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Research Article

Comparison of Dentinal Microcrack Formation during Root Canal Preparation by Niti Rotary Instruments and the Self-Adjusting File - An *In Vitro* Study

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Abstract

Introduction

Techniques for biomechanical preparation of the root canal employ various methods like use of hand files, rotary endodontic files, sonic and ultrasonic preparation among others. Rotary root canal instrumentation has the potential to induce dentinal damage and to generate cracks on the apical surface. Self-Adjusting File (SAF) has a novel design with a compressible NiTi lattice framework and provision for continuous irrigation through the hollow core.

Aim: The purpose of the present study is to compare the dentinal microcrack formation with three different NiTi rotary files (Pro Taper Universal, Heroshaper, Mtwo) and the SAF.

Materials and Method: 75 mandibular first molars were selected. Teeth were decoronated and distal roots of all teeth were removed by using diamond coated bur at high speed with water cooling, leaving mesial roots approximately 11 mm in length. Canal patency was established with a #10 K-File in both mesiobuccal and mesiolingual canals. Group I - Hand K-files (HF), Group 2 - ProTaper Universal (PT), Group 3 - Heroshaper (HS), Group 4 – Mtwo, Group 5 – SAF. Biomechanical preparation of mesial roots was completed. Root sections perpendicular to the long axis were done at 3, 6, and 9 mm from the apex. Digital images of each section were taken using the operating microscope at 24x magnification. Statistical analysis was done using Chi-square and Fisher exact tests and results were tabulated.

Results: Group 5 (SAF) showed significantly less cracks. ($p < 0.05$) when compared to group 2 (PT), group 3 (HS), group 4 (Mtwo). However, there was no statistically significant difference in the incidence of cracks between group 2 (PT), group 3 (HS) and group 4 (Mtwo) ($p > 0.05$).

Conclusion: All the rotary files used had comparable dentin microcrack formation. The SAF had significantly lesser incidence of crack formation than the rotary files.

Keywords: Dentin Microcrack; Heroshaper; Mtwo; Pro Taper Universal; Self-Adjusting File

Introduction

Biomechanical preparation of root canals is one of the main steps in endodontic treatment and is vital for its success. It involves removal of organic debris like necrotic pulp from the root canal system, along with infected root dentine. It aims to prepare the canal space to facilitate disinfection by irrigants and medicaments. Techniques for biomechanical preparation of the root canal differ in accordance with clinical observation and research discoveries. These include manual preparation, automated root canal preparation, sonic and ultrasonic preparation, use of laser systems and non-instrumentation technique [1].

Stainless steel instruments were used for the shaping of root canals earlier. NiTi instruments introduced later are more flexible and have 'shape memory' or the ability to come back to their original shape after flexure. These files use a 360 deg complete rotation with special gear reduction handpieces at low speed [2]. There are three major phases in these NiTi alloys. The austenite phase has a complex body-centered cubic structure and exists at higher temperatures and lower stresses. In contrast, the martensite phase exists at lower temperatures and higher stresses and has a monoclinic crystal structure. Transformation between austenite and martensite occurs by a twinning process at the atomic level, and the reversibility of this twinning is the origin of shape memory. The R-phase is an intermediate phase that can form during the forward and reverse transformation between austenite and martensite phases [2]. In 2007, manufacturers found that using alternate heating and cooling methods reduces cyclic fatigue and improves safety with rotary NiTi instruments. A non-grinding process and special-surface conditioning called R-phase heat treatment [2] was introduced by Sybron Dental. Here, the phase-transition point between martensite and austenite is identified and used to produce metals with more clinically advantageous properties. M-wire technology, a novel thermal process introduced by Dentsply (Tulsa Dental, OK) resulted in files with better resistance to cyclic fatigue and improved mechanical properties compared to conventional NiTi alloys [3].

There have been various single file systems like Wave One and Reciprocal (reciprocating motion), One Shape (rotary motion) and the Self Adjusting File. ReDent-Nova introduced the Self Adjusting File (SAF), a NiTi lattice framework with a hollow core designed to be compressible [4].

Rotary root canal instrumentation has the potential to induce dentinal damage and to generate cracks on the dentin [5]. Craze lines, complete and incomplete cracks in root canal dentin may develop into vertical root fracture [6]. Vertical root fracture is one of the complications of root canal treatment, having a poor prognosis. Over time, occlusal forces on the endodontically treated tooth can lead to catastrophic root fractures due to weakening effect of dentin microcracks [7].

In this study, the instruments used are Heroshapers, Protaper Universal files, Mtwo rotary files and the Self Adjusting File. Heroshaper files have a triple helix cutting edge with a safe ended tip with variation in the helical angle from the tip to the shank. Sizes of these files range from #20-45 having a choice of tapers (.02, .04, and .06).

The ProTaper Universal (Dentsply Tulsa Dental, Tulsa, OK) system comprises of a unique design element with varying tapers along the instrument's long axes. The system has three shaping and three finishing files. Shaping files have coronally increased tapers and finishing files have tapers which are more apically. The cross section is triangular resulting in a reduction of the contact area between the file and the dentin. The greater cutting efficiency inherent in this design has been safely improved by balancing the pitch and helix angle, preventing the instruments from inadvertently threading into the canal [8].

The Mtwo endodontic instruments (VDW Dentsply, Munich, Germany) have an S shaped cross-section and two cutting blades. The rake angle is very effective with enhanced cutting efficiency and it has a safe ended tip [9].

Self-adjusting File (SAF) technology provides a continuous flow of irrigant throughout the procedure through its hollow centre which has no central metal core. The file takes the shape of the canal after insertion, i.e. compressing in narrow canals and expanding in wider canals, thus adapting itself to the canal shape [10].

The purpose of this study was to compare the dentinal microcrack formation of three different NiTi rotary files (ProTaper, Heroshaper, Mtwo) with the SAF. The null hypothesis was that all the NiTi rotary files and the SAF have similar dentin microcrack formation.

Material and Methods

Seventy-seven extracted mandibular first molars were collected from the Dept of Oral Surgery and stored in purified filtered water. Inclusion criteria was that the patients should be in the age group of 30 to 50 years and the teeth should have straight roots or roots with moderate curvature Teeth with root caries, pre-existing cracks in the root, fused roots, roots with fluting and grooves and those with severe curvature (more than 30-degree curvature) are excluded from the study.

The teeth were decoronated and distal roots of all teeth were removed by using a high-speed diamond coated abrasive point with water cooling. All mesial roots were inspected with transmitted light and operating microscope (Moller Wedel, Germany) under 12x magnifications to detect any preexisting craze lines or cracks. Canal patency was established with a #10 K-File (Dentsply Maillefer, Switzerland) in the mesial root for both mesiobuccal and mesiolingual canals. A #15 K file (Mani, Matsutain Seisakusho Co., Tochigi-Ken, Japan) was introduced into the canal till the tip of the instrument was visible at the apical foramen. This length was measured, and the working length was kept at 1mm short of this length. The outer cemental surface of the mesial roots was covered with light body silicon impression material (Dentsply Caulk, Milford, DE, USA) to simulate periodontal ligament space. Cold cure acrylic blocks (DPI RR, Mumbai, India) were prepared and the roots were embedded. Controls were taken as two unprepared roots, and the remaining 75 teeth were divided into 5 groups (n = 15 each).

- Group 1 – Instrumentation done with Hand K-files (HF)
- Group 2 - Instrumentation done with ProTaper (PT).
- Group 3 - Instrumentation done with Heroshaper (HS).
- Group 4 - Instrumentation done with Mtwo.
- Group 5 - Instrumentation done with the SAF system.

In the hand file (HF) group, K files were used to prepare the canals to an apical file size #40. In the Heroshaper (Micro-Mega, France), Mtwo (VDW Dentsply, USA) and ProTaper (Dentsply Maillefer) groups, canal preparation was performed with rotary files using an endo motor by a single operator. Calibration of the technique to be followed by the operator was done initially. To prevent operator fatigue, break was taken after every 10th canal preparation. Files were changed after every second tooth.

In the HS group, HS files were used in crown-down pressure less technique up to file 25 (6%) at 300 rpm. In the PT group, canal preparation was done at 300 rpm till F2 (#25, 0.06 taper). Mtwo rotary instruments were used, with a sequence of 10/.04, 15/.05, 20/.06, 25/.06. In the SAF group, canals were initially enlarged till ISO #25 apical size with a K-file. The SAF 1.5-mm file, which corresponds to an apical size of 20, was used with an amplitude of 0.4 mm and 5,000 vibrations per minute. Pecking motion was used on the SAF for a total of 4 minutes in each canal. Continuous irrigation with 2.5% sodium hypochlorite was done at a rate of 3 ml/min.

In the HF, HS, Mtwo and PT groups, irrigation was performed with 2.5% sodium hypochlorite (Prime Dental Products, Mumbai, India) between each instrument during the preparations of root canals. Totally, 12 ml of sodium hypochlorite was used in each canal.

Sectioning and Microscopic Examination

All roots were sectioned perpendicular to the long axis at 3, 6, and 9 mm from the apex using a diamond coated disc in a straight handpiece with continuous water cooling. A new disc is taken after every tenth tooth. Digital images of each section were taken using the operating microscope at 24x magnification.

No defect: Root dentin without craze lines or microcracks both on the external surface of the root and at the internal surface of the root canal wall.

Defect: Lines, microcracks, or fractures seen in root dentin.

With three sections in each specimen, a total of 45 sections were examined in each group.

The Chi-square and Fisher exact tests were used for statistical analysis of differences between groups. The results were given as the number and percentage of roots of each group and tabulated.

Results

There was significantly more crack formation in Groups 2, 3, 4 at all levels as compared to Groups 1 and 5. Amongst the sections at 3, 6 and 9 mm from apex, greater number of cracks were seen at 9 mm for Groups 2, 3, 5. Group 4 had more cracks in the middle third (Table 1).

File groups	3 mm	6 mm	9 mm	Total sections with defects
Control group n = 2	0	0	0	0
Group 1 HF (n = 15)	0/15	0/15	0/15	0/45
Group 2 PT (n = 15)	2/15 13.33%	2/15 13.33%	13/15 86.66%	17/45 37.77%
Group 3 HS (n = 15)	3/15 20%	6/15 40%	10/15 66.66%	19/45 42.22%
Group 4 Mtwo (n = 15)	1/15 6.66%	9/15 60%	7/15 46.66%	17/45 37.77%
Group 5 SAF (n = 15)	0/15 -	0/15 -	2/15 13.33%	2/45 4.44%

Table 1: Crack formation at different levels

Group 1 (HF) along with the control group showed no cracks and had statistically significant difference ($p < 0.05$) when compared to all other groups except group 5 (SAF). There was no difference between group 1 (HF) and group 5 (SAF) ($p = 0.48$).

In group 2 (PT), there was no difference in the incidence of cracks at 3mm and 6 mm. However, there were significantly higher cracks at 9 mm ($p = 0.00007$) (Figure 1a-1c).

Figure 1a,b and c: Protaper group – Section with Cracks at 3mm, 6mm and 9mm

In group 3 (HS), there were significantly higher cracks at 9mm compared with cracks at 3 mm ($p = 0.013$). However, there was no statistically significant difference in the occurrence of cracks at 3 mm and 6 mm (Figure 2a-2c). There was no difference in crack formation at 6mm and 9mm.

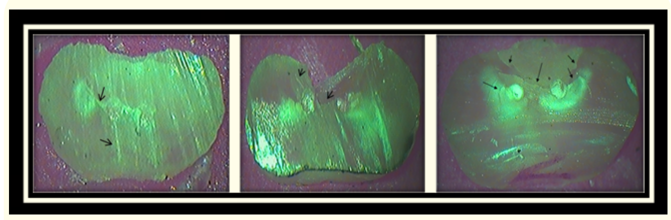

Figure 2a,b and c: Heroshaper group- Section with Cracks at 3mm, 6mm and 9mm

In group 4 (Mtwo) the results for incidence of cracks at different levels was similar to group 3 (HS). There were significantly higher cracks at 9 mm compared to at 3 mm ($p = 0.018$). However, there was no statistically significant difference in the occurrence of cracks at 3mm and 6mm. There was no difference in crack formation at 6 mm and 9 mm (Figure 3a-3c).

Figure 3a,b and c: Mtwo group – Section with Cracks at 3mm, 6mm and 9mm respectively

Group 5 (SAF) showed significantly less cracks. ($p < 0.05$) when compared to group 2 (PT), group 3 (HS), group 4 (Mtwo). However, there was no statistically significant difference in the incidence of cracks between group 2 (PT), group 3 (HS) and group 4 (Mtwo) ($p > 0.05$)

Discussion

The microstructure of dentin suggests a hierarchical approach to the understanding of its mechanical properties. At the smallest length, scales are the constituent materials: a carbonated nanocrystalline apatite mineral phase (approximately 50% by volume) and a felt-work of type I collagen fibrils. The collagen fibrils, approximately 30% by volume, are roughly 50 - 100 nm in diameter; they are randomly oriented in a plane perpendicular to the direction of dentin formation [11]. The mineral occupies two sites within this collagen scaffold: intrafibrillar (inside the periodically spaced gap zones in the collagen fibril) and extrafibrillar (in the interstices between the fibrils). The partitioning between these two sites is uncertain, although it is believed that between 70 and 75% of the mineral may be extrafibrillar [11]. Dentin can be modeled as a continuous fiber-reinforced composite, with the intertubular dentin forming the matrix and the tubule lumens with their associated cuffs of peritubular dentin forming the cylindrical fiber reinforcement [11].

The elastic properties of dentin are of paramount importance in all discussions of tooth strength. Indentation and sonic measurements of the Young's modulus of hydrated dentin gives its magnitude between 18 and 25 GPa. Values of compressive strength range from 275 to 300 MPa [11]. Disparity in values of the shear strength could be attributed to tubule orientation and location within the tooth. The lowest values of lap shear strength were obtained in less mature dentin nearer the pulp, with the tubules oriented parallel to the shear plane (54 MPa). The highest values were obtained in mature cuspal dentin with the shear plane perpendicular to the tubules (92 MPa) [12]. In the absence of intrinsic flaws, it appears that fatigue failure will not occur in human teeth. However, the nature of tensile failure indicates that there is an inherent population of preexisting flaws in normal dentin [12].

Stainless steel hand files have an inherent stiffness that increases with increasing instrument size, causing high lateral force, especially in curved canals. These forces try to bring the instrument back to its original shape resulting in an increase in the amount of dentin removed. The forces are more seen at the instrument tip. This instrument's stiffness straightens the canal and its effects are seen in the apical, middle and coronal third [13].

With NiTi files, more dentin removal occurs at the inner curve of the canal and the root apex due to the action of a lever arm and fulcrum. NiTi rotary files have a reaming action resulting in reduced straightening of the canal. Due to the crown down pressureless technique used in this study, less debris was extruded resulting in decreased incidence of postoperative inflammation and pain [13].

Protaper files have tapers which are not constant over the length of its cutting blades. During use, this progressively tapered design helps in improving flexibility and cutting efficiency. These files have helical angle and pitch over their cutting blades which vary and reduces the potential of an instrument from inadvertently screwing into the canal [13].

Flutes of the Heroshaper files have pitch distances which are progressive and a noncutting tip. The blade has a triple helix cutting edge. These files have constant taper, positive rake angle with three cutting edges [14]. Heroshapers are available in 4 percent and 6 percent with tip sizes 0.20, 0.25, 0.30 available with both the tapers. The files are used in a sequence depending on the level of difficulty. In this study, the Red sequence is used for intermediate cases with No 25-6% to two third of the working length followed by 25-4%, 30-4% to the working length. Yellow is used for complex cases and Blue sequence is used for the easy cases.

The Mtwo system has four instruments with tip sizes from #10 to #25, and tapers ranging from .04 to .06. These instruments are also produced with an extended cutting portion of 21 mm as well as the conventional 16 mm cutting part, allowing the instrument to cut in the coronal portion of the canals, on the cavity access walls, where dentin interferences are often located. The rake angle is one of the most effective measured in NiTi rotary instruments, enhancing the cutting efficiency of this instrument. The tip is non-cutting [4]. The helical angle is defined as the angle formed by the instrument's cutting surface and the dentin wall observed in longitudinal section. For bigger sizes, the number of flutes is less for the instrument length and more for the smaller sizes. The flutes are deeper moving from the tip to the handle; increasing the capacity to remove debris coronally [4].

The SAF system has a hollow core NiTi file operated with a vibrating in-and-out motion with continuous flow of fresh irrigant during biomechanical preparation [15]. It has a thin NiTi lattice, with an asymmetrical tapered tip. The thickness of the lattice is ~100 micron giving the file a bucco-lingual expansion as much as 2.4 mm. The asymmetrical tip of the SAF is particularly helpful while cleaning curvatures in the canal [15].

The special handpiece head, RDT3 converts the rotation of the motor into an in-and-out vibrating motion of the file. It has vibratory motion of 5000/min with amplitude of 0.4 mm. The RDT3 has a special clutch element that has a rotator motion out of the canal and vibratory up and down motion when the file is inserted into the canal. This ensures that every time the file is taken out an inserted, a different part of the file comes in contact with the canal wall [15]. The surface of the SAF is rough with 3 μm elevations present on every part of the lattice framework. The file when in the canal, generates a pressure all around on the canal walls. Gentle removal of the dentin surface is done resulting in an uniformly prepared canal wall [15].

In a study by Lui R., *et al.* [16], SAF file systems caused less root cracks than the ProTaper Universal and OneShape files. Hin E., *et al.* [6] reported that SAF has a tendency to cause lesser number of dentinal cracks as compared with other files. The findings of this study are in agreement with Bier., *et al.* [17] in that they did not observe any defect in the HF group.

Bier., *et al.* [17] stated that increasing the taper of the files leading to excessive removal of root dentin is one of the factors for crack formation in root dentin. PT have more taper (0.07, 0.08, and 0.09, respectively) than the HSs (0.04 and 0.06). This explains the reason for the formation of more cracks in the PT group, as reported earlier by Bier., *et al.* [17], Liu., *et al.*[18] and Barreto., *et al.* [19]. Furthermore, increased stiffness with less flexibility of the HS may have contributed to greater number of defects in HS group in the present study.

Arbab-Chirani., *et al*. were of the opinion that progressive taper of files in PTU system makes the file very stiff. This reason may be the root cause of increased dentinal defects created with this system in the present study. On the other hand, Mtwo files are up to three times more flexible than PTU [20]. In the results seen in table 1, both PTU and Mtwo files showed similar amount of dentin cracks. This could be in part be due to the same degree of taper that was chosen in both systems.

In the present study, the occurrence of microcrack formations in the coronal third was more than that in the middle third and in the apical third. Also, microcrack formation was lesser in the apical third than in the middle third. This was in accordance with Versluis., *et al* [21]. All rotary systems used in the study have a similar apical taper design (tip diameter of 0.25 mm) and this could be the reason for the similar results in apical third. Lesser incidence of microcrack formation in apical third could be associated with the size and taper of the master apical file and their non-cutting tip design. The greater number of cracks in the coronal aspect with PT, HS and Mtwo in this study can be attributed to the greater taper and larger diameter of the files. Hand K files #25 (2% taper) have a diameter at D16 of 0.57 mm whereas files with similar apical diameters in HS and Mtwo files (constant 6% taper) have a diameter at D16 equal to 1.1 mm while PT (variable taper) correspond to 1.2 mm. This would lead to more aggressive removal of dentin in the coronal aspect contributing to greater cracks in the coronal aspect than the middle and apical aspects.

Conclusion

There was no statistically significant difference ($p > 0.05$) in the incidence of microcrack formation in the radicular dentin between the NiTi rotary file systems, Protaper Universal, Heroshapers and Mtwo. The incidence of cracks was greater in the coronal and middle thirds as compared to the apical third in the three NiTi rotary systems. The Self Adjusting file system caused significantly lesser incidence of dentinal microcrack formation ($p < 0.05$) when compared to the three NiTi rotary systems, with no cracks in the apical and middle third and minimal cracks in the coronal third.

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