A reconstructed computerized tomographic comparison of Ni–Ti rotary GT™ files versus traditional instruments in canals shaped by novice operators

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Abstract

Gluskin AH, Brown DC, Buchanan LS. A reconstructed computerized tomographic comparison of Ni–Ti rotary GT™ files versus traditional instruments in canals shaped by novice operators. *International Endodontic Journal*, **34**, 476–484, 2001.

Aim The aim of this study was to compare the effects of preparation with conventional stainless steel Flexofiles® and Gates Glidden burs versus nickel–titanium GT™ rotary files in the shaping of mesial root canals of extracted mandibular molars.

Methodology A total of 54 canals from 27 mesial roots of mandibular molar teeth were prepared using one of two methods by novice dental students. One canal in each root was prepared by a crown-down approach, utilizing stainless steel Flexofiles® and Gates Glidden burs. The other canal was prepared using nickel–titanium GT™ rotary files in a crown-down fashion as recommended by the manufacturer. Preoperative CT scans of each root were recorded and 50 canal specimens were available for postoperative comparisons. Following canal shaping, postoperative scans were superimposed on the original images. Changes in canal area, canal transportation and thickness of remaining root structure at strategic levels of the root were analyzed. The time taken for each method was also noted.

Results At the coronal and mid-root coronal one-third sections, the rotary GT™ files produced a significantly smaller postoperative canal area ($P < 0.05$). In the mid-root sections there was significantly less transportation of the root canal toward the furcation, and less thinning of the root structure with GT™ files compared to the stainless steel files ($P < 0.05$). Overall, there was greater conservation of structure coronally and more adequate shape in the mid-root level. The GT™ rotary technique was significantly faster than the stainless steel hand-held file technique ($P < 0.0001$). Two GT™ instruments fractured during the study.

Conclusions Under the conditions of this study, novice dental students were able to prepare curved root canals with Ni–Ti GT™ rotary files with less transportation and greater conservation of tooth structure, compared to canals prepared with hand instruments. The rotary technique was significantly faster.

Keywords: canal shaping, canal transportation, computerized tomography, nickel–titanium rotary files, remaining root structure, 3D reconstruction.

Received 16 May 2000; accepted 25 October 2000

Introduction

Contemporary literature contains numerous assessments of cleaning and shaping, undertaken in a range of experimental models. These studies have compared and contrasted types and styles of instruments as well as rotary and hand systems for root canal shaping (Gambill *et al.* 1996, Coleman & Svec 1997, Tucker *et al.* 1997, Pettiette *et al.* 1999, Porto Carvalho *et al.* 1999). Researchers have investigated cleanliness (Hülsmann *et al.* 1997), canal transportation and shape (Calhoun & Montgomery 1988, Gambill *et al.* 1996, Kosa *et al.* 1999), and debris extrusion (Al-Omari & Dummer 1995). The investigations have additionally evaluated mishap outcomes such as ledging, instrument breakage, strip perforation, and structural loss after cleaning and

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shaping of root canals (McCann *et al.* 1990, Isom *et al.* 1995, Pettiette *et al.* 1999). One of the most popular methods of evaluation is the *in vitro* 'muffle system' or a variation (Bramante *et al.* 1987, Hülsmann *et al.* 1999) which provides a plaster block around a resin-indexed experimental tooth. The block can be custom-machined and sectioned in various planes to allow exact repositioning of the complete block or sectioned parts of the tooth. Simultaneous evaluation of numerous parameters are possible, such as canal area, shaped form, and centring (Calhoun & Montgomery 1988, Short *et al.* 1997, Kosa *et al.* 1999). Another key advantage that has been exploited by the muffle system is that data can be gathered both pre- and postoperatively. The pre- and postoperative measurements can be compared and statistically contrasted. Evaluations of shaping with and without the muffle system have been made using the scanning electron microscope (Hülsmann *et al.* 1997), radiographic evaluation (Esposito & Cunningham 1995, Pettiette *et al.* 1999), photographic assessment (Barthel *et al.* 1999), and computer manipulation (Coleman & Svec 1997, Tucker *et al.* 1997, Porto Carvalho *et al.* 1999) for comparative analysis. Most of these methodologies compared the root canal system before and after shaping.

Finally, a non-destructive technology has been advocated for the comparison of pre- and postinstrumentation images. Micro-computed tomography can render cross-sectional (cutplane) and 3D images that are highly accurate and quantifiable (Nielsen *et al.* 1995, Bjørndal *et al.* 1999, Rhodes *et al.* 1999). Comparisons using computed tomography have provided repeatable and non-invasive experimentation of various aspects of endodontic instrumentation (Gambill *et al.* 1996).

Several investigators have elucidated the instrumentation outcomes of traditional ISO standardized instruments in the hands of both seasoned and novice practitioners, especially when trying to create a tapered root canal preparation (Weine *et al.* 1975, Kessler *et al.* 1983, Esposito & Cunningham 1995, Pettiette *et al.* 1999). Contemporary objectives of root canal shaping advocate a continuously tapered and flowing conical form with the smallest diameter at the end-point of the preparation. Most difficult for novice practitioners is the significant challenge to measure and create safe and tapered canal shapes with traditional ISO instruments.

Recently a series of Greater Taper™ nickel–titanium rotary files has been introduced (Dentsply/Tulsa Dental, Tulsa, OK, USA; Dentsply/Maillefer, Ballaigues, Switzerland). These files have maximum flute diameters of 1.0 millimetre and exhibit flute tapers that are three, four, five and six times the standardized ISO 0.02 taper.

The purpose of this investigation was to compare the effects of preparation by traditional ISO stainless steel files and two Gates Glidden burs to an all-rotary technique with three nickel–titanium GT™ files.

Materials and methods

Twenty-seven mesial roots exhibiting a total of 54 separate canals in extracted human mandibular molars were used in the study. All roots were selected on the basis of mature apices and a range of canal curvature from slight to severe and two distinct, separate canals and portals of exit. All canals with abrupt canal curvatures, contraindicated for rotary file use, were eliminated.

Standard access cavities were made, and the teeth were sectioned into mesial and distal halves. Each canal was negotiated by a trained endodontist, using a no. 8 through 15 hand-held stainless steel file, until the no. 15 file was visible apically, flush with the root surface. The length of the file from a fixed reference point coronally to the foramen was recorded for each canal. The mesial roots were radiographed from the mesio-distal and bucco-lingual views to assess anatomy and canal curvature, using a computed dental radiography system (Schick Technologies Inc., NY, USA). Direct measurement of root canal curvatures were made from the images according to the Schneider (1971) technique. Whichever curvature was the larger (MD or BL) was recorded as the curvature. This was done for both mesial canals of each root. Students exhibiting a range of clinical skill abilities, as demonstrated by class ranking, were selected to provide a balanced group of operators. The teeth were randomly distributed within this group.

Image analysis

The mesial roots were X-rayed, both pre- and postoperatively, using a high-resolution industrial CT scanner (G. E. non-Destructive Testing Lab, Cincinnati, OH, USA) with each tooth being scanned at 50 micron intervals for a total of approximately 400 cross-sectional CT views per tooth. These 2D data were reconstructed into 3D voxel models using a silicon graphics workstation and G.E.'s PointCloud reconstructive software. For the purposes of this study, a total of four horizontal cutplanes from each root were viewed through the voxel model. The first two cutplanes were 1 mm from the apical end of the root (apical level) and 1 mm below the orifice (coronal level).

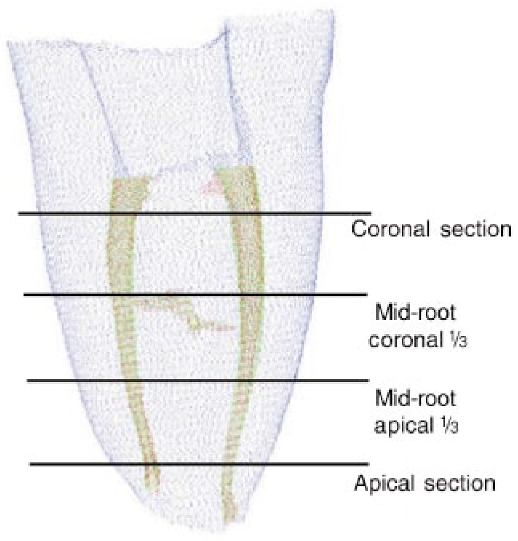

Figure 1 Illustration of the CT reconstruction cutplane levels.

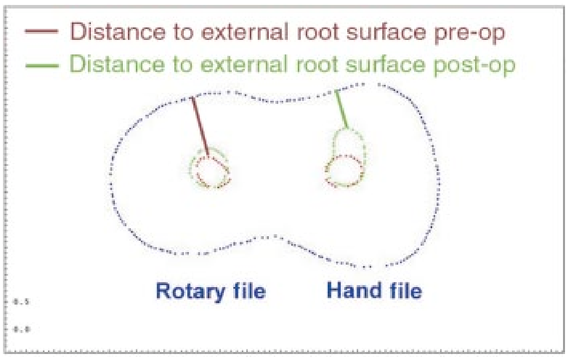

Figure 2 Graphic of computed pre-/postoperative canal distance to the nearest external root surface.

Two further sections were recorded, dividing the distance between the cutplanes into three equal lengths (Fig. 1). The preoperative and postoperative cutplanes were programmed to be in identical positions through the voxel model. All CT images were imported to a Macintosh PowerBook G3 computer (Apple Computer, Cupertino, CA, USA). The Image 1.55 software package (NIH Bethesda, MD, USA) was used for image analysis. Canal outlines were traced at each level. The area of the canal and the shortest distance from the canal wall to the nearest root surface at these four levels were measured to the nearest 0.01 mm (Fig. 2). The preinstrumentation and postinstrumentation images were superimposed for comparison to obtain data on the effects of instrumentation.

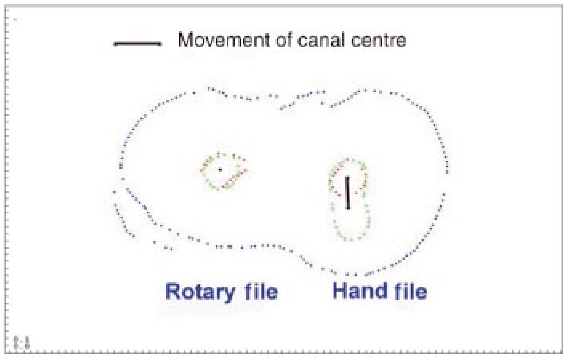

Figure 3 CT cutplane illustrating extent of canal centre movement.

Instrumentation protocol

Method 1

Each root had a single mesial canal shaped using a crown-down technique and stainless steel Flexofiles® and two Gates Glidden burs (nos 2, 3, Dentsply/Maillefer).

Method 2

The other canal was prepared using three Ni–Ti GT™ rotary files in a crown-down method (nos 20–.10, 20–.08, 20–.06, Dentsply/Tulsa Dental). Canals were prepared by dental students at the University of the Pacific School of Dentistry. The students had completed 24 h of formal preclinical endodontic training in the use of traditional instruments. The experimental group of students were selected from all levels of the class ranking. Each had additionally treated an average 10 clinical canals using the UOP crown-down step-back procedure with Flexofiles®. The students were given a 30 min tutorial and practical demonstration of the GT™ rotary system prior to the study. This was the first time that the students had worked with the rotary system. A student who had prepared the mesiobuccal canal with method 1 used method 2 to prepare the mesiolingual and vice versa. An equal number of lingual and buccal canals were prepared by each technique. All canals were negotiated to a no. 15 and lengths were determined by the authors prior to student manipulation to control procedural errors.

Method 1

The basic crown-down methodology of instrumentation taught at UOP, namely crown-down step-back using stainless steel Flexofiles® and Gates Glidden burs, was followed. The technique is: Patency verified with a no. 10 file. A no. 15 file placed to the canal terminus (this length was supplied to the student preoperatively). File cycling in the coronal half of the canal was performed to obtain good coronal access, using both Balanced Force and circumferential manipulations. File cycling is defined as using a series of files to create shape from coronal to apical. Radicular access was completed using a Gates Glidden 2 and 3. When the student felt the canal was wide enough to receive the instruments, the Gates Glidden burs were to be placed passively with minimal binding. Patency was maintained and demonstrated with a 10 file throughout the procedure. Apical terminus preparation involved a 20 file taken to the terminus, 25 to within 0.5 mm, 30 to within 1 mm, 35–2.0 mm, 40–3.0 mm, and a 45–4.0 mm. In canals with higher curvatures, the 35, 40 and 45 were taken to lesser depths in the step-back. Gentle push–pull filing was used with precurved files in the apical third.

Method 2

Canal preparation was completed using three Ni–Ti GT™ rotary files in a crown-down mode as recommended by the manufacturer. The technique was: Patency verified with a 10 file. A 15 file placed to canal terminus (length supplied to student preoperatively). All canals were prepared with a MicroMega MM324 gear reduction rotary hand piece (Besançon, France), using a speed of approximately 300 r.p.m. The crown-down phase involved using a 0.10 GT™ followed by a 0.08 and 0.06 GT™ rotary file, each of them taken to comfortable lengths without any force. The files were removed as soon as they stopped advancing apically during cutting, the flutes cleaned, and the GT™ file was used again. If the flutes were free of debris, the next narrower instrument in the sequence was chosen for continued shaping. If the 0.06 taper file reached the canal terminus, preparation was considered to be complete. If the 0.06 did not reach the canal terminus, further coronal shape was developed using the 0.10 and 0.08 to successive deeper positions in the canal. The final stage then involved placing an 0.06 taper GT™ rotary file to the canal terminus in a final crown-down mode.

All canals in both groups were copiously irrigated with 2% sodium hypochlorite before preparation and after use of each instrument using disposable syringes. Approximately 30 mL of sodium hypochlorite were used per canal. Files were wiped regularly on a sponge to remove dentine debris. Canal lubrication was accomplished with Glyde® (Dentsply/Maillefer). Maintenance of patency was confirmed throughout the procedure. All teeth were hand held throughout the procedure. Each set of instruments was used to prepare only one canal. The length of time taken to prepare each canal was recorded by the investigators to the nearest second.

Following instrumentation, the preoperative and postoperative CT reconstructions were superimposed and the canal circumferences were traced using the Image 1.55 software. Only areas that could reasonably be expected to be reached by instruments were traced. Narrow communications between canals were excluded. Figure 3 represents a typical CT model tracing. The postinstrumentation canals were compared at each level, and the amount and direction of transportation was measured by assessing the change in canal centre position. Canal centre was determined by the measurement macros plug-in of the Image 1.55 software. Postoperative canal areas and the shortest distance from the canal outline to the closest adjacent root surface were also measured by the Image 1.55 software. These data, as well as the length of time for preparation, were statistically analyzed using ANOVA to determine significant differences between the two groups at the $P = 0.05$ level.

Results

In total, 25 postoperative mesial root scans were deemed acceptable for data analysis. Two reconstructions in which instrument separations occurred in the teeth were not used. This allowed for data from 50 canal specimens.

Instrument failure

There were two GT™ rotary files that separated during preparation (one 0.06 GT™ and one 0.08 GT™). There were no hand file separations.

Canal area

The data resulting from changes in canal area due to the two instrumentation techniques are presented in Table 1. No significant differences were found for the preoperative canal area measurements between groups at any level. Postoperatively, there were significant differences at the coronal and mid-root coronal third; the hand files and Gates Glidden burs produced a significantly larger canal area than the GT™ rotary system ($P < 0.05$). There was no significant difference between the two groups at the apical and mid-root apical third.

Table 1 Canal area in mm^2 (mean ± SD)

	Coronal section		Mid-root coronal third		Mid-root apical third		Apical section	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Flexofile (hand) no. = 25	0.42 ± 0.24	0.99 ± 0.37*	0.27 ± 0.16	0.56 ± 0.20*	0.18 ± 0.20	0.31 ± 0.06	0.10 ± 0.06	0.14 ± 0.09
GT (rotary) no. = 25	0.41 ± 0.20	0.73 ± 0.19*	0.24 ± 0.11	0.45 ± 0.15*	0.16 ± 0.11	0.23 ± 0.13	0.11 ± 0.07	0.13 ± 0.08

*Shows a significant difference ($P < 0.05$) between groups.

Table 2 Canal transportation from centre in mm (mean ± SD)

	Coronal section	Mid-root coronal third	Mid-root apical third	Apical section
Flexofile (hand) no. = 25	0.12 ± 0.12	0.17 ± 0.07*	0.14 ± 0.14*	0.08 ± 0.09
GT (rotary) no. = 25	0.09 ± 0.09	0.12 ± 0.08*	0.06 ± 0.10*	0.06 ± 0.09

*Shows a significant difference ($P < 0.05$) between groups.

Table 3 Distance from the canal to the root surface in mm (mean ± SD)

	Coronal section		Mid-root coronal third		Mid-root apical third		Apical section	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Flexofile (hand) no. = 25	1.54 ± 0.36	1.20 ± 0.36	1.08 ± 0.23	0.68 ± 0.22*	1.03 ± 0.21	0.85 ± 0.25	0.71 ± 0.26	0.61 ± 0.25
GT (rotary) no. = 25	1.55 ± 0.46	1.32 ± 0.40	1.09 ± 0.23	0.84 ± 0.26*	0.97 ± 0.19	0.88 ± 0.21	0.62 ± 0.32	0.58 ± 0.29

*Shows a significant difference ($P < 0.05$) between groups.

Canal transportation from centre

The data from changes in canal centre as a result of the instrumentation techniques are given in Table 2. The GT™ rotary files remained significantly better centred than the stainless steel instruments in both mid-root sections ($P < 0.05$). There was no significant difference in the centring of the canal at the apical or coronal cut-plane of the canal. The direction of the canal transportation was consistently toward straightening the canal in most cases. In the mid-root sections, the transportation was consistently toward the furcation.

Remaining tooth structure (distance from the canal to the closest surface of the external root)

The data for changes in dentine thickness from the root canal to the root surface as a result of the instrumentation techniques are given in Table 3. No significant differences were found for the preoperative dentine thickness between the instrumentation groups at any level. The GT™ rotary files removed significantly less dentine at the mid-root coronal third ($P < 0.05$), however, there was no significant difference at the apical, mid-root apical third or coronal levels.

Time of preparation

The GT™ rotary technique was significantly faster than the stainless steel hand held file technique ($P < 0.0001$). The mean time for the GT™ rotary technique was 5.9 ± 3.1 min, and for the hand held file technique 23.2 ± 9.0 min.

Discussion

The trend to tapered canal shapes for cleaning efficacy and obturation mechanics has been a slow and measured conversion in the last two decades (Buchanan 1991). Step-back and/or crown-down strategies for shaping have been the established paradigm for creating tapered shapes in the last 20 years (Schilder 1974, Goerig *et al.* 1982). The advent of predefined tapered shapes to root canals was given great impetus with the introduction of nickel–titanium instruments. This strong and highly flexible alloy has allowed innovations in taper and flute design which had been impossible with stainless steel instruments. In addition, increased taper combined with nickel–titanium alloy, allowed more predictable use of rotary methods to provide consistent canal shapes (Short *et al.* 1997). Research also showed improved clockwise and counter-clockwise torsion over stainless steel instruments, making them more resistant to fracture (Walia *et al.* 1988).

Most dangerous for even experienced clinicians is the increased potential for structural loss during shaping, or actual strip perforation whilst trying to create adequate radicular access. Adequate radicular access increases the efficacy of irrigants, the control of instruments and the quality of root canal sealing. However, the use of traditional ISO instruments in combination with Gates Glidden burs, Peeso reamers, and larger flaring instruments increases the potential incidence of furcation strip perforations and canal transportation.

The use of the CT scan at 50 micron resolution provided a practical and non-destructive technique for assessment of canal morphology before and after shaping. Longitudinal cutplanes were viewed to evaluate canal transportation, as well as the cross-sectional cutplanes used in this study to evaluate pre- and post-operative dentine thicknesses. The CT scans were an improvement over the technique designed by Bramante *et al.* (1987) and enhanced by other subsequent investigators. No destructive sectioning of the specimens is required and there is no loss of root material during sectioning which could affect instrumentation outcomes. There are also no instrumentation problems passing through sections or around curvatures. In addition, each cutplane is an exact sectioning of the specimens at right angles to the root canal. The voxel model allows the computer software to demonstrate planes at right angles to the long axis of the canal. The CT scans allow easy measurement of canal changes, as each image has an accurate scale, decreasing the potential of a radiographic or photographic transfer error. However, due to the anatomic complexities of the apical root canal, it was difficult to interpret the canal configuration from the CT scans in some specimens. Microcomputed tomographic data with smaller than 50 micron slices will improve resolution. The cost of the scanning procedure is also a consideration which currently inhibits the universal utilization of this methodology.

The shaping outcomes of this investigation confirm other studies (Coleman & Svec 1997, Pettiette *et al.* 1999, Porto Carvalho *et al.* 1999) that found Ni–Ti instruments to stay better centred in the canal and reduce preparation time compared to hand instrumentation with stainless steel files and engine-driven Gates Glidden burs. Of major interest was the new nickel–titanium GT™ files and the comparison of the degree of encroachment upon the furcation area. Because stainless steel is relatively inflexible, this property has been shown to contribute to the development of furcal thinning, a critical limitation in the attempt to create deep radicular shape. The risk of stainless steel is compounded in narrow curved canals with morphologic limits on apical enlargement. This has been shown to hinder cleanliness and obturation.

The results of this study show the mean root canal areas of the hand-instrumented roots to be significantly larger ($P < 0.05$) at the coronal and mid-root coronal one-third level compared to the GT™ rotary-instrumented roots. These results may seem somewhat unexpected when the largest diameter instrument used in method 1, a number 3 Gates Glidden, is 0.9 mm in diameter compared to any rotary GT™ with a maximum flute diameter of 1.0 mm. The explanation for this outcome must lie in the rigidity of the stainless steel instruments and the Gates Glidden burs and their tendency to cut the inner curve and excessively thin the furcation.

The thickness of the remaining dentine between the root canal and the external aspect of the root was significantly thinner at the mid-root coronal one-third section following hand instrumentation ($P < 0.05$). A mean of .40 mm of dentine was removed from the root adjacent to the furcation during hand instrumentation, compared to .25 mm with GT™ files at this level. This may be a result of the increased straightening of the canal at this level by stiffer stainless steel instruments or by less adept instrumentation with the Gates Glidden drills by the novice operator. The result is a structurally weakened root.

Transportation of the canal was most marked at both mid-root sections above the apical in the hand-instrumented teeth. This is the area of the canals in which stiffer stainless steel instruments were introduced for step-back. Transportation was minimal at all levels with Ni–Ti files. The minimal transportation, in combination with the more selective removal of dentine in the mid-root apical third segment, may be the reason for the apparent improvement in 'deep shape' that the GT™ files appear to create (Fig. 4). Generally, the GT™ rotary preparations were better centred, and did not cause the unnecessary loss of structural dentine associated with transportation (Fig. 5a–d).

It was surprising that there were no significant differences in canal area, transportation, or distance from the canal to the outer portion of the root at the apical section.

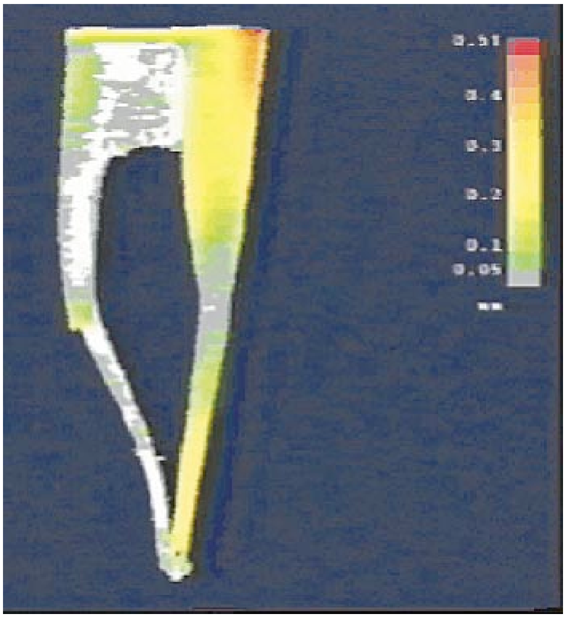

Figure 4 Transparent volumetric model of pre- and postoperative root canal shapes. Notice lack of deep shape and ledging in hand-instrumented canal on left.

Whilst this is not in agreement with other studies (Short *et al.* 1997), it is reasonable to expect this resulted from the fact that the students were instructed to minimally prepare the canal terminus with hand instruments, because larger apical sizes are strongly associated with transportation. It was necessary to take a Flexofile 20 to the canal terminus for standardization purposes, since all the rotary GT™ files used are size 20 at the tip.

The time taken for preparation of the canals with the rotary instruments was considerably shorter compared to the hand instrument series. It would appear that rotary nickel–titanium instruments have the potential to facilitate canal preparation. Indeed, a number of other studies have also confirmed that such techniques are more efficient than preparation with hand instruments. (Esposito & Cunningham 1995, Glosson *et al.* 1995). If overall quality of canal shape is enhanced using rotary instruments, the advantage of rapid preparation in reducing operator and patient fatigue is obvious.

Two GT™ files fractured (separated) during this study; one 0.06, and one 0.08. It should be stressed that the operators were novice dental students. Using the GT™ rotary system for the first time, with minimal instruction

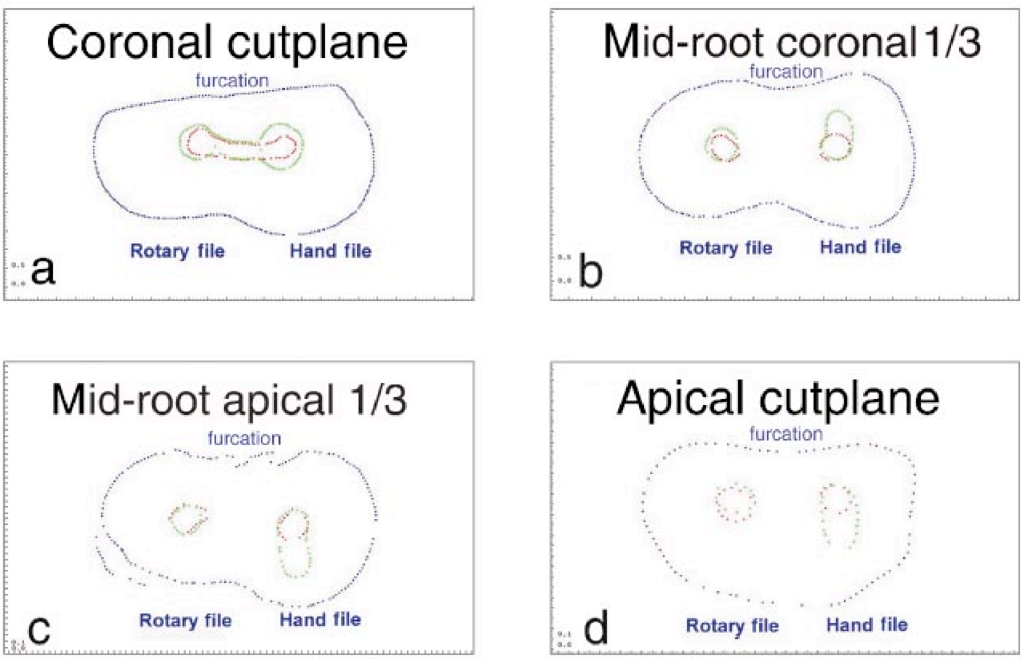

Figure 5(a–d) Representative canal cutplanes at each level. Overall, the direction of canal transportation was consistently toward straightening the canal with hand instruments.

students will often exceed directions. Further refinement of technique, including correct file selection for various apical morphologies and minimal handpiece pressure, will reduce the potential for file breakage. Inappropriate file selection in a canal with severe apical curvature and excessive handpiece pressure were noted as the cause of instrument failures in this study. In the future, torque limitation handpieces may result in less instrumentation separation, but this concept needs to be investigated.

The results of this study justified the incorporation of rotary files into the clinical curriculum at the University of the Pacific School of Dentistry. The Endodontic Department currently teaches the use of nickel–titanium rotary GTs™ in combination with stainless steel Flexofiles® as our clinical standard. Instrument separations are closely monitored.

Conclusions

Under the conditions of this study, novice dental students were able to prepare curved root canals with Ni–Ti rotary GT™ files with less transportation and greater conservation of tooth structure, compared to canals prepared with hand instruments. The shapes prepared with Ni–Ti rotary GT™ files were better-centred and more conservative of dentine in the critical furcation levels.

Acknowledgements

This study was supported by a research grant to the University of the Pacific School of Dentistry by Dentsply/Tulsa Dental.

The authors are grateful to Mrs Teresa Kuhlman for her invaluable aid in the production of this manuscript.

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