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Effect of Four NiTi Rotary Instruments on Root Canal Morphology: A Micro-CT Study

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Aim: The research's aim was to evaluate the effects of four different rotary nickel-titanium (NiTi) endodontic file systems on the ability to alter the root canal space volume, generation of apical transportation, and file-centering ability using micro-CT imaging.
Materials and Methods: A total of 40 extracted mandibular premolars with straight-root canals were selected and instrumented using four NiTi rotary file systems namely ProTaper Next™ (PTN), ProTaper Gold™ (PTG), WaveOne® Gold (WOG), and Reciproc® Blue (RCB).
Results: The Kruskal-Wallis H test revealed no statistically significant differences in canal transportation at the 1 mm [H (3) = 6.22, p = 0.891], 3 mm [H (4) = 1.724], and 5 mm locations among the four tested instruments. Although all file systems contributed to some degree of canal transportation, PTN, and PTG did so to the least extent. The optimum file-centering efficiency was demonstrated by PTN and WOG, while PTG and RCB showed the least.
Conclusion: This study revealed that all tested files caused an increase in root canal volume and exhibited a tendency for apical transportation due to their inability to remain centered within the canal during preparation.

Keywords: Root Canal Preparation, Root Canal Volume, Transportation, NiTi instrument, MicroCT

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Introduction

Root canal therapy involves various critical aspects, and one of them is root canal preparation. This procedure aims to reduce the bacterial load in the canal while maintaining the natural architecture of the root canal system. However, the complex and varied morphology of root canals still poses a significant challenge for cleaning, shaping, and disinfection, even with the use of rotary endodontic instruments.[1]

Canal instrumentation is necessary to eradicate the organic and inorganic contents of the root canal system, shape the entire root canal while preserving its original geometry, and obtain a continuously tapering conical form with the smallest diameter at the apical limit of instrumentation. This design allows for hermetic sealing of the apical portion with a filling material.[2] A good instrument design is crucial in reducing procedural errors, improving performance, durability, and safety, and decreasing the apical transportation of canal preparation procedures. To achieve this, manufacturers have been exploring ways to modify the presently available and extensive range of root canal instrument designs, including altering the surface of the alloy or changing the alloy microstructure through post-machining or post-twisting heat treatment. [3]

Studies have shown that NiTi rotary instruments retain the original shape of the canal more effectively than stainless steel files[4–6], which is crucial for achieving better root canal shaping and cleaning with predictable results and less iatrogenic damage. The flexibility and shape memory of NiTi alloys contributes to the ability of the file to maintain the canal shape.[7,8] However, it is important to note that NiTi rotary instruments may also straighten in the root canal under excessive stress or torque during instrumentation, leading to deviations from the original canal path which may result in potential damage to the tooth structure. This phenomenon is known as "shape memory" and its occurrence is dependent on various factors such as the design of the instrument, the diameter and taper of the canal, and the operator's technique and experience.[7]

Canal transportation, which is caused by instrument deviation from the original path during shaping, can result in asymmetrical dentin removal and compromise root canal cleaning. Overly removing dentin on one side can weaken the tooth structure and compromise its long-term survival.[9] Other studies[10,11] have demonstrated that canal transportation is most significant in the apical area and changes the canal geometry, which can perpetuate microorganisms and tissue remnants on dentin walls, hindering disinfection and sealing of the root canal system, and potentially leading to postoperative pain.[12]

Recent advancements in manufacturing, design, and metallurgy have led to the development of improved titanium alloys, such as M-wire, control-memory alloy, and heated-treated NiTi alloy. The ProTaper Next™ (PTN) files are made of M-wire alloy, whilst the latest endodontic files, such as ProTaper Gold™ (PTG), WaveOne® Gold (WOG), and Reciproc® Blue (RCB), is made of heat-treated NiTi gold and blue wire, which is claimed to offer better flexibility thus minimize the risk of apical transportation. In addition to these advancements in titanium alloys, researchers have also leveraged technological advancements in imaging, such as micro-computed tomography (micro-CT), to analyse root canal morphology and estimate the spatial features after root canal instrumentation.

Micro-CT has become an increasingly popular tool in endodontic research due to its ability to generate non-destructive 3D images that can be used to analyse the microstructure, shape, density, and internal structure of mineralized tissues without damaging the tooth. Micro-CT, in particular, has been utilized to study the anatomy of root canals and assess the morphology of dental roots following root canal instrumentation.[13] This method has several advantages over conventional techniques such as accurate analysis, non-destructive and reproducible. Conventional techniques that were used include resin block models, histological sections, silicone impressions of instrumented canals, serial sectioning, radiographic superimposition, and computer manipulation for comparative analysis using computer software.

Micro-CT's non-invasive and high-resolution imaging capabilities enable the visualization of the intricate details of root canal systems, providing insights into root canal morphology and the spatial features after root canal instrumentation.[14,15] Additionally, it has been utilized to assess root canal volume and cervical dentin thickness in endodontic research.[13]

Despite all the advancements in the design and manufacture of NiTi endodontic rotary files to reduce the occurrence of complications during root canal treatment, the knowledge of how these different instruments affect canal symmetry and its potential for iatrogenic error is lacking. Therefore, the objective of this study was to measure the volume changes in the root canal space, the apical canal transportation, and the centering ability of four types of nickel-titanium endodontic files on the mandibular premolar teeth utilizing micro-CT imaging.

Materials and methods

The methodology employed in this study consisted of sample selection, instrumentation, and analysis of root canal space volume alteration, apical transportation, and file-centering capability using micro-CT scanning. The G*Power v3.1.9.7 software for Windows (Heinrich, Heine, Universitat Düsseldorf) was utilized to perform the sample calculation, employing an ANOVA: Fixed effect, omnibus, one-way test from the F test family. The effect size (0.7) was determined based on data obtained from a previous study[16] examining root canal transport and centralization. Assuming an alpha error of 0.05, a beta power of 0.95, and a group size of four, a recommended total sample size of 10 samples per group were deemed optimal for detecting significant differences.

The sample selection process entailed choosing 40 extracted mandibular first and second premolars with single-rooted straight-root canals, mature apices, and a single foramen corresponding to the initial apical file size 20 K-file or less. Roots with open apices, sclerosed canal or foramen, pulp stones, calcified canals, dilaceration of canals, presence of external and internal resorptions, any form of caries, restorations including root canal treatment, tooth surface loss, and external root-surface cracks were excluded.

For instrumentation, four distinct rotary nickel-titanium (NiTi) endodontic file systems, namely PTN, PTG, WOG, and RCB, were evaluated for their effects on root canal space volume alteration, apical transportation, and file-centering capability. Dentin thickness assessment and root canal volume determination were performed before and after instrumentation using a SkyScan 1076 micro-CT scanner (Bruker®, Kontich, Belgium) with a voltage of 100 kV, current of 100 µA, and exposure time of 400 ms.

Micro-CT image scan was conducted pre- and post-instrumentation of the canal, and images were imported into CTAn software (version 1.0, Bruker®, Belgium) for analysis (Figure 1). The software's automatic thresholding binary format was utilized to identify the dentin, and the axial view of the sample at distances of 1 mm, 3 mm, and 5 mm from the radiographic apex was used to ascertain the degree and direction of canal transportation (Figure 2). Pre- and post-instrumentation segmented scans were compared for segmentation accuracy. Canal transportation and centering ability were calculated using formulas introduced by Gambill et al.[17] as illustrated in Figure 3.

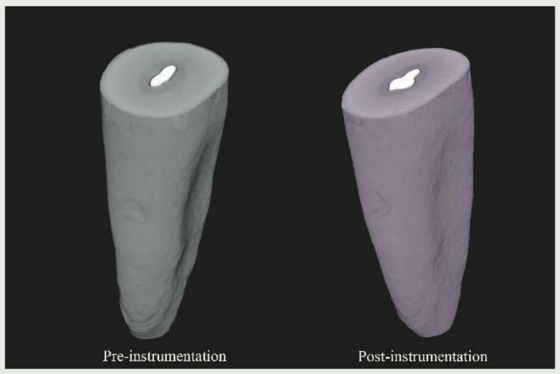

Figure 1: Microcomputed tomography reconstructions of the root before and after root canal instrumentation.

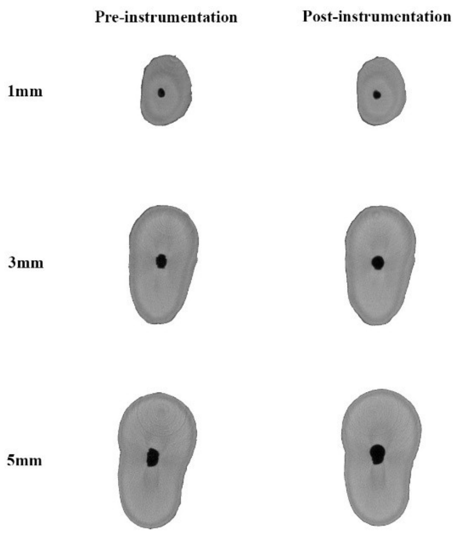

Figure 2: Microcomputed tomography reconstructions of the root canal cross-section before and after instrumentation at 1mm, 3mm, and 5mm from the apex, respectively.

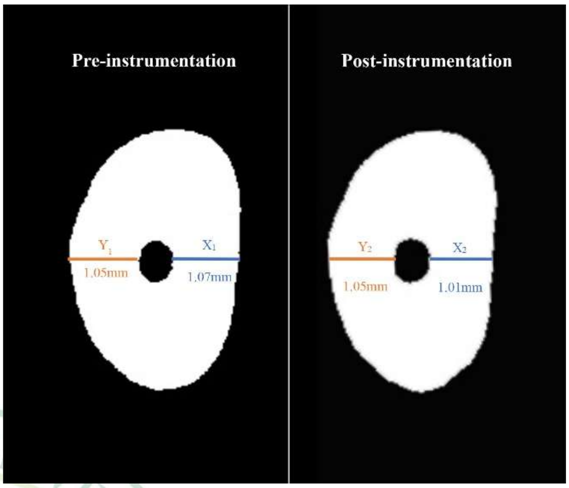

Figure 3: Microcomputed tomography reconstructions of the root canal cross-section before and after instrumentation. X1, X2 and Y1, Y2 represent root canal wall widths before and after canal preparation.

Data analysis involved 3D image construction and statistical evaluation using the Statistical Package for the Social Sciences (SPSS). Paired-samples t-test, Mann-Whitney U test, and Kruskal-Wallis's test were employed to examine various aspects of the data, such as differences in volume, motion of the NiTi instruments, volume gain, canal transportation, and centering ability (n = 40 for each test). The study set the significance threshold at 0.05 and the power at 95%, with a minimum effect size of 0.70 required for 95% power to generalize the conclusions to the population.

Results

The results of the study are presented in Tables 1-3 and Figure 4-5. Table 1 displays the mean and standard deviation values for pre- and post-instrumentation in each experimental group utilizing NiTi instruments. A one-way ANOVA test (n=40) was employed to compare root canal volume gain across the four NiTi instruments. Although normality tests indicated the data were statistically normal, the homogeneity of variance assumption was violated (Levene's F test, p = 0.00). Consequently, the Welch's F test was used, revealing no statistically significant difference in the mean volume gain among the four NiTi instruments [F (3, 17.701) = 2.998, p = 0.58].

Table 1: Mean and standard deviation of root canal volume before and after instrumentation, and results of one-way ANOVA test for comparisons of percentage volume gain in the four groups.

NiTi instrument	PTN (*n*=10)	PTG (*n*=10)	WOG (*n*=10)	RCB (*n*=10)	*P*-Value
Pre-instrumentation (mm^3)	10.84 ± 2.79	9.63 ± 1.90	10.47 ± 3.85	8.33 ± 3.70	
Post-instrumentation (mm^3)	12.12 ± 3.18	10.18 ± 1.99	11.13 ± 3.93	9.18 ± 3.49	
Volume difference (mm^3)	1.28 ± 1.09	0.55 ± 0.19	0.66 ± 0.41	0.85 ± 0.49	
Volume gain (%)	9.22 ± 4.65	5.76 ± 1.87	6.91 ± 4.16	12.81 ± 9.33	<0.05

***Significant at P≤0.05**

Table 2: Median and mean (SD) of canal transportation value at three locations after instrumentation

Location		PTN	PTG	WOG	RCB	*P*-Value[1]
1mm	Median (Range)	-0.032 (0.17)	-0.025 (0.17)	-0.016 (0.12)	-0.023 (0.30)	0.891
	Mean SD)	-0.138 (0.050)	-0.026 (0.051)	-0.007 (0.042)	0.008 (0.090)	
3mm	Median (Range)	-0.020 (0.21)	-0.014 (0.08)	-0.020 (0.26)	0.000 (0.20)	0.632
	Mean (SD)	-0.020 (0.062)	-0.002 (0.028)	-0.008 (0.078)	0.005 (0.129)	
5mm	Median (Range)	0.005 (0.35)	-0.005 (0.13)	-0.050 (0.30)	-0.005 (0.44)	0.845
	Mean (SD)	0.002 (0.091)	-0.023 (0.044)	-0.008 (0.093)	-0.049 (0.129)	

***Significant at *P*≤0.05**
[1] Results of Kruskal–Wallis test comparing the 4 groups at each location.

Table 2 and Figure 4 presents the dentin wear patterns in the apical region at 1 mm, 3 mm, and 5 mm from the radiographic apex after instrumentation with various NiTi instruments. The PTN and RCB groups exhibited bidirectional dentin removal patterns in the apical region, while PTG and WOG demonstrated unidirectional transportation patterns. PTN displayed slightly higher canal transportation values at the 1 mm and 3 mm levels compared to the other files at the same locations. WOG consistently showed apical transportation values at all levels. The Kruskal-Wallis H test results revealed no statistically significant differences in canal transportation at the 1 mm [H (3) = 6.22, p = 0.891], 3 mm [H (3) = 1.724, p = 0.632], and 5 mm [H (3) = 1.724, p = 0.845] locations among the four tested instruments.

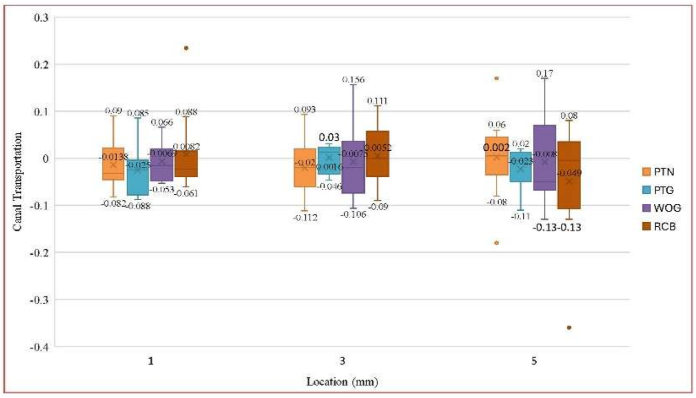

Figure 4: Box plot representing mean and range values for canal transportation at three locations after instrumentation in the four groups (stars and circles represent outliers)

Table 3 and Figure 5 displays the file centering ability ratios at 1 mm, 3 mm, and 5 mm from the radiographic apex following instrumentation with various NiTi instruments. Notably, all files exhibited the highest centering ratio at the 3 mm location (range: 0.46–0.65) compared to the 1 mm (range: 0.23–0.31) and 5 mm (range: 0.23–0.33) locations. The Kruskal-Wallis H test results revealed no statistically significant differences in file centering ability at the 1 mm [H (3) = 1.517, p = 0.678], 3 mm [H (3) = 2.641, p = 0.450], and 5 mm [H (3) = 2.862, p = 0.413] locations among the four tested instruments. Overall, the results indicate that there were no significant differences in the volume gain, canal transportation, and file-centering ability ratios among the four NiTi instruments.

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Table 3: Median and mean (SD) of file centering ratios at three locations after instrumentation

Location		PTN	PTG	WOG	RCB	*P*-Value[1]
1mm	Median (Range)	0.245 (0.80)	0.200 (0.94)	0.180 (0.99)	0.350 (0.55)	0.678
	Mean (SD)	0.270 (0.258)	0.325 (0.367)	0.228 (0.303)	0.306 (0.198)	
3mm	Median (Range)	0.330 (2.05)	0.645 (0.39)	0.530 (0.76)	0.560 (1.59)	0.450
	Mean (SD)	0.572 (0.639)	0.645 (0.129)	0.463 (0.246)	0.531 (0.453)	
5mm	Median (Range)	0.165 (0.95)	0.660 (1.05)	0.390 (0.67)	0.275 (0.79)	0.413
	Mean (SD)	0.270 (0.258)	0.325 (0.367)	0.228 (0.303)	0.306 (0.198)	

***Significant at $P \leq 0.05$.**
[1] Results of Kruskal–Wallis test comparing the 4 groups at each location.

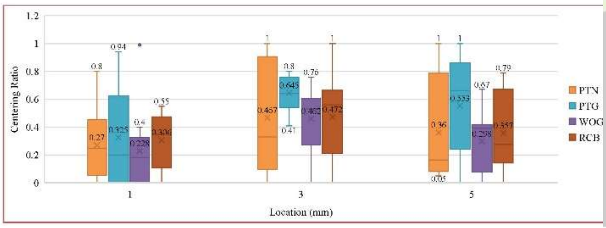

Figure 5: Box plot representing mean and range values for file centering ratio at three locations in the four groups (stars and circles represent outliers)

Discussion

Canal instrumentation plays a vital role in root canal treatment by removing infected or necrotic tissue and shaping the root canal for effective cleaning and filling. The success of endodontic treatment hinges on thorough cleaning and shaping, which can be challenging due to the complex and varying anatomy of the root canal. Maintaining the original canal shape is essential as it promotes better shaping, cleaning, and predictable outcomes while minimizing unintended damage.

The main objective of this study was to evaluate the effects of four distinct rotary nickel-titanium (NiTi) endodontic file systems on root canal space volume alteration, apical transportation, and file-centering capability. Our findings provide valuable insights into the performance of these endodontic files and their potential impact on the success of endodontic treatment.

Significant differences were observed in mean volume measurements before and after root canal instrumentation, supporting findings from previous studies.[16,18] The PTG group exhibited the lowest mean volume gain, while the RCB group had the highest. These results could be attributed to the RCB instrument's double-cutting edge and larger taper, which removed more dentin and created a larger cavity. However, the differences in mean volume gain among the tested instruments were not statistically significant. The amount of dentin removed, and the size of the cavity created during canal instrumentation can have both beneficial and detrimental effects on the root canal. While removing more dentin and creating a larger cavity can promote better shaping, cleaning, and predictable outcomes, excessive removal of dentin can weaken the tooth structure and increase the risk of root fracture. Moreover, creating a larger cavity can also elevate the chances of leakage and failure of the root canal filling.[19]

Effective root canal preparation in the apical third region is vital, as this area may harbour a higher concentration of bacteria and contaminated dentinal debris. Canal transportation can lead to procedural errors and weaken the root structure, ultimately affecting the root canal obturation and resulting in a poor apical seal. This study found that WOG and RCB had the lowest apical transportation values at the 1mm location near the apical foramen, indicating their ability to maintain the apical foramen size. The finding may indicate kinematic motion of NiTi files may contribute to the formation apical transportation similar finding in other study.[20] However, all tested files did not exceed the critical limit of 0.30 mm, which represents the maximum acceptable amount of canal transportation.[21]

Maintaining the integrity of the apical seal is crucial for the success of endodontic treatment as it prevents the entry of bacteria and other irritants into the root canal system, which can result in reinfection and treatment failure. [22] These findings are consistent with previous studies that have demonstrated the importance of preventing canal transportation. [23,24]

Centering ability is inversely related to canal transportation. Better centering ability reduces the risk of procedural errors and ensures conservative and centred shaping. All files in this study demonstrated better centering ability at the 3mm level than at the 1mm and 5mm locations, which is consistent with the findings of other studies. [23,24] No significant differences were found in the centering ability of the tested files at any location. However, it is crucial to note that all files tended to create transportation and could not remain centred in the canal, as observed by Othman Ahmed et al.[25] in different types of NiTi files regardless of different metallurgy. This transportation may increase uninstrumented areas and accumulation of residual necrotic tissue, and debris, which would potentially affect endodontic treatment success. These findings are consistent with previous studies that have emphasized the importance of achieving good centering ability. [26–28] In addition, the findings underscore the importance of careful selection of endodontic files and the need for continued research into the development of improved instruments.

Gambill et al.[17] suggested that a theoretical value of 0 for canal transportation represents the absence of this procedural error, while a theoretical value of 1 for centering ability indicates perfect centering. This study could not compare experimental values with theoretical values due to the small sample size and the inability to achieve normal distribution data. Furthermore, the study encountered limitations in accurately categorizing the performance of the tested files based on their centering ability. This is primarily due to the lack of sufficient literature that establishes a clear correlation between the centering ability ratio value and the overall endodontic file performance. However, our findings suggest that all files tended to create transportation and could not remain centered in the canal, highlighting the importance of further research in this area.

It is essential to consider the limitations of this study, such as the small sample size and the inability to achieve normal distribution data. Despite these limitations, the findings of this study provide valuable insights into the performance of the four tested NiTi endodontic files and their potential impact on the success of endodontic treatment. Furthermore, the use of the latest advanced analysis tools, including micro-CT scanning and 3D image construction, to accurately evaluate the effects of these files on root canal space volume alteration, apical transportation, and file-centering capability were at par with other recent studies.

Future studies should aim to address the limitations of this study by increasing the sample size, assessment in curved roots, complex micro-CT image manipulation, and using more advanced statistical methods to achieve normal distribution data. Additionally, further research could investigate the effect of other variables such as root canal anatomy, operator experience, and the use of glide path preparation on the performance of these files. These studies could contribute to the development of guidelines for selecting the appropriate NiTi files for specific clinical cases and could ultimately improve the success rates of endodontic treatments.

Conclusion

Based on the limitations of the present study, it can be inferred that root canal preparation induces significant alterations in

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the morphometric parameters of the root canal space, specifically in the root canal volume, irrespective of the NiTi instrument type and kinematic motion. All four instruments tested exhibited a tendency to cause canal transportation and were incapable of maintaining the file's centrality within the canal. Consequently, it can be concluded that while these instruments are safe and demonstrate comparable performance, clinicians must be mindful of their limitations in root canal preparation.

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Data availability

Data is available upon request.

Declaration

Ethical approval was obtained from the National University of Malaysia (UKM) ethics committee (UKM PPI/111/8/JEP-2018-513)

Competing interest

The authors declare no competing interests

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