

An in vitro study of the ability of three new continuous rotary heat-treated nickel-titanium files to shape curved root canals

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Abstract

Objectives: To compare the shaping ability of three new continuous rotary heat-treated nickel-titanium files in curved root canal. **Methods:** Sixty standard resin simulated root canals were randomly divided into three groups (n = 20): i-FILE X, Orodeka PLEX2.0, NIC GF File were used to instrument root canals. The instrumentation time was meticulously recorded. The root canals before and after instrumentation were injected with black and red ink respectively and images of the canals before and after instrumentation were captured using a digital camera. The images were imported into Photoshop 2019 software, overlaid, and the amount of root canal resin removed was measured using ImageJ 1.54f. The centering ability was recorded. Post-instrumentation root canal curvature was also measured by the Schneider method and with ImageJ 1.54f. The differences between the three groups were statistically analyzed in terms of 3 aspects: instrumentation time, centering ability and curvature. **Results:** The i-FILE X group had the shortest instrumentation time, followed by the GF File group, and the Orodeka group had the longest instrumentation time ($P < 0.05$). The i-FILE X group had better centering ability at 1 mm, 2 mm, 3 mm, 4 mm, and 9 mm from the simulated root canal observation point than the other two groups, and there was no statistically significant difference among the three groups at the 5 mm to 8 mm ($P > 0.05$). The working curvature of the simulated root canals was reduced in all three groups and there was no statistical significance in the intergroup comparison of the curvatures of the three groups ($P > 0.05$). **Conclusions:** The three continuous rotary heat-treated nickel-titanium files exhibited commendable preparatory molding capabilities and were able to adequately preserve the original curvature of the root canals. The i-FILE has been demonstrated to exhibit a reduced instrumentation time and enhanced centering ability within the apical curved area.

Keywords: new nickel-titanium instruments; curved root canal; shaping ability; centering ability; root canal deviation; simulated canal

Introduction

The process of root canal instrumentation entails the shaping of the root canal while removing infected and necrotic tissues from the root canal system, and the cutting of the irregular root canal surface into a tapered, continuous funnel pattern. This facilitates root canal irrigation and three-dimensional tight filling (1, 2). As the core tools of root canal instrumentation, the performance of root canal instrumentation instruments has a direct impact on the effectiveness and safety of root canal treatment (3). The efficiency



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of root canal instrumentation has been significantly enhanced by the continuous improvement and innovation of machine-made NiTi instruments, as well as the simplification of their utilization procedures. And continuous rotary motion NiTi files have seen increased utilization in clinical practice.

Following the advent of minimally invasive dentistry in 2000, the concept of minimally invasive endodontics has also emerged as a trend in contemporary clinical treatment. The evolution of minimally invasive endodontics has been propelled by the advancement of endodontic instruments. In the process of root canal instrumentation, minimally invasive treatments impose novel demands on the instruments employed, as these instruments are required to adequately clean the root canal while preserving as much of its original morphology as possible (4, 5). The instrumentation of small, curved root canals is a technically demanding aspect of endodontic treatment. In clinical practice, the intricacies of root canal anatomy and the constraints imposed by instruments render root canal instrumentation susceptible to apical deviation, thereby compromising the efficacy of endodontic treatment (6, 7). As the general practitioner's knowledge of complex curved root canals has increased, the requirements for instrumentation instruments of curved root canals have increased concomitantly.

The objective of this research was to compare the root canal instrumentation time, curvature variation, and centering ability of three new continuous rotary heat-treated nickel-titanium files by preparing curved resin simulated root canals.

Materials and Methods

Resin Block

A total of 60 standard resin simulated root canals (E-END1001-30-#20, Nissin Dental Products Inc., Japan) were selected. All canals had 30-degree curvature according to Schneider method (8) and each apical canal diameter was equivalent to an ISO size #15 (9). The specimens were randomly assigned to three groups (n=20) on the base of files used in root canal instrumentation: group A (i-FILE X), group B (Ordeka PLEX2.0) and group C (NIC GF File).

Preparation For Instrumentation and Image Taking

The 20 resin blocks within each group were numerically marked with numbers 1-20, and were positioned by marking with a "+" on each side of the root canal orifice of the resin simulated root canals. Root canal patency was verified by inserting a size #10 K-file (Dentsply Sirona Endodontics, Tulsa, OK, USA) into the apical foramen and the working length was determined. The canals were negotiated with a #15 K-file (Dentsply Sirona Endodontics, Tulsa, OK, USA) and then irrigated with 2 mL distilled water. The canals were dried with paper points (Dentsply Sirona Maillefer, Switzerland) and subsequently injected with black ink (Hero, Shanghai, CHN). The resin simulated root canal was then affixed to a custom-built fixation device, with a scale fixed adjacent to it. Pre-instrumentation images were captured using a digital camera (EOS850D, Canon Inc., Japan) perpendicular to the mid-axis of the root canals and numbered for storage to document the original morphology of the root canals. The ink in the root canal was rinsed out afterwards.

Root Canal Instrumentation

All specimens were instrumented by the same operator, a specialist in endodontics. Instrumentation was completed with X-smart plus (Woodpecker, Guilin, China) and continuous rotary nickel-titanium files by using the manufacture's recommendations as illustrated in Table 1. All instruments were used in a slow in-and-out pecking motion and 17% EDTA (Longly Biotechnology, Wuhan, CHN) was used for root canal lubrication. The file flutes were cleaned with 75% alcohol cotton balls and root canal was irrigated with 2 mL distilled water at each instrument change. Apical patience was maintained using a size #10 K-file. Once the rotary instrument had negotiated to the end of the canal and had rotated freely, it was removed. Each file was in the root canal for no more than 5 s at a time and was used to prepare five canals only as the file systems are recommended to be used. During each root canal instrumentation, files were inspected for any deformation or cracks and were immediately replaced as any are detected. The root canal instrumentation time, the time during which the files were actively

Table 1. The procedures of the three nickel-titanium systems

Group	Nickel-titanium Systems	Manufacturer	Procedure of Instrumentation	Speed/ (r-min-1)	Torsion / N-cm)
A	i-FILE X	Henry Schein,USA	(20#/0.07)→ (15#/0.04)→ 20#/0.04)→ 25#/0.06)→	300	2.5
B	PLEX2.0	Ordeka, CHN	(15#/0.08)→ (15#/0.03)→ (20#/0.05)→ (25#/0.06)→	500→300→500→500	2.5→1.5→2.5→2.5
C	GF File	NIC, CHN	(19#/0.04)→ (17#/0.02)→ (20#/0.04)→ (20#/0.06)→ (25#/0.06)→	450	3.0→1.5→1.5→3.0→3.0

engaged within the root canal, was recorded and with the values measured to an accuracy of 0.01 s.

Image Taking and Software Evaluation

After root canal instrumentation was completed, the canals were dried with paper points and subsequently injected with red ink (Hero, Shanghai, CHN). The resin simulated root canal was then affixed to a custom-built fixation device, with a scale fixed adjacent to it. Post-instrumentation images were captured in the same way. The images captured before and after instrumentation were imported into Photoshop 2019 for overlapping, and the scales were converted uniformly using a scale.

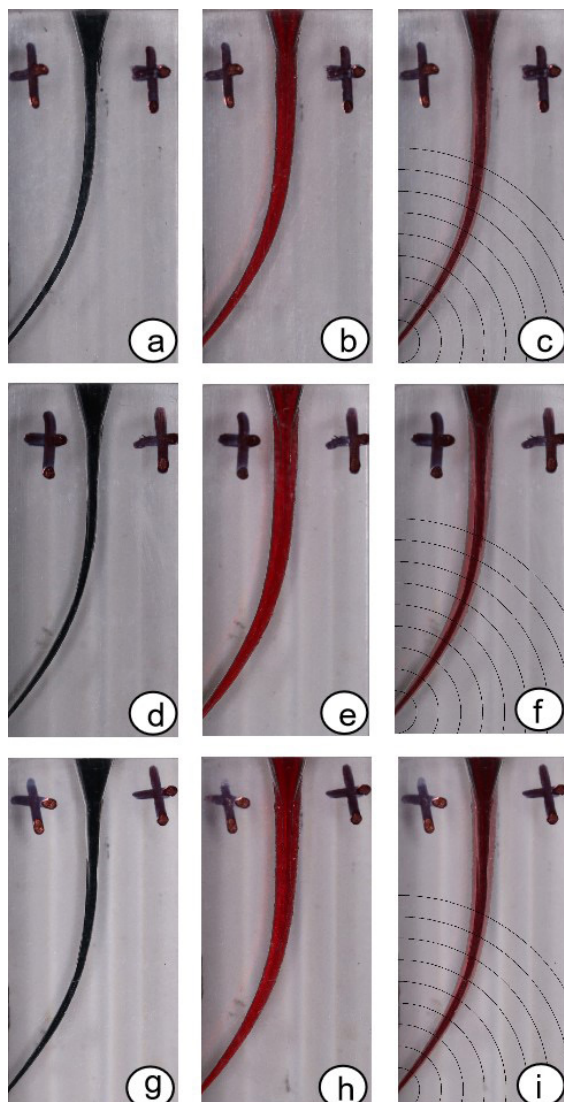


Figure 1. Pre- and post- instrumentation images of resin blocks, as well as overlapped images for the three groups. (a) Pre-instrumentation image of the Group A; (b) Post-instrumentation image of the Group A; (c) Overlapped image of the Group A. (d) Pre-instrumentation image of the Group B; (e) Post-instrumentation image of the Group B; (f) Overlapped image of the Group B. (g) Pre-instrumentation image of the Group C; (h) Post-instrumentation image of the Group C; (i) Overlapped image of the Group C.

With the pre-instrumentation apical foramen as the center, nine concentric circles were drawn with radii starting from 1 mm and increasing by 1 mm increments up to 9 mm. These nine circles defined nine measurement sites, designated as D1 to D9. D1 to D3 represent the apical curvature (bending towards the root apex), D4 to D6 represent the coronal curvature (bending towards the crown), and D7 to D9 represent the straight canal pathway in the coronal third of the root canal. The processed images were imported into ImageJ 1.54f and magnified to 300%. The distances from the inner and outer black edges to the red edges were measured at each overlapping site. These measurements correspond to the amount of resin removed from the inner and outer sides of the root canal and were recorded with an accuracy of 0.001 millimeters. The absolute value of the difference in the amount of removal at the nine measurement sites inside and outside the root canal indicates the centering ability of the nickel-titanium instruments. The post-instrumentation images were processed using ImageJ 1.54f and the canal curvature after instrumentation was measured using Schneider's method. Each measurement was repeated three times, and the mean value was calculated with an accuracy of to 0.001°.

Statistical Analysis

Statistical analysis was performed using SPSS 27.0. The normality of the data was assessed using the Shapiro-Wilk test. The Kruskal-Wallis H-test was employed to analyze the data due to its non-normal distribution. A p-value of less than 0.05 was considered to indicate a statistically significant difference.

Result

The root canal instrumentation times for Group A ($28.84s \pm 3.88$), Group B ($31.75s \pm 3.32$) and Group C ($28.98s \pm 4.63$) were statistically significant ($F = 3.391$, $P = 0.041$). Groups A and C were statistically significant compared with Group B ($P < 0.05$). Group A was statistically significant compared with Group C ($P < 0.05$).

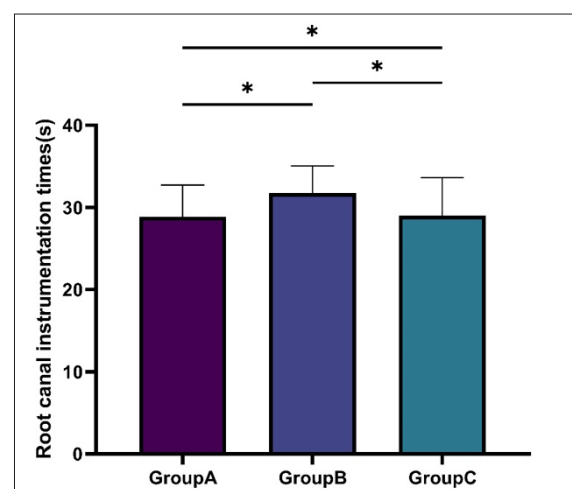


Figure 2. The root canal instrumentation times for three groups.

The root canal curvature after instrumentation for group A ($29.195^{\circ} \pm 0.451$), group B ($28.839^{\circ} \pm 0.603$), and group C ($28.806^{\circ} \pm 0.709$) were not statistically significantly different.

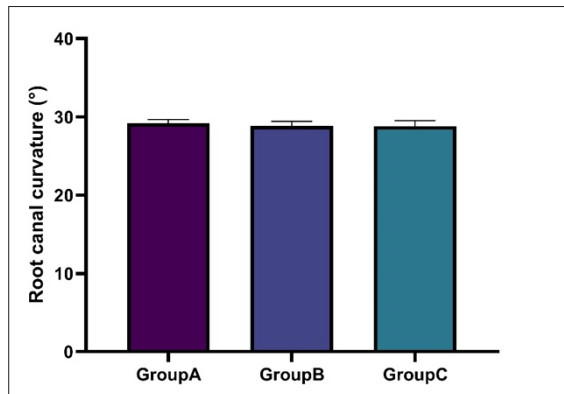


Figure 3. The root canal curvature for three groups.

As illustrated in Table 2, the apical displacement at distances of 1, 2, 3, and 4 mm from the apical foramen was significantly lower in Group A than in Groups B and C ($P < 0.05$). The apical displacement at distances of 9 mm from the apical foramen was significantly lower in

Group C than in Groups A and B ($P < 0.05$).

Discussion

Root canal instrumentation is a critical and challenging step in root canal treatment. Apical displacement during this process can easily result in damage to the original anatomical structure of the root canal, incomplete debridement and subsequent microleakage, which can ultimately lead to treatment failure (10). As the first and critical step in infection control, root canal instrumentation can directly influence the therapeutic outcome. Any deviation during root canal preparation can lead to incomplete eradication of the infectious source within the root canal system. Excessive deviation may even directly affect the quality of the subsequent root canal obturation (11, 12). Therefore, the study of the shaping ability of different nickel-titanium files in the instrumentation of curved root canals is of great reference value for the clinical evaluation of the quality of root canal obturation. Nickel-titanium alloy is a binary alloy composed of nickel and titanium elements. It typically exists in three crystalline phases: austenite, R-phase, and martensite. These phases can transform into each other in response to changes in temperature or external stress (13). Conventional nickel-titanium alloys typically exhibit the austenite phase at room temperature, which is relatively less flexible. Heat treatment can alter the phase composition

Table 2. Comparison of the centering deviation of the three nickel-titanium systems

Distance to apical foramen(mm)	Group	centering deviation M(P25,P75),mm.	P
1	A	.014(.004,.028)	0.023
	B	.038(.016,.063)a	
	C	.041(.012,.058)a	
2	A	.017(.011,.023)	0.047
	B	.035(.011,.058)a	
	C	.032(.017,.068)a	
3	A	.013(.007,.037)	0.026
	B	.034(.018,.064)a	
	C	.028(.010,.077)	
4	A	.023(.013,.030)	0.020
	B	.043(.022,.060)a	
	C	.043(.015,.057)	
5	A	.036(.021,.057)	0.757
	B	.034(.020,.072)	
	C	.046(.016,.062)	
6	A	.046(.024,.085)	0.179
	B	.059(.037,.074)	
	C	.031(.015,.067)	

To be continued

7	A	.067(.016,.102)	0.361
	B	.057(.017,.086)	
	C	.027(.019,.052)	
8	A	.048(.023,.120)	0.128
	B	.062(.044,.089)	
	C	.029(.008,.082)	
9	A	.077(.038,.126)c	0.006
	B	.092(.066,.137)c	
	C	.022(.013,.068)	

of NiTi instruments at ambient temperatures, thereby enhancing the flexibility of the instruments. Various heat treatment techniques are widely used in the manufacturing of NiTi files, including M-wire, R-phase wire, CM-wire, blue wire, and gold wire.

Given the complexity of the dental root canal system and the significant anatomical variations, to minimize experimental error, this study utilized resin simulated root canals, with standardized variables including root canal curvature, length, and orifice diameter. And all specimens were instrumented to 25#/0.06 by the same operator. Root canal preparation time is indicative of the efficacy of the procedure, with factors such as the number of instruments utilized, the operator's expertise, and variations in experimental conditions contributing to its variability (14). In this study, the instrumentation time was recorded exclusively for the duration that the nickel-titanium file was in motion within the root canal, with the objective of minimizing errors attributable to factors such as root canal rinsing and reaming. The GF File sequence consisted of five NiTi files, whereas both the Orodeka PLEX2.0 and the NIC GF File were composed of four NiTi files. However, based on the study results, the instrumentation time was shorter for the GF File compared to the Orodeka PLEX2.0 and the i-FILE X exhibited the shortest time among the three groups. Yu et al. demonstrated that the Orodeka file, a safe guiding tip devoid of a blade, offers enhanced guidance rather than cutting ability. This property reduces the extrusion of dentin debris from the root canal apex (15). The GF File system features a unique design with convex triangular and rectangular cross-sections. The gradually increasing taper and variable pitch of the files enhance cutting efficiency. And the i-FILE X features a parabolic cross-sectional design and positive cutting angles, which maximize cutting efficiency. It can be deduced that during the process of root canal instrumentation utilizing a sequence of files, the instrumentation time does not necessarily exhibit a direct correlation with the quantity of nickel-titanium files employed. The instrumentation time is also associated with the taper span of NiTi files utilized across various groups. When selecting rotary NiTi files for clinical application, this factor should be taken into consideration.

Maintaining the curvature of the root canal is imperative

during the instrumentation of curved root canals (6). In this study, the curvature of all three groups diminished in comparison to their pre-instrumentation state, though the changes were minimal. And there were no significant statistical differences among the three groups. Three types of NiTi files were manufactured using heat treatment processes, which significantly enhanced their torsional and bending fatigue resistance. In addition, the ability to pre-bend the tips of these NiTi files allows for better adaptation to the curvature of the root canals, thereby improving their flexibility and reducing the risk of instrument breakage during canal instrumentation.

During the instrumentation of curved root canals, conventional NiTi instruments frequently demonstrate considerable rigidity and inadequate flexibility, which may lead to complications such as root canal deviation, perforation, and step formation (16). Apical displacement of less than 0.15 mm shows no significant effect on root canal obturation. However, apical displacement of more than 0.3 mm can substantially increase the risk of microleakage, prevent effective removal of bacteria and other microorganisms from the apical region, and severely compromise the outcome of root canal obturation (17). The novel heat-treated NiTi files, including those fabricated from M-wire, CM-wire, and R-phase alloys, demonstrate enhanced flexibility and diminished spring-back force, thereby markedly reducing the likelihood of root canal deviation. The deviation of the root canal is directly linked to the assessment of centering ability, which is predominantly quantified by measuring the offset distance of the axial centerline at observation points before and after root canal instrumentation. The closer this distance is to zero, the superior the instrument's centering ability is deemed to be (18). In this study, to evaluate the centering ability of instruments during root canal instrumentation, pre- and post-instrumentation images of the simulated curved root canals were overlapped. With the pre-instrumentation apical foramen as the center, circular arcs were drawn at 1 mm increments from the center up to 9 mm, defining nine observation points (D1-D9). The offset at each observation point was calculated by subtracting the change in the inner diameter from the change in the outer diameter, with the absolute value indicating the centering ability (18). Specifically, the i-FILE X group exhibited significantly

lower apical displacement at observation points D1-D4 compared to both the Orodeka PLEX2.0 and NIC GF File groups ($P < 0.05$). The i-FILE X exhibited superior centering ability in the apical segment in comparison to Orodeka PLEX2.0 and the NIC GF File. This may be attributed to its use of processed with a heat treatment technique. Compared to conventional nickel-titanium alloys, the transformation temperature of this alloy is elevated to 47°C, resulting in a higher proportion of stable martensite at room temperature. Given that the elastic modulus of martensite is 28.0 GPa (19), which is lower than that of austenite, the enhanced flexibility of the instruments allows for better adaptation to the curvature of root canals, thereby reducing the risk of root canal deviation. Besides, the cross-sectional design of EuroEndo files features a triangular convex surface, while the GF File system incorporates multiple cross-sectional designs, including convex triangular and rectangular configurations. In contrast, the i-FILE X is characterized by its parabolic cross-sectional design and a filleted transition angle at the tip. This design enables the instrument to exhibit a serpentine or “snake-like” motion within the root canal, thereby reducing contact with the canal walls and minimizing the insertion torque during instrumentation. At observation points D1-D4, there was no statistical difference in centering ability between the Orodeka PLEX2.0 and GF File groups. Similarly, at points D5-D8, no statistical differences in centering ability were observed among the three types of instruments. At the D9 observation point, the GF File group demonstrated significantly lower displacement in comparison to the i-FILE X and Orodeka PLEX2.0 groups. However, no statistically significant difference in displacement was observed between the i-FILE X and Orodeka PLEX2.0 groups. It may be attributed to its use of a gradient-decreasing taper and variable pitch design, which facilitates a smooth and flexible transition along the midsection of the NiTi file, in GF File. During the process of root canal shaping, the GF File system employs a sequential enlargement strategy, progressing from 20#/0.04 to 20#/0.06 and finally to 25#/0.06. This method ensures a safer and more stable transition during canal enlargement.

During the preparation process, nickel-titanium instruments generate heat, which has the potential to soften the resin. Additionally, the microhardness of the resin used to simulate root canals is significantly lower than that of human dentin (20). Therefore, the results obtained may deviate from actual clinical conditions and the experimental data must be viewed with caution. Micro-CT scanning, as a non-destructive technique, facilitates the precise three-dimensional reconstruction of teeth and enables both quantitative and qualitative analyses of root canal anatomy, emerging as a reliable assessment tool (21). Future experiments will leverage micro-CT to comprehensively evaluate the shaping ability of instruments from multiple perspectives, including debris removal and the formation of microcracks in the root canal during preparation.

Conclusion

In this study, three novel continuous rotary heat-

treated nickel-titanium instruments were evaluated for their ability to prepare curved root canals. All three instruments demonstrated safe and effective canal preparation. The i-FILE X system exhibited a significant advantage in terms of preparation time and superior centering ability in the apical curvature segment. Clinicians are advised to select heat-treated nickel-titanium instruments, which boast superior flexibility and adaptability when instrumenting curved root canals. These instruments can effectively reduce the risk of root canal deviation and other complications, thereby enhancing the efficiency of root canal instrumentation and improving the success rate of endodontic treatment.

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