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Deformation and fracture of RaCe and K3 endodontic instruments according to the number of uses

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Abstract

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Aim To evaluate, by scanning electron microscopy, the deformation and fracture of NiTi RaCe and K3 size 25, 0.04 taper instruments.

Methodology Ten sets of instruments from RaCe and K3 NiTi rotary systems were used to prepare 100 simulated canals in epoxy resin blocks with 20 or 40 degree curvatures beginning 8 or 12 mm from the orifice. Each instrument set was used to prepare five simulated canals using a crowndown technique. The size 25, 0.04 taper instruments were analysed by SEM when new and again after each use. Three observers scored images of the instruments after each use for distortion of the spirals (no distortion, distortion of one spiral or distortion of more than one spiral), wear (no wear, small, moderate or severe wear) and fracture (yes or no). Two-way ANOVA was used to analyse differences between instruments for distortion and wear; Fisher's exact test looked for differences related to fracture of instruments.

Results No fractures occurred with K3 instruments, whereas six RaCe instruments fractured ($P = 0.005$). A statistically significant difference occurred between RaCe and K3 instruments in terms of distortion of spirals and surface wear ($P < 0.001$). Distortion of spirals and wear increased with progressive use of RaCe instruments, whereas K3 instruments remained relatively undamaged after their fifth use. The simulated canals with smaller radii of curvature were positively associated with fracture of RaCe instruments.

Conclusions A significant difference was found between RaCe and K3 in terms of deformation and fracture of size 25, 0.04 taper instruments; K3 instruments had more favourable results.

Keywords: endodontics, nickel, root canal preparation, scanning electron microscopy, titanium.

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Introduction

Root canal treatment is fundamentally dependent on root canal preparation. This phase of the treatment consists of cleaning and shaping the canal, and is a challenge particularly when shaping curved canals. Stainless steel endodontic instruments, whose characteristics include stiffness that increases with size, may set limitations to successful shaping. During enlargement of the apical third, this characteristic may be responsible for curvature defects such as apical transportation, ledging or zipping (Goldberg & Araujo 1997), which might compromise the outcome of treatment.

The introduction of endodontic instruments made of a nickel–titanium alloy (NiTi) opened a new perspective in endodontics because of their superelasticity. Superelasticity allows instruments to remain centralized inside the root canal (Schäfer *et al.* 1995), which results in satisfactory root canal preparations even for curved root canals (Chan & Cheung 1996, Thompson

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& Dummer 1997a), respecting the anatomy and contributing to a better prognosis (Chan & Cheung 1996, Schäfer *et al.* 2004).

Stainless steel and NiTi endodontic instruments differ in their process of manufacture and their crystallographic structure. The manufacturing process required by the NiTi alloy is machining, whereas stainless steel instruments are most often manufactured by twisting. Machining of NiTi instruments may be responsible for the production of manufacturing defects on the instrument surface, which increase their resilience because they act as points of tension concentration capable of initiating fracture (Kuhn *et al.* 2001).

The crystallographic structure of NiTi instruments at rest and at room temperature is austenitic, i.e. they have a face-centred cubic crystal structure. When the NiTi alloy is cooled or undergoes stress, such as in preparation of curved root canals, the austenite changes into the martensitic phase of the metal (Thompson 2000). In this phase, the atoms have a complex structure and give the alloy its superelasticity. As the stress is discontinued or the temperature rises, the metal recovers its austenitic structure (Thompson 2000). This capacity of reversible transformation is called shape memory, which, in practical terms, translates into the capacity of the instrument to return to its original form as soon as the force that caused distortion stops (Thompson 2000, Bergmans *et al.* 2001, Kuhn *et al.* 2001).

Unfortunately, each of these crystallographic phase transformations weakens the instrument and reduces its resistance to fracture by cyclic fatigue (Machado & Savi 2002), which may lead to an unexpected breakage called flexural fracture (Sattapan *et al.* 2000). Such fracture is caused by a defect in the internal structure of the metal alloy and, consequently, is not accompanied by deformation of its external structure (Sattapan *et al.* 2000).

Another type of fracture of NiTi endodontic instruments is torsional, as a result of its engagement inside the root canal. This type of fracture is always accompanied by the creation of defects on the external surface of the instrument (Sattapan *et al.* 2000).

To minimize the forces that lead to deformation and fracture of NiTi rotary instruments, several manufacturers have developed new systems with the shaft carefully designed to achieve this objective. Examples of such instruments include the K3 System (Sybron Endo, Orange, CA, USA) and the RaCe System (FKG Dentaire, La Chaux-de-Fonds, Switzerland).

Considering the fact that no consensus has been agreed on the number of times that a NiTi instrument may be safely used, the purpose of this study was to evaluate, by scanning electron microscopy (SEM), the deformation and fracture of size 25, 0.04 taper NiTi instruments of the RaCe and the K3 Systems when used in the preparation of up to five simulated root canals with 20 or 40 degree curvatures beginning 8–12 mm from the orifice.

Materials and methods

One hundred simulated canals made of an epoxy resin (Stycast, Westerlo, Belgium) were used (Thompson & Dummer 1997a,b, 1998). The simulated canals were 21–24 mm long and their initial diameter was equivalent to a size 10 instrument. Four different simulated canal configurations were used, varying the degree of curvature and the beginning of the curvature in relation to the orifice (Table 1).

Nickel–titanium (NiTi) instruments from two different systems were used: RaCe System (FKG Dentaire) and K3 System (Sybron Endo). The instruments comprised 10 boxes for each system. The boxes of RaCe instruments were coded R and each instrument box was numbered from R1 to R10. K3 instruments were coded K and the instrument boxes were numbered K1–K10.

Each box of instruments was used to prepare five simulated canals. The allocation of the four types of simulated canals to the groups was performed by stratified randomization so that each box of instruments would be used for all the curvature types in a random sequence.

Immediately after the instruments of the two systems were removed from their boxes, they underwent an initial cleaning procedure, with scrubbing and sonication in a Biocleaner tray (Biodont, São Paulo, Brazil) containing Riozyme II enzyme detergent (Rioquímica, São Paulo, Brazil) for 20 min (Filippini 2003). The instruments were then stored in metal boxes identified with the group and the specimen number, and placed in envelopes for sterilization. They were processed in a Vitale autoclave (Cristófoli, Paraná, Brazil)

Table 1 Canal configurations with varying degrees and position of the curvature

Canal type	Curvature (°)	Position of curvature (mm)
A	20	8
B	20	12
C	40	8
D	40	12

and sterilized by exposure to humid heat at 1 atm pressure and 127 °C for 20 min.

The first SEM analysis was conducted before the instruments were used. The microscope used was a Phillips XL 20 (Philips, Eindhoven, the Netherlands). The instruments evaluated by SEM were confined to size 25, 0.04 taper for both systems, as this was the instrument that predictably touched the canal walls at the full length. These instruments were mounted on a specific stub that held six instruments, in a standardized position so that the flat area on the instrument handle faced the observer and 9–10 mm of its shaft could be observed.

Two observers analysed 9–10 mm of the tip of the instrument and 180° of its circumference at 100 times magnification to investigate deformation in the body of the instrument. Two images of the instrument were recorded, one of its tip and the other 5 mm from the tip, both at ×100 magnification. When deformation was identified, an additional image was recorded at ×250 or ×500 magnification, and the distance from the site of deformation to the tip was also recorded. This distance was measured using the software in the scanning electron microscope, with an accuracy of 0.1 mm.

The preparation of the first simulated canal using each of the instrument sets was conducted after the initial analysis of the size 25, 0.04 taper instrument by SEM. The preparation followed the crowndown pressureless technique and the instruments from each set were engine-driven with speed and torque control (Endo Pro Torque/Driller; Endo Pro, São Paulo, Brazil). The speed used for both systems was 300 rpm and torque was 2 N cm as recommended by the manufacturers. Light push and pull movements were applied to instruments of both systems in a pecking motion and minimal crowndown pressure was applied for approximately 10 s. Each simulated canal was wrapped in gauze and held in place by a vice (Vacu Vise, North Andover, MA, USA). The operator who prepared the simulated canals in both groups was an experienced endodontist previously trained both for the technique of use of the two different systems and for the work with simulated canals. The technical sequences followed for K3 and RaCe systems are shown in Table 2.

Table 2 Instrument sequences followed with K3 and RaCe systems

Sequence	RaCe	K3
Exploration	Size 10 K file	Size 10 K file
Establishment of working length	Visual method	Visual method
First instrument	Size 40, taper 0.10	Size 25, taper 0.10
Second instrument	Size 35, taper 0.08	Size 25, taper 0.08
Third instrument	Size 25, taper 0.06	Size 30, taper 0.06
Fourth instrument	Size 25, taper 0.04	Size 25, taper 0.04
Fifth instrument	Size 25, taper 0.02	Size 25, taper 0.02

For both systems, the sequences were repeated as many times as necessary to allow the size 25, 0.04 taper instrument to reach the working length. At each instrument change, a master file was introduced to the working length. Before and during preparation, the canals were irrigated with 1 mL anionic detergent solution (Tergensol; Inodon, Porto Alegre, Brazil) at each instrument change. The solution was injected into the canal using a 1 mL luer-lock syringe (Ibrás, São Paulo, Brazil) with a 25/5 needle (Becton-Dickinson, São Paulo, Brazil). Following irrigation, the spent solution was aspirated with a 40–20 size cannula (CBO; Ibrás). Gauze soaked in detergent was used to clean the shaft of the instruments and remove resin chips every time the instrument was inserted into the simulated canals.

After preparation was complete, the instruments were cleaned and autoclaved following the same procedures described above and analysed by SEM for a second time. The instruments that completed the preparation of the apical stops, i.e. size 25, 0.04 taper, were again evaluated by SEM to investigate the occurrence of deformation or fracture in the body of the instruments. The sequence followed for this procedure was the same as the one used for the first SEM analysis. Even if the instrument had some deformation identified by SEM, its use was continued, i.e. it was not discarded. A set of instruments was discarded only when the instrument fractured during preparation.

After the first use and the second SEM analysis, each set of instruments was used for a second time, preparing another simulated canal using the same technique and following the same sequence of instruments. After preparation, cleaning and autoclaving of all the instruments, the same instrument was analysed by SEM for the third time following the procedure described for the preceding SEM analysis. This sequence was repeated for both the R and K groups until five uses were completed.

All the electron-micrographs of each of the 20 instruments analysed were coded and stored digitally. All the images obtained by the analysis of the instruments after a number of uses were displayed at the same time, and each image was identified only by the area recorded (distance in mm from the tip of the instrument) and the magnification used to obtain it. Three observers scored

Table 3 Scores for the instruments conditions according to the instrument's spiral distortion, surface wear and fracture

Score	Spiral distortion	Surface wear	Fracture
1	No unwinding, reverse winding or shortening of spirals along the shaft examined	No wear along the shaft examined	No fracture
2	Unwinding, reverse winding or shortening of only one spiral along the shaft examined	Small amount of wear: one to three areas with defects along the shaft examined	Fracture
3	Unwinding, reverse winding or shortening of more than one spiral along the shaft examined	Moderate wear: four to five areas with defects along the shaft examined	–
4	–	Severe wear: more than five areas with defects along the shaft examined	–

the condition of each instrument using three different criteria: distortion of the instrument's spirals, instrument surface wear and instrument fracture. Each observer completed a table with the deformation scores for each instrument from each group on each use (Table 3).

The intraclass correlation coefficient (ICC) was used to evaluate agreement between observers. The deformation and wear scores were summarized by mean values and standard deviations and compared using repeated measures ANOVA. The Fisher's exact test was used for the evaluation of the categorical variables of instrument fracture.

Data were analysed using the SPSS 11.0 software (V.11.0; SPSS, Chicago, IL, USA). The level of significance was $\alpha = 0.05$.

Results

The ICC was 0.92 for spiral distortion, 0.89 for surface wear and 1.00 for instrument fracture.

Figure 1 shows that, after the fifth use, no distortion was observed in the spirals of K3 instruments, whereas an increase in the mean score of spiral distortion was observed as RaCe instruments were progressively used ($P < 0.001$).

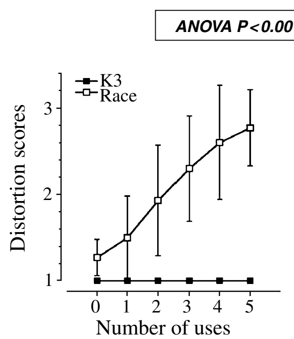
Figure 2 shows that K3 instruments had lower surface wear scores over the five uses than RaCe instruments. A progressive increase in both spiral distortion and surface wear was observed for RaCe instruments. This phenomenon was not observed for K3 instruments, which remained virtually the same up to the fifth use. The differences between the two systems for the two outcomes were statistically significant ($P < 0.001$).

No K3 instruments fractured whereas six RaCe instruments fractured. This difference was statistically significant ($P = 0.005$). Of the six fractures, four occurred in type D canals (40 degree curvature, beginning at 12 mm) and two in type B canals (20 degree curvature, beginning at 12 mm).

Figures 3–10 are examples of instruments from both systems at each use.

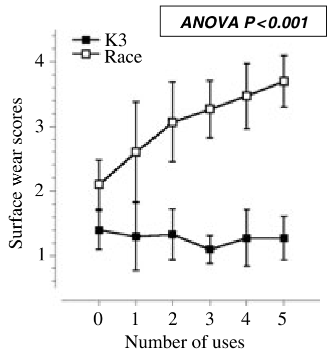
Discussion

Simulated canals were chosen for the preparations to standardize the groups, in agreement with the proce-



	Use 0	Use 1	Use 2	Use 3	Use 4	Use 5
Race						
Mean	1.27	1.50	1.93	2.30	2.60	2.77
Standard deviation	0.21	0.48	0.64	0.61	0.66	0.44
K3						
Mean	1.0	1.0	1.0	1.0	1.0	1.0
Standard deviation	0.0	0.0	0.0	0.0	0.0	0.0
n	10	10	10	10	10	10

Figure 1 Mean and standard deviation – progression of distortion scores (categorized under observations of SEM images) of RaCe and K3 instruments according to the number of uses.



	Use 0	Use 1	Use 2	Use 3	Use 4	Use 5
Race						
Mean	2.10	2.60	3.07	3.27	3.47	3.70
Standard deviation	0.39	0.78	0.62	0.44	0.50	0.40
K3						
Mean	1.40	1.30	1.33	1.10	1.27	1.27
Standard deviation	0.30	0.53	0.38	0.22	0.44	0.34
n	10	10	10	10	10	10

Figure 2 Mean and standard deviation – progression of surface wear scores (categorized under observations of SEM images) of RaCe and K3 instruments according to the number of uses.

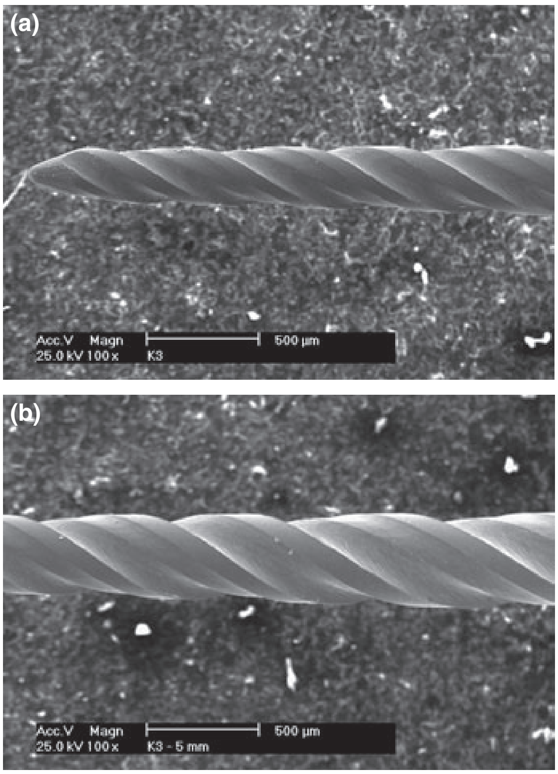


Figure 3 New K3 instruments (no use) (a, tip; b, 5 mm from tip); 100× magnification.

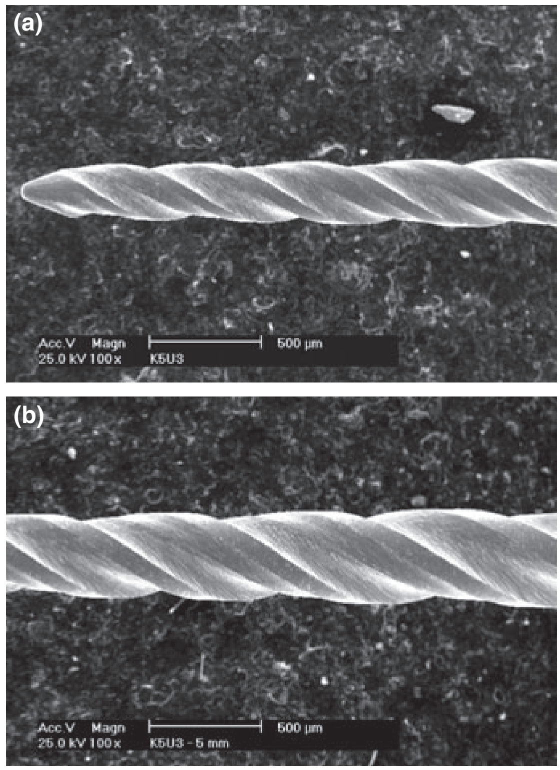


Figure 4 K3 instrument after third use (a, tip; b, 5 mm from tip); 100× magnification.

dures followed in other studies (Thompson & Dummer 1997a,b, 1998, Yared & Kulkarni 2003, Yared 2004). The four types of curvature were assigned to different groups so that each set of instruments underwent a similar degree of use and could be compared. The effect of different root canal curvatures on endodontic instrument fracture was established by Zelada *et al.* (2002).

The method chosen for the evaluation of instrument distortion after each use was SEM. This method has been used in other studies (Zuolo & Walton 1997, Rapisarda *et al.* 2001, Svec & Powers 2002). In addition, SEM seems to be the most adequate method for the accurate evaluation of deformation of instruments.

The size 25, 0.04 taper instrument was chosen for the analysis because it is the instrument that was used to complete the preparation of the apical stop. In addition, this instrument is used in all the extension of the root canal and, therefore, undergoes both torsional

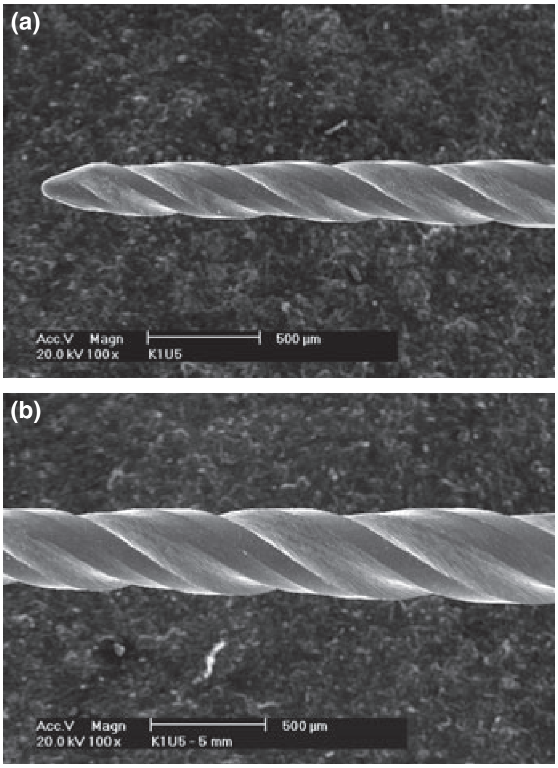


Figure 5 K3 after fifth use (a, tip; b, 5 mm from tip); 100× magnification.

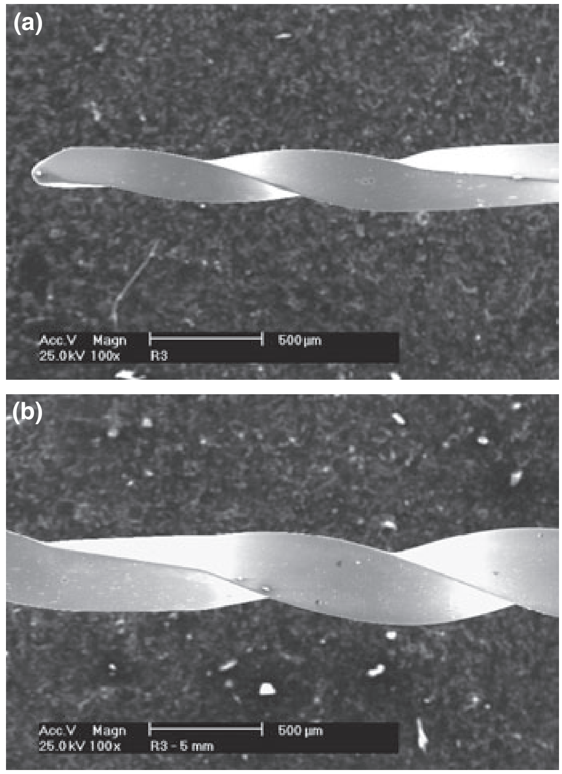


Figure 6 New RaCe instrument (no use) (a, tip; b, 5 mm from tip); 100× magnification.

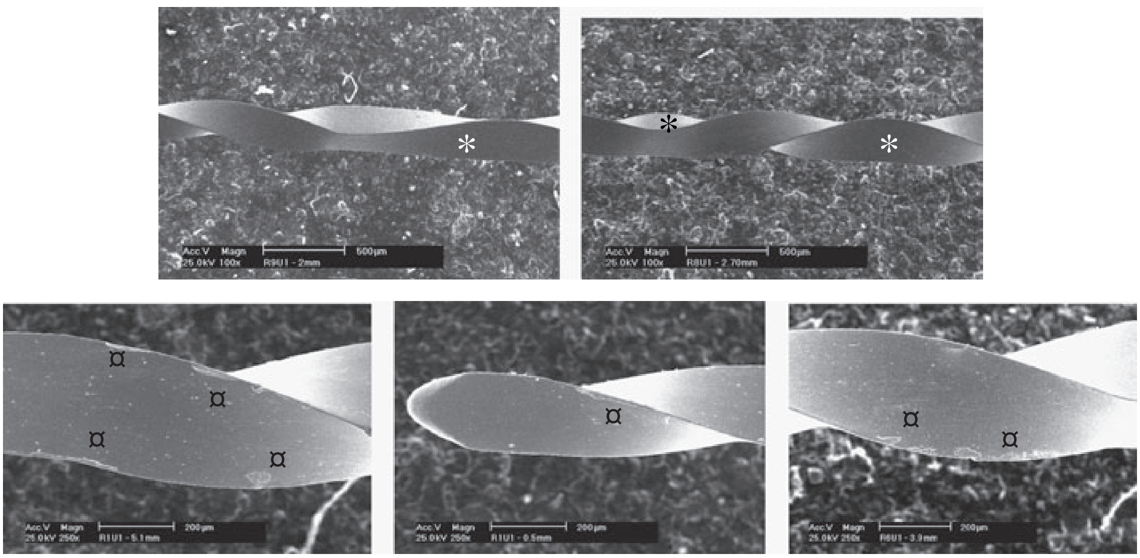


Figure 7 RaCe instrument after first use (*, spiral distortion; ¤, surface wear); 100 to 250× magnification.

and flexural loads. Other studies have also used this instrument (Rapisarda *et al.* 2001, Li *et al.* 2002, Pessoa 2003).

The criteria to determine deformation were established for this study as no previous reports have attempted to evaluate this topic. The images of the

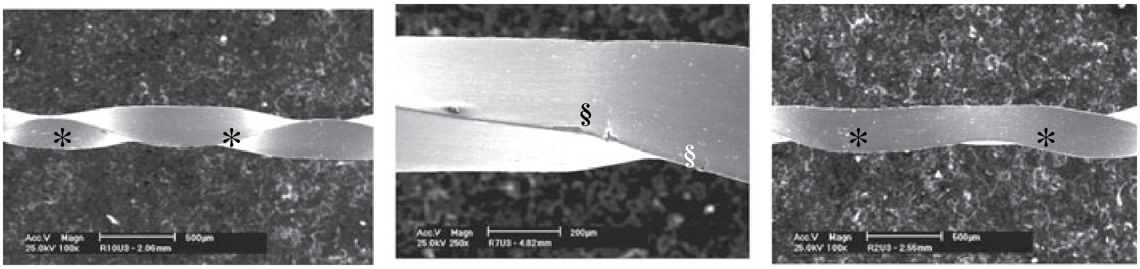


Figure 8 RaCe instruments after third use (*, spiral distortion; ¤, surface wear; §, cracks); 100 to 250× magnification.

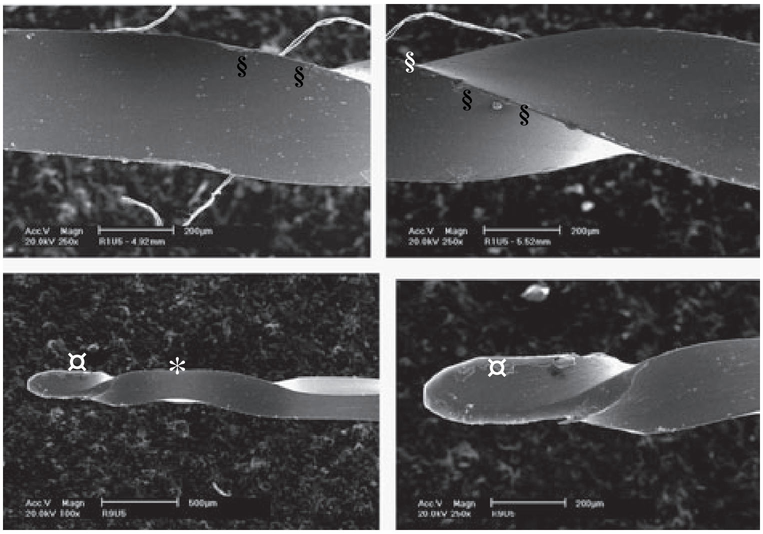


Figure 9 RaCe instruments after fifth use, no fracture (*, spiral distortion; ¤, surface wear; §, cracks); 100 to 250× magnification.

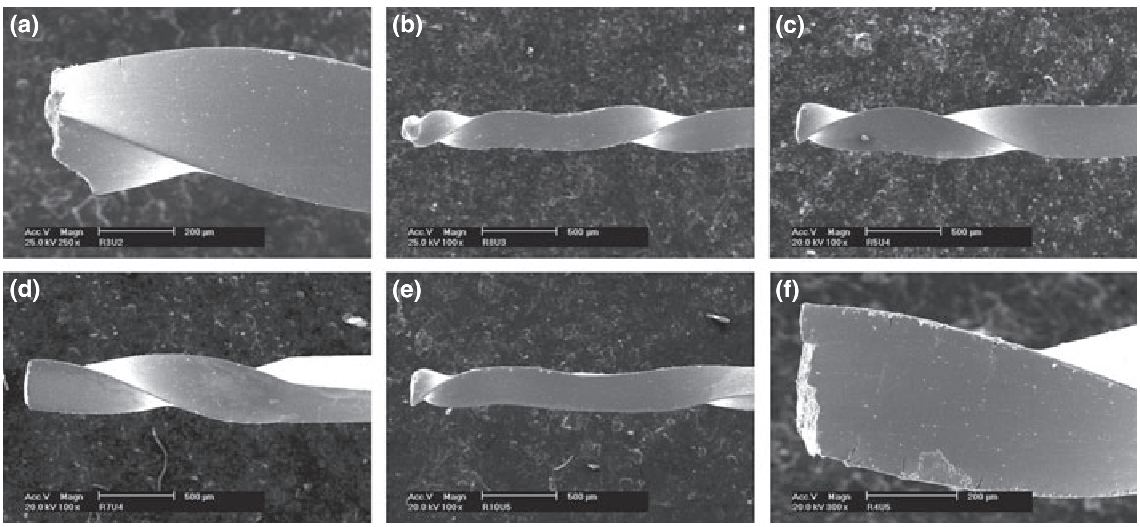


Figure 10 RaCe instruments fractured during study; 100, 250 or 300× magnification (a, fractured at second use; b, at third use; c and d, at fourth use; e and f, at fifth use).

instruments were evaluated by three observers in an attempt to validate the method. Intra-observer calibration was established by the ICC because it is a test capable of establishing general and simultaneous agreement between three different observers.

The results of this study show that spiral distortion and surface wear increased for RaCe instruments as the number of uses increased. These findings are in agreement with other studies that investigated the occurrence of defects on NiTi rotary instruments after use. Several authors (Thompson & Dummer 1997a, 1998, Zuolo & Walton 1997, Svec & Powers 2002) have investigated the effect of use on ProFile (Dentsply Maillefer, Ballaigues, Switzerland) instruments and reported a number of defects, such as unwinding and deterioration of the cutting edges, which increased with prolonged use.

Studies of RaCe instruments after use (Schäfer & Vlassis 2004a,b) found a significant rate of deformation and fracture when these instruments were used in the preparation of simulated curved canals. Similar findings were observed when the instruments were used in root canals of extracted human teeth. In addition, Pessoa (2003) showed that RaCe instruments after five uses had reduced resistance to cyclic fatigue. Fessenden (2004) also found RaCe to be less resistant to torsional load than K3 and Profile. These data are all in agreement with the present findings, which showed a high incidence of deformation and a 60% fracture rate of size 25, 0.04 taper instruments after five uses.

This pattern for RaCe instruments was not observed for the K3 instruments in the present study, which remained intact, with no distortion and little surface wear up to the completion of the fifth use. These findings differ from those reported in the literature. Schäfer & Florek (2003) reported 17 deformed and 11 fractured K3 instruments after the preparation of only one simulated canal with each set of instruments. Schäfer & Schlingemann (2003) found five instrument fractures in the first use when using K3 instruments in the preparation of molar curved canals. This difference may be explained by the fact that their studies enlarged canals to a size 35, 0.06 instrument; the size 30, 0.06 and size 35, 0.06 instruments fractured most frequently. Ankrum *et al.* (2004) reported similar findings, and Yared *et al.* (2003) reported that resistance to torsional fracture of K3 instruments used in the preparation of five simulated root canals was significantly lower than that of new instruments.

The surface wear scores of K3 instruments occasionally decreased from one use to the next in this study. This phenomenon was observed by Eggert *et al.* (1999) when they analysed the effects of use on the surface of Lightspeed instruments using SEM. They attributed this finding to the possibility that, each time the instrument came into contact with the canal walls, its surface was abraded. This would make surface defects, such as areas of surface wear, disappear.

Of the six fractures, all were ductile and four of them were preceded by deformation at the site were the fracture later occurred. Unfortunately, this previous deformation could only be identified by SEM at ×100 magnification. In addition, of the six fractures, three were torsional and three flexional; four occurred in type D canals (40 degree curvature, beginning at 12 mm) and two in type B canals (20 degree curvature, beginning at 12 mm). This demonstrates the importance of carefully considering the radius of the curvature and not only its degree.

One limitation of this study was the fact that it was conducted with simulated canals. Although Stycast resin closely simulates the hardness of dentine, the findings cannot be directly transposed to clinical practice, mainly because of the circular cross-section of simulated canals, which will influence the torsional load of instruments (Peters & Barbakow 2002). Schäfer & Vlassis (2004a,b) reported similar findings of deformation and fracture of RaCe instruments when working with teeth and simulated canals. However, Schäfer & Florek (2003) and Schäfer & Schlingemann (2003) found lower deformation and fracture rates of K3 instruments for teeth than for simulated canals. Peters & Barbakow (2002) compared the torque generated by the instrumentation of natural canals (dentine) and simulated canals (resin) and found higher torque values for simulated canals, which also required a greater number of rotations to complete each phase of the canal preparation using the crowndown technique. This may mean that if an instrument resists the tension produced by contact with the resin of the simulated canal until after the fifth use, as was the case for K3 instruments in this study, their resistance in natural canals is probably even greater. Conversely, the fact that RaCe instruments showed great deformation after five uses in simulated canals should be carefully considered, because there is no evidence that the same would occur if the instruments were used in the preparation of natural tooth canals.

Conclusions

Under the conditions of this study, it may be concluded that:

1. Deformation and fracture were not observed for the K3 size 25, 0.04 taper instruments and wear was not obvious after five uses.

2. The continued use of RaCe size 25, 0.04 taper instruments progressively increased deformation rates, i.e. distortion of spirals and surface wear scores.

3. A significant difference was found between the two systems in deformation and fracture of size 25, 0.04 taper instruments; K3 instruments had more favourable results than RaCe instruments.

4. Simulated canals with smaller curvature radius led to more fractures of RaCe instruments.

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