Rotary Ni-Ti profile systems for preparing curved canals in resin blocks: influence of operator on instrument breakage

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Abstract

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Aim The aim of this study was to determine the incidence of fracture of ProFile 0.4 and 0.6 taper *Series 29* nickel-titanium instruments with respect to operator experience.

Methodology A total of 125 simulated root canals in resin blocks with the same geometrical shape in terms of angle and radius of curvature and coronal and apical orifice diameter were used. Five operators prepared all the specimens using an identical step-down instrument sequence, each one preparing 25 canals. The operators included two endodontists and three general practitioners. Statistical data concerning the incidence of instrument failure was compiled using Statlab and Fisher's partial least square difference analysis of variance.

Results A total of 21 (16.8%) instruments fractured, all had 0.04 tapers. Nine size 25 instruments failed, 9 size 20 instruments failed and 3 size 15. During the study, the Binary Tree analysis of instrument failure revealed two operator populations belonging to two different study periods. The first period, which represented the first 13 root canal preparations, was called the 'learning period', and the second period, which represented the next 12 sample preparations, was called the 'application period'. A greater number of instruments failed during the first period than during the second. In the 'learning period', both groups of operators learned the same way. In the 'application period', two groups could be distinguished; the first group consisted of a general practitioner who produced worse results, and the second group consisted of the other four operators.

Conclusions The results indicate the necessity of mastering this rotary canal preparation technique, and the importance of improving competence through learning and experience.

Keywords: instrument fracture, Nickel-Titanium, root canal preparation, rotary files, simulated canals.

Introduction

The cleaning and shaping of root canals are important phases in root canal therapy. The clinical goal is to satisfy biological and mechanical objectives. A total debridement achieves the first objective, and developing a continuously tapering conical form and maintaining the original shape and position of the apical foramen achieves the second (Schilder 1974). These objectives are simple to satisfy in relatively straight root canals. However, total debridement of curved canals is difficult and poses a challenge clinically. Moreover, during preparation of narrow and curved canals, instrument breakage, ledging, blockages, root perforation, apical zipping, elbowing, strip perforation and extrusion of the debris are frequently encountered, as demonstrated by Weine

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et al. (1975). These procedural accidents, called 'mishape' by Torabinejad (1990), seem to develop to a variable degree independent of the instrumentation techniques and devices (McKendry 1990, Lim & Stock 1987) and of the differently designed instruments used (Martin & Blaskovic-Subat 1997, Luiten *et al.* 1995, Al-Omari *et al.* 1997). Instrument breakage is a serious concern in the preparation of root canals. Because stainless-steel instruments usually deform before they break, one can inspect them for visible signs of damage. A suspect instrument usually exhibits severe deformation of the flutes, indicating that the elastic limit of the metal has been exceeded and the instrument should be discarded.

More recently, Nickel-Titanium (Ni-Ti) endodontic instruments were introduced to facilitate instrumentation of curved canals. Ni-Ti instruments are known to be superelastic and will flex far more than stainless-steel instruments before exceeding their elastic limit (Walia *et al.* 1988). This flexibility is an important property which facilitates preparation of a curved canal whilst minimizing procedural accidents and 'mishape' generally associated with stainless-steel instruments larger than size 30 (Esposito & Cunningham 1995). Early studies by Zmener & Balbachan (1995) on extracted maxillary incisors showed that more centred and tapered preparations were obtained with the use of the Ni-Ti files than with the conventional K-type files. Since then, other studies have confirmed these findings (Bou Dagher & Yared 1995, Lodd Tharuni *et al.* 1996, Bishop & Dummer 1997). The unique low modulus of elasticity of Nickel-Titanium has also allowed instruments to be manufactured for use in a continuously rotating handpiece which has been shown to be effective in canal instrumentation (Glosson *et al.* 1995). Further developments include the introduction of files of increased taper such as a ProFile 0.04 and 0.06 taper series 29 instruments (Maillefer, Ballaigues, Switzerland). Generally, studies have concluded that canal shape was maintained by rotary Ni-Ti ProFiles, and this has also been associated with a saving of time (Thompson & Dummer 1997a, 1997b). In an evaluation *in vitro* of canal preparation using ProFile 0.04 and 0.06 taper instruments compared with ProFile hand Files, Kavanagh & Lumley (1998) concluded that apical canal transportation showed no significant differences between techniques. These results indicate that the use of 0.06 taper files and Orifice Openers improves canal shaping compared to 0.04 taper files alone and hand instrumentation. It was noticed, however, that two rotary 0.04 tapers fractured in the 20 mesiobuccal root canals of maxillary molars included in this study, which represents a relatively high incidence of failure. Thus, despite the superior bending flexibility, instrument separation is still a concern with Ni-Ti instruments, and unexpected fracture has been reported in an early study (Zuolo & Walton 1995).

The study by Pruett *et al.* (1997) introduced, for the first time, a new parameter to describe canal curvature. This parameter, rather than the angle of the curvature, as described by Schneider in 1971, demonstrates differences in the abruptness of the curve. Moreover, these results indicate that, for Ni-Ti engine-driven Profile Rotary root canal instruments, the radius of curvature, angle of curvature, and instrument diameter are more important than operating rotation speed for predicting fracture. The purpose of this study was two-fold: first, to determine the incidence of Profile Rotary Ni-Ti Profile instrument fracture during instrumentation of simulated narrow and curved artificial canals when all other parameters such as angle of the curvature, radius of the curvature, and instrument sequence remain the same and secondly, to determine the incidence of this failure with respect to the operator experience.

Materials and methods

A total of 125 simulated canals in clear resin blocks (Maillefer-Caulk Dentsply) were manufactured in such a way that they all had perfectly round cross-sections and the same reproducible geometric proportions, including radius of curvature, angle of the curvature, coronal access orifice, and apical orifice diameter. The radius of curvature and the angle of the curvature were determined according to the Pruett *et al.* (1997) method. The simulated root canals used in this study all had an angle of curvature equal to 50° and a radius of curvature equal to 6.5 mm. The radius of curvature is the radius of a circle that coincides with the path taken by the canal in the area of the most abrupt curvature. A more abrupt curve corresponds to a smaller radius of curvature. The angle of curvature is formed between the points of deviation on the circle, or the angle formed between the perpendicular lines drawn from the tangents intersecting at the centre of the circle (Fig. 1). The 125 samples were divided into five groups A, B, C, D and E, each one consisting of 25 preparations. Each group was instrumented by a different operator, and the operators included two endodontists and three general practitioners.

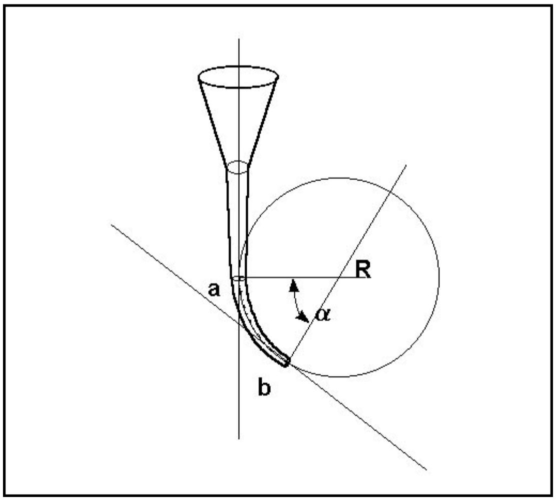


Figure 1 Degree of canal curvature determined according to method of Pruett *et al.* (1997). Radius of curvature (R) and angle of curvature (α) were the parameters taken into account in describing canal geometry of samples used in this study. Angle of curvature is determined, using a circle gauge, of the angle formed by the line that intersects the circle centre. Points *a* and *b* are the points where the canal deviates from the straight lines at the beginning and end of the curved path of the canal. Angle *a* is the angle formed by the arc in degrees between points *a* and *b*. The 'R' is the circle's radius of the curved portion of the artificial canal and defines the degree of the curve's abruptness.

Instruments

Ni-Ti Profile instruments are made from nickel-titanium and have two taper sizes: 0.04 and 0.06. The taper of the instrument affects the increase in file diameter along its cutting length, e.g. for ISO standard instrument of 0.02, taper D2 is 0.32 mm wider than D1; for a 0.04 ProFile instrument D2 is 0.64 mm wider than D1, and for ProFile 0.06 tapered instrument D2 is 0.96 mm wider than D1. The file design incorporates the U-type pattern with flat radial lands, and noncutting tip. The rate of increase in diameter of the tips between files is a constant 29% so that compared to the ISO standards, there is a much greater incremental increase in size with larger instruments than with the lower size range (Table 1). The references of the Profile instruments (i.e. size 15, size 20 or size 25) used in the present study are the manufacturers' references and are not ISO root canal instrument sizes.

Simulated canals

Manufactured simulated curved root canals embedded in clear casting resins with standardized canal shape were used (Maillefer-Caulk Dentsply).The apical orifice of the simulated canal was opened on the side of the resin block, its diameter was 10/100 mm, whilst the coronal orifice was opened on the top of the resin block, with a diameter was 50/100 mm. A conical 'access orifice' was present at the coronal orifice (3 mm diameter, 5 mm deep). (Fig. 2).

Instrumentation of simulated canals

Each group of 25 simulated canals was prepared by a different operator. A total of 125 units were prepared by five operators A, B, C, D and E. Working length for each block was 21 mm and instrumentation was performed 0.5 mm short of the apical orifice. All groups were instrumented with Rotary Ni-Ti ProFile Variable Taper series 29 System engine-driven instruments using a high torque handpiece (Maillefer, Ballaigues, Switzerland). Instruments were moved in a predetermined rotary motion at a speed of 315 r.p.m. during root canal instrumentation for all five groups. Copious irrigation with water was performed before and after the use of each instrument using disposable syringes (Monoject, Ballymoney, N. Ireland) and 27 gauge irrigating tips (Endo-Tips, Ultradent Products Inc., Utah, USA). Approximately 25 mL of water was used per canal. Prior to use, each file was coated with RC-Prep. (Premier Dental Products Co., Philadelphia, PA, USA) to act as a lubricant. Files were wiped regularly on a sponge to remove resin debris. The instrumentation sequence was identical for all five experimental groups using a modified double flare concept (Fava 1983) with coronal preparation being performed first in a crown-down

Table 1 Manufacturer's specifications of the Profiles used in this study (according to Maillefer, Ballaigues, Switzerland)

Taper	0.06		0.04		
Manufacturer's size	No. 20	No. 25	No. 15	No. 20	No. 25
Length of the U-type flat radial land			16mm		
Noncutting tip diameter (D1)	18/100 mm	22/100 mm	13/100 mm	18/100 mm	22/100 mm
Max working diameter (D2)	114/100 mm	118/100 mm	77/100 mm	82/100 mm	86/100 mm

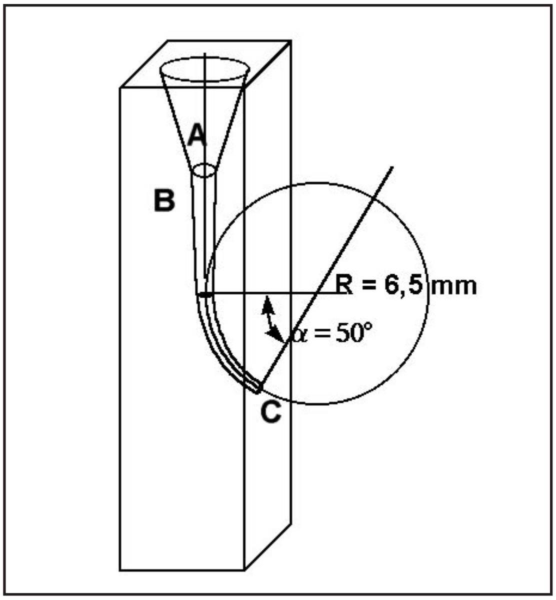


Figure 2 Manufactured simulated root canals in resin: A: 'access orifice' (3 mm diameter, 5 mm deep); B: 'coronal orifice' (diameter 0.50 mm); C: 'apical orifice' (diameter 0.1 mm).

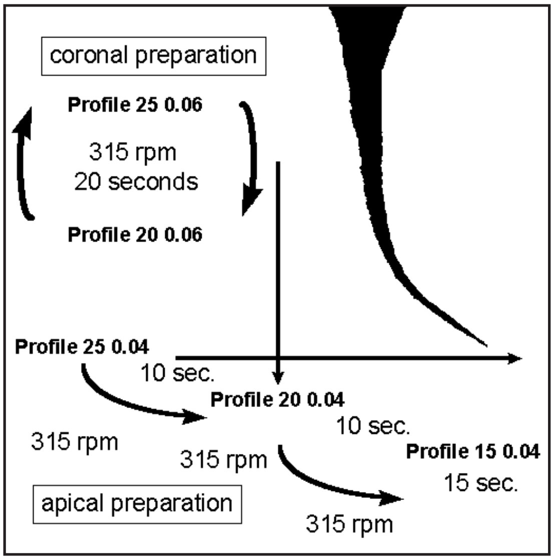


Figure 3 Identical instrumentation sequence carried out for five experimental groups using a modified double flare concept, with coronal preparation being performed first in a crown-down manner, followed by apical shaping.

manner followed by apical preparation including two steps as recommended by the manufacturer. These were (Fig. 3):

A) Preflaring of the accessible canal path above the apical curvature

1. A size 25 Profile 0.06 taper in the Ni-Ti Matic handpiece (1 : 16, Anthogyr, Sallanches, France) was inserted to preflare the accessible coronal path of the canal in an apical direction, i.e it was slowly advanced with light apical pressure until resistance was encountered. The file was withdrawn 2 or 3 mm and then reinserted until the file again engaged the canal walls. Once apical resistance was detected, this type of pumping action was continued until the file had rotated for 20 s. It was then removed.
2. A size 20 Profile 0.06 taper was subsequently inserted to prepare a coronal portion closer to the apical curvature, using the same motion. Once the file had negotiated to this length and had rotated for 20 s, it was removed.
3. The patency of the apical orifice was then checked with size 08 pathfinder manual precurved K-File.
4. Steps 1 and 2 were repeated in order to improve the preflaring of the walls, but at a depth closer to the apical curvature.
5. The patency of the apical orifice was then checked as described in step 3.

B) Apical path instrumentation

1. A size 25 Profile 0.04 taper was used to prepare an accessible apical curvature of the canal in a gentle in-and-out (pecking) motion. Once the file had rotated freely for 10 s, it was removed.
2. A size 20 Profile 0.04 taper was used to prepare an accessible path of apical curvature closer to the apical orifice with the same motion as described in the previous step.
3. A size 15 Profile 0.04 taper was used to prepare the ultimate working length of the canal. Once the file had rotated freely for 15 s, it was removed.
4. The patency of the apical orifice was then checked as described above. All the files used in this study were not precurved except for the size 08 pathfinder manual K-File. Files with 0.06 taper were used twice, whereas files with 0.04 taper were changed for the preparation of each sample.

Assessment of instrument fracture

An assessment was made in terms of distribution of total number of fractured instruments in each group of 25 units and between the five groups during instrumentation of the 125 simulated canals. Statistical data concerning the incidence of instrument failure was gathered using StatLab (StatLab 3.02 version SLP Infoware, Chicago, IL, USA) and Fisher's partial least squares difference analysis of variance to determine if there were significant differences between the five instrumentation groups using $P > 0.95$ ($\alpha < 5\%$) in terms of instrument failure. Means and standard deviation (SD) were calculated for this variable.

Results

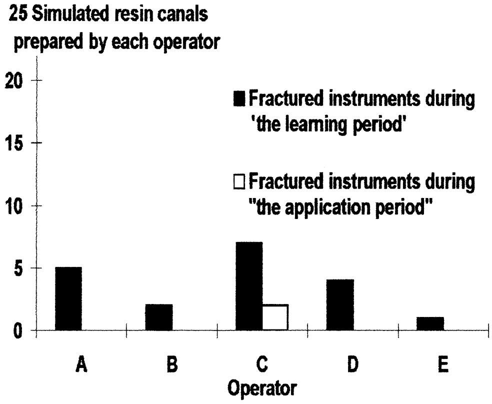
Inter- and intragroup analysis of instrument fracture

There were a total of 21 fractured instruments (16.8%). Instruments did not fracture at the head, but rather at the point of maximum flexure of the shaft, corresponding to the midpoint of the curvature within the simulated root canals. The incidence of total fractures between the five groups was not uniform. The distribution of this failure for the first 13 units and the 12 following, within each group, is not equal (Fig. 4). In each group of 25 units, a greater number of instruments failed during the first 13 simulated canal preparations ('learning period') than during the next 12 preparations ('application period'), and the differences in the mean values of the five groups is great enough to raise the possibility that these differences are not due to random sampling variability. There was a statistically significant difference between the study groups ($P = 0.999$).

The binary tree analysis of the relative number of instrument failures during instrumentation of the 125 samples shows an increase in the operators' competence throughout the preparation of the 25 canals in each group, according to these two periods (Fig. 5). Instrument failure always occurred with the 0.04 tapered files and there were nine failures using the size 25 files, nine failures using the size 20 files and three failures using the size 15.

Discussion

This study explains the circumstances in which instrument breakage occurs during rotary Ni-Ti ProFile instrumentation. When the other factors, such as canal geometry of the canal and instrument sequence and rotary speed are maintained as constants, the ability of the operator seems to be an important clinical factor of instrument failure. Under these conditions, the results of the present study suggest that the effect of operator experience as an independent variable was the most consistent and predictible parameter in instrument fracture, whilst other parameters remained identical. This must be considered when evaluating studies of Profile canal instrumentation. In an experimental study of cyclic fatigue of Ni-Ti engine-driven instruments carried-out by Pruett *et al.* (1997), the effect of canal curvature and operating speed on the breakage of instruments was determined. This explains why the samples used in the present study included 125 artificial canals having a standardized radius of curvature, using identical instrument sequence but including five different operators. Using the method described by Pruett *et al.* 1997, the geometrical parameters determining the curvature path shape of



Operator	Fractured instruments during the 'learning period'	Fractured instruments during the 'application period'	Total fractured instruments
A	5		5
B	2		2
C	7	2	9
D	4		4
E	1		1
Total	19	2	21

Figure 4 Instrument fractures during the first 13 referred to in the text as the 'learning period' and the subsequent 12 canal instrumentations referred to as 'application period', does not show a homogeneous distribution amongst the five groups of operators.

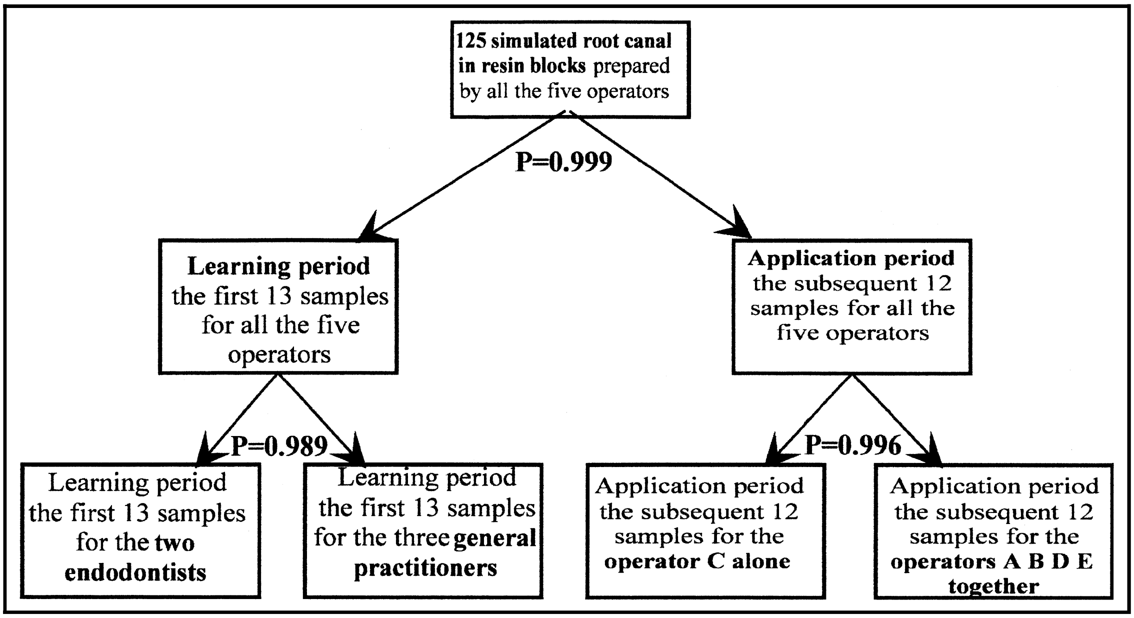


Figure 5 The birary-tree analysis of instrument fractures: The binary tree analysis of instrument failure amongst the 125 simulated root canal preparations by the five operators reveals two different periods ($P = 0.999$). The first period, which represents the first 13 root canal preparations, is called the 'learning period', and the second period, which represents the next 12 samples preparations, is called the 'application period'. During the 'learning period' one can separate the endodontists and the general practitioners ($P = 0.989$). During the 'application period' all the operators except one seems to be working in the same way. ($P = 0.996$).

the artificial canals used in this study had a 6.5-mm radius of curvature determining a relatively abrupt canal curvature. The angle of the curvature of the artificial canals was 50 degrees. In the present study, there were 21 fractured instruments amongst the 125 instrumented simulated canals prepared. Instruments did not separate at the head, but rather at the point of maximum flexure of the shaft, corresponding to the midpoint of curvature within the simulated root canals (Fig. 6). This corroborates the results of the Pruett *et al.* (1997) study, which showed that the instruments with larger diameter shafts, size 40, failed after significantly fewer cycles than did the size 30 instruments under identical test conditions. However, the present results indicate that with the same root canal curvature abruptness and the same operating speed, the duration of the rotation, which was 20 s for the sizes 25 and size 20 taper 0.04 and 15 s for the size 15, should be considered as an important variable in instrument breakage. In other words, more than operating speed, the number of rotations seem to determine the number of the cycles to failure. In fact, it has been found that metal fatigue leading to breakage is caused by canal curvature (Sotokawa 1988). Each rotation within a curved canal causes a Ni-Ti engine-driven instrument to undergo one complete tension-compression stress cycle which is the most destructive form of cyclic loading. Such fatigue mechanisms occur microscopically within the elastic limit of the metal and therefore are not detectable to the eye; visible inspection is thus not a reliable method for evaluation of used Ni-Ti instruments. Pruett *et al.* (1997) also introduced the concepts of cyclic fatigue failure which occur at the point of maximum flexure of the shaft, corresponding to the midpoint of curvature. It must be noted, however, that in the Pruett *et al.* (1997) study, instruments were able to rotate freely in the test apparatus, whereas, in the present study using fine, simulated curved root canals, rotary instruments underwent a torque effect on their tip. Under these dynamic conditions, resistance of engine-driven rotary instruments to torsional loading is reduced and sudden instrument breakage occurs more frequently. In addition, cross-sections of the simulated root canals used in the present study had a perfectly round shape, whereas, generally, the more curved and fine the canal is, the more oval or ribbon-shaped it is in cross-section.

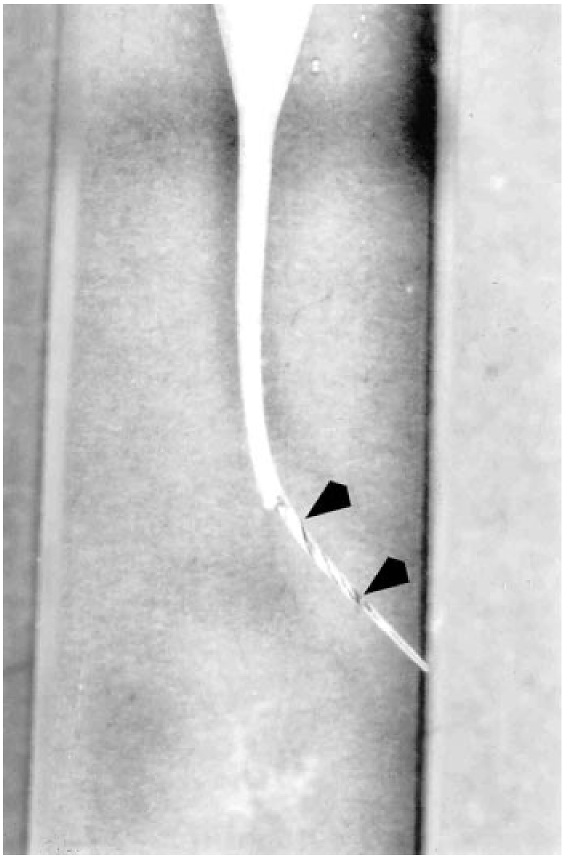


Figure 6 Instrument fracture occurred not at the head, but rather at the point of maximum flexure of the shaft, corresponding to the mid-point of curvature within the simulated root canals.

The number of instrument fractures was not the same for each operator; it was five for operator A, two for B, nine for C, four for D and one for E. During the 'learning period', the best results were found amongst the more experienced operators (operators B and E), who were endodontists, than amongst the less experienced operators (operators A, C and D) who were general practitioners (Fig. 7 a,b). During the 'application period', all operators showed similar results, except operator C who used the technique less efficiently. On the other hand, the incidence of instrument failure in each group decreased during the instrumentation of the 25 blocks, which showed that there is a 'learning process' during instrumentation of the 25 units by each operator. The results of the present study indicate the necessity of mastering this new technique and the importance of improving operator competence through learning and experience.

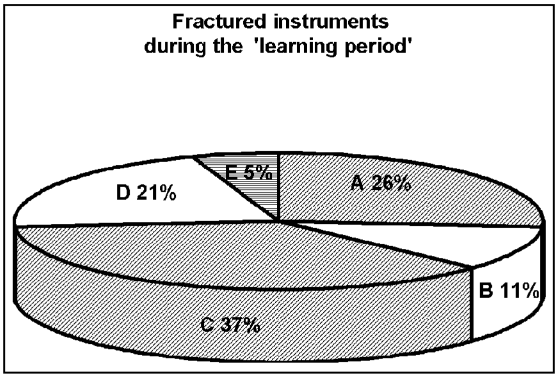


Figure 7a During the 'learning period', the number of instrument fractures is five for operator A; 2 for B; 7 for C; 4 for D; and one for E. The best results were found amongst the more experienced operators (operators B and E) who were endodontists, than amongst the less experienced operators A, C and D) who were general practitioners.

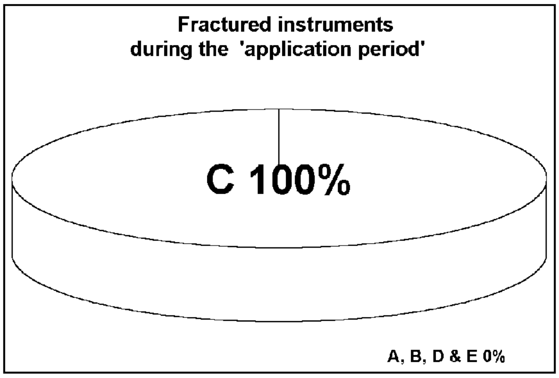


Figure 7b During the 'application period' all operators, operator C excepted, showed similar results: no fracture happened. Operator C broke twice because he used the technique with less efficiency.

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