A comparison of stainless steel hand and rotary nickel-titanium instrumentation using a silicone impression technique

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Abstract

Background: Root canal preparation using rotary nickel-titanium instruments has been reported to be superior to hand instrumentation in terms of root canal shape, centring and frequency of procedural errors. The purpose of this study was to evaluate canal preparations using a sequential silicone impression technique to assess root canal morphology.

Methods: Pre-operative canal impressions were obtained from 24 extracted single-rooted premolars. Canals were randomly assigned to be firstly, instrumented with stainless steel K-type files or rotary nickel-titanium instruments (Profile), then further apically enlarged with rotary nickel-titanium instruments (Profile or Lightspeed). Post instrumentation impressions were taken and digitally photographed in a bucco-lingual and mesio-distal orientation at low-power magnification. Images were evaluated for procedural defects, changes in canal curvature, canal enlargement and canal rounding at 1, 3 and 7mm from the working length.

Results: Silicone impressions could accurately reproduce the detailed root canal morphology of single-canal premolars. Repeated impressions of each canal using a standardized procedure allowed a detailed comparison of instrumentation techniques at various stages. Hand instrumentation incurred more errors than rotary nickel-titanium instrumentation (Profile). Further apical enlargement using Lightspeed instruments incurred fewer errors than with Profile instruments. Differences among techniques were highly significant (p<0.005). All techniques resulted in slight canal straightening, as well as rounder and enlarged canals particularly in the apical third.

Conclusions: Rotary nickel-titanium instrumentation, especially Lightspeed, may produce better canal shape by reducing procedural errors.

Key words: Rotary nickel-titanium, root canal preparation, silicone impressions, procedural errors.

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INTRODUCTION

The role of root canal instrumentation in successful endodontic treatment is to clean the canal of organic debris and to shape the canal for three-dimensional hermetic obturation and effective chemical irrigation.1 The optimal canal shape has been defined by Schilder as a tapering funnel that follows the original shape and direction of the canal, while retaining the position and size of the apical foramen.1 Apical enlargement is performed to ensure cleanliness and improve obturation.2 As with all restorative dentistry, instrumentation should be balanced with minimal destruction and weakening of remaining tooth structure.

Traditionally, stainless steel endodontic files have been used for cleaning and shaping root canals. The stiffness of the files, which rises with increasing sizes,3 causes them to straighten in naturally curved canals4 and results in apical over-enlargement and problems such as ledging, apical transportation, zipping and elbows.5 In recent years, new techniques such as rotary nickel-titanium instrumentation have been developed and numerous types are commercially available. Nickel-titanium files are more flexible and durable than stainless steel files.6 They have been reported to be able to adapt to curved canals and maintain the original canal curvature better.7-10 Some authors have advocated extensive apical enlargement, including the use of Lightspeed instruments, to allow better penetration of anti-bacterial irrigants and to remove bacterially infected dentine.11,12

To evaluate the effectiveness of various instrumentation systems, numerous methods have been used experimentally to examine different aspects of instrumentation. Simulated canals in resin blocks6,13,14 provide good experimental controls but are not as representative of clinical conditions as extracted teeth. Extracted teeth may be examined by radiography,4,7,14,15 or sectioned at different levels and examined by light microscopy,6 scanning electron microscopy,7 histological sections,7 video9 or photographic imaging10 and digitally analysed. Most authors have been able to obtain measurements after instrumentation, such as by reassembling the sectioned tooth with the Bramante muffle system.7,11 However, radiography is limited in what it may assess and sectioning the tooth causes loss of

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information. Computed tomography can produce three-dimensional images of the root canal pre- and post-instrumentation, but they may be inaccurate. Rubber-based impressions have also been used to examine root canal anatomy in three dimensions. However, because the tooth is dissolved to obtain the impression, an accurate pre-operative assessment is not possible. Recently, Barthel et al. showed that it is possible to use polyvinylsiloxane impression material (low-viscosity), which is currently the most elastic and dimensionally stable dental impression material, to take repeated impressions of the root canal without destruction of tooth structure. They used this new method to compare three systems of instrumentation for dentine removal and errors of preparation. Though they only performed the assessment in one direction, they recognized the potential for the technique to assess root canals three-dimensionally, which is important as the root canal curves in different directions.

The objective of this study was to use a sequential silicone impression technique to compare instrumentation using stainless steel hand (K-type files) and rotary nickel-titanium instruments (Profile), as well as additional apical enlargement by rotary nickel-titanium instruments (Profile and Lightspeed). Root canal morphology was assessed in two directions at three levels of the root canal: mesio-distally and bucco-lingually, for the frequency of procedural defects, changes in canal curvature, enlargement and rounding.

MATERIALS AND METHODS

Preparation

After a pilot study was conducted to develop the technique of taking root canal impressions, extracted single rooted premolars with varying degrees of curvature were collected. The orientation of each tooth was noted before it was de-coronated at the cemento-enamel junction (CEJ) level. Apical patency was checked with an ISO #08 file. Teeth which had more than one root canal or which were not apically patent were excluded from the study. The pulp was removed with a barbed broach and 2.5 per cent sodium hypochlorite solution. The canal orifices were flared with a #3 Gates-Glidden bur to eliminate interferences to straight-line access, and beveled around the periphery to reduce possible stress concentration in the resulting impression.

A system of taking indexed impressions under vacuum was set up (Fig 1), modeled after the technique used by Barthel et al. Each tooth was mounted onto a 20×20mm polymethylmethacrylate sheet, on top of which another piece could be attached. A 10mm hole drilled through the centre of both pieces formed the base of the impression. Vertical grooves cut on the inside of the hole served as an index for orientation and reproducible positioning of successive impressions of the same root. To ensure a tight vacuum, a universal cylindrical mould with a conical cavity was made with polyvinylsiloxane impression material (President Medium-body; Coltene, Switzerland). A tooth could be inserted into the mould from one side and the vacuum pump applied from the apical end.

Impression taking

Pre-instrumentation impressions of the root canals were taken for baseline control after the canals were cleaned and dried. Low-viscosity polyvinylsiloxane impression material (President Light-body; Coltene, Switzerland) was injected into the canal while the vacuum pump pulled the material out through the apex. After the material had set, excess material extruding from the apex was removed and the impression cut flush with the top piece of the setup. When the top piece was detached, the base of the impression could be gripped and the impression withdrawn parallel to its long axis. A total of 24 impressions were successful after discarding roots with fragments of impression material remaining in the canal.

Instrumentation

In the first stage of instrumentation, these 24 teeth were randomly assigned to be instrumented with stainless steel K-type files (Kerr Co, Romulus, Michigan) or rotary nickel-titanium Profile instruments (engine-driven Profile .04 and .06 Tapers Series; Tulsa, Oklahoma). The master apical or rotary file size was designated to be three sizes larger than the diagnostic file size, which was assessed with a K-type file. Hand instrumentation with K-type files was performed using the conventional step-back technique up three sizes. Larger-sized files were pre-curved before instrumentation. The Profile system was applied using a crown-down technique according to the manufacturer’s instructions.
The depth to which each file instrumented was recorded for each tooth. Copious sodium hypochlorite solution (2.5 per cent) was used for irrigation during instrumentation. After instrumentation, canals were flushed with EDTA (contains 15 per cent disodium edetate, 0.85 per cent cetrimide w/v) (Colgate, Australia) to remove the smear layer, and apical patency was checked before impressions were taken again.

For the second stage of instrumentation, the teeth were randomly assigned again for further apical enlargement to three additional sizes, using Profile or Lightspeed instruments (Lightspeed Co, San Antonio, Texas). A third set of impressions was taken. All successful impressions were carefully labeled and stored covered at room temperature to avoid any accumulation of dust.

Recording

Impressions were digitally photographed at a fixed low magnification (18×). The impression was placed on a small X-Y table (Daedal Inc, Harrison City, Pennsylvania) that was adjustable for fine focus and rotation to obtain views from all angles. A ruler and a file of each type were photographed to calibrate the magnification. Placing the indexed base on a 1mm grid allowed accurate positioning of impressions of the same tooth. Each impression was photographed in the bucco-lingual and mesio-distal direction (Fig 2). The images were stored as TIFF files. Images of the same tooth in the same direction, pre- and post-instrumentation were aligned for analysis (Fig 3).

Analysis

Firstly, the frequency of errors of instrumentation was recorded. Canal straightening was noted when there was a detectable widening of the canal on the inside of the curve (Fig 3). Other errors, i.e., ledging, apical transportation, loss of apical stop (without zipping) and zipping were easily noticeable (Fig 4). For the second set of instrumentation, an error was recorded if it was newly created. The number of teeth
that incurred errors was also recorded. In addition, incomplete wall preparation was observed when an irregular outline of canal wall remained unchanged after instrumentation.

Secondly, the curvature of each impression in both the mesio-distal and bucco-lingual directions was determined using a modified Schneider technique. The mid-point of the apical termination of instrumentation in post-instrumentation impressions was used instead of the apex to provide a more accurate representation of post-instrumentation canal curvature. The angle of curvature was formed by a line joining the apical termination to the point of departure from a straight line drawn through the middle of the coronal part of the impression. Three impressions with 5 bends and 11 impressions with loss of apical ends in each direction respectively were excluded from comparison. The mean change in canal curvature was obtained for each technique after calculating it for each tooth.

Thirdly, the width of the canals was measured at 1, 3 and 7mm from the working length on all impressions in both the mesio-buccal and bucco-lingual directions. Subtracting the pre-instrumentation width from the post-instrumentation width provided the measurement of canal enlargement after instrumentation. Canal enlargement was assessed at each level, in both directions for each technique.

Fourthly, the roundness of the canal was determined at each level by calculating the ratio of the bucco-lingual to mesio-distal diameter. This ratio represents a measure of the symmetry of the canal, which increases as the ratio approaches a value of one. A reduction in the ratio after instrumentation would indicate that instrumentation has rounded the canal.

Statistical analysis

It was necessary to ensure that the randomization of canals after the first stage of instrumentation produced two similar groups of canals, before the second stage using Lightspeed and Profile instruments, in order to ascertain the independence of the results of the second stage from the first. Unpaired students’ t tests were used to determine that there was no significant difference between the groups (p>0.05).

As there may be more than one error for each tooth, the frequency of errors among the instrumentation techniques was compared using Poisson regression, which determined if the rates of errors were the same. The paired t-test was performed to compare the samples of each technique before and after instrumentation for any significant change in canal curvature, increase in canal width and rounding of the canals after instrumentation.

A single factor analysis of variance was conducted to assess any difference between the abilities of the four instrumentation groups to cause changes in canal curvature. It was also conducted to assess global changes in canal enlargement and canal rounding at the 1mm level, because changes in the apical region, especially after apical enlargement, are of the most interest. The level of significance was set at 0.05 for all analyses.

RESULTS

Impression technique

During the pilot study, attempts to take impressions of the mesio-buccal canal of mandibular molars failed in all specimens. The success rate for taking pre-operative impressions of single-rooted premolars with slight to moderate curvature was 46 per cent (24 out of 52). Attempts to take impressions of molar canals and premolars with two canals failed, because the impression material connected neighbouring canals via fins or at the apex, which caused the impression to tear when it was withdrawn from the root. It was also difficult to withdraw impressions from canals that were sclerosed or severely curved. Three roots (that were instrumented with Profile instruments in both stages) had unsuccessful post-operative impressions and were thus unsuccessful.

Table 1. Frequency of errors of instrumentation

<table>
<thead>
<tr>
<th>Instrumentation technique</th>
<th>1 Hand</th>
<th>1 Profile</th>
<th>2 Profile</th>
<th>2 Lightspeed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ledging</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Elbow</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Canal straightening</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Apical transportation</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Zipping</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Loss of apical stop (without zipping)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Broken instruments</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total errors</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Total teeth assessed</td>
<td>12</td>
<td>9</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Total teeth with errors</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Proportion of teeth with errors</td>
<td>0.5</td>
<td>0.1</td>
<td>0.7</td>
<td>0.08</td>
</tr>
</tbody>
</table>

1 Hand = first stage of instrumentation using stainless-steel K-type files.
1 Profile = first stage of instrumentation using Profile instruments.
2 Profile = second stage of instrumentation using Profile instruments.
2 Lightspeed = second stage of instrumentation using Lightspeed instruments.
Defective impressions from subsequent instrumentation steps of the remaining canals were mostly due to breakages that have occurred in the apical third. These were excluded from the analysis, reducing the sample size unevenly among the four groups of instrumentation.

### Shape of canals

Where good impressions were obtained, they were able to show detailed canal morphology, with the exception of accessory canals that tended to tear and remain in the root when the impression was withdrawn. In general, instrumentation with K-type files and Profile instruments resulted in smooth, tapering canals, while further apical enlargement with Lightspeed instruments resulted in very smooth, parallel walls. This was observed less when viewing the canal in the mesio-distal direction, where many of the canals were wider and had more morphologic variations.

### Procedural errors

The frequency of procedural errors incurred during instrumentation is shown in Table 1. Canal straightening was the most common, followed by elbow formation and ledging. There were very few occurrences of zipping, apical transportation and loss of apical stop. Instrumentation with large Profile sizes during the second stage incurred the highest number of errors, followed by K-type files and smaller Profile instruments during the first stage. Lightspeed instrumentation caused only the loss of apical stop for one canal. The difference in the rate of errors incurred between the various techniques was highly significant (p<0.05). At times more than one error occurred on the same canal. Most of the canals instrumented with large Profile instruments (second stage) had errors, followed by instrumentation with K-type files, while only one canal instrumented by smaller Profile instruments (first stage) and Lightspeed instruments had errors. Most of the canal walls were incompletely prepared, particularly when viewed in the mesio-distal direction.

### Canal curvature

All techniques of instrumentation resulted in slight canal straightening in both directions (Table 2). Initial canal curvatures ranged from 6° to 33° mesio-distally and 1° to 24° bucco-lingually. These were reduced by an average of 2.6° and 1.9° respectively. The mesio-distal curvature change was significant for hand instrumentation and the second stage Profile instrumentation (p<0.05), and highly significant for Lightspeed instrumentation (p<0.005). For the bucco-lingual curvature, only Lightspeed instrumentation caused a significant reduction in curvature (p<0.05). There was no global difference between the instrumentation techniques in both directions (p>0.5).

### Canal enlargement

In general, the canals were enlarged the greatest at the 1mm level and the least at the 7mm level, and more so mesio-distally than bucco-lingually (Fig 5). Overall, no particular technique caused significantly more canal enlargement than the others, at the 1mm level and in both directions (p>0.05). However, there was a trend that hand and Lightspeed instrumentation enlarged canals more than Profile instrumentation (first and second stage) at the 1mm and 3mm levels. At the 7mm level, most canal enlargement occurred after instrumentation with large Profile sizes during the second stage in the mesio-distal direction.

### Canal rounding

In general, instrumentation resulted in the rounding of the canals at all levels (Fig 6). Overall, there was an evident decrease in the ratio of bucco-lingual to mesio-distal width after instrumentation. However, some canals in each group did become more asymmetrical. The use of the smaller apical file sizes during the first stage of instrumentation rounded the canals to a certain extent,

### Table 2. Reduction in canal curvature

The reduction in curvature was calculated by subtracting the canal curvature after instrumentation from the initial curvature for each canal, and the mean calculated for each technique.

<table>
<thead>
<tr>
<th>Instrumentation technique</th>
<th>Pre-Instrumentation</th>
<th>Reduction in Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
</tr>
<tr>
<td>Mesiodistal Curvature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Hand</td>
<td>7</td>
<td>18.0</td>
</tr>
<tr>
<td>1 Profile</td>
<td>3</td>
<td>19.3</td>
</tr>
<tr>
<td>2 Profile</td>
<td>7</td>
<td>16.9</td>
</tr>
<tr>
<td>2 Lightspeed</td>
<td>11</td>
<td>14.5</td>
</tr>
<tr>
<td>Buccolingual Curvature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Hand</td>
<td>6</td>
<td>12.2</td>
</tr>
<tr>
<td>1 Profile</td>
<td>4</td>
<td>17.5</td>
</tr>
<tr>
<td>2 Profile</td>
<td>8</td>
<td>11.3</td>
</tr>
<tr>
<td>2 Lightspeed</td>
<td>10</td>
<td>12.8</td>
</tr>
</tbody>
</table>

1 Hand = first stage of instrumentation using stainless steel K-type files.
1 Profile = first stage of instrumentation using Profile instruments.
2 Profile = second stage of instrumentation using Profile instruments.
2 Lightspeed = second stage of instrumentation using Lightspeed instruments.
n.s. = not significant (p>0.05).
after which the larger apical file sizes rounded the canals further. Initially, the canals were the most nearly round at the 1mm level and became less round closer to the coronal. Instrumentation rounded the canal most at the 1mm level and less towards the coronal. At the 1mm level, hand instrumentation was found to significantly round the canals (p<0.05). At 3mm, instrumentation with large Profile instruments and Lightspeed instruments in the second stage significantly rounded the canals.

Fig 5. Canal enlargement at three levels, comparing the mesio-distal and bucco-lingual increase in canal width. Measurements were taken by subtracting the pre-instrumentation width from the post-instrumentation width of the canal. (A) 1mm from the working length. (B) 3mm from the working length. (C) 7mm from the working length.

1 Hand=first stage of instrumentation using stainless steel K-type files, 1 Profile=first stage of instrumentation using Profile instruments, 2 Profile=second stage of instrumentation using Profile instruments, 2 Lightspeed=second stage of instrumentation using Lightspeed instruments. MD=mesio-distal direction, BL=bucco-lingual direction * denotes p<0.05, ** denotes p<0.01, *** denotes p<0.005.

Fig 6. Roundness of canals, comparing the pre- and post-instrumentation roundness. Roundness was indicated by how close the bucco-lingual to mesio-distal width ratio was to 1. (A) 1mm from the working length. (B) 3mm from the working length. (C) 7mm from the working length.

1 Hand=first stage of instrumentation using stainless steel K-type files, 1 Profile=first stage of instrumentation using Profile instruments, 2 Profile=second stage of instrumentation using Profile instruments, 2 Lightspeed=second stage of instrumentation using Lightspeed instruments. Pre=pre-instrumentation, Post=post-instrumentation. *denotes p<0.05.
At 7mm, no instrumentation system rounded the canals significantly. There was no significant difference in rounding between the instrumentation techniques at 1mm (p>0.05).

**DISCUSSION**

Contrary to the results of Barthel *et al.*,14 successful impressions under present conditions were limited to teeth with a single, moderately sized (mean diagnostic file size: ISO #20) and moderately curved (mean: 18.4°) canal. This may limit the use of the technique in assessing canals that are smaller and more curved, such as mesial canals in mandibular molars, that have been generally accepted as the benchmark in the evaluation of instrumentation efficacy and safety.9,15,18,21 The success rate of taking impressions may improve with use of a low-viscosity silicone material that has higher tear strength, or an improved system of withdrawing impressions. In this study, the loss of more than half of the available teeth due to the impression technique precluded a more ideal comparison of instrumentation systems (a two stage enlargement of canals with each instrumentation technique), and necessitated a modified experimental design. Because impressions could not be withdrawn totally intact in all canals, the resultant sample sizes for each analysis varied between instrumentation techniques and levels.

Nonetheless, the technique of using sequential silicone impressions and digital imaging was able to record and compare detailed root canal morphology in three dimensions, with the exception of accessory canals. Inter-sample variation could be reduced by repeated measurements of the same samples to determine the effects of an instrumentation technique. Using an index and mounting the impressions on a rotational table facilitated observation and assessment of the root canal in all directions, though only two directions were used in this study. Canal curvature, variations in canal morphology and procedural errors could be observed and evaluated from other directions using this technique. It is important to realize that radiographs could only assess mesio-distal curvature clinically, and thus may be misleading in assessing the root canal curvature for instrumentation.

The procedural errors assessed in this study portray different aspects of instrumentation difficulties. Most of the errors were canal straightening, apical transportation, zipping, elbow formation and ledging, which reflect the tendency of a file to straighten in a curved canal to cause these errors in the canal wall.1 This is often assessed in other studies as canal transportation, centering or asymmetry instead.7,9,12,15 On the other hand, the loss of an apical stop is probably due to over-instrumentation and file breakage because of file fatigue. The frequency of procedural errors differs from other studies,11,14,21 probably because the results of this study reflect the instrumentation of canals that are larger and less curved. Nagy *et al.*16 and Byrant *et al.*15 found that the pre-operative shape of canal curvature affected the type and frequency of instrumentation errors.

The results showed that instrumentation to apical sizes of #30 to #35 by K-type files incurred more errors than by Profile instruments. Apical enlargement to sizes of about #45 using Profile instruments incurred more errors than with Lightspeed instruments. Profile instruments performed better at smaller sizes while Lightspeed instruments still performed very well at sizes as large as #90 (Table 1). Barthel *et al.*21 did not find any difference between the performance of Profile instruments and K-type files in molars, but other studies have demonstrated that Profile instruments remain better centred in the canal than stainless steel hand instruments, hence they are less likely to incur these errors.6,9,10 Studies have also found that Lightspeed instruments caused little or no apical transportation and less dentine removal during instrumentation.8,17 The difference observed between Profile and Lightspeed instruments may be explained by considering their geometric designs. A Profile instrument with its tapering shape would still be less flexible at larger sizes and tend to straighten. In contrast, a Lightspeed instrument consists of a single diamond-shaped head on a long, thin shank that is able to go around a bend very easily. Though such large file sizes are generally not recommended for use in practice, including for apical enlargement after canal preparation,2 rotary nickel-titanium instruments, particularly Lightspeed, are indicated when larger file sizes are needed in canals that are more curved to reduce the potential for problems during instrumentation.

The walls of the root canals were often incompletely prepared even when the file sizes were increased to a significant extent, no matter which technique was used. As the single canals of premolars are predominantly ribbon-shaped (Fig 2), most of these untouched walls were the tapered bucco-lingual ends of the canals. Similarly, other studies have demonstrated that instrumentation is unable to achieve total planing and debridement of the root canal system, regardless of extensive apical preparation or the instrumentation technique used.17,19,24 It is more important to eradicate bacteria by combining instrumentation with the use of anti-bacterial irrigants, such as sodium hypochlorite, and anti-microbial intra-canal medications, such as calcium hydroxide, before obturation.2,25

All instrumentation techniques resulted in canal straightening, but the changes were very small and similar. Canals with S bends were excluded from the analysis, because it may be postulated that a pull stroke with hand instrumentation would remove the apical bend and result in a single gentle curve.

The canals were enlarged the most at the 1mm level and least at the 7mm level, demonstrating that the action of instrumentation occurred mainly in the apical region to produce a tapering canal. The canals were enlarged more mesio-distally than bucco-lingually, demonstrating the rounding action of the instrument in
the ribbon-shaped canals. Rounding of the canal apically is desirable for gutter percha to be compacted against the canal walls and form a seal. However, rounding of the middle and coronal portions of an ovoid or flattened canal may be undesirable because it destroys much tooth structure. In this study, instrumentation rounded the canals, particularly in the apical region and progressively less towards the coronal. This is in agreement with the findings of Schneider, who also noted that the roundness of coronal. This is in agreement with the findings of Schneider, who also noted that the roundness of canals decreased with increasing curvature. Surprisingly, apical enlargement with large sizes of Lightspeed and Profile instruments during the second stage did not cause significant rounding of the canal at 1mm but at 3mm. This may be because the first stage of instrumentation with K-type files and Profile instruments had already rounded the canals significantly (Fig 6A). This indicates that apical enlargement to large sizes may not be necessary to round the canals in the apical region.

Based on the results of this study, it may be recommended that rotary nickel-titanium instrumentation, especially Lightspeed instruments be used when larger file sizes and flexibility are needed in curved canals, because they may produce better canal shape with less errors. The silicone impression technique could be improved with the development of low viscosity impression materials with higher tear strengths.

CONCLUSIONS

The silicone impression technique was difficult to use reliably. It was limited to single canals of moderate size and curvature. Where successful, impressions were able to reproduce accurately the details of root canal morphology in three-dimensions. Repeated impressions of each canal using a standardized procedure and digital imaging allowed a detailed comparison of different techniques at various stages of instrumentation.

Within the limitations of this study, it was found that:

- rotary nickel titanium instrumentation, particularly with Lightspeed instruments, may produce better canal shape with less procedural errors than with hand instrumentation with K-type files;
- all instrumentation techniques resulted in slight canal straightening bucco-lingually and mesio-distally. All techniques also resulted in canal enlargement and rounding, particularly in the apical region. However, differences among techniques were not statistically significant;
- most of the canal walls were incompletely prepared despite the use of large file sizes, particularly the tapered bucco-lingual ends of the ribbon-shaped canals;
- apical enlargement to large sizes may not be necessary to round the canals in the apical region.

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