Original Article

Fracture resistance of endodontically treated teeth after instrumentation with different nickel titanium systems

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ABSTRACT

Aim: To compare the vertical root fractures (VRFs) resistance of teeth instrumented with ProTaper Universal, ProTaper Next, HyFlex CM and HERO Shaper nickel titanium (NiTi) rotary systems and obturated with compatible gutta-percha cones using the single-cone technique.

Materials and Methods: The present study was performed in 72 extracted mandibular premolars. After removing the coronal parts of the teeth and determining working length, the roots were mounted in Eppendorf tubes. The samples were divided into five experimental groups, and one control group (n = 12). In Group 1, teeth were instrumented by hand K files; Group 2 ProTaper Universal (PTU); Group 3 HERO Shaper (HS); Group 4 HyFlex CM (HCM); Group 5 ProTaper Next (PTN); and Group 6 (Controls): the root canals were not shaped or filled. After the preparations were completed, roots were obturated with gutta percha. All the mounted samples were subjected to fracture resistance testing.

Statistical Analysis: One-way ANOVA test and *post hoc* Tukey's test at a significance level of $P < 0.05$.

Results: Fracture resistance of hand K file did not differ significantly from, HERO Shaper, HCM, and PTN NiTi rotary files ($P = 0.929$; $P = 0.996$; $P = 1.000$, respectively). PTU showed significantly less fracture resistance than hand K file (0.044). Among all NiTi rotary files, PTN depicted the highest fracture resistance, whereas PTU showed the least fracture resistance with statistically significant difference ($P = 0.048$). However, PTN did not differ significantly from HERO Shaper and HCM regarding fracture resistance.

Conclusion: All rotary files showed similar fracture resistance values to Hand K file group except ProTaper Universal, which demonstrated significantly lower fracture resistance.

Keywords: Microcracks, nickel titanium rotary files, vertical root fracture

INTRODUCTION

One of the main steps in the root canal treatment is mechanical instrumentation to create sufficient space for irrigating agents, intracanal medicaments, and obturating materials.[1] Using stainless steel hand instruments for root canal preparation is generally time-consuming and difficult in curved canals. Nickel titanium (NiTi) alloy due to their increased flexibility and shape memory, potentially allow shaping of narrow, curved root canals without causing aberrations.[2] However, mechanical instrumentation of root canal system with NiTi instruments may result in the development of microcracks, as a result of thinned dentinal walls and increased strain.[3] The strength of endodontically treated teeth may be affected due to several factors such as excessive loss of tooth structure due to caries or trauma, dehydration of dentin, access cavity preparation, instrumentation with rotary files, undesirable effects of

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irrigation solutions, and excessive pressure during filling procedures which predispose a tooth to vertical root fracture (VRF), thereby decreasing the long-term survival.[4,5] Clinically, 10.9%–31% of root canal treated teeth result in the extraction because of VRFs that occur during or after root canal treatment procedure.[6]

As the prevalence of microcracks increases, the risk of VRFs may increase in teeth.[7] VRF associated with endodontically treated teeth is one of the most difficult clinical complications that may occur due to instrument design, kinematics, and mechanical behavior following root canal treatment procedures.[8,9] During shaping, geometric design of various rotary instruments also affects the root stresses.

There are many kinds of NiTi systems, with different production phases (M-wire, R phase, austenite, and martensite), alloys, cutting edges, body taper, tip configuration, and working motion available in the global market.[10] ProTaper Universal files (Dentsply Maillefer, Ballaigues, Switzerland) have multiple tapers of increasing and decreasing size in a single file. Cross section is convex triangular with three-cutting edges.[11] HERO Shaper files (Micromega, Besancon, France), with their pronounced tapers, are designed for the use with the crown-down technique to progressively remove constraints and flare the canal. ProTaper Next (PTN) (Dentsply, Tulsa Dental Specialties) is a 5th-generation file designed such that the center of mass and/or the center of rotation are offset.[11]

HyFlex (Coltene-Whaledent, Allstetten, Switzerland) files are manufactured utilizing a unique process in which the crystallographic phase transitions from austenite to martensite occurs at the room temperature in contrast to conventional NiTi files, making the files extremely flexible and fracture resistant.

Despite the obvious clinical advantages of these techniques over hand instrumentation, the influence of the design of the cutting blades is still controversial and could generate increased friction and stresses within the root canal.[12] Rotary instrumentation requires less time to prepare canals as compared with hand instrumentation but result in significantly more rotations of the instruments inside the canal.[13] This may cause more friction between the files and the canal walls. Kim *et al*. reported a potential relationship between the design of NiTi instruments and the incidence of VRFs.[14] The diameter of the prepared canal is another potential factor that could affect the tendency to VRFs. Excessive taper may result in excessive removal of dentin and weakening of the root.[15] Other factors such as loss or dehydration of dentin and the negative effect of irrigation solutions may enhance the possibility of VRFs.[4] Many studies have confirmed the association between NiTi systems and dentinal microcracks, which may result in VRFs, but there is insufficient information in the literature on the resistance of teeth instrumented with different NiTi systems to VRFs.[16]

Therefore, the aim of the present study was to compare the VRFs resistance of teeth instrumented with ProTaper Universal, ProTaper Next, HyFlex CM, and HERO Shaper NiTi rotary systems and obturated with compatible gutta-percha cones using the single-cone technique.

MATERIALS AND METHODS

Seventy-two extracted mandibular premolar teeth were collected. Teeth were extracted within the previous 3 months for orthodontic reasons from patients. Teeth were thoroughly cleaned using ultrasonic scaler and stored in 0.5% aqueous chloramines for 1 week. All the teeth were then stored in distilled water for not more than 3 months. The samples were examined under a stereomicroscope at × 10 magnification to exclude teeth with open apices, root caries, any craze lines or microcracks. The roots with standardized dimensions and weights were selected to ensure homogeneity.[8] Periapical radiographs were taken by exposing both mesiodistal and buccolingual sides to ensure that the teeth had a single root with a mature apex. Teeth with mesiodistal root curvatures <5° were included (according to the method of Schneider).[17] The coronal parts of the teeth were removed using a diamond-coated disc under water cooling, leaving the root 15 mm in length. The working length of the canals was determined by inserting a size 10-k type file till the root canal terminus and subtracting 1 mm from this measurement.

Mounting

The external root surface of all the samples was covered with a layer of aluminum foil. Seventy-two Eppendorf tubes were taken, their stoppers were separated, and a hole was made in each stopper. The roots were fixed into the stoppers with cyanoacrylate up to the level of the cement enamel junction. They were subsequently placed in Eppendorf tubes filled with self-curing acrylic (DPI® RR Cold Cure, India). After the acrylic had polymerized, the roots along with aluminum foil lining were removed from the tubes, and the aluminum foil was replaced with a layer of additional silicone impression material (GC Flexceed light body, India) to simulate periodontal ligament. Roots were then returned to the tubes. The tubes were then further mounted in acrylic cylinders.

A glide path was prepared manually using size 15 k-type file. The final apical preparation was completed with a size 40 NiTi or stainless steel K file. All NiTi rotary files were used with a torque-controlled endodontic motor (X-Smart; DENTSPLY Maillefer) and each instrument was used in five canals only. The samples were divided into five experimental groups, according to different NiTi rotary systems or hand files used and one control group (n = 12).

Group 1 Hand K file (KF)

Teeth were instrumented by hand K files in a step-back manner. Apical preparation was done up to size 40.

Group 2 ProTaper Universal (PTU)

The root canals were prepared with the PTU system, which was used at 300 rpm and 2 Ncm. An SX file was used as orifice opener followed by S1 and S2 shaping files and F1 (20/0.07), F2 (25/0.08), F3 (30/0.06), and F4 (40/0.06) finishing files which were used at the full WL.

Group 3 HERO Shaper (HS)

Modified crown-down preparation technique was used. The file system was used according to the manufacturers' recommendations and modified to standardize the apical preparation to size 40. Used in the sequence of instruments 40, 0.04 taper (short of working length), 35, 0.04 taper, 30, 0.04 taper, 25, 0.04 taper, and 20, 0.04 taper (till working length). Apical enlargement was done until the 40, 0.04 taper reached the working length. The sequence used was more closely adapted to the crown-down approach. The modification allowed the larger and more tapered files to be used in the coronal and the middle thirds of the canal. All the instruments were used with a light in- and out-pecking motion until resistance was felt, in this case, the smaller instrument in the series was used, and then the sequence was repeated.

Group 4 HyFlex CM (HCM)

The HyFlex files were used in a gentle in- and-out motion with a rotational speed of 500 rpm and 2.5 N-cm torque. The HyFlex files were used in the following sequence: 0.08/#25 (orifice shaper) → 0.04/#20 (apical enlargement/working length) → 0.04/#25 (apical enlargement/working length) → 0.06/#20 (apical finishing/working length) → 30/0.04 → 40/0.04.

Group 5 ProTaper Next (PTN)

The root canals were prepared with the PTN system using a gentle in-and-out motion at 300 rpm and 2 Ncm torque with a torque-controlled endodontic motor. File X1 (17/0.04), X2 (25/0.06), X3 (30/0.06), and X4 files (40/0.06) were used sequentially at the full WL.

Group 6 the root canals were not shaped or filled (control)

During the preparation, all the root canals were irrigated with 2.5% NaOCl solution after each instrument. After instrumentation, a final flush was applied using 5 ml 17% EDTA for 1 min and 5 ml 2.5% NaOCl for 1 min followed by the final rinse with 5 ml distilled water for 1 min. After the preparations were completed, roots prepared with rotary files were filled with their respective gutta-percha systems using the single-cone technique. The single cone was cut at the same level with the cementoenamel junction by using a gutta-percha cutter. While the roots in Group 1 (K file) were obturated using lateral compaction technique. The canals were then sealed with a temporary filling material, and periapical radiographs were taken. The roots were kept in an environment of 100% moisture for 2 weeks. A single operator performed the procedures to eliminate bias.

Preparation for fracture resistance testing

The root samples mounted in acrylic blocks were then placed on the universal testing machine (Instron Corp, Canton, MA, USA). The tip with a diameter of 0.5 mm and conical shape was used. The conical tip was centered over the cut root surface, and a gradually increasing vertical force was exerted (1 mm/min) until fracture. The maximum force required to fracture each sample was recorded in Newton (N).

Statistical analysis

Mean fracture resistance values are presented in Table 1. Data analysis was done using the Statistical Package for the Social Sciences software (SPSS) version 20 (SPSS Inc., Chicago, IL, USA). Data were normally distributed as tested using the Shapiro–Wilk W test (P value was more than 0.05). Therefore, analysis was performed using the parametric test "One-way ANOVA test" (for comparing more than two groups). Level of statistical significance was set at $P < 0.05$. *Post hoc* Tukey's test was used for the pair wise comparison of subgroups.

RESULTS

The fracture resistance of roots instrumented with PTU, HyFlex CM, and HERO Shaper was significantly lower than

Table 1: Fracture resistance values among six groups

Groups	Mean ($n \pm$SD)
Group I (KF)	1060.93±471.89^{b,c}
Group II (PTU)	622.53±102.35^{a}
Group III (HS)	904.78±332.74^{a,c}
Group IV (HCM)	978.55±978.55^{a,c}
Group V (PTN)	1068.65±348.34^{b,c}
Group VI (C)	1502.33±364.33^{b}

Same lowercase superscript letters indicate no statistically significant difference within the column (P<0.05). KF: Hand K File; PTU: ProTaper Universal; HS: Hero Shaper; HCM: Hyflex CM; PTN: ProTaper Next; C: Control that of the uninstrumented control group (P = 0.001, P = 0.012, P = 0.003 respectively) [Table 1]. However, roots instrumented with PTN and hand K files demonstrated similar fracture resistance values with no significant difference compared to the control group (P = 0.096, P = 0.052 respectively). Among different NiTi rotary file systems used, PTU demonstrated the least fracture resistance and Pro Taper Next depicted the highest fracture resistance with statistically significant difference (P = 0.048). When compared with hand K files, all rotary files showed similar fracture resistance values except ProTaper Universal. However, PTU demonstrated significantly lower fracture resistance than that of hand K file group (P = 0.044) and PTN (0.048) system in addition to the control group.

DISCUSSION

Fracture resistance following endodontic treatment is vital both for the restoration and the functioning of the tooth.[8] As early as 1931, it was suggested that root canal treatment was a factor influencing the incidence of VRFs.[18] During root canal preparation, the dentin walls could be excessively thinned, and fracture risk could be increased.[8] VRF occurs most commonly in the buccolingual plane, may be initiated anywhere at or between the apex and the crown, and is responsible for 4.3% of endodontic failures.[19] Contact between NiTi rotary instruments and dentin walls can cause many momentary stress concentrations in dentin[20] inducing dentinal defects during instrumentation and thus VRF risk.[14] The extent of such complications is related to the mechanical behavior of different preparation systems and geometric shape (the tip design, constant or progressive taper, constant or variable pitch) of NiTi rotary instruments.[14]

Craze lines and incomplete cracks are induced during instrumentation of the root canals. When an external force is applied, the craze lines and incomplete cracks in the dentin may become high-stress concentration areas from which the crack may gradually propagate to the root canal surface.[21] VRFs are the end results of the propagation of a crack.[15]

The prepared canal diameter and taper may also influence propensity for VRFs. In general, taper should be sufficient to permit the deep penetration of spreaders or pluggers during filling but should not be excessive to the point where procedural errors occur, and the root is unnecessarily weakened.[22] Holcomb *et al*. remarked that there must be a point at which increased canal width and taper begin to weaken the root.[23] It can be speculated that increasing the taper of the canal preparation by removing more dentine from the canal wall would diminish the structural integrity of the root. Using finite-element analysis, Ricks-Williamson *et al*. found the magnitude of generated radicular stresses to be directly correlated with the simulated canal diameters.[24] Wilcox *et al*. found that root surface craze lines formed on roots where greater percentages of the canal wall were removed.[25] Conversely, it has been reported that no significant correlation exists between fracture load and size of the root, size of the prepared canal, width of the canal walls after instrumentation, and taper of the root or of the canal.[26] In addition, greater flaring allows compaction forces to be delivered more effectively to the apical third of the canal and imparts better stress distribution.[27] Thus, it can be assumed that fracture resistance of endodontically treated teeth is not affected by a single factor, but may be influenced by other variables related to the instruments. Yoldas *et al*. claimed that the tip design of rotary instruments, cross-sectional geometry, constant or variable pitch and taper, and flute form could be related to crack formation.[28] All of the tested instruments in the present study had noncutting tips and a variable pitch. The PTU and HF instruments have a triangular cross-sectional geometry, whereas that of the PTN is rectangular.[28] HS has a triple helix cross-section. In addition, both PTU and PTN instruments have a variable taper design, whereas HF and HERO Shaper have constant tapers.

In the current study, fracture resistance of the roots was least after instrumentation with PTU while the roots prepared with PTN showed the maximum fracture resistance. Kim *et al*., in their finite element analysis study, showed that tapered files cause increased stress on the canal walls.[14] Bier *et al*. stated that the taper of the files could be a contributing factor in dentinal crack formation.[7] PTU files involve the use of SX which has significantly more taper than the other rotary files systems used. Moreover, PTU files are manufactured in austenite phase, whereas PTN files are made of martensite phase. M-Wire introduced in 2007 exhibits greater flexibility than conventionally processed NiTi wire. The elastic moduli of martensite is lower than that of austenite.[29,30] Therefore, martensite NiTi alloy is softer and more ductile than austenite.

HyFlex CM files are also controlled memory (CM) files. CM Wire which was introduced in 2010 is the first thermomechanically treated NiTi endodontic alloy that does not possess superelastic properties at neither room nor body temperature.[31] In contrast to austenitic NiTi files, CM wire instruments do not tend to fully straighten during the preparation of curved root canals. Despite increased flexibility, which is considered to affect cutting efficiency negatively, Hyflex CM instruments have an enhanced cutting efficiency in lateral action compared to electropolished and conventional NiTi instruments.[32]

The HERO Shaper (Micro-Mega, Besancon, France) is a new system that supplements the existing Hero 642 system (Micro-Mega). They both have the same triple helix crosssection, but the helix pitch and helix angle have been modified, whereas the handle has been shortened for improved access. The HERO Shaper helix angle increases from the tip to the shank, and this has been claimed to reduce threading, while the pitch varies according to the taper with are ported increase in efficiency, flexibility, and strength of the instrument.[33] Final taper of 4% (size 40/04) in Hero Shaper system may have contributed to its superior fracture resistance than PTU group which has much more aggressive taper. Similarly in HyFlex instruments canals were prepared till size 40/0.04, which may explain the poor fracture resistance observed in the PTU group, where F4 had 6% taper.[7,34]

Similar to our study, Cicek *et al*. compared the fracture resistance of teeth instrumented with different NiTi rotary systems and reported that the roots instrumented with the PTN were the most resistant to VRF.[35] However, Capar *et al*. reported that instrumentation with self-adjusting file or PTU did not change the fracture strength of roots when compared to uninstrumented control.[8] Capar *et al*. evaluated dentinal crack formation after instrumentation with rotary files and reported that PTN and HyFlex instruments caused fewer dentinal cracks compared with the ProTaper Universal instruments.[36] Similarly, Cicek *et al*. also reported that PTN system caused slightly fewer microcracks than the PROTAPER PTU.[37]

Out of all NiTi rotary systems used in the study, PTN files demonstrated the highest fracture resistance. The design of the file could affect the shaping forces on root dentin.[38] The forces generated during instrumentation have been linked to an increased risk of root fracture.[14] The off-centered rectangular design of the PTN instrument may have contributed to the higher fracture resistance observed in this study. This design generates a swaggering motion, which decreases the screw effect, dangerous taper lock, and torque on any given file by minimizing the contact between the file and the dentin.[39] Previous studies reported that endodontic instruments manufactured with M-wire alloy and CM NiTi wire have more flexibility than those made from conventional NiTi wire.[30,32] The relatively high flexibility of the PTN and HyFlex (manufactured with M-wire alloy and CM NiTi wire) instruments may have contributed to their better fracture resistance in this study than the PTU group.

Garg *et al*., Liu *et al*., Shori *et al*., and Ustun *et al*. reported more dentinal cracks/defects with NiTi rotary files as compared to H and K files.[34,40-42] Similarly, in our study also, hand K file treated group depicted higher fracture resistance value than the groups instrumented with NiTi rotary files except PTN.

CONCLUSION

Amongst all NiTi rotary files, PTN depicted the highest fracture resistance, whereas PTU showed the least fracture resistance with statistically significant difference. However, PTN did not differ significantly from HERO Shaper and HyFlex CM regarding fracture resistance. Fracture resistance of Hand K file did not differ significantly from PTN Next, HERO Shaper and HyFlex CM NiTi rotary files. On the other hand, PTU showed significantly less fracture resistance than Hand K file.

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Conflicts of interest

There are no conflicts of interest.

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