Original Article

Comparative Analysis of Apical Root Crack Propagation after Root Canal Preparation at Different Instrumentation Lengths Using ProTaper Universal, ProTaper Next and ProTaper Gold Rotary Files: An *In vitro* Study

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Abstract

Aim: To compare the incidence of apical root crack formation after root canal preparation at different instrumentation lengths using ProTaper Universal (PTU), ProTaper Next (PTN) and ProTaper Gold (PTG) file systems. **Subjects and Methods:** Eighty-four mandibular first premolars with single and straight root canal were mounted in resin block after simulating periodontal ligaments. 1–2 mm of root apex was exposed followed by sectioning of 1 mm of root tip for better stereomicroscopic visualization. While the Control group was left unprepared, experimental groups were instrumented up to root canal length (RCL) and (RCL-1 mm) respectively using PTU, PTN and PTG. After staining the root apex with 1% methylene blue dye, stereomicroscopic images were obtained for evaluating apical root cracks. The data were analyzed using Chi-square, phi and Cramer test. The significance level was set at $P < 0.05$. **Results:** Significantly less dentinal defects were seen between PTG and PTU while there was no significant difference between PTU-PTN and PTN-PTG. Furthermore, samples instrumented up to RCL-1 mm showed lesser cracks as compared with samples instrumented up to RCL. **Conclusion:** PTG produced least number of cracks followed by PTN and PTU. Furthermore, instrumenting short of RCL reduced the crack formation risk.

Keywords: *Apical root crack, instrumentation length, ProTaper Gold, ProTaper Next, ProTaper Universal*

Introduction

The contemporary endodontic triad for success includes diagnosis, anatomy, and debridement of tooth followed by three-dimensional obturation. Furthermore, the immutable endodontic aim of three-dimensional unblemished seal of root canal system can be achieved by its perfect biomechanical preparation. However, root canal shaping procedures and rotary instrumentation with nickel–titanium (Ni–Ti) instruments have the potential to induce crack formation.[1] It is also speculated that these micro-cracks or craze lines can later propagate into vertical root fractures (VRFs) if the tooth is subjected to repeated stresses from endodontic or restorative procedures[2] which would lead to failure of treatment. Improving the flexibility of endodontic files would reduce iatrogenic errors resulting from canal transportation; and the efficiency and safety of root canal treatment would increase.[3] The geometry and composition of the metal and its thermomechanical treatments affect the flexibility of Ni–Ti rotary files.[3]

ProTaper Universal (PTU, Dentsply Tulsa Dental Specialities, Tulsa, OK) Ni–Ti rotary system is machined from conventional superelastic (SE) austenitic Ni–Ti wire. It features variable taper over the entire cutting blade length with convex triangular cross-sections.

Later ProTaper Next (PTN, Dentsply Maillefer) Ni–Ti rotary system was introduced which was based on M-wire technology. It was subjected to proprietary novel thermomechanical processing. It incorporated an off-centered rectangular cross section giving it a unique swaggering movement and greater flexibility.

Recently ProTaper Gold (PTG, Dentsply Maillefer, Ballaigues, Switzerland) instruments

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were introduced. It is considered as a twin of PTU since it has similar file sequence and design. Its advanced metallurgy with two stage-specific transformation behavior and high austenite finish temperature is responsible for its increased flexibility.

Till date, there are no studies that have evaluated the relation between the instrument length and apical root cracks using these Ni–Ti rotary file systems. Hence, the aim of this *in vitro* study was to compare the incidence of apical root crack propagation after root canal preparation at different instrumentation lengths using PTU, PTN and PTG rotary files.

Subjects and Methods

Selection of teeth

Eighty-four extracted human mandibular first premolars were selected and stored in distilled water. Teeth with immature root apices, caries, developmental anomalies, calcified canals and resorption were excluded from the study. Preoperative radiographs using radiovisiography were taken from both proximal and buccal view to ensure single and straight root canal (<5°).

Tooth preparation

A single layer of aluminum foil (Superwrap, Hindalco, India) was used to wrap the root portion of the teeth and then embedded into autopolymerizing resin set in an aluminum hollow block such that 1–2 mm of apical root end portion was exposed. Later, the aluminum foil was peeled off and the root was coated with a thin layer of hydrophilic vinyl polysiloxane impression material (Kerr, Take 1 Advanced, USA) to simulate periodontal ligament. The teeth were then repositioned immediately into the acrylic block. To ensure a straight line access and to provide a reference plane, decoronation from the cementoenamel junction was done using a diamond disc under water cooling. Thus, the roots were standardized to 15 mm length using digital vernier caliper (Con Air Equipments Pvt. Ltd., India). Later, approximately 1 mm of the apical root tip was cut for obtaining flat surface and stained with 1% methylene blue (Qualikems, India) to have better visualization under stereomicroscope (×20). Teeth with preexisting cracks or craze lines were excluded from the study.

The specimens were then randomly divided into six experimental and one control group with 12 teeth in each group respectively. Patency of the canal and glide path was established using no. 10 K and no. 15 K file (Mani, Japan) respectively. The distance between the reference point and the tip of the file was defined as root canal length (RCL), while RCL-1 mm represented the specimens with 1 mm short of RCL.

Root canal preparation

Control group specimens were left unprepared. Experimental groups were instrumented as per following criteria:

- Group I: PTU
- Subgroup A: RCL
- Subgroup B: RCL-1 mm
- Group II: PTN
- Subgroup A: RCL
- Subgroup B: RCL-1 mm
- Group III: PTG
- Subgroup A: RCL
- Subgroup B: RCL-1 mm

The following sequences were used for PTU (Dentsply Maillefer, Ballaigues, Switzerland) and PTG (Dentsply Maillefer, Ballaigues, Switzerland): SX file (1/2 of working length), S1 and S2 files (2/3 of the working length), and F1 file (full working length). All the files were used with a torque-controlled endodontic motor (X-Smart, Dentsply Maillefer, Ballaigues, Switzerland) at 300 rpm with a torque of 3.0 Ncm for SX and S1 instruments and 1.5 Ncm for S2 and F1 instruments. PTN (Dentsply Maillefer, Ballaigues, Switzerland) was instrumented with file sequence of X1, X2 and X3 at 300 rpm with 2.0 Ncm torque. All the files were used in brushing motion along the root canal except for F1 which was used in "in-and-out" motion. Irrigation was done after each file using 2 ml of 1% sodium hypochlorite (NaOCl) solution (Clorox Corp., Oakland, CA).

Evaluation

Apical root tip was then evaluated under stereomicroscope at 20X (OLYMPUS S2 × 12, Tokyo, Japan) and their digital images were captured. Specimens were classified as "Crack" – if any lines, microcracks or fractures were present in the root dentine [Figure 1] and "No Crack" – root dentin devoid of craze lines, microcracks on the external surface of the root, and microcracks at the internal surface of the root canal wall[4] [Figure 2].

Statistical analysis

Chi-square test, phi and Cramer tests were used to analyze the data using SPSS software 20.0 with the level of significance kept as $P < 0.05$.

Results

Control group showed no crack formation while crack formations were seen in all experimental groups. Least dentinal cracks were observed with PTG followed by PTN and PTU. There was a significant difference between PTU and PTG when total incidence of cracks was evaluated. However, no significant difference was seen between PTU-PTN and PTN-PTG [Table 1]. The samples instrumented 1 mm short of RCL showed fewer cracks than samples instrumented up to RCL although the difference was statistically insignificant [Table 2].

Discussion

VRF is one of the most common clinical complications following crack propagation in dentin of the root once the tooth has been endodontically treated.[5] Hence, importance is laid to ensure minimal iatrogenic harm to the root dentin during endodontic treatment procedures, thus improving the prognosis of the tooth.

There are studies which state that the metallurgical characteristic of various Ni–Ti file systems is a more important factor in determining the dentin damaging potential than the motion of instrumentation. Hence, PTU (conventional superelastic Ni–Ti alloy), PTN (M-wire technology) and PTG (two-stage-specific transformation behavior) file systems were used for the study, thus differentiating all the groups based on their metallurgical properties.

In this study, extracted mandibular first premolars were used because their smaller dimensions and thin dentinal walls are more prone to the forces generated during instrumentation. If large tapered files cannot induce cracks in mandibular premolar, chances of rotary files inducing cracks in other teeth are unlikely.[6]

The apical root of 1–2 mm was exposed because an exposed apex is not uncommon in teeth having chronic apical periodontitis or periapical cysts. Later, the apical 1 mm of the root was removed as it is common for periapical pathosis to damage the anatomical apex and apical constriction of the root. Furthermore, the increased incidence of apical delta ramification in apical 1 mm of root may mimic cracks and affect the interpretation of results, thus avoiding it by the removal of 1 mm of apical root. And also, it provided a flat surface for better visualization of cracks under stereomicroscope and helped in determining the working length accurately.[7]

Higher concentrations of NaOCl solution significantly decrease the elastic modulus and flexural strength of human dentin compared with physiologic saline and solutions of lower concentrations.[8] Henceforth, the use of 1% NaOCl solution was considered for irrigation purpose.

One percent methylene blue dye was used since it has a smaller molecular size (120 nm) than the bacterium. Moreover, eventually, it penetrates more deeply than other dyes since it has a low molecular weight (318.85) which is even lower than basic fuchsine (323.45).[9]

Several strategies have been implicated as to improvise the mechanical properties of Ni–Ti endodontic instruments

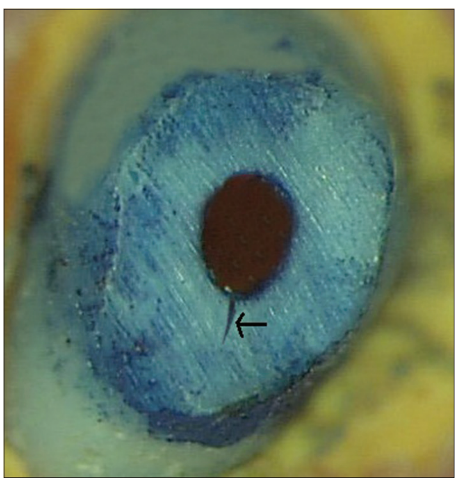


Figure 1: Crack

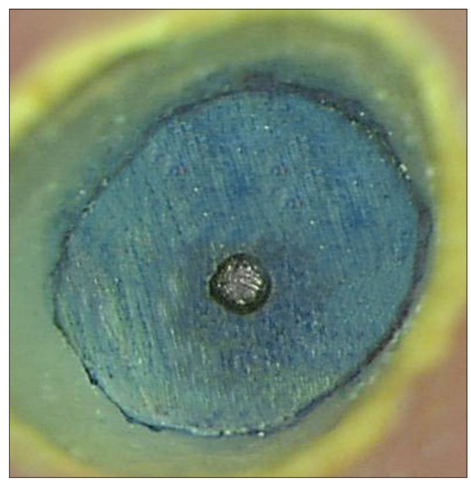


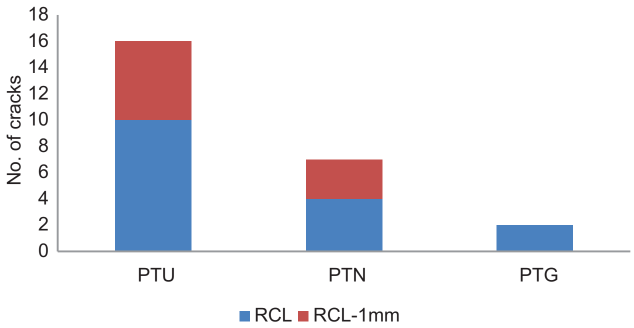
Figure 2: No crack

Table 1: Comparison between groups using Chi-square test

Groups	Subgroups	χ^2	Phi	Cramer	*P*	Significance
PTU versus PTG	RCL	5.455	−0.674	0.674	0.020*	Significant
	RCL-1 mm	1.091	−0.302	0.302	0.296	Nonsignificant
	Total	4.364	−0.426	0.426	0.037*	Significant
PTU versus PTN	RCL	0.300	−0.158	0.158	0.584	Nonsignificant
	RCL-1 mm	0.444	−0.192	0.192	0.505	Nonsignificant
	Total	0.403	−0.130	0.130	0.525	Nonsignificant
PTN versus PTG	RCL	2.182	0.426	0.426	0.140	Nonsignificant
	RCL-1 mm	0.364	−0.174	0.174	0.546	Nonsignificant
	Total	0.458	0.138	0.138	0.498	Nonsignificant

*P level<0.05 was considered significant. RCL: Root canal length; PTU: ProTaper Universal; PTN: ProTaper Next; PTG: ProTaper Gold

Table 2: Incidence of cracks at different instrumentation lengths



RCL: Root canal length; PTU: ProTaper Universal; PTN: ProTaper Next; PTG: ProTaper Gold

including electropolishing, surface coatings, and heat treatment.[10] However the near equiatomic Ni–Ti alloys explains whether a single-stage transformation or a two-stage transformation will occur according to the thermomechanical treatment applied. Ni–Ti alloys which are rich in Ni generally demonstrate a one-stage transformation from austenitic to martensitic and Austenitic-R-Martensitic following additional heat treatment which leads to finely spread Ni–Ti particles in the matrix.[3] Since PTG is having a two-stage-specific transformation behavior, indicative of the reverse transformation of the alloy which passes through the intermediate R-phase explains the added advantage during the manufacturing process. Thus, PTG showed the least presence of cracks among all the groups [Table 2] owing to the thermomechanical treatment of Ni–Ti alloys which has a strong impact on their transformation behavior and high transition temperature (A_f) explaining the superelasticity of PTG.[11] This transition temperature is determined by adjusting the thermal processing along with the Ni–Ti content of β-phase.[12]

In the present study, significant difference was seen for crack formation between PTG and PTU [Table 1] which can be attributed to the stiffness of the PTU file system. A recent finite element analysis study concluded that stiffer file designs generate higher stress concentration in the apical root dentin, resulting in higher risk of crack initiation.[13] Hence, PTG showed significantly least crack formation than PTU [Table 1] owing to its superelasticity.

In contrast, the tapered files are reported to cause increased stress on canal walls.[14] Hence, in the present study, the taper of the files was kept constant in all experimental groups, i.e., 0.07%. This can be attributed as a reason for no significant difference between PTG-PTN and PTN-PTU. Along with the constant taper, difference in study model can also be considered for the same. Previous studies have evaluated crack formation at 3, 6 and 9 mm of root, but the present study examined only the apical resected portion.[7]

However, PTN having M-Wire technology showed more cracks than PTG [Table 2] because the PTN file system has an offset mass of rotation which generates a mechanical wave of motion analogous to the oscillation noted along a sinusoidal wave. This results in cutting off a bigger envelope of motion as compared to a similar sized file with a symmetrical mass and axis of rotation. Furthermore, PTG has the most recent metallurgical characteristic making it more flexible than PTN.

Moreover, it was also evident that PTN files showed lesser crack formation than PTU [Table 2]. This can be attributed to the incorporation of M-wire technology in PTN imparting increased flexibility compared to the conventional Ni–Ti wire (PTU).[5,6,15] In addition, PTN has off centered rectangular design which generates swaggering motion, decreasing the screw effect, the dangerous taper lock, and torque on any given file by minimizing contact between the file and root dentin,[6] henceforth reducing the crack formation.

Here, PTU showed maximum crack formation which is in correlation to previous studies.[1,4-6,15,16]

Table 1 states that samples instrumented up to RCL showed more cracks than their counterpart instrumented 1 mm short of RCL although there was no significant difference. To maintain the strength and fracture to resistance of the tooth structure, it is necessary to conserve the dentin adjacent to the apical root canal. At RCL, file tips had proximity to the apical root dentin which resulted in more cracks. However file tips reaching RCL-1 mm were left with sufficient amount of dentin adjacent to the file tip resisting the formation of cracks; although cracks were seen in fewer samples.[17] Thus, as the files contact more to the root dentin, forces are generated directly adjacent to it resulting in root dentin defects.

Conclusion

Within the limitations of this *in vitro* study, PTG showed least dentinal damage followed by PTN and PTU owing to its manufacturing advantages and its thermomechanical treatment. The flexibility of these files can be graded as (from most flexible to least flexible) PTG > PTN > PTU. Samples which were instrumented up to RCL showed more cracks than their counterparts which were instrumented 1 mm short of RCL, but the difference was statistically insignificant.

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Conflicts of interest

There are no conflicts of interest.

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