Factors influencing the fracture of nickel-titanium rotary instruments

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Abstract

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Aim To evaluate the effect of rotational speed and the angle and radius of curvature of root canals on the fracture of two types of nickel-titanium rotary instruments: K3® and ProTaper®.

Methodology A total of 240 root canals of extracted human maxillary and mandibular molars were divided into two groups of 120, according to the angle of the canal curvature (group A: <30°, group B: >30°). Each group was then divided into two subgroups of 60 canals in order to perform instrumentation using K3® and ProTaper® rotary instruments at three different rotational speeds: 150, 250 and 350 r.p.m. (20 canals at each rotational speed). Each instrument was used a maximum of 20 times and at one rotational speed only. The angle and radius of canal curvature were measured in the only group in which fractures actually took place (group B).

Results There were a total of 22 instrument fractures; all of these occurred in canals with curves >30°. In a multivariate analysis, it was demonstrated that the files used at a rotational speed of 350 r.p.m. were more likely to fracture than those used at 250 r.p.m. (OR: 1113.88; 95% CI: 2.36–526420.05) and than those used at 150 r.p.m. (OR: 13531.33; 95% CI: 5.37–34120254.00). A decrease in the angle of curvature of the canal also significantly reduced the likelihood of fracture (OR: 0.2083; 95% CI: 0.068–0.6502). These relationships remained significant after being adjusted for the potential interactions between the remaining variables. No significant differences were found between the files or the radii of the canals.

Conclusions Instrument fracture was associated with rotational speed and the angle of curvature of the canal.

Keywords: fracture, nickel-titanium, rotary instruments, rotational speed.

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Introduction

There is a potential risk of rotary nickel-titanium instruments fracturing within the canals. This is a major concern, since it can jeopardize the success of treatment. In most situations, fracture occurs in the apical third of the canal and the remaining portion is often difficult to remove, especially if the canal is narrow (Serene *et al.* 1995, Pruett *et al.* 1997, Schrader *et al.* 1999). The fragments that remain block the root canal system and impede adequate cleaning, shaping and sealing (Haikel *et al.* 1999, Cohen & Burns 2000).

The manufacturers of rotary instruments recommend that they be constantly checked for defects that might alert the user prior to fracture. However, it remains a concern that rotary nickel-titanium instruments might break without warning, that is without there being any previous, permanent, visible defect or deformation. Further, unlike their steel counterparts, early signs of metal fatigue are not usually detected in nickel-titanium instruments (Marending *et al.* 1998). Therefore, although visible inspection is to be commended, it would not seem to be the ideal way of evaluating nickel-titanium instruments in order to prevent fracture.

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Fracture of rotary instruments takes place in two different ways: due to torsion or due to fatigue through flexure (Serene *et al.* 1995). Fracture due to torsion occurs when the tip or any other part of the instrument binds in the canal whilst the handpiece keeps turning. When this occurs and the elastic limit of the metal is exceeded, fracture of the instrument becomes inevitable. This type of fracture has been associated with the application of excessive apical force during instrumentation (Sattapan *et al.* 2000a,b).

Fracture due to fatigue through flexure occurs because of metal fatigue. The instrument does not bind in the canal but rotates freely until the fracture occurs at the point of maximum flexure (Sattapan *et al.* 2000b). This type of failure is believed to be an important factor in the fracture of nickel-titanium rotary instruments in clinical usage and may be due to their use in curved canals (Pruett *et al.* 1997).

Torque is another parameter, which might influence the frequency with which instruments break. When a motor that generates a high degree of torque is used, it is possible to exceed the instrument's fracture point within the canal. A potential solution would be to use a low-torque endodontic motor, which would run within the maximum permissible torque limit for each rotary instrument. Low-torque motors stop rotating and then begin to rotate in the opposite direction when the instrument has to withstand levels of torque equivalent to those produced by the motor, thus preventing fracture (Gambarini 2000).

There are a number of factors that are associated with fracture of engine-driven rotary instruments including the speed of rotation, and the angle of curvature and the radius of the canals in which they are used. However, few studies have attempted to explain the extent to which each of these factors is important. The aim of this project was to evaluate the effect of speed, and the angle of curvature and the radius of root canals on the fracture of nickel-titanium rotary instruments.

Materials and methods

Two hundred and forty canals from extracted human maxillary and mandibular molars were used in this study. Those molars whose apices were not completely closed, those that had extensive caries or whose roots were dilacerated or bayonet shape were rejected. Mesial–distal and buccal–lingual directional radiographs were taken of all the teeth and the angle of curvature of each root canal was ascertained by following the methodology of Pruett *et al.* (1997). Two parameters

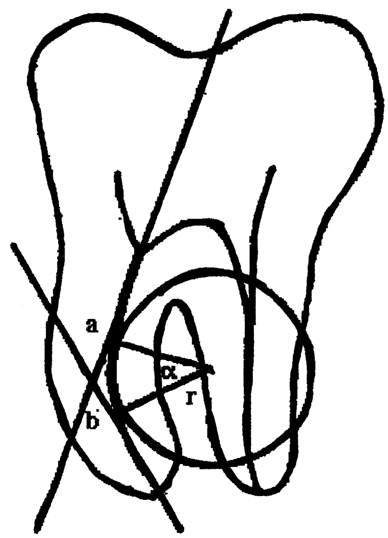

Figure 1 Determination of the angle (α) and radius (*r*) of curvature of the root canal.

were taken into account when determining the curvature of each root canal: the radius and the angle of curvature. Measurements were made by drawing a straight line along the main axis of the coronal part of the root canal and a second line along the main axis of the apical portion of the canal (Fig. 1). The angle of curvature may also be defined as the angle formed by the perpendicular lines traced from the points of deviation, *a* and *b*, that intersect in the centre of the circle. The radius of the curvature (r_1 and r_2) represents the severity with which the canal deviates from a straight line.

The parameters of the angle and the radius of curvature are mutually independent in such a way that even if two canals have the same angle of curvature they may have different radii of curvature, which indicates that some curves are sharper than others.

After determining the angle of curvature, the teeth were divided into two groups of 120 canals according to whether the angle of curvature was less than 30° (group A), or greater than 30 degrees (group B). The most severe angle in each root was used to categorize the canals.

Once the canals had been classified according to their angle of curvature, both groups A and B were then divided into three subgroups of 40 canals, which subsequently underwent instrumentation at different constant rotational speeds: 150, 250 and 350 r.p.m. Each file was used at one rotational speed only. The instrumentation was carried out using two types of nickel-titanium endodontic rotary files: K3® (Kerr Europe, Herts, UK) and ProTaper® (Dentsply Maillefer, Ballaigues, Switzerland). Thus, a total of 120 canals (60 canals from group A and 60 canals from group B) were instrumented using each type of file. The files were mounted on a low-speed, high-torque electric motor handpiece (TC Motor 3000, Nowag, Goldach, Switzerland) with a contra-angle 16 : 1 reduction (WH 975, Dental Work, Burmoos, Austria).

The root canal orifices were made accessible and the entrance to each root canal located with an endodontic explorer. The canals were then made patent using a size 08 K-file. The same operator prepared all canals and used a crown-down technique using sequence recommended by the manufacturers.

Light pressure during the instrumentation procedure was used together with back and forth movements of an amplitude of between 2 and 3 mm. The usage time for each instrument was maintained between 5 and 10 s.

The root canals were irrigated, frequently with copious quantities of 5.25% sodium hypochlorite and a water-soluble preparation containing 15% EDTA and urea peroxide (Dentsply Glyde™ file prep) in order to reproduce normal clinical conditions. All files were inspected and sterilized after each use. Each file was used to a maximum of 20 times; when fractures occurred, the instruments were replaced. K3® and ProTaper® files were used in the order shown in Tables 1 and 2.

Table 1 Instrument sequence for the K3® files

	Conicity	Size
K3	0.01	25
K3	0.08	25
K3	0.06	40
K3	0.06	35
K3	0.06	30
K3	0.06	25
K3	0.06	20
K3	0.06	15

Table 2 Instrument sequence for the ProTaper® files

ProTaper	Type of file	Tip size
Shaping file	SX	19
Shaping file	S1	17
Shaping file	S2	20
Finishing file	F1	20
Finishing file	F2	25
Finishing file	F3	30

Statistical analysis

The following variables were included in the analysis:

- File type: K3® and ProTaper®.
- Speed of instrumentation: 150, 250 and 350 r.p.m.
- Angle of curvature of the canals.
- Radius of curvature.

Given that instruments in canals with curvature $<30^\circ$ did not fracture, the baseline variables of the two groups (fracture yes or no) were compared using the chi-square test for all the samples of an angle of $>30^\circ$. Values of 95% CI and $P < 0.05$ were applied for all of the tests. For the multivariate analysis, in order to estimate the factors influencing file fracture a binary, nonconditional, logistic regression model was used with the fracture as dependent variable and file design, rotational speed, angle and radius of curvature as independent variables.

Results

From a total of 240 root canals, instrumented using two different designs of files, 22 files fractured in a total of 22 canals: 12 ProTaper® and 10 K3®. All fractures occurred in group B canals whose curvature was greater than 30°. There were no file fractures in the group A teeth, i.e. those specimens with slightly curved or relatively straight canals.

At a rotational speed of 150 r.p.m., five of the instrument fractured (two K3® and three ProTaper®). At 250 r.p.m., seven instruments fractured (four K3® and three ProTaper®). At 350 r.p.m., 10 instruments fractured (four K3® and six ProTaper®) (Tables 3 and 4).

All the fractures occurred in the apical third of the canal, a few millimetres from the tip of the instruments. The fractures occurred in mesial–buccal and distal–buccal canals in maxillary molars and mesial–buccal and mesial–lingual canals in the mandibular molars.

Table 3 K3® fractures and their relationship to rotational speed, and angle and radius of the curvature of the canal

Rotational speed (r.p.m.)	Angle	Radius
150	40°	5 mm
150	50°	5 mm
250	52°	5 mm
250	56°	3 mm
250	42°	3 mm
250	35°	4 mm
350	42°	3 mm
350	45°	4 mm
350	30°	4 mm
350	35°	5 mm

Table 4 ProTaper® fractures and their relationship to rotational speed, and angle and radius of the curvature of the canal

Rotational speed (r.p.m.)	Angle	Radius
150	45°	5 mm
150	38°	4 mm
150	50°	5 mm
250	57°	4 mm
250	48°	3 mm
250	35°	3 mm
350	40°	3 mm
350	42°	3 mm
350	35°	4 mm
350	30°	5 mm
350	50°	2 mm
350	46°	3 mm.

The logistic regression model found fracture statistically associated with rotational speed and angle of curvature. The instruments, which were used at a speed of 350 r.p.m., fractured more often than those used at 250 r.p.m. (OR: 1113.88; 95% CI: 2.36–526420.05; $P < 0.05$) and more often than those used at 150 r.p.m. (OR: 13531.33; 95% CI: 5.37–34120254.00; $P < 0.05$). A reduction in the angle of curvature produced a significant decrease in the incidence of fracture (OR: 0.2083; 95% CI: 0.068–0.6502; $P < 0.01$). These relationships remained significant after their adjustment in order to assimilate the potential interactions between variables. No significant differences were found with respect to the file design or with respect to the radii (Table 5).

Discussion

There are many factors that influence the fracture of nickel-titanium rotary files. Rotational speed is not generally considered to be a significant factor with respect to the fracture of nickel-titanium endodontic rotary instruments (Glickman 1997, Pruett *et al*. 1997). Some studies, however, have shown that rotational speed does indeed influence instrument fracture in curved canals (Gabel *et al*. 1999, Dietz *et al*. 2000), and this might be explained by the fact that the contact between the file and canal walls may cause sufficient stress to cause fracture. Increased rotational speeds augment the rubbing of the file within the canal, and thus these files break more readily than those, which are used at lower speeds (Gabel *et al*. 1999, Sattapan *et al*. 2000a). In our study, the files which were used at 150 and 250 r.p.m. fractured less frequently than those used at 350 r.p.m.

The life expectancy of an instrument is related to a specific number of rotary cycles (Yared *et al*. 1999). A lower rotational speed, therefore, should mean that the life span of an instrument is prolonged, breaking only after reaching a specific number of rotations.

Clinically, the fatigue of an instrument may be related to the degree of flexure that the instrument undergoes when placed in a curved root canal. When the curvature of canals is more pronounced, the cyclical fatigue that the instrument undergoes is greater, and thus its life expectancy is lower (Pruett *et al*. 1997). In this study, all instrument fractures occurred in canals with accentuated angles. The radius of curvature, however, was not a factor that influenced instrument fracture significantly, a fact which contradicts the findings of other studies in which both the angle and radius were found to be significant.

In a study conducted by Sattapan *et al*. (2000a), it was observed that the files that broke due to excessive torsion exhibited signs of deterioration above the point of fracture. On the other hand, the files that broke due to fatigue through flexure did not exhibit defects linked to their subsequent fracture.

It would appear that the resistance of files differs depending on whether the canals are relatively straight or slightly curved or, conversely, whether the curvature of the canals is pronounced and acute. In the first type of canal, it was possible to work using high rotational speeds whilst using each file at least 20 times without fear of fracture. The second type of canal, on the other hand, demands that files should be used at minimum speed.

Table 5 Logistic regression analysis for file fracture (only significant variables are shown)

Variable	SE	*P*-value	Odds ratio	95% CI Lower	95% CI Upper
Speed (250 r.p.m.)*	3.1420	<0.05	1113.8811	2.3569	526420.05
Speed (150 r.p.m.)*	3.9963	<0.05	13531.329	5.3662	34120254.00
Angle	0.5807	<0.01	0.2083	0.0668	0.6502

*Rotational speed of 350 r.p.m. as the reference velocity value.

Conclusions

The results of this study imply that instrument fracture is linked to rotational speed and the angle of curvature of the canal.

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