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Original research

The retreatment abilities of ProTaper Next and F6 Skytaper: a micro-computed tomography study

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Purpose
The aim of this study was to evaluate the retreatment abilities of the ProTaper Next (PTN) and F6 SkyTaper (F6) systems by using micro-computed tomography (micro-ct), radiographic and microscopic imaging techniques.

Materials and Methods
The root canals of twenty-six extracted mandibular premolar teeth were prepared and obturated. For the retreatment procedure, the teeth were randomly divided into two equal groups according to endodontic instruments: PTN (X4) and F6 (#40/.06). Pre- and post-operative filling material volumes were measured with micro-ct, and areas were measured with radiographic and microscopic imaging techniques. The percentages of residual material were calculated, and then statistically compared. The significance level was set at $p<0.05$.

Results
There was no statistically significant difference between F6 and PTN for retreatment efficacy in the micro-ct and radiographic imaging techniques ($p>0.05$). PTN demonstrated better cleaning ability when evaluated by microscopic imaging. ($p<0.05$). The correlation was moderate between micro-ct and radiographic, and micro-ct and microscopic imaging groups; however, it was strong between radiographic and microscopic imaging methods.

Conclusion
The PTN and F6 files had similar effects in the removal of filling material with micro-ct evaluation. The radiographic imaging method gave similar results with micro-ct imaging.

Keywords: *Micro-computed tomography, Microscopy, ProTaper next, Radiography, Retreatment*

Introduction

Non-surgical retreatment is the treatment of choice for teeth that have undergone failed root canal treatment. This procedure includes the total removal of previous root canal filling material, disinfection, reshaping and refilling (1). Remnant filling material on the root canal surface might cause the persistence of microorganisms and prevent the monobloc structure formation of new filling material with dentin (2). Therefore, the efficacy of the instruments used for retreatment procedures is important for the successful removal of the gutta-percha.

There are several techniques for the removal of gutta-percha, such as hand-files, rotary instruments, heated instruments, ultrasonic instruments, and lasers. The ProTaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) produced from M-Wire alloy is a multi-file system, and the F6 SkyTaper (F6) (Komet, Lemgo, Germany) is a single-file NiTi system. These rotary systems are originally manufactured for endodontic treatment and proved to be efficient for retreatment procedures in previous studies (3-11).

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Micro-ct evaluation has been widely used to evaluate the amount of residual root filling material in recent studies (3-5, 12-14). It is accepted as the gold standard for being a reproducible and non-destructive method that provides a detailed evaluation of the three-dimensional morphological features of the observed object and also provides quantitative data (9). There are several other methods to evaluate remnant filling material, such as longitudinally dividing the roots to evaluate the canal walls microscopically or radiographically (11, 15-24). Evaluating residual material radiographically is a method based on detecting the radiopacity of filling material. Previous studies have compared microscopic and radiographic methods for evaluating retreatment procedures (19-21).

Until recently, there has been no study comparing PTN and F6 for retreatment efficacy or comparing microscopic and radiographic evaluation with micro-ct for retreatment. The aim of this study is to compare PTN and F6 in their ability to clean gutta-percha and as methods for retreatment evaluation. The null hypothesis is that there is no difference between PTN and F6 for gutta-percha removal and that there is no difference between the methods for retreatment evaluation.

Materials and Methods

Study design

The Ethical approval was obtained from the Ethics Committee of the Ankara Yildirim Beyazit University (research ID: 2018-242, decision date and number: 28.06.2018-11). Twenty-six mandibular premolar teeth extracted for periodontal or orthodontic reasons were stored in 0.1% thymol until the beginning of the experiment. The teeth were confirmed to have a single root and root canal, complete apex formation, and no internal calcifications/resorptions via radiographic and visual examinations.

Root canal filling

The teeth were decoronated by using diamond disks to standardize the root lengths at 17 mm. After decoronation procedure, the coronal openings of the root canals were examined under a dental operation microscope (Leica M320, Leica Microsystems, Wetzlar, Germany) to confirm to have a round shape at horizontal section. The working lengths were established as 16 mm. Root canal preparation was performed with PTN system instruments with the size of X3 (Dentsply Maillefer, Ballaigues, Switzerland). The root canals were irrigated with 2 mL of 17% EDTA and 2 mL 2.5% NaOCl solution. Apical patency was performed with #10 K-file. Then, the root canals were dried by paper-points. The root canals were obturated by lateral condensation technique using #30 master and #25 accessory gutta-percha cones. As root canal paste, AH Plus (Dentsply, Detrey, Konstanz, Germany) was used. The access cavity was sealed temporarily with CavitG (3M ESPE, Seefeld, Germany). The teeth were stored at 37°C and 100% humidity for four weeks.

Retreatment procedure

After the removal of the temporary sealing material, 2 mm of gutta-percha at the coronal part was removed with a #3 gates-glidden drill. A few drops of chloroform were used at this created space. After 30 seconds, the retreatment procedure was performed. The teeth were randomly divided into two groups for retreatment procedure as follows:

The PTN group (n=13): The root canal fillings were removed with X3 and X4 ProTaper Next instruments. In each instrument change, 3 mL of 2.5% NaOCl solution was used for irrigation procedure.

The F6 group (n=13): #30, #35 and #40 sizes of F6 SkyTaper instruments were used respectively for filling material removal. In each instrument change, 2 mL of 2.5% NaOCl solution was used for irrigation procedure.

A total of 6 mL 2.5% NaOCl solution was used for each tooth during the retreatment process. The instruments were used respectively with an electric torque-controlled motor (EndoTouch TC2; SybronEndo, Glendora, USA) at a speed of 300 rpm and a torque of 2.0 N/cm in brushing motion until reaching the working length. After the apical foramen was reached, a size 15 K-file was inserted 1 mm beyond the apical foramen to maintain apical patency. Each file was used once, and no instrument separation was observed during the procedure. The retreatment procedure was performed by a single operator.

Micro-ct Evaluation

For volumetric analysis of the filling materials, the teeth were scanned using micro-ct (SkyScan 1174, Bruker Micro-ct, Kontich, Belgium) before and after retreatment procedures with following scanning parameters: 50 kVp, 800 µA, a pixel size of 33 um, a beam hardening correction of 30%, a smoothing of 2 and a ring artifact correction of 6. Scanning was performed by 180° rotation around the vertical axis, a camera exposure time of 2.700 ms, a rotation step of 0.4°, and frame averaging of 3. Flat field correction and geometric correction for random movement were performed in all scans. The scanning procedure took approximately one hour per sample. Three-dimensional reconstruction data were obtained by NRecon software (version 1.6.9.4, Bruker micro-CT). For the calculation of the volume of the filling material, CTAn software (version 1.17.7.2, Bruker micro-CT) was used. Three-dimensional visualization and qualitative evaluation of the filling material were performed with CTVox software (version 3.3.0, Bruker Micro-ct). The examination of the images was performed by a blinded observer. Pre- and post-operative volumes of filling material were measured in mm^3, and then the percentage volumes were calculated (Figure 1, A-D).

Radiographic evaluation

The roots were digitally radiographed in approximal directions (Figure 1-E). The radiographic procedure was performed using a dental X-ray unit (Planmeca ProX, Helsinki, Finland) at 50 kVp, 8 mA and 0.01 s exposure time with a digital sensor (MPS, Progeny Dental, Buffalo Grove, USA). The digital software used was Soredex, Digora Optime (Kavo, Brea, CA, USA), which allowed the researchers to use all the options available such as brightness, contrast adjustment and magnification. The areas of remaining material and total root canal surface were measured using a software (ImageJ;

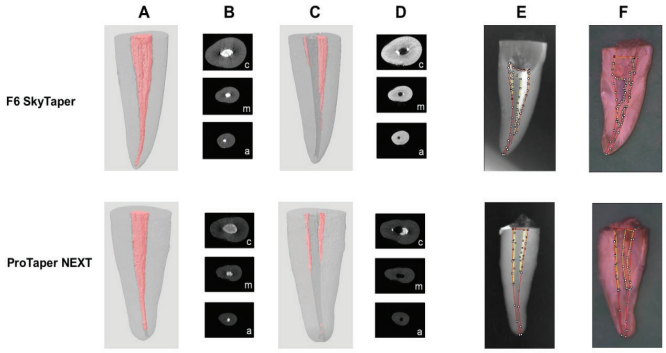

Figure 1. *Images obtained with different observational methods: (A) pre-treatment and (C) post-treatment 3D images observed with micro-ct 3D imaging. (B) pre-treatment and (D) post-treatment cross-sectioning images with micro-ct; c = coronal, m = middle, a = apical. (E) radiographic, (F) microscopic images. Yellow lines mean filling material borders and red lines mean root canal borders at (E) and (F).*

Wayne Rasband, NIH, MD, USA). The percentage value calculation was obtained by dividing these two values. The percentage values were recorded for each sample.

Microscopic evaluation

The roots were longitudinally separated by using a diamond disk. The root halves with more remaining material for each tooth were chosen for analysis. The root halves were photographed under a dental operation microscope (Leica M320, Leica Microsystems, Wetzlar, Germany) at 25x magnification (Figure 1-F). By using the software (ImageJ), the areas of remnant material and total root surface were measured, and the ratio between the values was recorded as a percentage value.

The obtained percentages of PTN and F6 were compared with the methods of micro-ct, radiography and microscopy separately. The correlations for the three observational methods were analyzed.

Statistical analysis

The Shapiro-Wilk test was used to evaluate the assumption of normality. The percentage volumes of the remnant material for each file were normally distributed for micro-ct, while radiographic and microscopic techniques were distributed non-normally ($p<0.05$). For statistical comparison of the files with micro-ct, the independent sample t-test was used. The Mann-Whitney U test was used to compare the systems with radiography and microscopy. The Spearman correlation test was performed in order to evaluate the correlation between the observational methods. The significance level was set to $p< 0.05$ (SPSS v22.0 for Windows; SPSS Inc, Chicago, IL, USA).

Results

Comparison of files for retreatment efficacy

There was no significant difference between F6 and PTN for retreatment efficacy when the analysis was performed by micro-ct (P = 0.08) or radiographically (P = 0.057), while PTN proved to have better cleaning ability when evaluated by microscopy (P = 0.039) (Table-1). The study was completed with a statistical power of 50% (effect size = 0.80, α = 0.05) (G*Power 3.1.9.4 software; Heinrich Heine University, Dusseldorf, Germany)

Table 1. *Comparing remnant material percentages after instrumentation with ProTaper Next and F6 SkyTaper using different observational methods PTN: ProTaper Next, F6: F6 SkyTaper, SD: Standard deviation.[a] t value for t-test (normally distributed data), [b] Z value for Mann Whitney U test (non- normally distributed data).*

Imaging Methods	Instruments (n=13)	Residual material (%)		Test	P
		Mean ± SD	Median		
Micro-ct	PTN	0.14±0.09	0.13	0.031[a]	0.08
	F6	0.22±0.11	0.20		
Radiography	PTN	0.14±0.13	0.09	1.923[b]	0.057
	F6	0.27±0.21	0.22		
Microscopy	PTN	0.12±0.19	0.05	2.08[b]	0.039*
	F6	0.26±0.20	0.20		

Correlations among the evaluation techniques

The correlation (Spearman test) of the results obtained by radiography and microscopy was strong (rho = 0.744; P = 0.000), while the correlation was moderate for micro-ct and microscopy (rho = 0.466; P = 0.016), as well as the micro-ct and radiography groups (rho = 0.568; P = 0.002).

Discussion

This study investigated the filling material cleaning ability of F6 and PTN and compared them with three observational methods: micro-CT (the gold standard), radiography and microscopy. For the analysis and evaluation of filling material removal from the root canal space, the results obtained from micro-ct were accepted as the gold standard and the other observational methods were compared with micro-ct. When files were compared with micro-ct and radiography, there was no significant difference between the tested instruments in their ability of to remove gutta-percha. The tested null hypotheses were accepted when a comparison was made with micro-ct and radiographic techniques, but they were rejected for microscopy because PTN was found to be more effective with this method.

F6 and PTN files are both single-file systems and used in continuous rotation motion (25, 26). The differences between the systems are their cross-sections and the alloy type from which they were produced. F6 is a nickel-titanium system has an S-shaped section with two sharp cutting edges, and greater chip space, while PTN has a rectangular cross section with two cutting edges, and manufactured from M-Wire (25, 26). The rectangular cross-section design of the PTN system and greater chip space of F6 could be a facilitating factor for debris removal in the coronal direction, and may also remove filling material efficiently (26).

Although the mean percentage of remnant material for F6 was higher, there was no significant difference between the

instruments statistically. A previous study comparing the F6 SkyTaper, Reciproc and Mtwo for residual material on the root canal walls filled with gutta-percha and AH Plus found no difference between them (11). There is no other study evaluating F6 for retreatment ability. Studies evaluating PTN and Reciproc systems for gutta-percha removal found similar results for these techniques (5, 9). Another study comparing WaveOne, PTN and RaCe also found no difference for retreatment ability (3). In all these studies, the final apical sizes of the groups were kept similar. In this study, initial enlargement was finished with PTN X3 file, and root canal filling was performed with lateral condensation technique with #30 master and #25 accessory cones in two groups. Lateral condensation technique with AH Plus was performed for the filling technique for its common usage (27-30). Apical preparation size after retreatment was set two sizes beyond the initial preparation size to reduce remnant material (31, 32). The retreatment procedure was finished with X4 file for the PTN group and #40 file for the F6 group; therefore, the final apical sizes and tapers for the groups were equal (#40/.06). It could be said, for the retreatment procedure, that the initial and final preparation enlargements were similar for the groups. The similarity for the percentages of the remnant material of the groups could be related to this methodological similarity between groups.

Total irrigant volume for groups during the retreatment procedure were equal to avoid a possible difference in remaining filling material depending on the different volumes of solution. Chloroform was used to solve gutta-percha to simulate clinical conditions, although it has been claimed that this pushes the softened gutta-percha into irregularities of the root canal walls and prevents the cleaning procedure (20).

When the groups were compared by micro-ct or radiography, there was no significant difference between them. But with microscopic evaluation, PTN proved to have better cleaning ability. One study comparing microscopic and radiographic methods for retreatment evaluation found radiographic evaluation more reliable because microscopic evaluation requires splitting the tooth and material removal might exist during the cutting procedure (33). Some other previous studies have claimed microscopy to be superior to radiographic evaluation, as regarding magnification and distortion possibility during radiographic imaging, small volumes of remnant material may not be visualized as detailed as in microscopic evaluation (19, 21, 34). In this study, some totally cleaned samples were detected only in microscopic evaluation groups, but residual filling material could be seen in these samples when evaluated with radiography or micro-ct. Although the correlation between radiography and microscopy was strong, the comparisons of the two files with these methods were different. Radiography gave similar results in the retreatment efficacy comparison of files with micro-ct.

Radiography gives two-dimensional information about a three-dimensional structure, while micro-ct is a non-invasive technique that provides qualitative and quantitative three-dimensional data for retreatment procedures (21, 35, 36). In this study, there was no significant difference when PTN and F6 were compared by micro-ct and radiography, but the correlation between micro-ct and radiographic techniques was moderate.

For radiographic and microscopic evaluation, the values were calculated as pixels and for micro-ct the values were calculated as mm^3. For all observational methods, the cleaning ability evaluation was made with percentages. Values were obtained by dividing pre- and post-operative values, to overcome the differences.

The option to use the radiographic method to assess the removal of filling material simulates clinical procedures as radiographs are used to detect the presence of remnant material on the root canal space for retreatment procedures (19, 23). Its clinical reliability was supported with the present study, as radiography gave similar results as micro-ct.

Conclusion

The efficencies of ProTaper Next and F6 SkyTaper files had similar effects in the removal of residual filling material from root canal space when evaluated with micro-ct. The radiographic method gave similar results with micro-ct, while the microscopic technique found the ProTaper Next to be more effective.

Türkçe Özet: *Protaper Next ve F6 Skytaper Sistemlerinin Tekrarlayan Kanal Tedavisindeki Yeteneği Açısından Farklı Görüntüleme Yöntemleriyle Karşılaştırılması: Mikro-Bilgisayarlı Tomografi Çalışması. Amaç: Bu çalışmanın amacı, mikro-bilgisayarlı tomografi (mikro-bt), radyografik ve mikroskobik görüntüleme tekniklerini kullanarak ve karşılaştırarak ProTaper Next (PTN) ve F6 SkyTaper (F6) sistemlerini tekrarlayan kök kanal tedavisindeki etkinlikleri açısından değerlendirmektir. Gereç ve Yöntemler: Yirmi altı adet çekilmiş alt çene küçük azı dişinin kök kanalları endodontik olarak genişletildi ve dolduruldu. Tekrarlayan kök kanal tedavisi prosedürü için dişler kullanılan eğelere göre rastgele iki eşit gruba ayrıldı: PTN (X4) ve F6 (# 40 / .06). İşlem öncesi ve sonrası kanal içi dolgu materyali hacimleri micro-ct ile, alanları ise radyografik ve mikroskobik görüntüleme teknikleriyle ölçüldü. Artık materyal yüzdeleri, iki enstrümantasyon sistemi için mikro-bt, radyografik ve mikroskobik görüntüleme yöntemleriyle karşılaştırıldı. Eğelerin etkinliğini istatistiksel açıdan karşılaştırmak amacıyla t-testi ve Mann-Whitney U testi kullanıldı. Görüntüleme yöntemleri arasındaki korelasyonu değerlendirmek için Spearman korelasyon testi yapıldı. Anlamlılık seviyesi $P < 0.05$ olarak belirlendi. Bulgular: Analiz mikro-bt ve radyografik görüntüleme teknikleriyle yapıldığında tekrarlayan kanal tedavisi etkinliği için F6 ve PTN arasında istatistiksel olarak anlamlı bir fark yoktu ($P > 0.05$), ancak mikroskobik görüntüleme ile değerlendirildiğinde PTN'nin daha iyi temizleme etkinliğine sahip olduğu görüldü ($P < 0.05$). Mikro-bt ve radyografik, ve mikro-ct ve mikroskobik görüntüleme teknikleri arası korelasyon orta düzeyde olup; radyografik ve mikroskobik görüntüleme teknikleri arasında yüksek düzeyde idi. Sonuç: PTN ve F6 sistem eğelerinin, mikro-bt ile değerlendirmede kanal dolgu materyalinin uzaklaştırılmasında benzer etkili olduğu görüldü. Radyografik görüntüleme yöntemi mikro-bt görüntüleme yöntemiyle benzer sonuçlar verdi. Anahtar Kelimeler: Mikro-bilgisayarlı tomografi, Mikroskop, ProTaper next, Radyograf, Tekrarlayan kanal tedavisi*

Ethics Committee Approval: Ethical approval was obtained from the Ethics Committee of the Ankara Yildirim Beyazit University (research ID: 2018-242, decision date and number: 28.06.2018-11).

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: ES participated in designing of the study. ES and SİY participated in generating the data for the study. ES, SİY, MO and HHC participated in gathering the data for the study. ES, SİY, MO and FG participated in the analysis of the data. ES wrote the majority of the original draft of the paper. ES participated in writing the paper.

ES, SİY, MO, FG and HHC have had access to all of the raw data of the study. ES, SİY, MO, FG and HHC have reviewed the pertinent raw data on which the results and conclusions of this study are based. ES, SİY, MO, FG and HHC have approved the final version of this paper. ES guarantees that all individuals who meet the journal's authorship criteria are included as authors of this paper.

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