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Cover Page
Original paper

Title: Effect of Root Canal Transportation by Minimally Invasive Endodontic Shaping of Canal Orifice Dentin

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Abstract

Background : The purpose of this study is to analyze the effect of minimally invasive (MI) shaping of canal orifice dentin by evaluating the shaping characteristics of TruNatomy(TN), which was developed as a Ni-Ti file capable of MI endodontics.

Methods: A J-shaped canal model was used to compare final canal prepared morphology using a minima11y invasive shaping TN and a conventional shaping Pro Taper NEXT (PTN) file. The TN files of the experimental were classified into 2, no straight-line access (straight-line) (A) and straight-line (B). The PTN files of the control were also classified into 2, no straight-line (C) and a straight-line (D group), and the amount of increase in canal width and the amount of median displacement (transportation) were compared.

Results: The analysis of the canal width by TN showed that the displacement of the inner increased at 5 mm in both groups A and B, but the displacement of the outer increased at the other measurement sites. In groups C and D using PTN, the displacement of the inner increased at 3 to 5 mm. On the other hand, the displacement on the outer increased at 8 mm, and the displacement in group D increased significantly. The canal transportation used by TN was 0.1 mm or less in both groups A and B, although PTN preparation showed a significant transported to the inner side of 3 to 5 mm in group D compared to groups A and B.

Conclusion: TN shaping has been shown to preserve tooth structure and canal geometry without straight-line. It has been shown that TN developed based on the concept of MI Endo enables accurate root canal shaping and reduces transportation.

Key words: Canal transportation, shaping ability, straight-line access, TruNatomy, Pro Taper NEXT

Introduction

It has been reported that endodontic treated teeth have a higher risk of fracture depending on the morphology and amount of residual tooth substance (1-3). Seo et al (4) reported that 79% of vertical root canal fractured teeth were endodontic treated teeth. The relation between endodontic treated tooth and root canal fractures has been shown to be involved in stress during root canal shaping(5). Dentin cracks that occur during root canal shaping are thought to be the cause of vertical root fracture along with long-term disinfectant administration in the root canal and excessive vertical filling pressure during root canal obturation (6).

In recent years, minimally invasive endodontics (MI Endo) has been advocated, and root canal shaping by minimal dentin removal that preserves the dentin on canal orifice is root canal fracture (7, 8). In the basic process of canal shaping, straight-line access was one of most important procedures and a prerequisite step for shaping and obturation (9 -11). The removal of infected dentin at the canal orifice by straight-line access and relief of the degree of root canal curvature facilitate accurate root canal shaping. However, straight-line access has been reported to be associated with excessive shaping of the orifice dentin, reducing dentin stiffness and reducing fracture resistance (12,13). It has been reported that orifice dentin preservation of the upper 1/3 of the root canal is more important than preservation of crown occlusal surface dentin to prevent root canal fracture (14,15). It has been reported that the contouring of the access cavity by MI Endo is related to the structural maintenance of the crown dentin, but the minimally invasive access of the cervical dentin to the fracture resistance of the root was controversial (16,17,18). However, it has been reported that root canal shaping by MI Endo of orifice dentin maintains high fracture resistance compared to root canal shaping by straight-line access (19).

Currently, MI Endo (20) is being implemented mainly on the west coast of the United States with the concept of preventing root canal fracture, unlike the conventional root canal formation method. MI Endo advocates maximal preservation of dentin and also influences caries diagnosis, treatment choices, access cavity design, and root canal or restoration choices (21,22). The access cavity was considered to be a prerequisite for improving the prognosis of endodontic treatment because it enables apical closure by proper root canal filling by maintaining the apical root canal morphology during root canal preparation(23). However, new generation Ni-Ti files, microscopy, and cone-beam computed tomography are making it possible for dentists to make access cavities as minimally invasive as possible and maintain the dentin structure of the tooth being treated.

The TruNatomy (TN; Dentsply Sirona, Ballaigues, Switzerland) file was designed based on the concept of MI Endo and was developed as a file capable of accurate root canal shaping without straight-line access, and rotates at high speed. It is a unique thin Ni-Ti wire with a 0.8 mm, maximum flute diameter instead of 1.2mm, which is commonly used in other Ni-Ti file. Also, it has a regression taper and an off-centered parallelogram cross section in the file system as used by Peters et al. (24). (24). The TN file consists of a file system designed according to the conventional *ProTaper Next* file (PTN, Dentsply Sirona). Since the PTN file (25) is used based on the conventional root canal shaping concept that requires straight-line access, it can be compared with the minimally invasive shaping TN file as a study control of this study. The physical characteristics of PTN files have been reported to be extremely flexible(26,27). Similar

to PTN, the TN file is constructed as a cross-sectional form in which the file cutting surface is off-centered axis, but the characteristics of the alloy are different. On the other hand, both the TN and PTN file tapers are variable, but the apical 3 mm both have a 6% taper. In addition, the file system has a similar format, but the PTN file tip size is X1 (#17), X2 (# 25), and X3 (# 30), while the TN is Small (# 20), Prime (# 26), and Medium (# 36). Both file systems are usually designed to complete root canal shaping in two files: X1, X2 for PTN, Small for TN, and Prime for cases of pulp ectomy in the root canal.
The purpose of this study was to evaluate the canal preparation characteristics by TN based on the MI Endo concept. For the evaluation of root canal preparation was performed using a minimally invasive cutting type TN and a conventional cutting type PTN, and the total amount of removed root canal wall and the canal transportation were measured and compared. The results of this study can verify the relationship between straight-line access during root canal preparation and final canal morphology.

Materials and Methods

1. Operator and test canal model

The canal preparation was performed by a single operator (specialist of JEA and JCD) using the Ni-Ti (PTN) files in strict accordance with the manufacturer's recommendations for each system.
For the experiment, a total of 40 J-type root canal model (curvature degree 30 °, apex diameter # 15, taper 02, canal length 16.5 mm: End Training block canals, Dentsply - Sirona) made by epoxy resin were used. All root canal models were attached to the *Endo Training Model Castillo* (VDW, Frankfurt, Germany), and root canal preparation was performed in a situation where the root canal morphology could not be confirmed.

Figure 1 | Table 1

2. Root canal preparation

To analyze the effect of straight-line access on the final canal morphology after root canal preparation, TN and PTN were compared. TN files in the experimental group were classified into two groups, a no straight-line group (A group) and a straight-line group (B group). PTN file of the control group was also classified into two groups, a no straight-line group (C group) and a straight-line group (D group), and the root canal width diameter increase amount and canal transportation were compared. In each experimental group, the PTN Access Opener XA of the PTN file system was used for the straight-line group, and the Orifice Modifer (OM) of the TN file system was used for the no straight-line group to enlarge the root canal orifice.
In each experimental group, the final preparation morphology was set to TN Prime (file tip diameter # 26 / average taper 04 (Variable:V): ISO # 26/04V) and PTN file X2 (ISO # 25/06). Figure 1 shows the dimentions of TN and PTN files. Table 1 showed the files used up to the root canal preparation in each experimental group.
For root canal preparation by TN in the experimental group, after confirming penetration to the apex with stainless-steel K file # 10 (Dentsply Sirona, Ballaigues, Switzerland) before the start of root canal preparation, straight-line access using Orifice Modifer 20/08 to shape the canal orifice. The experimental TN group was classified into no straight-line group A used by Orifice Modifer 20/08 for the root canal orifice opening, and straight-line group B used by TN Access Opener XA. Then, a glide path

was formed by TN Glider. Root canal reparation by TN was shaped using X Smart plus (Dentsply- Maillefer) by the following procedure. For root canal preparation, after shaping with TN small (20/04V), use TN prime (26/04V), set both files to 500 rpm and 1.5 Ncm, and perform three vertical movement operations. The working length was reached in 3 cycles as 1 cycle, and root canal formation was completed by cleaning the root canal with 2 ml DW at the end of each cycle.

The control group, Pro Taper Next (PTN, Dentsply-Sirona), confirmed penetration to the apex with K file # 10 before the start of root canal preparation. After confirmation of penetration, the group was classified into no straight-line group C used by Orifice Modifer 20/08, and straight-line group D using by PTN Access Opener XA. Then, a glide path was formed in the TN Glider group (n = 20). Root canal formation by PTN was performed using X Smart plus (Dentsply- Maillefer) by the following procedure. For root canal preparation by PTN, two X1 (17/04) and X2 (25/06) files were used, and both files were set to 300 rpm and 2.0 Ncm. The first X1 and the second X2 files were reached to the working length three times to complete the root canal preparation. Root canal preparation was completed by cleaning the root canal with 2 ml DW at the end of each cycle

3. Evaluation of root canal morphology

The amount of root canal morphological displacement was analyzed by measuring the total amount of removed root canal wall in the outer and inner sides of the curved root canal. A stereoscopic microscope Olympus SZX16 (Olympus, Tokyo) and a digital camera DP71 (Olympus) are used for measurement, and transparent root canal models pre- and post-preparation are superimposed on digital images, and the obtained image data is captured on a PC for measurement. Measurements were performed using software (WinRoof, Tokyo) (Fig. 2). To measure the amount of root canal wall shaping in the root canal model, set the positions 1, 2, 3, 5, and 8 mm from the apex as the measuring unit, and increase the root canal width diameter on each of the outer and inner canal sides. (The distance from the root canal wall of pre- to the post-preparation) and the median root canal value as canal transportation were measured and statistically processed.

Figure 2

4. Statistical processing

The measured values of root canal wall cutting were statistically processed with a risk factor of 5% using one-way ANOVA, multiple comparison test by *Bonferroni Dunn*, and *Mann-Whitn*ey U test (comparative analysis between two groups).

Figure 3.4

Results

The root canal morphology in post-preparation is evaluated by measuring the increase in root canal width diameter and median displacement on the inner and outer sides at positions 1, 2, 3, 5, and 8 mm from the apex. Comparing the canal prepared morphology (Fig. 2) of the canal models in pre- and post- root preparation of groups A, B, C, and D, the flare formation on canal orifice was not observed in group A without straight-line access. However, in group C in which straight-line access was not formed, the flare formation on canal orifice was observed as similar in groups B and D in which straight-line was formed. Furthermore, in group D with straight-line, an increasing tendency was observed in the amount of cutting in the inner side at the curved start position of 5 to 3 mm.

There are showed the results of measuring the total amount of removed root canal wall

(Fig. 3) and canal transportation (Fig. 4) in all experimental groups.
According to the analysis result of the increase in total amount of removed root canal wall by TN, the displacement on the inner side increased at the measurement site 5 mm at the start position of root canal curvature in both groups A and B, but the displacement on the outer bay side increased in other measurement sites. On the other hand, in both groups C and D, the displacement on the inner side increased at the measurement site of 3 to 5 mm, the displacement on the outer bay side increased at the measurement site of 8 mm, and the displacement of group D increased in particular (Fig. 3).
The median displacement as canal transportation by TN was 0.1 mm or less at all measurement sites in both groups A and B. The median displacement by PTN showed a significant median displacement to the inner at the measurement site of 3 to 5 mm in group D compared to groups A and B, and a significant median displacement to the outer bay at 8 mm. The amount was shown. On the other hand, the median displacement of group C was not significantly different from that of groups A and B (Fig. 4).

Discussion
Endodontic treated teeth has been suggested that the treatment process itself such as access cavity and root canal enlargement has a risk of root canal fracture, and in particular, the relationship between the distribution of occlusal stress and root canal fracture has been reported (28). To reduce the risk of root canal fracture, the concept of MI Endo is recommended when minimal access cavity and root canal preparation using Ni-Ti files. It is essential to negotiation for a root canal using K file at the start of root canal preparation. Anatomical root canal information such as curvature, calcification, apical foramen diameter, and root canal length can be obtained by this step. Furthermore, in curved root canals, removal of the orifice dentin ridge is considered to be the most important step in root canal preparation, and this operation facilitates file insertion to the apical foramen is formed. That is, removal of dentin ridges by straight line access and establishment of glide paths have been regarded as essential techniques for the safe use of Ni-Ti files.
On the other hand, it is being reported that straight-line access, which has been considered as the basic concept of root canal preparation, reduces fracture resistance and causes root fracture due to excessive cutting of orifice dentin. Endodontic treated-teeth have high stress concentration in the cervical region (29, 30), and excessive cutting of orifice dentin is considered to be a factor that increases the susceptibility to fracture (31). These study reports have shown that minimizing flare formation due to straight-line access may reduce the risk of cervical fracture. In addition, the straight-line access unformed root canal causes stress dispersion in the orifice dentin when normal stress is applied to the occlusal surface, whereas the straight-line access formed root canal concentrates stress and has weak fracture resistance (19). The results showed that endodontic treated-teeth performed at MI Endo were less susceptible to cervical fracture. Previous studies have been supported in which the possible preservation of orifice dentin correlates with long-term occlusal function maintenance in endodontic treated-teeth (14, 15).
These research reports have discussed the need for straight-line access in root canal preparation. For straight-line access unformed root canals, it is assumed that it will be difficult to limit the operation of instruments and directly reach the direct view due to the reduction of the surgical field at the start of root canal preparation. Inadequate

morphological follow ability is predicted. This study analyzes the relationship between the final canal morphology by Ni-Ti preparation and straight-line access, and enables accurate root canal preparation even in MI Endo, which reduces the risk of root canal fracture. The 30° degree of curved root canal model used in this study was selected because it is easy to obtain the effect of reduced curvature due to straight line access.

Furthermore, the TN used in this study was developed with the concept of MI Endo, which maintains a high occlusal strength of endodontic treated teeth by forming a root canal with minimally invasive shaping. In the results of this study, it was shown that TN enables proper root canal preparation without straight-line access. The amount of increase in root canal width and the amount of median displacement were measured in TN canal preparation. Even in the comparison between the no straight-line access (A) group and the straight-line access (B) group, no significant difference was observed between the increase in root canal width and the median displacement used by TN. The accurate canal preparation was shown to require no straight-line access.

On the other hand, as a result of comparing the PTN with the no straight-line access (C) group and the straight-line access (D) group, extremely interesting results were obtained. The amount of increase in root canal width and the amount of median displacement in the group without PTN straight-line access (C) showed the same amount of displacement as in groups A and B of TN at the apex 1 to 3 mm. Furthermore, the displacement amount of TN in groups A and B increased only on the inner bay side of 5 mm and the outer side of 8 mm, but no significant difference was observed, and straight-line access was not formed even in root canal formation by PTN. It was shown that proper root canal preparation is possible. Since the PTN X2 file has a large taper, flare of the upper 1/3 of the root canal is prepared even in the no straight-line access (C) group when using X2, similar to the straight-line access formation, at the apex. It was also shown that accurate root canal preparation on was possible.

In addition, on the apical side 1 to 2 mm, accurate root canal preparation was possible in both the TN and PTN groups regardless of the presence or absence of straight line access, and the median root canal value was also the same.

This result shows that both TN and PTN files have a 6% taper up to 3 mm on the apical side, TN (apical 0, 1, 2, 3 mm = # 26, # 32, # 38, # 44) and PTN (apical 0, 1, 2, 3mm = # 25, # 31, # 37, # 43). It is probable that the fact that the file diameters were the same had an effect. On the other hand, The displacement of the inner side of 3, 5 and 8 mm was significantly increased, showing a tendency of straightening on the inner side of the curved root canal in the PTN straight-line access formation (D) group. This result is considered to be influenced by the difference in flexibility and file taper (4 mm or more from the apex) between the PTN file and the TN file. Peters et al reported that TN was found to be more fatigue resistant and showed significantly more predicable torque and threading-in force compared with PTN (24).

It was shown that the root canal preparation by PTN that formed the straight-line access, which was considered to be essential for maintaining the anatomical root canal morphology, straightened the curved root canal inner side.

The PTN has two files, X1 and X2, which can obtain the final root canal morphology that enables sufficient root canal cleaning and root canal filling, and at the same time, the elasticity of the file itself is improved. The file operability is easy and it is expected to reduce accidents and is used clinically. The file shape of PTN is characterized by having a rectangular cross section of the file and always cutting at only two points in contact with the root canal wall in order to reduce the bite into the root canal wall. Therefore, PTN is the most frequently used file system in Europe and the United States because there are few accidents during root canal preparation and accurate root canal preparation is possible even in curved root canals. TN file system was constructed with a similar system based on PTN, and was designed to have a final root canal morphology that can be filled with root canals using two files, small and prime. However, since there is no straight-line access, there is a concern that the root canal follow ability of the apical curved root canal may be inadequate due to the restriction of instrument operation due to the reduction of the operation field. The results of this study proved that there is no need for straight-line access, which has been considered an essential procedure for accurate root canal preparation. Insufficient flare preparation in the upper part of the root canal when straight-line access is not formed suggests the difficulty of root canal cleaning and the effect of insufficient pressurization of root canal obturation. However, for root canal preparation by minimally invasive shaping type TN, it is recommended to use a dedicated needle with an improved tip for root canal cleaning and pressure root canal obturation or single point root canal obturation with a dedicated gutter core by root canal obturation. In recent years, a bioceramic sealer has been developed for root canal obturation, and it has been reported that it has excellent biological properties such as hard tissue forming ability in addition to biocompatibility and non-cytotoxicity (32). In particular, bioceramic sealers are expected to have a higher tight-sealing chain than other sealers by forming hard tissue at the dentin interface and apical foramen. Currently, the root canal obturation method uses multiple chemically and physically stable guta-percha cones to tightly seal the root canal by lateral and vertical obturation with heated guta-percha. A obturation method has been established and high clinical results have been reported. However, the single-point root canal filling method (33) using a bioceramic sealer capable of root canal preparation and hard tissue formation, which reduces the risk of root canal fracture due to minimally invasive cutting type TN, will follow the flow of endodontic treatment in the future. The possibility of accelerating to MI Endo was shown.

Conclusion

The root canal preparation by TN has been shown to maintain the original anatomical root canal morphology without straight-line access. It has been shown that the minimally invasive shaping type TN developed based on the concept of MI Endo enables accurate root canal preparation and reduces the amount of root canal displacement after root canal preparation due to the file shape and flexibility.

Acknowledgment

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References

1. Fransson H, Dawson VS, Frisk F, Bjørndal L, EndoReCo O, Kvist T. Survival of root-filled teeth in the Swedish adult population. J Endod 2016; 42: 216–220.
2. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent 2002; 87: 256–263.
3. Pratt I, Aminoshariae A, Montagnese TA, Williams KA, Khalighinejad N, Mickel A. Eight-year retrospective study of the critical time lapse between root canal completion and crown placement: its influence on the survival of endodontically treated teeth. J Endod 2016; 42: 1598–1603.
4. Seo DG, Yi YA, Shin SJ, Park JW. Analysis of factors associated with cracked teeth. J Endod 2012; 38: 288-92.
5. Liu R, Kaiwar A, Shemesh H, Wesselink PR, Hou B, Wu MK. Incidence of apical root cracks and apical dentinal detachments after canal preparation with hand and rotary files at different instrumentation lengths. J Endod 2013; 39: 129-32.
6. Fain WD.Fain WD. Tooth Fractures and Cracks. J Am Dent Assoc 2021; 152: 423-424
7. Krishan R, Paqué F, Ossareh A, KishenA, Dao T, Friedman S. Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars. J Endod 2014; 40: 1160-1166
8. Moore B, Verdelis K, Kishen A, Dao T, Friedman S. Impacts of Contracted Endodontic Cavities on Instrumentation Efficacy and Biomechanical Responses in Maxillary Molars. J Endod 2016; 42: 1779-1783.
9. Goerig AC, Michelich RJ, Schultz HH. Instrumentation of root canals in molars using the step-down technique. J Endod 1982; 8: 550-554
10. Swindle RB, Neaverth EJ, Pantera EA Jr, Ringle RD. Effect of coronal-radicular flaring on apical transportation. J Endod 1991; 17: 147-149
11. Torabinejad M. Passive step-back technique. Oral Surg Oral Med Oral Pathol 1994; 77: 398-401
12. Lang H, Korkmaz Y, Schneider K, Raab WH. Impact of endodontic treatments on the rigidity of the root. J Dent Res 2006; 85: 364–368.
13. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010; 36: 609–617.
14. Pierrisnard L, Bohino F, Renault P, Barquins M. Corono-radicular reconstruction of pulpless teeth: a mechanical study using finite element analysis. J Prosthet Dent 2002; 88: 442–448.
15. Clark D, Khademi JA. Case studies in modern molarendodontic access and directed dentin conservation. Dent Clin North Am 2010; 54: 275–289.
16. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010; 36: 609-17.
17. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. J Endod 1989; 15: 512–516.
18. Pradeep P, Kumar VS, Bantwal SR, Gulati GS. Fracture strength of endodontically treated premolars: an In-vitro evaluation. J Int Oral Health 2013; 5: 9–17.
19.Yuan K, Niu C, Xie Q, Jiang W, Gao L, Huang Z, Ma R. Comparative evaluation of the impact of minimally invasive preparation vs. conventional straight-line preparation on tooth biomechanics: a finite element analysis. Eur J Oral Sci 2016; 124: 591–596.
20. Burllein S, Schafer E. Minimally invasive endodontics.

Quintessence Int 2015; 46: 119–124.
21. Murdoch-Kinch CA, Mclean ME.
Minimally invasive dentistry. J Am Dent Assoc 2003; 134: 87–95.
22. Gutamann JL. Minimally invasive dentistry (Endodontics).
J Conserv Dent 2013; 16: 282–283.
23. Kenneth MH, Stephen C. Cohen’s pathways of the pulp, 10th St. Louis, MO, USA: Elsevier, 2011; 137–138.
24. Peters OA, Arias A, Choi A
Mechanical Properties of a Novel Nickel-titanium Root Canal Instrument: Stationary and Dynamic Tests. J Endod 2020; 46: 994-1001.
25. Arias A, Singh R, Peters OA. Torque and force induced by ProTaper universal and ProTaper next during shaping of large and small root canals in extracted teeth
J Endod 2014; 40: 973-976
26. Nguyen HH, Fong H, Paranjpe A, Flake NM, Jonson JD, Peters OA. Evaluation of the resistance to cyclic fatigue among ProTaper Next, ProTaper Universal, and Vortex Blue rotary instruments. J Endod 2014; 40: 1190-1193
27. Shim KS, Oh S, Kum K, Kim YC, Jee KK, Chang SW. Mechanical and metallurgical properties of various nickel-titanium rotary instruments. 2017;2017:4528601 doi: 10.1155/2017/4528601
28. Chen G, Fan W, Mishra S, El-Atem A, Schuetz MA, Xiao Y. Tooth fracture risk analysis based on a new finite element dental structure models using micro-CT data. Comput Biol Med 2012; 42: 957– 963.
29. Al-Omiri MK, Rayyan MR, Abu-Hammad O. Stress analysis of endodontically treated teeth restored with post-retained crowns: a finite element analysis study. J Am Dent Assoc 2011; 142: 289– 300.
30. Belli S, Eraslan O, Eraslan O, Eskitascioglu G. Effect of restoration technique on stress distribution in roots with flared canals: an FEA study. J Adhes Dent 2014; 16: 185– 191.
31. Sathorn C, Palamara JE, Palamara D, Messer HH. Effect of root canal size and external root surface morphology on fracture susceptibility and pattern: a finite element analysis. J Endod 2005; 31: 288– 292.
32. Sanz JL, Rodríguez-Lozano FJ, Llena C, Sauro S, Forner. Bioactivity of bioceramic materials used in the dentin-pulp complex therapy: A Systematic Review. Materials . 2019; 12: 1015. doi: 10.3390/ma12071015
33. Yu YH, Kushnir L, Kohli M, Karabucak B. Comparing the incidence of postoperative pain after root canal filling with warm vertical obturation with resin-based sealer and sealer-based obturation with calcium silicate-based sealer: a prospective clinical trial. Clin Oral Investig 2021; 25: 5033-5042.

Figure Legends

Figure 1. The dimensions of TN (A: Small 20/04V, B: Prime 26/04V) and PTN (C: X1 17/04, D: X2 25/06) files.

Figure 2. Superimposition of pre- and postpreparation images.
TN no straight-line group (A), TN straight-line group (B), PTN no straight-line group (C), and PTN straight-line group (D). * straight-line access, ** final preparation by PTN X2 file.

Figure 3. Total amount of removed canal wall(mm) at the different levels in post preparation by TN no straight-line group (A), TN straight-line group (B), PTN no straight-line group (C), and PTN straight-line group (D). *Significant difference ($p<0.05$) .

Figure 4. Canal transportation at the different levels from apex in post preparation by TN no straight-line group (A), TN straight-line group (B), PTN no straight-line group (C), and PTN straight-line group (D).
*Significant difference ($p<0.05$) between TN (A ,B) and PTN (D)

Table 1. The files used up to the root canal preparation in each experimental group.

Experimantal Groupe	Ni-Ti file system Straight-line(+/-)	Scout	Orifice Open	Glide path	Preparation Start file	Preparation Final file
A	TruNatomy Straight Line(-)	#10	O.Modifer 20/08	Glider 17/02V	Small 20/04V	Prime 26/04V
B	TruNatomy Straight Line(+)	#10	A.Opener XA	Glider 17/02V	Small 20/04V	Prime 26/04V
C	ProTaper NEXT Straight Line(-)	#10	O.Modifer 20/08	Glider 17/02V	X1 17/04	X2 25/06
D	ProTaper NEXT Straight Line(+)	#10	A.Opener XA	Glider 17/02V	X1 17/04	X2 25/06

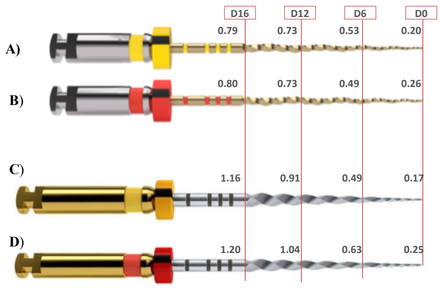

Figure 1. The dimensions of TN (A: Small 20/04V, B: Prime 26/04V) and PTN (C: X1 17/04, D: X2 25/06) files.

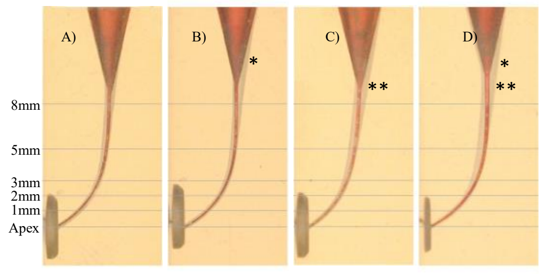

Figure 2. Superimposition of pre- and post-preparation images.
TN no straight-line group (A), TN straight-line group (B), PTN no straight-line group (C), and PTN straight-line group (D).
* Straight-line access, ** Final preparation by PTN X2 file.

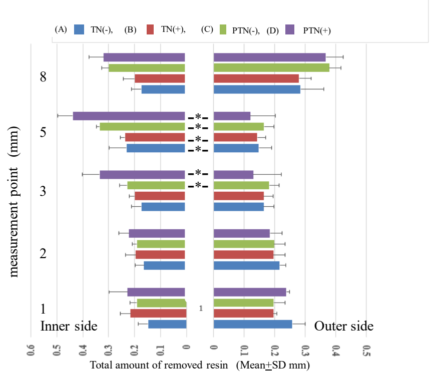

Figure 3.Total amount of removed resin (Mean±SD (mm)) at the inner and outer sides *Significant difference ($p<0.05$)

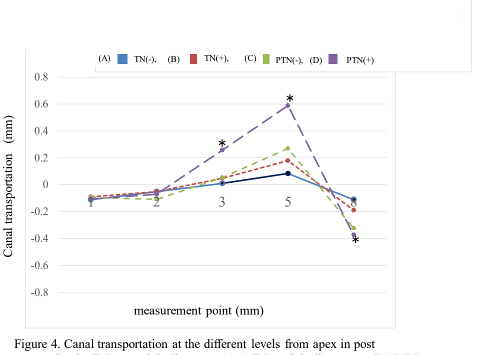

Figure 4. Canal transportation at the different levels from apex in post preparation by TN no straight-line group (A), TN straight-line group (B), PTN no straight-line group (C), and PTN straight-line group (D).
*Significant difference ($p<0.05$) between TN (A ,B) and PTN (D)