Effect of Root Canal Transportation by Minimally Invasive Endodontic Access on Canal Orifice Dentin

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Research Article

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Abstract

Background: Minimally invasive endodontics (MI Endo) with minimal dentin shaping prevents root canal fracture in endodontically treated teeth. Alternatively, reduction of the surgical field and limitation of the visual field by MI Endo make root canal shaping difficult. 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), a Ni–Ti file developed for MI Endo.

Methods: A J-shaped canal model was used to compare the final canal morphology formed using a MI shaping TN or conventional shaping *ProTaper NEXT* (PTN) file. The TN files were used in two experimental groups: no straight-line access (A) and straight-line access (B). The PTN files of the control were similarly classified: no straight-line access (C) and straight-line access (D). The increase in canal width and the median displacement (transportation) among the groups were compared.

Results: The analysis of the canal width prepared with the TN file showed that the displacement of the inner canal curve increased at the point 5 mm from the apex in Groups A and B; however, the displacement of the outer width increased at the other measurement sites. In Groups C and D using PTN, the displacement of the inner canal curve increased at points 3–5 mm from the apex. Alternatively, the displacement on the outer width increased at 8 mm, and the displacement in Group D increased significantly. The canal transportation in the case with a TN file was 0.1 mm or smaller for Groups A and B, although the PTN preparation showed significant transport 3–5 mm from the apex on the inner curve of Group D compared with Groups A and B.

Conclusions: TN shaping preserves the tooth structure and canal geometry without straight-line access. The TN file developed based on the concept of MI Endo facilitates accurate root canal shaping and reduces transportation.

Background

Endodontically 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 endodontically treated teeth. The relation between an endodontically treated tooth and root canal fractures are attributed to stress created during root canal shaping (5). Dentin cracks that occur during root canal shaping, long-term disinfectant administration in the root canal, and excessive vertical filling pressure during root canal obturation cause vertical root fracture (6).

In recent years, minimally invasive endodontics (MI Endo) have been advocated, and root canal shaping by minimal dentin removal that preserves the dentin on the canal orifice is root canal fracture (7, 8). In the basic process of canal shaping, straight-line access is one of the 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 facilitates accurate root canal shaping. However, straight-line access is associated with excessive shaping of the orifice dentin, reducing

dentin stiffness, and reducing fracture resistance (12, 13). Preservation of the orifice dentin of the upper 1/3 of the root canal is more important than preservation of the crown occlusal surface dentin to prevent root canal fracture (14, 15). The contouring of the access cavity by MI Endo is related to the structural maintenance of the crown dentin; however, MI access of the cervical dentin to the fracture resistance of the root is controversial (16, 17, 18). Overall, root canal shaping by MI Endo of the orifice dentin maintains a higher fracture resistance than root canal shaping by straight-line access (19).

MI Endo (20) is mainly used on the west coast of the United States for preventing root canal fracture. MI Endo maximizes dentin retention and also influences caries diagnosis, treatment choices, access cavity design, and root canal or restoration choices (21, 22). The access cavity is considered to be a prerequisite for improving the prognosis of endodontic treatment because it enables apical closure with proper root canal obturation by maintaining the apical root canal morphology during root canal preparation (23). However, a new generation Ni–Ti files, microscopy, and cone-beam computed tomography are making it possible for dentists to make MI access cavities and to 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. The file is capable of accurate root canal shaping without straight-line access and it can rotate at high speed. It is a unique thin Ni–Ti wire with a 0.8 mm, maximum flute diameter instead of the common 1.2 mm diameter Ni–Ti file. Additionally, the TN file has a regression taper and an off-centered parallelogram cross section in the file system as used by Peters et al. (24). The TN file is a file system designed according to the conventional *ProTaper Next* file (PTN, Dentsply Sirona). Because the PTN file (25) is in conventional root canal shaping that requires straight-line access, it can be compared with the MI shaping TN file as a control in this study. The physical characteristics of the PTN files are extremely flexible (26, 27). Similar to PTN, the TN file is constructed as a cross-sectional form in which the file cutting surface is an off-centered axis; however, the taper and characteristics of the alloy are different. The file system also has a similar format; however, the PTN file tip size is X1 (#20), 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 using the MI Endo concept. Root canals were performed using MI cutting type TN and a conventional cutting type PTN, and the total amount of removed root canal wall and canal transportation were measured and compared. The relationship between straight-line access during root canal preparation and final canal morphology were verified.

Methods

Operator and test canal model

A single experience operator using Ni–Ti rotary files performed all procedures. A total of 40 J-type root canal models (curvature degree 30°, apex diameter #15, taper 02, canal length 17.0 mm: End Training block canals, Dentsply Sirona) made with epoxy resin were used.

Root canal preparation

TN and PTN were compared to analyze the effect of straight-line access on the final canal morphology after root canal preparation. The TN file was used in two experimental groups, a no straight-line group (A group) and a straight-line group (B group). The PTN file was used in two control groups, a no straight-line group (C group) and a straight-line group (D group). The root canal width diameter increase and canal transportation of each group 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 Modifier (OM) of the TN file system was used for the no straight-line group to increase the root canal orifice.

In each experimental group, the final preparation morphology was set to TN Prime (file tip diameter #26 / taper 04: ISO #26/04) and PTN file X2 (ISO #25/06). For each file of the TN and PTN system, all files in the experimental group used the dedicated engine X Smart plus (Dentsply Sirona) with forward rotation (TN; 500 rpm / 1.5 N cm, PTN; 300 rpm / 2 N cm) and a working length of 3 cycles with 3 vertical movement operations as 1 cycle. The root canal preparation was completed by cleaning with 2 ml distilled water (DW) at the end of each cycle.

Table 1 shows the files used for the root canal preparation in each experimental group. For root canal preparation with TN in the experimental group, after confirming penetration to the apex with the K file #10 (Dentsply Sirona) before starting root canal preparation. For the root canal orifice opening, the experimental TN group no straight-line Group A used the Orifice Modifier 20/08 and the straight-line Group B used the PTN Access Opener XA. A glide path was then formed by a TN Glider. Root canal preparation by TN was shaped using X Smart plus (Dentsply Sirona) with the following procedure. For root canal preparation, after shaping with TN small (20/04), TN Prime (26/04) was used. Both files were set to 500 rpm and 1.5 N cm, and three vertical movement operations were performed. The working length was reached in 3 vertical movements, which was considered as 1 cycle. The root canal preparation was completed by cleaning the root canal with 2 ml DW at the end of each cycle.

Table 1

Files used in the root canal preparation in each experimental group.

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

For the PTN as control group, the apex penetration was confirmed with K file #10 before starting the root canal preparation. The controls were classified as no straight-line Group C with the Orifice Modifier 20/08, and straight-line Group D with the PTN Access Opener XA. A glide path was then formed in the TN Glider group (n = 20). Root canal preparation by PTN was performed using X Smart plus (Dentsply Shirona) with the following procedure. Two X1 (17/04) and X2 (25/06) files were used, and both files were set to 300 rpm and 2.0 N cm. The first X1 and second X2 files reached the working length three times to complete the root canal preparation. The root canal preparation n was completed by cleaning the root canal with 2 ml DW at the end of each cycle.

Evaluation of the root canal morphology

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

Statistical processing

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

Results

The post-preparation root canal morphology was evaluated by measuring the increase in root canal width diameter and median displacement on the inner and outer curves 1, 2, 3, 5, and 8 mm from the apex. Comparing the canal prepared morphology (Fig. 1) of the canal models in pre- and post-root preparation, the flare formation on the canal orifice was not observed in Group A that did not use straight-line access. However, in Group C without straight-line access, flare formation on the canal orifice was observed, similar to Groups B and D with straight-line access. Furthermore, in Group D with straight-line access, an increasing tendency was observed in the amount of cutting in the inner curve from 5 mm to 3 mm. The total amount of removed root canal wall and canal transportation for all experimental groups are shown in Fig. 2 and Fig. 3, respectively.

According to the analysis of the increase in total amount of root canal wall removed by TN, the displacement on the inner curve increased at the 5 mm measurement site at the start position of the root canal curvature in both Groups A and B; however, the displacement on the outer canal curve increased at other measurement sites. Alternatively, in both Groups C and D, the displacement on the inner canal curve increased from the 3 mm measurement site to the 5 mm measurement site, whereas the displacement on the outer curve increased at the measurement site of 8 mm. Furthermore, the displacement of Group D increased (Fig. 2).

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 was significantly different at the measurement sites from 3 mm to 5 mm of the inner curve in Group D than Groups A and B, and had a significant median displacement in the outer curve at 8 mm. Alternatively, the median displacement of Group C was not significantly different than Groups A and B (Fig. 3).

Discussion

Endodontic treatments of teeth have been suggested because cavity access and root canal enlargement risk 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, MI Endo is recommended for MI access of a cavity and root canal preparation using Ni–Ti files. It is essential to use a K file when preparing a root canal. Anatomical root canal information, such as curvature, calcification, apical foramen diameter, and root canal length, can be obtained at this step. Furthermore, in curved root canals, removal of the orifice dentin ridge is the most important step in root canal preparation, and this

operation facilitates file insertion to the apical foramen. Specifically, removal of dentin ridges by straight-line access and use of glide paths have been regarded as essential techniques for the safe use of Ni–Ti files.

Straight-line access, which is a basic concept of root canal preparation, reduces fracture resistance and causes root fracture because of excessive cutting of orifice dentin. Endodontically treated teeth have high stress concentration in the cervical region (29, 30), and excessive cutting of the orifice dentin is considered to be a factor that increases fracture susceptibility (31). These study reports have shown that minimizing flare formation by straight-line access may reduce the risk of cervical fracture. In addition, the root canal without straight-line access causes stress dispersion in the orifice dentin when normal stress is applied to the occlusal surface, whereas the root canal with straight-line access concentrates stress and has weak fracture resistance (19). The results in this study showed that teeth treated with MI Endo were less susceptible to cervical fracture. Previous studies have shown the preservation of orifice dentin correlates with long-term occlusal function maintenance in endodontically treated teeth (14, 15).

These research reports have discussed the need for straight-line access in root canal preparation. For straight-line access in unformed root canals, it is assumed that it will be difficult to limit the instrument operation and have a direct view of the site because of the reduced surgical field at the start of root canal preparation. As a result, inadequate morphological tracking 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 TN used in this study was developed with the concept of MI Endo, which maintains a high occlusal strength of endodontically treated teeth by forming a root canal with MI shaping. TN also enables proper root canal preparation without straight-line access. The increase in root canal width and the median displacement were measured in TN canal preparation. Even when comparing the no straight-line access (Group A) and the straight-line access (Group B), no significant difference was observed between the increase in root canal width and median displacement when using TN. As a result, straight-line access was not required for accurate canal preparation.

Interesting results were obtained with the PTN no straight-line access (Group C) and straight-line access (Group D). The increase in root canal width and the amount of median displacement in the PTN without straight-line access (Group C) showed the same amount of displacement as in Groups A and B with TN at points 1–3 mm from the apex. Furthermore, the displacement by TN in Groups A and B increased only on the inner curve at 5 mm and the outer curve at 8 mm; however, no significant difference was observed, and straight-line access was not formed even in the root canal formation with PTN. As a result, proper root canal preparation is possible. Because the PTN X1 and X2 files have a large taper, flare of the upper 1/3 of the root canal occurs even in the no straight-line access (Group C) similar to the straight-line access formation at the apex. The displacement of the inner curve at 3, 5, and 8 mm was significantly increased, showing a tendency of straightening on the inner curve of the root canal in the PTN straight-line access (Group D). The root canal preparation by PTN with straight-line access, which is considered to

be essential for maintaining the anatomical root canal morphology, straightened the inner curve of the root canal.

The PTN has two files, X1 and X2, that can be used to obtain the final root canal morphology for sufficient root canal cleaning and root canal filling. At the same time, the elasticity of the file itself is improved. The file operability is easy and it is expected to reduce clinical accidents. The file shape of PTN is characterized by a rectangular cross section, which allows for cutting at only two points in contact with the root canal wall to reduce transportation. 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. The TN file system was constructed with a system similar to PTN, and the system was designed to have a final root canal morphology that can be filled with root canals using two files, Small and Prime. However, because there is no straight-line access, there is concern that tracking of the apical curved root canal may be inadequate because of restricted instrument operation in the reduced operation field. The results of this study proved that there is no need for straight-line access, which had previously 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 MI shaping type TN, a dedicated needle with an improved tip is recommended 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 with excellent biological properties, such as hard tissue forming ability, biocompatibility, and non-cytotoxicity, has been developed for root canal obturation (32). Such bioceramic sealers are expected to have a tighter sealing chain than other sealers by forming hard tissue at the dentin interface and apical foramen. The root canal obturation method currently uses multiple chemically and physically stable gutta-percha cones to tightly seal the root canal by lateral and vertical obturation. An obturation method has been established and promising clinical results have been reported (33). However, the single-point root canal filling method using a bioceramic sealer capable of root canal preparation and hard tissue formation (34), which reduces the risk of root canal fracture caused by the minimally invasive cutting type TN, will follow the flow of endodontic treatment in the future. The possibility of accelerating MI Endo was shown in this study.

Conclusion

Root canal preparation by a TN file maintains the original anatomical root canal morphology without straight-line access. A MI shaping type TN file was developed based on the concept of MI Endo for accurate root canal preparation, and the file shape and flexibility contributed to reducing the amount of root canal displacement after root canal preparation.

Abbreviations

MI Endo: Minimal invasive endodontics, TN: *TruNatomy*, PTN: *ProTaper NEXT*, DW : distilled water

Declarations

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Authors' contribution

Tomoyuki Tsubaki contributed to experimental procedures and manuscript writing.

Mai Utsunomiya and Kaori Shimojima contributed to experimental procedures, results analysis and manuscript writing and revision. Noriko Mutoh contributed to conceptualization, results analysis and manuscript revision. Nobuyuki Tani-Ishii contributed to literature review, manuscript writing and revision. All authors have read and accepted the final version of this manuscript.

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Ethics approval and consent to participate

This article does not contain any studies with human participants or animal performed by any of the author.

Consent for publication

For this type of study, formal consent is not required.

Conflicts of interest

The authors deny any conflicts of interest related to this study.

Author detail

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Figures

Figure 1

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

Figure 2

Total amount of removed canal wall (mm) at the different post-preparation positions by the 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).

Figure 3

Canal transportation at the different positions from the apex in post-preparation by the 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)