Comparative evaluation of effect of different manufacturing process in different torque settings on root dentine crack formation using Micro - CT: An in vitro study

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Comparative evaluation of effect of different manufacturing process in different torque settings on root dentine crack formation using Micro - CT: An in vitro study

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ABSTRACT

Objectives. To compare the effect of different manufacturing processes of NiTi rotary instruments with two different torque levels on the cracks formation in root dentin using Micro-CT.

Materials and Methods. Forty mandibular single rooted premolars were selected for the study. Samples were randomly divided into four groups (n-10) with two subgroups(n-5) each. **Group 1(A)**-(PTU-HT), **Group 1(B)-(**PTU-LT), **Group 2(A)**-(PTN-HT), **Group 2(B)-(**PTN-LT), **Group 3(A)-(**HYF-HT), **Group 3(B)-(**HYF-LT), **Group 4(A)-(**TF-HT), **Group 4(B)-(**TF-LT). Pre-operative Micro-CT scanning was done. Instrumentation was done in high and low torque based on the rotary instruments. The samples were subjected to Post-operative Micro-CT analysis. Preoperative and post-operative Micro-CT images were superimposed by automatic superimposition process with Seg 3D v.2.1.4 software to detect the presence of dentinal cracks. Based on the images, samples were divided into specimens with cracks and without cracks. Statistical analysis was done with Mann-Whitney U test with p-value <0.05 regarded to be significant.

Outcomes. High torque Group1(A)-(PTU-HT) showed more cracks compared to Group 4(A)-(TF-HT),2(A)-(PTN-HT) and 3(A)-(HYF-HT). In low torque group only one sample in Group 1(B)-(PTU-HT) showed the presence of crack compared to no cracks in other groups. Statistically no difference was found between the groups.

Conclusion. Given the limitations of this study, it can be determined that the manufacturing process and the torque settings could play a major role in dentinal crack formation. Nevertheless, no statistical significance were found between the tested groups.

Key words: Dentinal Cracks, Micro-CT, High Torque, Low Torque, NiTi Rotary Instruments

Abbreviations. Protaper Universal High Torque - PTU HT, Protaper Universal Low Torque - PTU LT, Protaper Next High Torque - PTN HT, Protaper Next Low Torque - PTN, Hyflex CM High Torque HYF HT, Hyflex CM Low Torque - HYF LT, Twisted files High torque - TF HT, Twisted files Low Torque - TF LT.

Introduction

Effective endodontic therapy requires the elimination and debridement of all microorganisms within the root canal system, preventing reinfection [1]. Previously, stainless steel files were utilised for root canal instrumentation; however, it was observed that these instruments caused canal abnormalities such as transportation, ledge formation, and zipping during canal preparation [2]. The advent of nickel-titanium rotary files, which are more flexible with superior cutting ability, results in more fast and centred root canal shaping with fewer procedural errors, thus overcoming the limitations of stainless steel files [3].

Despite NiTi files possessing various advantages over stainless steel files, instrument separation seems to be the primary disadvantage of NiTi files [4]. In addition to instrument separation, root canal treatment with NiTi files may induce dentinal stress and, as a result, dentinal cracks, which might evolve into vertical root fractures under functional loading[5]. Several studies have examined the relationship between dentinal microcracks and motor-driven nickel-titanium files and have established that regardless of the motion of the file, dentinal microcracks are created following instrumentation [6-9].

Several generations NiTi instruments are available based on their designs and manufacturing process such as Conventional NiTi (Protaper Universal, Dentsply Maillefer, Ballaigues, Switzerland), R-phase technology (Twisted files, SybronEndo, Orange, CA the USA), Controlled memory files(Hyflex CM, ColteneWhaledent, Allstetten, Switzerland) and M-wire technology(Protaper next, Dentsply Maillefer, Ballaigues, Switzerland). Kim et al suggested that the design of the instrument may increase the dentinal defects and canal deviations during instrumentation, which is in turn associated with the increased susceptibility to vertical root fractures [10]. Yoldas et al, confirmed the finding and concluded that tip of the rotary instrument, cross-sectional geometry and variable pitch taper could be related to the formation of dentinal defects [5]. However, the relationship between different NiTi instruments manufacturing processes and root dentin crack formation have not been tested.

Dane et al compared the incidence of dentinal cracks induced by the ProTaper universal system at low and high torque settings. They concluded that the system caused a greater number of cracks at higher torque values compared to lower torque values [11].

Though previous studies have reported that preparation of root canals with rotary instruments causes dentinal microcracks, the methodology used for detecting cracks was based on sectioning of roots, and observation by stereomicroscope or scanning electron microscope [11]. Additionally, samples were optically assessed with or without the aid of surgical loops, microscopes, dyes, transillumination for the presence of dentinal cracks [12,13].

Although several investigations have reported the incidence of crack formation in the Protaper Universal system and other rotary systems, the destructive nature of these experiments is regarded as the most significant limitation when assessing dentin cracks [11]. Although improvements have been demonstrated in detecting and classifying dentinal cracks using enhanced magnification and transillumination, the optical methods lack the ability to evaluate the severity/depth of subsurface dentinal cracks [10,12].

To overcome these limitations Micro-computed tomography can be used in the detection of dentinal microcracks. Micro-computed tomography (microCT) imaging is an extremely precise and nondestructive method, which facilitates the creation of three-dimensional (3D) images with extremely high resolution [14]. This non-destructive imaging technique can generate 3D images and 2D maps with voxels approaching 1μm in size, resulting in an enhanced resolution [15].

Literature search revealed that presently, there is a lack of data determining the influence of various manufacturing processes of rotary instruments with variable torque levels on dentinal crack formation using Micro-CT. Thus, the purpose of our research was to compare the impact of different manufacturing processes of NiTi rotary instruments with two different torque settings on formation of dentinal cracks using Micro-CT. Null hypothesis is that there will no difference in root dentin crack formation with use of rotary instruments with different manufacturing processes at different torque settings.

Materials and Methods:

Collection of samples:

The ethical review board at SRM Medical College Hospital and Research Centre, SRM Institute of science and Technology, provided approval for this study (IEC no:1082/IEC/2016). 40 single rooted mandibular permanent premolars with single canal and mature apices were selected for the study. The study excludes samples exhibiting cracks/defects, carious lesions, internal or external resorption, developmental anomalies, multiple roots and canals. Radiographs were obtained at the buccolingual and mesiodistal angles using Radiovisiography (RVG, Satelec Aceton Sopix 2) to validate the root canal morphology and to ensure that the teeth had a single straight canal [11].

Sample preparation:

All samples were prepared and instrumented by a single operator. All samples were decoronated with a diamond carbonated disc (Ray foster BX43) to acquire a standardised root length measurement of 16mm. The specimens were then examined using a stereomicroscope (OLYMPUS BX43) with 25 x magnification to exclude the external cracks /defect produced during decoronation. The roots were then wrapped with an aluminium foil and embedded in a clear acrylic resin blocks. Subsequently, the roots were removed from the acrylic resin to remove the aluminium foil and a light body silicone-based material (Dentsply Caulk- Aquasil LV) was utilised to mimic the periodontal ligament by covering the area left by the foil. The apical 3mm of the roots have been exposed and submerged in water to prevent the sample from dehydration [11].

Preoperative Micro-CT assessment:

To assess the presence of preexisting cracks, pre-operative micro-CT imaging (Skyscan 1172; Bruker micro-CT, Belgium) was performed at 70kV and 114μA, and image reconstruction was performed with NRecon 1.6.3 software (Bruker micro-CT, Belgium)[14].

Root canal Preparation:

The working length was established with a size 10 K-file(MANI, Inc Tochigi, Japan), by passing the file beyond the apex and then subtracting 0.5mm from the actual length [16]. Upon randomly dividing the samples into four groups of two subgroups each (Table 1), rotary instrumentation was performed using two separate torque settings (High & low torque) and speed settings (X-smart plus Endomotor Dentsply sirona, USA) per the manufacturers' instructions (Table 1). A highly experienced endodontist with over seven years of professional practise performed the instrumentation of the root canals. During root canal instrumentation, 17% gel form of EDTA (RC help, Prime dental Pvt. ltd., India) was employed as a lubricant, canals were intermittently irrigated with 5.25% Sodium hypochlorite solution (Prime dental Pvt. ltd., India) and the debris was cleared with 5 ml of normal saline (Otsuka Pvt Ltd, India) [11].

Postoperative MicroCT Imagining:

Post instrumentation, all the samples were subjected to post- operative Micro-CT scan. Post-operative images were reconstructed with NRecon1.6.3n software (Bruker micro-CT, Belgium). The Pre-operative and post-operative images of the specimens were superimposed by an automatic superimposition process with Seg3D v.2.1.4 software to detect the presence of dentinal cracks [14].

Two blinded endodontists who were not part of the study evaluated the presence of cracks in the specimens. Based on the images, the samples were divided into specimens with crack and without crack. The results were then tabulated based on the findings and statistical analysis was performed [11].

RESULTS

Crack presence (Independent) is categorical in nature and will not adhere to a normal distribution. Hence, non-parametric Mann-Whitney U test was utilised to examine the presence of fractures between groups (intra-group) (Independent). The purpose of this test is to determine a value randomly selected from one group is either less than or greater than a value randomly selected from another group.

Out of the forty samples tested, nine samples showed the presence of cracks (Table 2, Chart 1). In High torque group, out of the twenty samples tested, eight samples showed the presence of cracks.In low torque group, out of the twenty samples tested only one sample showed the presence of cracks. (Table 3) shows the Intragroup comparison between the High torque and Low torque groups.

Discussion

The objective of cleaning and shaping is to eliminate all necrotic tissues from the root canal system, hence allowing for three-dimensional obturation [17]. Despite the fact that Nickel titanium rotary instruments are preferable to conventional stainless steel files due to their greater flexibility and superior cutting ability, they have a tendency to induce dentinal cracks. These cracks and fractures occur when the tensile stress in the root canal wall exceeds the tensile stress in the root dentin [11]. These dentinal cracks have the potential to progress into vertical root fractures when subjected to physiological loading [5].

The present study assessed the occurrence of cracks in dentin during the process of canal preparation using two different torque settings on different instrument manufacturing process using micro CT. Micro-CT was used as an imaging tool to evaluate the presence of dentinal cracks because it is more accurate and non-destructive method than those previously used to detect dentinal cracks. In addition, it permits quantitative and qualitative evaluation of the root canal before and after endodontic procedures [18]. Although several investigations have reported the occurrence of crack formation using rotary systems, the methodology employed by these studies involved sectioning, which could potentially damage the samples owing to the destructive nature of the procedure [15].

Torque is a parameter that has a significant effect on instrument locking and deformation in the canal. The level of torque produced by rotating instruments through the process of canal instrumentation is dependent on many variables, including the extent of contact between the instrument and the walls of the canal, the force exerted at the apical region, the diameter of the instrument, and the volume of the canal prior to the procedure [19]. In general, instruments with higher torque settings are more active, resulting in a greater incidence of instrument locking, instrument separation, and instrument deformation. In the meanwhile, instruments with a low torque will have a decreased cutting efficiency, making its progression through the canal difficult [20].

Although manufacturers set different speed and torque settings for different instruments and manufacturing designs, a greater torque is typically required to rotate the instrument and its fragile tip to reach the apical terminus with the least amount of resistance and less of auto reverse motion [6,9]. Dane et al, studied the effects of ProTaper Universal files with various torque settings on dentinal crack formation during instrumentation and concluded that higher torque settings tend to produce more cracks [11].

According to the findings of the present study, among the forty samples tested nine samples showed the presence of cracks. Four of the five samples tested (Table 3) from Group 1(A) PTU-HT (figure A) had cracks in the dentin, but only one sample from Group 1(B) PTU-LT (figure B) had cracks in the dentin. But statistically, there was no difference between the two groups. This was also comparable with a previous study by Dane et al., which observed that a protaper universal file with higher torque settings caused more cracks in the dentin than a protaper universal file with lower torque settings [11]. The reason for the formation of a greater number of cracks in higher torque levels may be associated to the significant amount of stress created on the root dentin during instrumentation [6].

Comparing Group 2(A)-PTN-HT to Group 2(B)-PTN-LT (Table 3), Group 2(A)-PTN-HT comprised one sample with a crack (figure C), while Group 2(B) featured none; however, no statistical significance was seen between the two groups. Protaper next manufactured with M-wire technology is more flexible, and employs a single-length preparation technique, which could result in fewer cracks. Additionally, to its greater flexibility, the instrument's off-centre rectangular design generates a swaggering motion that creates an asymmetric contact that reduces fastening effects, taper lock, and torque. This reduces the extent to which the instrument comes contact with the canal wall, resulting in different stress patterns [21,22].

Comparing Group 3(A)-HYF-HT and Group 3(B)-HYF-LT(Table 3), none of the samples exhibited cracks (figure D). In the present study, the absence of cracks in the group of Hyflex files is attributable to the instrument's tapered design and relatively high flexibility due to control memory, which could result in decreased contact with the canal wall. In addition, hyflex files possess a faster cutting speed, resulting in a higher cutting efficiency and reduced cracks [23]. This was in contrast with the previous study by capar et al, which reported the presence of fewer cracks in in protaper and Hyflex files, which could be due to the methodology used for testing the crack propagation in the previous study [18,23].

Comparing Group 4(A)-TF-HT to Group 4(B)-TF-LT (Table 3), three samples from the high torque group featured cracks (figure E), whereas none of the samples from the group with low torque contained cracks. In spite of the fact that a higher number of cracks were noted in the high torque group than in the low torque, the two groups were not statistically different from each other. Twisted files are manufactured by heat treatment, twisting the metals, and special surface conditioning to increase flexibility and cyclic fatigue resistance [24]. In the present study, the use of twisted files in high torque settings resulted in the formation of cracks. This might be a result of the instrument's design, which increases stress at the cutting edges during instrumentation. In addition to the cross-sectional geometry, Twisted files use two instruments, with the larger taper/first instrument taken to the coronal one-third or two-thirds of the canal, and the second or third instrument reaching the apex. In addition, constant taper of the instrument removes a larger amount of dentin from the canal's middle and apical thirds, which explains the reason for crack formation in twisted files when used in higher torque settings.

In the current study, Instrumentation using high torque settings with Protaper universal, protaper next, and twisted files revealed the presence of cracks in 45.5%, 11.0%, and 33.3% of samples, respectively. The crack propagation was also evaluated with low torque settings using Protaper universal, Protaper next, Hyflex, and twisted files.The incidence of crack was determined to be 11% in the Protaper universal group (PTU-LT) and 0% in the other groups. However, Hyflex files when used in high torque settings and low torque settings did not produce any cracks. The findings of the protaper universal group were in accordance with a previous study by Capar et al., which demonstrated that protaper universal had more cracks

[23]. Similar results were seen in the twisted file group, which exhibited 40% dentinal cracks [5]. However, the results for the protaper next and hyflex group contradicted the findings of the previous study, which indicated fewer cracks [23].

The reason for higher incidence of crack in high torque group with protaper universal system may be related to the larger taper of the instruments compared to twisted file, protaper next and hyflex files. Increasing the instrument's taper can result in increased contact of the file and walls of the canal, thereby increasing canal wall stress which may contribute to dentinal defects [6]. This observation is also corroborated by Wilcox et al., who concluded that the more dentin that is removed, higher the likelihood of root fracture [25]. Apart from the taper, Protaper also utilises a process of single length preparation in which, with the exception of the SX, all instruments are taken to the apex. This generates a greater peak torque and force due to the instrument's increased contact with the canal walls [21].

In 2010, Kim et al. reported that the design of the file impacted the apical stress strain concentration, which was associated with an increase in dentinal defects [10]. In accordance with Kim et al's study, Yoldas et al also showed that the potential to promote dentinal defects may be associated to the instrument's design, cross-sectional geometry, variable taper, and flute [5].

In the present study, all tested samples had distinct instrument designs and manufacturing processes. Protaper universal files made with a conventional NiTi system exhibited a greater number of fractures than files made with M-wire (Protaper next), R-phase (Twisted files), and controlled memory (HyflexCM), which exhibited fewer to no cracks [26]. Compared to files manufactured with R-phase, M-wire, and controlled memory, instruments manufactured with conventional NiTi are less flexible. The instrument produced with conventional super-elastic NiTi will have greater angular deflection than instruments made with other techniques; this, in turn, will increase the instrument's contact area with the canal wall [24], explaining the reason for the possible effect of protaper on the formation of cracks in root dentin.

In the current research, mandibular premolars with a single root and a single straight canals were used. The high peak stress generated by the instrument is low in case of straight canal because of its resistance to dentin removal is minimal compared to high resistance created by the instrument in case of curved or calcified canals, which could be considered as a major limitation of the present study [9].

Conclusion

Given the limitations of this study, it can be determined that the manufacturing process and the torque settings could play a major role in dentinal crack formation. Nevertheless, no statistical significance were found between the tested groups.

Conflict of Interest

The authors of this study disregard any potential conflicts of interest that may be related to this research.

Author's Contributions

1.Dr.Sindhu Shri Balasubramanian - Literature search, experimental studies, Data acquisition, Data analysis. Manuscript preparation, 2. Dr. Ranjith Kumar Sivarajan - Concept,Design, Definition of the intellectual content,Manuscript preparation, Manuscript editing, Manuscript review, 3. Dr.Ashwin Ravichandran - Manuscript editing, 4. Dr. Shyam Ganesh - Manuscript editing, 5. Dr. Vijay Venkatesh Kondas - Supervision. All authors have read and agreed to the published version of the manuscript.

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Table 1 - Groups

Group 1-ProTaper Universal - (PTU) Austenite-martensite technology			
Group 1(A) - Protaper Universal - High Torque (PTU -HT)		Group 1(B) - Protaper Universal - Low Torque (PTU -LT)	
File sequence	Torque (NCM)	Torque(NCM)	Speed in RPM
S1	4	2	250
S2	1.5	1	250
F1	2	1.5	250
F2	3	2	250
Group 2 - ProTaper Next - (PTN) M-Wire technology			
Group 2(A) - Protaper Next- High Torque (PTN -HT)		Group 2(B) - Protaper Next - Low Torque (PTN -LT)	
File sequence	Torque (NCM)	Torque (NCM)	Speed in RPM
X1	4	2	300
X2	4	2	300
X3	4	2	300
Group 3 - Hyflex CM - (HYF) Controlled Memory technology			
Group 3(A) - Hyflex CM- High Torque (HYF -HT)		Group 3(B) - Hyflex CM - Low Torque (HYF -LT)	
File sequence	Torque (NCM)	Torque (NCM)	Speed in RPM
20/0.4%	3	2	500
25/0.4%	3	2	500
20/0.6%	3	2	500

Group 4 - Twisted File - (TF) R-phase technology			
Group 4(A) - Twisted file- High Torque (TF -HT)		Group 4(B) - Twisted file - Low Torque (TF -LT)	
File sequence	Torque (NCM)	Torque (NCM)	Speed in RPM
25/0.8%	3	2	500
25/0.4%	3	2	500
20/0.6%	3	2	500

27.

Table 2 - Percentage of Cracks

Groups	Percentage of cracks
Group 1(A) PTU -HT	45%
Group 1(B) PTU -LT	11.10%
Group 2(A) PTN -HT	11.10%
Group 2(B) PTN -LT	0%
Group 3(A) HYF -HT	0%
Group 3(B) HYF -LT	0%
Group 4(A) TF-HT	33.30%
Group 4(B) TF-LT	0%

28.

Table 3 - Intra group comparison between High and Low Torque		
Intra group Comparison	N	P value
Group -1(A) High Torque Vs Group -1(B) Low Torque	5	0.072
Group -2(A) High Torque Vs Group -2(B) Low Torque	5	1.000
Group -3(A) High Torque Vs Group -3(B) Low Torque	5	0.317
Group -4(A) High Torque Vs Group -4(B) Low Torque	5	0.050

Chart 1: Overall percentage of cracks