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Original paper

Evaluation of three different rotary systems on dentinal defects formation in curved canals

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Abstract The rotary instruments are widely used for shaping the root canals. The aim of this study is to investigate the incidence of dentinal defects after preparation of curved root canals, using ProTaper Universal (Dentsply-Sirona, Ballaigues, Switzerland), ProTaper Next (Dentsply-Sirona, Ballaigues, Switzerland) and ProTaper Gold systems (Dentsply-Sirona, Ballaigues, Switzerland) rotary instruments. Eighty mesial roots of mandibular first molars were selected and randomly divided into three experimental groups (n=20). Twenty teeth were left unprepared and served as contol group. The mesial roots were separated and rotary prepared using ProTaper Universal, ProTaper Next and ProTaper Gold up to size 25, .06 taper. After root canal preparation, all the roots were sectioned horizontally at 3, 6 and 9 mm from the apex and the sections were examined through a stereomicroscope. The presence of dentinal defects (cracks, incomplete fractures or craze lines) were scored 0 for no defects and 1 for defects. Chi-square test andFischer's exact test were used to analyse the data, at a significance level of $P < 0.05$. The ProTaper Universal system produced the greater number of dentinal microcracks (37%), more than the ProTaper Gold (28%) and ProTaper Next (23%) systems. ProTaper Gold and ProTaper Next systems caused fewer dentinal defects than the Protaper Universal system ($P<0.05$), while no significant difference was seen between ProTaper Gold and ProTaper Next ($P>0.05$). The number of defects in the apical part was significantly lower for all the experimental groups ($P<0.05$). With the ProTaper Gold system, fewer dentinal defects were formed in the apical third than with the ProTaper Universal system ($P<0.05$). Within the limitation of this study, it seems all rotary instruments may induce dentinal defects. The ProTaper Gold files caused significantly fewer defects than the ProTaper Universal system, especially in the apical part of curved root canals. Further studies are required to evaluate the efect of these instruments on treatment outcomes.

Keywords Root canal instrumentation, dentinal defects, ProTaper Universal, ProTaper Next, ProTaper Gold.

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Introduction

The aims of root canal preparation are to remove the dentinal debris, to disinfect the endodontic space and to fill the entire root canal (O. YOLDAS & al [1]). However, the rotary instruments widely used for shaping have the potential to induce microcracks or dentinal defects on root canals (I.D. CAPAR & al [2]). Research has shown that these defects can later propagate into vertical root fractures on tooth subjected to repeated stress or occlusal trauma. (H. SHEMESH & al [3]). The Protaper Universal system (Dentsply-Sirona, Ballaigues, Switzerland) has a triangular cross-sectional design, is superelastic and stiff and needs a greater amount of dentin removal especially in the coronal and middle part (C.A. BIER& al [4]). These files are madefrom conventional Ni-Ti alloy, have various tapers on the files that produce a significant effect on microcrack formation (B.D. RUNDQUIST & A. VERSLUIS [5]). The ProTaper Next (Dentsply-Sirona, Ballaigues, Switzerland) instruments have an off-centered rectangular design, with progressive and regressive tapers on the files, are made from M-wire technology and present great flexibility. These features minimize the contact between the file and the dentin (C.J. RUDDLE [6]). Recently, the ProTaper Gold files (Dentsply-Sirona, Ballaigues, Switzerland) are another tipe of novel Ni-Ti system, made using a proprietary heat treatment technology. These files present a greater flexibility and fatigue resistance and showed well-centred preparations in severely curved canals (A.M. ELNAGHY & S.E. ELSAKA [7]; J. ZUPANC & al [8]). The purpose of this study is to investigate and to compare the incidents of dentinal defects on curved canal walls after procedures with ProTaper Universal, ProTaper Next and ProTaper Gold systems.

Matherials and Methods

A large group of mandibular first molars freshly extracted were collected from different private dental clinics. The mesial roots were separated using a low speed saw (Isomet; Buehler Ltd, Lake Bluff, NY, USA) under water cooling leaving root lenghts of 12 mm. All roots were examined under stereomicroscope (Zeiss Stemi 2000-C, Germany) to exclude external defects or cracks before the procedure. Proximal radiographs of the mesial roots were taken and only those with two separated canals from the orifice to the apex were selected. The anatomy and morphology of the mesial roots were assessed using the same proximal radiographs and radiographs made in a buccal direction. The angle of each mesial canal was determined following Schneider’s method (S.W. SCHNEIDER [9]) and the radius of curvature was calculated as decribed previously by Pruett et al, 1997 (J.P. PRUETT & al [10]). Eventually, eighty mesial roots without any external defect sand curvatures between 20-30 degrees and radii between 5-12 mm were selected and randomly divided into three experimental groups (n=20) and one group control (n=20). The homogeneity of the groups with respect to the canal lenght, radius and angle of curvature were assessed using analysis of variance (P=1.000).

The canal lenghts were measured with a 10 k-file until its tip became visible at the apical foramen. The working lenght (WL) was established by subtracting 1 mm and was standardized to 11 mm for all the experimental groups, except the control group which was left unprepared. A glide path was performed using a size 15 k-typefile. The teeth were embeded in acrylic blocks and the surfaces were coated with silicon impression material in order to simulate the periodontal ligament. The samples were randomly divided into 4 groups, as follows:

ProTaper Universal Group (group 1): the mesial roots were shaped by ProTaper Universal (Dentsply Sirona) up to size 25, .06 taper in a crown down manner. The endodontic engine was set at 300 rpm with 2 Ncm torque and an SX file was used in the coronal part of the canal. First, S1 and S2 were used with brushing motions in the two thirds of the canal and then at the entire WL. F1 (20.07) and F2 (25.08) were used with in-and-out pecking motions until the full WL was reached.

ProTaper NextGroup (group 2): the root canals were prepared using the same endodontic engine set at 300 rpm and 2 Ncm torque. The files X1 (17.04) and X2 (25.06) were used with a gentle in-and-out motion until the instruments had reached the full WL.

ProTaper Gold Group(group 3): the root canal were prepared by using the ProTaper Gold instruments SX, S1 and S2 with brushing motions and in a crown down manner as in the group 1. Then F1 and F2 were used with pecking motions until the full WL was reached. Each canal was irrigated with 2 ml 1% sodium hypoclorite between each instrument by using a syringe with a Navi tip irrigation needle (NaviTip 30 G; Ultradent, South Jordan, UT) placed at 1 mm from the WL. A total of 14 ml NaOCl was used for each root. After preparation, the root canals from the prepared groups were rinsed with 5 mLdistilled water.

Control group: twenty mesial roots were left unprepared and served as controls.

After removing the silicon impresion material, the root canals were cut perpendicular to the long axis with a low speed saw under constant water cooling (Isomet; Buehler Ltd) at 3, 6 and 9 mm from the apex and the slices were examined through a stereomicroscope with 20X magnification (Zeiss Stemi 2000-C, Germany). After cutting procedures, the specimens were slightly dried and the final interpretation of microscopic images was performedwithin 24 hours. Digital images were taken with a camera (Nikon D5100; Nikon Tokyo, Japan) attached to stereo microscope in order to determine the presence of dentinal cracks. A total of 60 slices were examined in each group.

No differences was attempted between dentinal defects. The dentinal defects were scored: 0 for no defect and 1 for defects. “Defect” was defined as any fractures, cracks or craze lines in root dentine (Fig. 1 and 2). “No defect” was defined as root dentine showed no cracks, incomplete fracture or craze lines at both the internal and external surfaces (Fig. 3 and 4).

Statistical analysis: the results was expressed as the number and percentage of slices with dentinal defects. The data were analyzed using Cochran's test for frequency of defects in sclices at 3, 6 and 9 mm and Mc Nemar test for comparative analysis between pair of sections. The Chi-square test andFischer's exact test were used to compare the number of defects between the groups, at a significance level of $P < 0.05$.

Results

No defects were observed in the unprepared group. A total of 48 dentinal defects were observed in 240 sections. The difference between control group and experimental groups was statistically significant (P<0,05). The distribution of defects in each group at the different levels are shown in the Table 1. Protaper Gold and Protaper Next systems caused fewer dentinal defects than the Protaper Universal system (P<0.05, Cochran's test) (Tabel 2). Instrumentation with ProTaper Universal increased the number of dentinal microcracks (37%) more than the ProTaper Gold (28%) and ProTaper Next (23%) systems (Fig. 5, 6, 7). No significant difference was seen between ProTaper Gold and ProTaper Next.The total number of defects in the apical part was significantly lower for all the experimental groups than the number of defects in the medium and coronal partof the canal (P<0,05,Chi-square test) (Tabel 3).

Regarding the different sections, only ProTaper Gold system produced significantly fewer defects at 3 mm comparative to 6 mm and 9 mm (P=0.001, McNemar test), whilst no significant difference was found for the other systems (P>0.05). Moreover, the incidents of dentinal defects at 3 mm were significantly fewer for Protaper Gold than for the Protaper Universal system (P=0.031, Fisher's exact test).

Table 1. Number and percentage of slices with dentinal defects at the different section levels

	Total number of defects (%)			**Total slices with defects per group**
	3 mm	6 mm	9 mm	
Control (n=20)	0 (0)^{c}	0(0)	0(0)	0(0)^{c}
ProTaper Gold (n=20)	2 (10)^{a}	13 (65)^{b}	13 (65)^{b}	28 (46.6)^{a}
ProTaper Next (n-20)	4 (20)	8 (40)	11 (55)	23 (38.3)^{a}
ProTaper Universal (n=20)	9 (45)^{b}	15 (75)	13 (65)	37 (61.6)^{b}
P value	0.031	0.067	0.754	0.287

The same superscript letters indicate no significant difference between groups (Fisher's exact test, P<0,05).

Table 2. Statistically different values between groups regarding the number of defects

Groups	**Cochran's Q test**	**p**
Protaper Gold	$X^2(2)$=17,386	<0,001*
Protaper Universal	$X^2(2)$=4,308	0,116
Protaper Next	$X^2(2)$=6,167	0,046*
Teeth with cracks	$X^2(2)$=23,744	<0,001*

Table 3. Statistically different values between groups at 3 levels

Level	**Differences between ProTaper Gold, ProTaper Universal and ProTaper Next**
3 mm	$X^2(2)$=6,933; p=,031*
6 mm	$X^2(2)$=5,417; p=,067
9 mm	$X^2(2)$=0,564; p=,754
Teeth with cracks	$X^2(2)$=2,500; p=,287
Chi-square test	

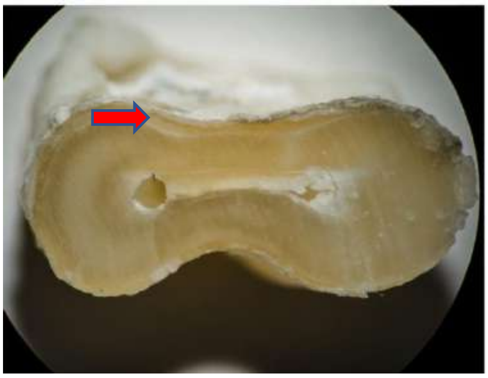

Figure 1. Cross-section at 6 mm level showing dentinal defect (ProTaper Gold system).

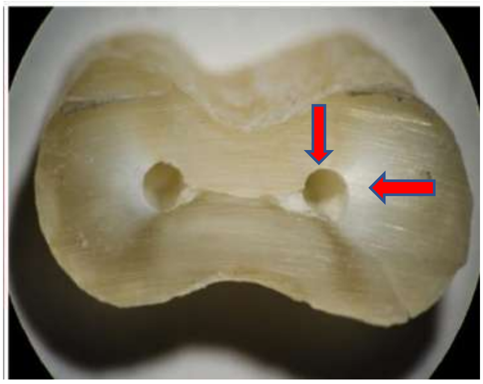

Figure 2. Cross-section al 9 mm level showing dentinal crack (ProTaper Universal system).

Figure 3. Cross-section at 3 mm level, without any dentinal defects (ProTaper Next system).

Figure 4. Control-group, section at 6 mm, no dentinal defects

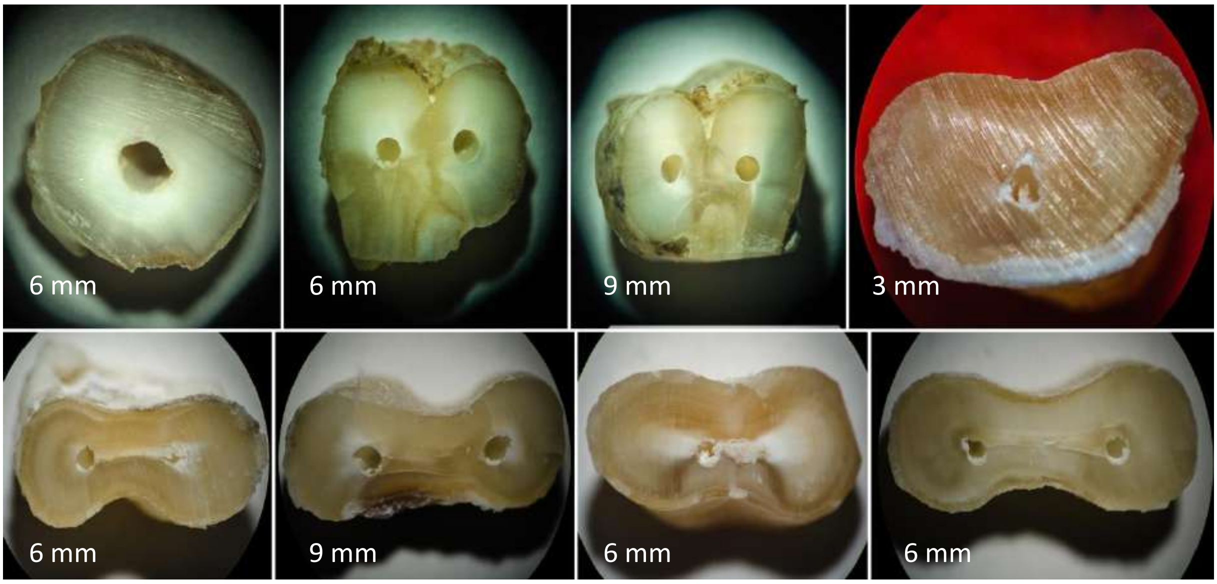

Figure 5. Different sections at 3, 6 and 9 mm level – **ProTaper Gold group**

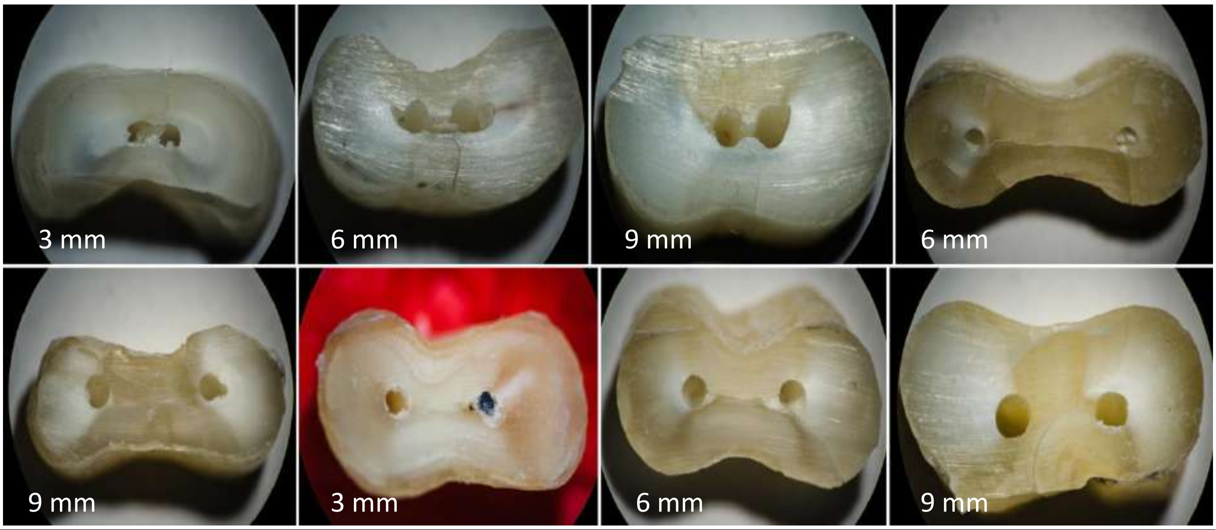

Figure 6. Cross-sections at 3, 6 and 9 mm level – **ProTaper Universal group**

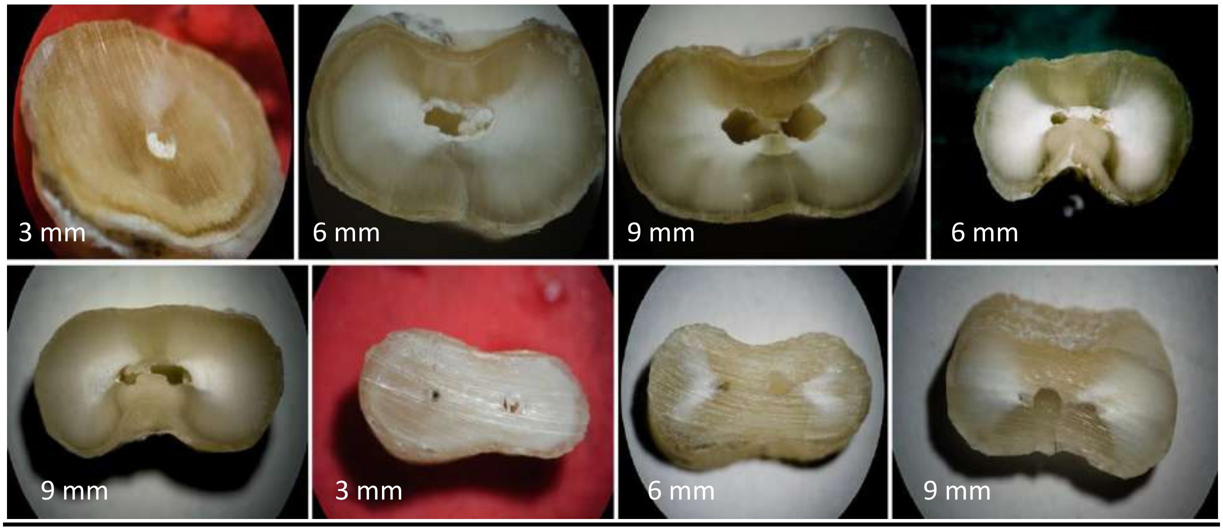

Figure 7. Cross-sections at 3, 6 and 9 mm level – **ProTaper Next group**

Discussions

Vertical root fractures have been reported as a complication following cracks and dentinal defects during and after root canal treatment using Ni-Ti instruments (O. YOLDAS & al [1]; V. ASHWINKUMAR & al [11]). Although many factors could lead to vertical root fractures (traumatic injury, internal resorbtion, occlusal overloading, parafunctional habits), it is not yet clear whether all dentinal defects may result in root fracture (L.H. BERMAN & G.R. HARTWELL [12]).

Some studies stated that the metallurgical characteristic and different cross-sectional design of Ni–Ti file systems are an important factors in determining the dentin defects during endodontic treatment (I.D. CAPAR [2]; S.V. NISHAD & G.B. SHIVAMURTHY [13]; E. KARATAS & al [14]; A. HIEAWY & al [15]). Hence, PTU (superelastic with convex triangular cross-sectional design), PTN (M-wire technology and off-centered rectangular design) and PTG (heat treated, two-stage transformation behaviour and convex triangular cross-sectional design) were used for investigate a causal relationship between instrumentation and dentinal defects.

In this study only freshly extracted teeth were used, involving collaboration between several dental clinics, because dehydration of dentinal tissue as well as storage substances, time and freezing temperatures could interfere the biomechanical properties of teeth and cause microcracks in non-endodontically treated teeth (G. DE-DEUS & al [16]). Mesial roots of mandibular molars were chosen due to their narrow mesio-distal diameter comparative to bucco-lingual one, which is susceptible to the dentinal cracks formation (S. SABER & al [17]). Also, the curvatures ofthe roots ranged from 20 to 30 degrees may increase the dentinal defects generated during instrumentation (K.T. CEYHANLI & al [18]). Despite the fact all teeth were examined with a stereomicroscope prior to the experiment, some defects could be internal and could not be detected on the external surface of the specimens (E.S. HIN & al [19]).

In the present study acrylic blocks and silicon impression layer were used to simulate both alveolar bone and periodontal ligament. This is in agreement with other studies (E. KARATAS & al [14]; S. SABER & al [17]; M. PRATIK & al [20]). The sectioning method using law speed saw under water cooling is in agreement with other studies (I.D. CAPAR & al [2]; V. ASHWINKUMAR & al [11]; S.V. NISHAD & G. B. SHIVAMURTHY [13]; E. KARATAS & al [14]; M. PRATIK & al [20]; E. KARATAS & al [21]; R. KANSAL & al [22]; S.E.D.M. SABER & E. SCHÄFER [23]). This method has its limitations, may induce possible damage, but we speculate it may not because there were no dentinal defects in the control group (G. DE-DEUS & al [24]).The same authors (G. DE-DEUS & al [25] recommand the non-distructive analysing methods such as micro-CT and reported there was no causal relationship between rotary instrumentation and dentinal microcracks, suggesting that the latest can occur during tooth extraction or tooth-sectioning(G. DE-DEUS & al [16]). On the other hand, other studies using micro-CT found that instrumentation systems significantly increased the number of microcracks compared with preoperative specimens (K.T. CEYHANLI & al [18]; A. JAMLEH & al [26]).

In this study were included the mesial canals where a glide path of at least 15 could be established prior to rotary instrumentation and the final apical preparation was set to size 25 in each group. The specimens were kept moist with sterile water until all the roots were cut,in order to avoid dentin dehydration which could develop spontaneosly dentin microcracks (M.A. VERSIANI & al [27]), butto avoid misinterpretation due to the poorer visibility of cracks in wet condition, the slices were slightly dried and examined within 24 hours (T. RÖDIG & al [28]).

The roots were instrumented up to size 25 and not to larger dimensions because, as was stated before, root canal instrumentation is associated with crack development and propagation (I.D. CAPAR & al [2]).

In the present study, after rotary instrumentation with Protaper Universal, Protaper Gold and Protaper next, the incidence of dentinal defects was 37%, 28% and 23% of specimens, respectively. Similarly, I.D. CAPAR & al [2] reported 28% defects in root shaped by Protaper Next and 56% inroots instrumented with Protaper Universal. Also, E. KARATAS & al [21] found 22% defects in specimens instrumented with Protaper Universal.

In the mesial roots of the mandibular teeth instrumented with Protaper Universal, K.T. CEYHANLI & al [18] observed microcracks in 42%, O. YOLDAS & al [1] in 30%. These different results may be attributed to the different root anatomy that generates stress which leads to dentinal defects (S. BÜRKLEIN & al [29]; Y. USTUN & al [30]). The curvature of selected roots in our study ranged from 20-30 degreese, lower then those selected by K.T. CEYHANLI & al [18] (20-40°) and O. YOLDAS & al [1](slightly curved mesial canals).

The results of this study revealed that there were significant differences between the groups in the number of dentinal defects. Comparing ProTaper Universal versus ProTaper Gold, instruments with the same taper and cross-section, ProTaper Universal produced significantly more defects, especially in the apical part than ProTaper Gold. The same result obtained V. ASHWINKUMAR & al [11]. It seems the greater flexibility, due to a proprietary heat treatment of ProTaper Gold, has led to fewer microcracks in general and at the apical section (E. KARATAS & al [14]).

Comparing ProTaper Universal versus ProTaper Next, the results were similar, the last showing the lowest percetage of all groups (23%). Previous studies reported that M-wire instruments alloy which contains Austenite, small amounts of Martensite and R-phase at body temperature and has austenite finish temperature A_f > 43-50° (J. ZUPANC & al [8]) shows more flexibility than those made from conventional Ni-Ti wire (I.D. CAPAR& al [2]; M. PRATIK & al [20]). Moreover, the cross-sectional geometry, taper and an offset design of PorTaper Next have an impact on the incidents of dentinal defects (S.E.D.M. SABER & E. SCHÄFER [23]; E. KARATAS & al [21]). Also, the swaggering effect of these instruments reduces the screw into de dentine and strain during preparation (E. KARATAS & al [21]; H.C. KIM & al [31]). Using ProTaper Next, less instruments are required and another important aspect is the smaller dimensions of 25.06. The taper and the stiffness files are reported to lead to increased stress on canal walls (I.D. CAPAR & al [2]; C.A. BIER & al [4]).

As we know, S_1 and S_2 ProTaper Universal first instruments have greater taper in their coronal and middle part and their aim is to produce early coronar enlargement. This leads to the fact that they are strongly engaged in the coronal dentine and the amount of it is high, which can creates the possibility of dentinal cracks formation. With the simultaneous approch of ProTaper next files, the engagement on the dentinal walls is much smaller and the space is created only with lateral movements and does not need apical pressure (V.A. MALAGNINO & al [32]).

J. GAGLIARDI & al [33] have reported that, despite the fact ProTaper Gold and ProTaper Next share neither geometric design nor metallurgy, they showed excelent centring ability and less canal transportation during instrumentation. Therefore, more dentine is maintained, which may explain the significantly fewer defects obtained comparative tothe ProTaper Universal system. A.M. ELNAGHY & al [34] founded that ProTaper Gold had a significantly higher resistance to cyclic fatigue and flexibility than ProTaper Next and therefore ProTaper Gold may be more suited for preparing canals with more abrupt curvature because of its gold fatigue resistance (A. HIEAWY & al [15]). However, we did not found significant difference betweenthese two systems.

The low incidents of dentinal defects in the apical portion of the canal may be explained by working length determination which was 1 mm short of the apical foramen. Other studies have reported that stress resulting from working length 1 mm short was one-third of the stress at middle or coronal part (S.E.D.M. SABER & E. SCHÄFER [23]; A. VERSLUIS & al [35]). More defects were shown at the middle and coroanl levels because of the presence of cervical constrictions (S. SABER & al [17]) due to the deposition of dentine. Thus, coronal shaping should be used in a brushing movement against the root wall opposite to the "danger zone" – Abou-Rass techniqueand therefore it increases the risk of microcracks formation at this level (M. ABOU-RASS & al [36]); R.A. VASCONCELOS & al [37]).

Only ProTaper Gold showed significantly fewer dentinal cracks in the apical region comparative to other levels and this is in agreement with Karataş's outcome (E. KARATAS & al [21]). When stress applied is above the critical level, a phase transformation beginsinto the Ni-Ti alloy, which occurs when temperature in the environment (in our case – in the canal, due to the friction to the canal walls) is higher than so-called A_f temperature of the material. Thus, the conventional Ni-Ti alloys must be treated at temperatures above $A_f$for being pseudo-elastic. ProTaper Universal instruments have A_f temperature lower than the body temperature (36°C), ProTaper Next has A_f= 43°-50°C, while ProTaper Gold has A_f > 50°C, with two specific transformation phases (J. ZUPANC & al [8]). ProTaper Gold was found to have a higher cyclic fatigue resistance than ProTaper Universal and ProTaper Next and alongside its incresed flexibility led to fewer dentinal defects in the apical part of the canal (A.D. UYGUN & al [38]).

Although this study found a lot of significant differencies between groups, the results remain questionable and may not be clinically relevant or affect the treatment outcomes (M. HÜLSMANN & al [39]).

Conclusions

Within the limitation of this experimental study, the ProTaper Universal instruments produced the most dentinal cracks compared to ProTaper Gold and ProTaper Next systems. Also, the ProTaper Gold files caused significantly fewer defects than the ProTaper Universal system, especially in the apical part of curved root canals. Further studies are required to evaluate the efect of these instruments on treatment outcomes.

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