Morphological Analysis of Apical Foramen Over-instrumented by Three Rotary NiTi Systems

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Objective: *To evaluate morphological changes of the apical surface after root canal preparation with 1 mm beyond the apical foramen using ProTaper Universal (PTU) files, K3 files and Twisted files (TF), respectively.*

Methods: *Seventy teeth with a centered apical foramen and 70 teeth with a deviated apical foramen were included as group A and group B respectively. In each group, 20 teeth were randomly assigned for root canal preparation with PTU, K3 and TF files, respectively; the remaining 10 teeth were used as the control group without any preparation. The apical foramens were examined with scanning electronic microscopy. The foramen integrity damage (FID) and dentin defects (DDs) were noted and compared between different groups.*

Results: *FID and DD were significantly less in Group A. DDs was not found in the control group. Preparation with PTU, K3, and TF files caused FID in 6.67%, 10%, and 3.33% of teeth in the group A, and in 20%, 26.67%, and 10% in Group B, respectively. Preparation with PTU, K3, and TF files caused DD in 6.67%, 6.67%, and 3.33% of teeth in Group A, and in 23.33%, 26.67%, and 6.67% in Group B, respectively. PTU and K3 files produced more DDS than TF files. However, no significant difference was found between groups using PTU and K3 files.*

Conclusion: *Rotary instrumentation caused less damage on the apical surface in foramen-centered root canals than foramen-deviated root canals when working beyond the canal length. TF files had a tendency to produce less DDS compared with PTU or K3 files during over-instrumented root canals.*

Key words: *nickel-titanium instruments, root canal preparation, dentin defects, apical foramen, scanning electron microscopy*

The growing use of nickel–titanium (NiTi) rotary files has made tremendous progress in endodontic practice allowing rapid, centered with less apical transportation shaping of canals than stainless steel instruments[1,2]. Therefore, most clinicians today prefer rotary NiTi instruments such as ProTaper Universal (PTU), K3 files and Twisted files (TF). The NiTi rotary instruments that are on the market vary considerably in cross-sectional design and taper. It is known that an increasing taper is directly related to the increased cross-sectional area and decreased flexibility[2]. Increased stress produced by larger tapered NiTi rotary instrumentation may induce dentin damage and generate dentin crack, ultimately resulting in vertical root fracture[3].

Inappropriate interpretation of working length and apical size during root canal cleaning and shaping (including under-prepared, over-prepared and lack of preparation) will affect the treatment outcomes[4,5]. The working length obtained from periapical radiograph was overestimated in more than 50% of premolar samples and 22% of molar samples[6]. Even with the use of

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an electronic apex locator such as Root ZX (J Morita Corp) or the Raypex 5 (VDW), there was still 15% to 40% protrusion of file beyond the major apical foramen[7,8]. In another aspect, the frequency of deviation of the major foramen ranged from 34% to 92%, and the distance between the major foramen and anatomical root apex ranged from 0.2 to 3.8 mm as studied by radiography, stereomicroscopy and scanning electron microscopy (SEM)[9-11]. These small but very critical variations of apical morphology, which are not readily detected during clinical procedures, may lead to over-instrumentation, overfilling and subsequently affect successful outcomes. A true working length is difficult to gain, especially when the apical foramen and anatomical apex do not coincide, thereby increasing the risk of over-instrumentation, which can lead to other problems such as postoperative pain, delayed apical healing, and apical cracks[12].

It can be postulated that the frequency of damage of the integrity of apical foramen and the incidence of dentin defects occurred in foramen-deviated teeth could be more than foramen-centered teeth when prepared by different rotary NiTi systems. Therefore, the aim of this study was to compare the frequency of integrity damage of apical foramen and the incidence of dentin defects after preparation with PTU, K3 file and TF file in foramen-centered and foramen-deviated groups at 1mm beyond working length.

Materials and methods

Samples preparation and groups

Extracted human maxillary central incisors were selected after examination under stereomicroscopy (XT-III, Jiangxi KongFungYi Technology Company) under 20 × magnification to exclude any cases with preexisting craze lines and cracks. In order to eliminate the influence of curvature factor on experiment results, the curvatures of the teeth between 0° and 8° were included. When the distance from the centre of their root tips to the major apical foramina was above 0.5 mm, it was regarded as a foramen-deviated tooth, otherwise, it was regarded as a foramen-centred tooth. Seventy foramen-centred and 70 foramen-deviated teeth were included as Group A and Group B, respectively. In each group, 20 teeth were randomly assigned for preparations with PTU files (Dentsply Maillefer, Ballaigues, Switzerland), K3 files (SybronEndo, Orange, CA) and TF files (SybronEndo, Orange, CA), respectively; the remaining 10 teeth were used as the control group without any preparation. The crowns were removed at 2 mm above the cementoenamel junction (CEJ) with diamond burs and the roots were embedded in acrylic blocks with silicon impression material coating as simulated periodontal ligament. The apical 2 to 3 mm of the root was exposed and immersed in physiological saline during instrumentation as previously described[12]. One hundred and twenty teeth (60 foramen-centred and 60 foramen-deviated) were subjected to six instrumentation procedures described below. Twenty teeth (10 foramen-centred and 10 foramen-deviated) were left untreated and served as the control.

Root canal instrumentation procedures

Canal patency was achieved and the working length was measured by inserting a size 10 K-file into the canal till the tip of the file was visible through the major apical foramen. Instrumentation with PTU, K3 and TF files were accomplished with a low torque motor (X-Smart; Dentsply Maillefer) at a torque and speed recommended by the manufacturer for each specific system. Canal patency was maintained by inserting a no.10 K-file until it protruded the apical foramen after each file and was irrigated by positive pressure with a 27-gauge needle using 2 mL of 2% NaOCl solution between the exchanges of each instrument.

In the PTU group, rotary NiTi files were used in the following sequence at 300 rpm to prepare the canals. S1 and Sx prepared the coronal two-thirds of the canal, and then, S1, S2, F1, and F2, were used to 1 mm beyond the full working length. In the K3 group, crown-down sequence by using 25/.10, 25/.08, and 25/.06 taper file while only 25/.06 was extruded to 1 mm beyond the apical foramen. In the TF group, canals were prepared with the following sequence at 500rpm: 25/.10, 25/.08, and 25/.06, with 25/.06 to 1 mm beyond the apical foramen.

Scanning electron microscopy examination

All samples were dehydrated through an ascending series of ethanol with 70% for 10 min, 80% for 10 min, twice with 95%, 100% for 15 min each time, and then dried in a vacuum, gold-palladium alloy plated prior to SEM. The morphology of the root apical foramen of all specimens were recorded under SEM (JSM-6360LV, JEOL) at a magnification at 50×, 100× and 500× before root canal instrumentation as baseline images. Marks on the samples were made to secure the same position for SEM observation and images taken before and after root canal instrumentation. All the teeth were then rehydrated in saline for 4 h prior to instrumentation. The teeth were

Table 1 The number of apical foramen integrity damage and dentine defects by three kinds of instruments in foramen-centred group and in foramen-deviated group.

Groups	PTU		K3		TF	
	FID	DD	FID	DD	FID	DD
Foramen-centred	4	4	6	4	2	2
Foramen-deviated	12	14	16	16	6	4
Control group	0	0	0	0	0	0

FID: foramen integrity damage; DD: dentin defects

then prepared for SEM imaging similarly after instrumentation. Three pre- and postinstrumentation images for each sample centred on the apical foramen with different angles were taken.

The integrity damage of the apical foramens and the presence of dentin defects were defined by comparing the baseline image of each root with the postinstrumentation images of the same root. Foramen integrity damage (FID) was evaluated and determined when more than one-third circumference of the apical foramen was damaged by nickel-titanium rotary files or other external forces. Dentin defects (DDs) include any cracks, detachment and fracture of tooth structure around the apical foramen as described in previous studies[12,13].

Statistical analysis

All statistical analyses were done using SPSS version 13.0 software (SPSS). The prevalence rates of integrity damage and dentin defects with 95% confidence interval among foramen-centered and foramen-deviated groups were calculated. The differences in PTU, K3 and TF groups were assessed by chi-square test at a significance level of $P < 0.05$. The correlation between destruction and integrity was analysed by logistic regression analysis.

Results

The imperfection related factors analysis

After logistic regression analysis, integrity was related to grouping (Group A, B), OR = 6.425, 95% CI (1.835, 22.488), by controlling equipment type, the advantage ratio of imperfections of Group B compared with Group A was 6.425 times (Table 1).

The destructive factor analysis

After logistic regression analysis, destruction was related to both the equipment type and grouping. Factors about the equipment type: there was no significant difference between Nickel-titanium rotary instruments K3 and PTU. There was significant difference between Nickel-titanium rotary instruments TF, K3 and PTU. Nickel-titanium rotary instruments TF, comparing with Nickel-titanium rotary instruments PTU, OR = 0.435, 95% CI (0.029, 0.837), which indicated that nickel-titanium rotary instruments TF was a protective factor.

Grouping factors (Group A, B): OR = 8.646, 95% CI (2.299, 32.523), by controlling equipment type, the advantage ratio of destruction of Group B compared with Group A was 8.646 times (Table 1).

DDs were not found in the control groups. Preparation with PTU, K3, and TF files caused FID in 6.67%, 10%, and 3.33% of teeth in Group A, and in 20%, 26.67%, and 10% in Group B, respectively. Preparation with PTU, K3, and TF files caused DDs in 6.67%, 6.67%, and 3.33% of teeth in the group A, and in 23.33%, 26.67%, and 6.67% in the group B, respectively. PTU and K3 files produced more DDs than TF files (P >0.05). However, no significant difference was found between groups using PTU and K3 files (P >0.05).

Discussion

Maxillary central incisors were the teeth used in the current experiment as although it has the thickest root, the diameter of the apical foramen in upper central incisors were reported to be 0.3 to 0.45 mm[11]. Therefore, instrumentation of these teeth requires the use of larger sized instruments to prepare the apical portion. However its inherent position in the maxillary arch makes radiographic interpretation of its length a challenge. When the

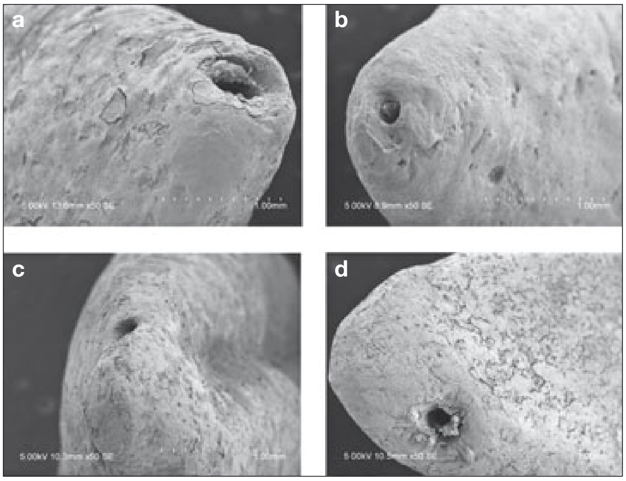

Fig 1 Foramen-centred and foramen-deviated group. Major foramen in the center of their root tips (**a, c**); foramen-deviated group with deviations of the major foramen >0.5 mm from the root apex (**b, d**).

foramen opens buccally or lingually, the root structure is often superimposed, making its radiographic visualisation difficult, which very often leads to over-instrumentation. Liu et al[13] using mandibular incisors noted that no cracks were generated when instrumentation was terminated at apical foramen -2 mm, possibly because the sharp apical curvature was located within the apical 2 mm. However, cracks were also observed in teeth with apical foramen in the centre of the root. In teeth with a deviated apical foramen, a curvature must have been present in the very apical region, and the radius of the curvature could be small. It has been recognised that canal curvature with a small radius results in increased fracture susceptibility.[14,15] In the current study, even with a larger root, there were significant cracks (dentin defects) noted when the canals was overinstrumented, however it was highly significant when the foramen was deviated especially for the stiffer K3 files and to a slightly lower extent the larger tapered PTU files.

Theoretically, root canal instrumentation files should be limited within the apical foramen and unintentional over-instrumentation must be avoided. However, using current available methods, such as radiographs and apex locators, overestimation of the working length occurred in 15% to 40% of the clinical cases[6-8]. In the current study, over-instrumentation was purposely performed to evaluate its effect with larger tapered NiTi files on the apical region of the tooth. It was noted that foramen integrity damage and the formation of dentine defects were significantly more in the foramen deviated group for all the instruments used. When instrumentation with K3 and PTU files was terminated at the apical foramen at +1 mm, cracks developed in 4 of 20 teeth (20%) in the foramen-centred group, and 16 out of 20 teeth (80%) in the foramen-deviated groups. The results are consistent with previous studies. Therefore, inadvertent instrumentation beyond the apical foramen increases the risk of apical dentinal defects, especially when larger tapered files are used and more so with stiffer files with a larger cross-section.

The taper of the rotary NiTi file and its corresponding tapered canal preparation could be a contributing factor in the generation of dentin defects. The finishing PTU instruments are three-bladed instruments in the form of a convex triangle with a variable taper that was larger at the apical 3 mm (e.g. F2 has a tip size of 25 with taper 0.08). The K3 has a positive rake angle, three radial lands and peripheral blade relief for reduced

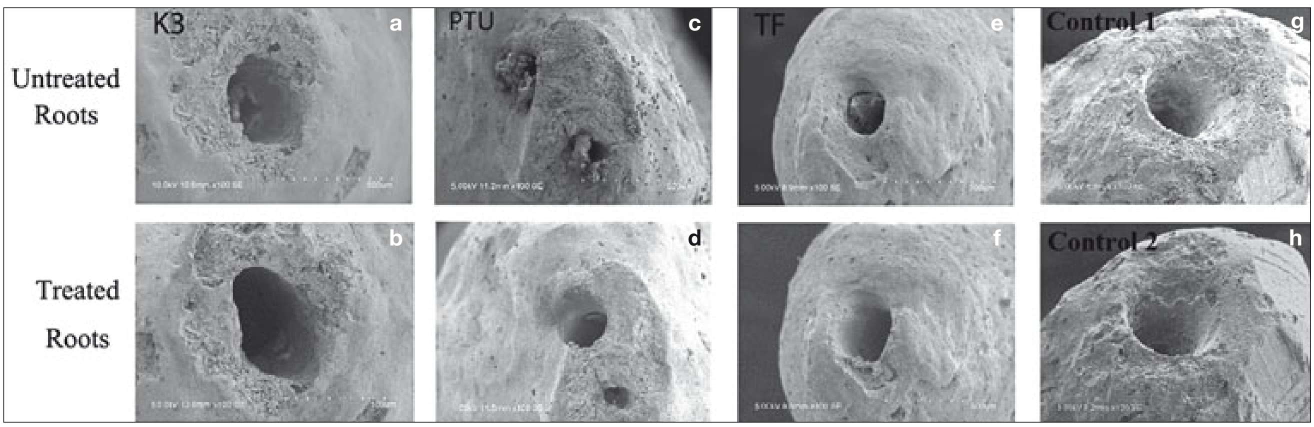

Fig 2 SEM of the apical foramen morphology before (**a,c,e,g**) and after (**b,d,f,h**) preparation with K3, PTU, TF files.

friction while TF was a three-bladed triangle are tapered uniformly at 0.06 taper. The primary design difference between the K3 and TF are the cross-section where the TF has a smaller cross-section and core as compared to K3 which makes it more flexible. In the present study, all groups prepared with tapered rotary NiTi files showed various degrees of damage supports the idea that tapered files may generate an increased stress on the dentin wall[16]. It has been reported that ProTaper F3 with a larger taper 0.09 compared with Mtwo (VDW, Munich, Germany) with 0.06 and SAF (ReDent-Nova) with no taper caused cracks in 35%, 25%, and 10% of teeth, respectively[17]. The larger taper is also related to the flexibility of the instrument wherein Yoldas et al[12] reported that the HERO Shaper (HS; Micro-Mega) with relatively low flexibility generated the highest number of DDs than PTU and TF files in their study. Through finite-element models, it was confirmed that Mtwo (VDW) is about twice as flexible as HERO Shaper and three times as flexible as Protaper[18]. Furthermore, Kim et al[19] concluded that the stiffer file might generate higher stress concentrations, rendering the higher risk of apical root cracking when used in preparation of the curved apical canal. TF, which is subjected to twisting coupled with heat treatment instead of traditional grinding to obtain the configuration of the instrument, has its superior flexibility and is much more flexible and bendable than K3 and Protaper[14]. Also the cross-sectional configuration and smaller cross-sectional area of TF, which is half of that of K3, could contribute partially to its superior elasticity[15]. In the current study, TF files had less apical foramen damage and dentin defect than K3 and PTU at the apical third of canals. Therefore, we agree with the recommendation that nickel-titanium files with tapers greater than .04 should not be restrained for apical enlargement of curved canals because these files are considerably stiffer than those with .02 or .04 tapers[20,21]. Accordingly, the integrity damage of apical foramen (circumference of the apical foramen prepared) by PTU files with .08 taper was significantly higher than by TF file with .06 taper. The incidence of dentin defect was highly correlated with the integrity damage of apical foramen. It is reasonable to speculate that the dentin cracks observed in apical area may be linked to an increased risk of root fracture as reported by Wilcox et al[22] where the presence of a craze line predisposed the root to fracture. The contact between the instrument and the canal wall creates many stress concentration sites from which a crack may initiate[19]. Obviously, the removal of more apical dentin requires more rotation of files to complete, which could exacerbate the formation of dentin defects.

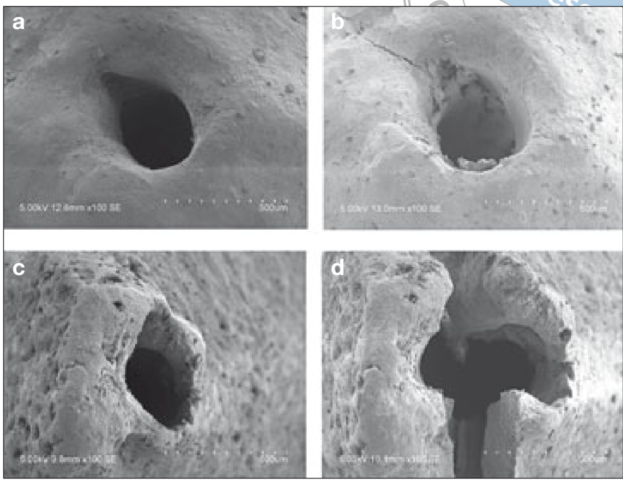

Fig 3 Dentin defects in foramen-centred group (**a, b**) and in foramen-deviated group (**c, d**).

Root canal preparation at the optimal length is a key step in root canal therapy. If the working length is too short, the microbes at the apical area will not be adequately cleaned to promote healing and may lead to failure of the treatment. On the other hand, if the length is too long, the cleaning of the apical region is enhanced but the damage to the apical foramen can result in over filling and dentinal defects at the apical region, which may preclude it to fracture.

Conclusion

Under the experimental conditions, it may be concluded that:

- Rotary instrumentation caused less damage on the apical surface in foramen-centred root canals than foramen-deviated root canals when working beyond the canal length.
- Files with a lower taper and cross-section with high flexibility (TF) had a tendency to produce less dentin defects compared with PTU or K3 files during over-instrumenting root canals.

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