of preparation closer to the anatomical apical foramen. Accordingly, frequent pecking may lead to iatrogenic enlargement of the minor foramen and thus result in over-instrumentation and reduction in the seal between gutta-percha and the canal wall.³⁵ Both the position and size of the resultant unintended apical preparation may contribute to the increase in apical debris volume, thus resulting in postoperative complications and adversely affecting the prognosis of root canal treatment. Taking these factors into consideration, a single pecking at WL is preferred. Caution should be exercised when applying frequent pecking at WL in curved canals during instrumentation, to minimize the risks of postoperative complications or even root canal treatment failures.

Notably, the present study was conducted using curved and oval-shaped canals because the meticulous shaping of these canal types is still a common and realistic clinical challenge.^{13,26} Whereas further studies over this subject including canals with different anatomical morphologies are warranted. Moreover, except for the debris extrusion, the shaping ability of single-file systems following different pecking frequencies also needs to investigate, for better optimizing their performances and improving the success rate of root canal treatment.

Within the limitations of the present study, all single-file systems extruded debris apically, irrespective of the pecking frequency at WL. To extrude less debris extrusion and obtain a predictable foramen size corresponding to the instrument tip size, a single pecking motion may be preferred when using single-file systems. However, there are many considerations in root canal instrumentation, including disinfection, irrigant accessibility, and the convenience of root canal filling. Caution should be exercised when applying the current results to clinical situations.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This work was supported by the Science and Technology Program of Guangzhou [grant number 201904010057] and the National Natural Science Foundation of China [grant number 81873712].

References

- Jeon HJ, Paranjpe A, Ha JH, Kim E, Lee W, Kim HC. Apical enlargement according to different pecking times at working length using reciprocating files. *J Endod* 2014;40:281–4.
- Gokturk H, Ozkocak I, Aydin U, Serefli ED. Effect of different chelating agents and their surface tension on the amount of apically extruded debris. *J Dent Sci* 2021;16:195–200.
- Uslu G, Ozyurek T, Yilmaz K, Gundogar M, Plotino G. Apically extruded debris during root canal instrumentation with Reciproc Blue, HyFlex EDM, and XP-endo Shaper Nickel-titanium files. *J Endod* 2018;44:856–9.
- Tamer T, Kursat E, Davut C, Hikmet A. An in vitro comparison of apically extruded debris using three rotary nickel-titanium instruments. *J Dent Sci* 2010;5:121–5.
- Caviedes-Bucheli J, Castellanos F, Vasquez N, Ulate E, Munoz HR. The influence of two reciprocating single-file and two rotary-file systems on the apical extrusion of debris and its biological relationship with symptomatic apical periodontitis. A systematic review and meta-analysis. *Int Endod J* 2016;49:255–70.
- Eliasz W, Czarnecka B, Surdacka A. Apical extrusion of debris during root canal preparation with ProTaper next, WaveOne gold and twisted files. *Materials (Basel)* 2021;14:6254.
- Keskin C, Sariyilmaz E. Apically extruded debris and irrigants during root canal filling material removal using Reciproc Blue, WaveOne Gold, R-Endo and ProTaper Next systems. *J Dent Res Dent Clin Dent Prospects* 2018;12:272–6.
- Alves FRF, Paiva PL, Marceliano-Alves MF, et al. Bacteria and hard tissue debris extrusion and intracanal bacterial reduction promoted by XP-endo Shaper and Reciproc instruments. *J Endod* 2018;44:1173–8.
- Elashiry MM, Saber SE, Elashiry SH. Apical extrusion of debris after canal shaping with three single-file systems. *Niger J Clin Pract* 2020;23:79–83.
- Boijink D, Costa DD, Hoppe CB, Kopper PMP, Grecca FS. Apically extruded debris in curved root canals using the WaveOne Gold reciprocating and Twisted File Adaptive systems. *J Endod* 2018;44:1289–92.

11. Caviedes-Bucheli J, Rios-Osorio N, Usme D, et al. Three-dimensional analysis of the root canal preparation with Reciproc Blue®, WaveOne Gold® and XP EndoShaper®: a new method in vivo. *BMC Oral Health* 2021;21:88.
12. Pawar BA, Pawar AM, Atram J, et al. Apical debris extrusion during instrumentation of oval root canals in primary teeth using manual versus motorized files: an ex vivo study. *Sci Rep* 2021;11:3859.
13. Lacerda M, Marceliano-Alves MF, Perez AR, et al. Cleaning and shaping oval canals with 3 Instrumentation systems: a correlative micro-computed tomographic and histologic study. *J Endod* 2017;43:1878–84.
14. Ha JH, Kwak SW, Sigurdsson A, Chang SW, Kim SK, Kim HC. Stress generation during pecking motion of rotary Nickel-titanium instruments with different pecking depth. *J Endod* 2017;43:1688–91.
15. Nathani TI, Nathani AI, Banode AM, et al. Apical preparation size after repetitive pecking to the working length using different endodontic file systems. *G Ital Endod* 2018;32:80–5.
16. Ha JH, Jeon HJ, Abed RE, Chang SW, Kim SK, Kim HC. Effect of repetitive pecking at working length for glide path preparation using G-file. *Restor Dent Endod* 2015;40:123–7.
17. Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol* 1971;32:271–5.
18. De-Deus G, Belladonna FG, Zuolo AS, et al. Effectiveness of Reciproc Blue in removing canal filling material and regaining apical patency. *Int Endod J* 2019;52:250–7.
19. Versiani MA, Carvalho KKT, Mazzi-Chaves JF, Sousa-Neto MD. Micro-computed tomographic evaluation of the shaping ability of XP-endo Shaper, iRaCe, and EdgeFile systems in long oval-shaped canals. *J Endod* 2018;44:489–95.
20. Xavier SR, de Lima CO, Marceliano-Alves MFV, Lacerda MFLS, Lopes RT, Campos CN. Shaping ability of two root canal instrumentation systems in oval-shaped canals: a micro-computed tomography study. *Aust Endod J* 2021;47:252–9.
21. Zuolo ML, Zaia AA, Belladonna FG, et al. Micro-CT assessment of the shaping ability of four root canal instrumentation systems in oval-shaped canals. *Int Endod J* 2018;51:564–71.
22. De-Deus G, Simoes-Carvalho M, Belladonna FG, et al. Creation of well-balanced experimental groups for comparative endodontic laboratory studies: a new proposal based on micro-CT and in silico methods. *Int Endod J* 2020;53:974–85.
23. De-Deus G, Belladonna FG, Zuolo AS, et al. 3-dimensional ability assessment in removing root filling material from pair-matched oval-shaped canals using thermal-treated instruments. *J Endod* 2019;45:1135–41.
24. Keskin C, Sariyilmaz E, Demiral M. Shaping ability of Reciproc Blue reciprocating instruments with or without glide path in simulated S-shaped root canals. *J Dent Res Dent Clin Dent Prospects* 2018;12:63–7.
25. Silva E, Belladonna FG, Zuolo AS, et al. Effectiveness of XP-endo Finisher and XP-endo Finisher R in removing root filling remnants: a micro-CT study. *Int Endod J* 2018;51:86–91.
26. Gu LS, Huang XQ, Griffin B, et al. Primum non nocere - the effects of sodium hypochlorite on dentin as used in endodontics. *Acta Biomater* 2017;61:144–56.
27. Frota MMA, Bernardes RA, Vivan RR, Vivacqua-Gomes N, Duarte MAH, Vasconcelos BC. Debris extrusion and foraminal deformation produced by reciprocating instruments made of thermally treated NiTi wires. *J Appl Oral Sci* 2018;26:e20170215.
28. Karatas E, Arslan H, Kirici DO, Alsancak M, Capar ID. Quantitative evaluation of apically extruded debris with Twisted File Adaptive instruments in straight root canals: reciprocation with different angles, adaptive motion and continuous rotation. *Int Endod J* 2016;49:382–5.
29. Keskin C, Yilmaz OS, Inan U. Apically extruded debris produced during glide path preparation using R-Pilot, WaveOne Gold Glider and ProGlider in curved root canals. *Aust Endod J* 2020;46:439–44.
30. Mendonca de Moura JD, Bueno C, Fontana CE, Pelegrine RA. Extrusion of debris from curved root canals instrumented up to different working lengths using different reciprocating systems. *J Endod* 2019;45:930–4.
31. Silva EJ, Carapia MF, Lopes RM, et al. Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. *Int Endod J* 2016;49:700–5.
32. Solda C, Padoim K, Rigo L, Silva Sousa YTC, Hartmann MSM. Assessment of apical extrusion using rotary and reciprocating systems during root canal retreatment. *J Contemp Dent Pract* 2020;21:238–41.
33. Topcuoglu HS, Zan R, Akpek F, et al. Apically extruded debris during root canal preparation using Vortex Blue, K3XF, ProTaper Next and Reciproc instruments. *Int Endod J* 2016;49:1183–7.
34. Toyoglu M, Altunbas D. Influence of different kinematics on apical extrusion of irrigant and debris during canal preparation using K3XF instruments. *J Endod* 2017;43:1565–8.
35. Yammine SD, Jabbour EA. Apically extruded debris following programmed over instrumentation of curved canals with three nickel titanium rotary instruments. *Eur J Dermatol* 2021;15:20–6.
36. Cuellar MRC, Velasquez-Espedilla EG, Pedrinha VF, Vivan RR, Duarte MAH, Andrade FB. Can kinematics, file diameter, and PUI influence the intracanal decontamination and apical bacterial extrusion? *Braz Oral Res* 2020;35:e003.
37. Sen OG, Bilgin B, Kocak S, Saglam BC, Kocak MM. Evaluation of apically extruded debris using continuous rotation, reciprocation, or adaptive motion. *Braz Dent J* 2018;29:245–8.
38. Ahmad MZ, Sadaf D, MacBain MM, Mohamed AN. Apical extrusion of debris with different rotary and reciprocating single-file endodontic instrumentation systems: a systematic review and meta-analysis protocol. *BMJ Open* 2020;10:e038502.
39. Topcuoglu HS, Demirbuga S, Topcuoglu G. Evaluation of apically extruded debris during the removal of canal filling material using three different Ni-Ti systems and hand files in teeth with simulated apical root resorption. *Int Endod J* 2020;53:403–9.