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Assessment of three root canal preparation techniques on root canal geometry using micro-computed tomography: *In vitro* study

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In this article

Abstract

Aim: To assess the effects of three root canal preparation techniques on canal volume and surface area using three-dimensionally reconstructed root canals in extracted human maxillary molars. **Materials and Methods:** Thirty extracted Human Maxillary Molars having three separate roots and similar root shape were randomly selected from a pool of extracted teeth for this study and stored in normal saline solution until used. A computed tomography scanner (Philips Brilliance CT 64-slice) was used to analyze root canals in extracted maxillary molars. Specimens were scanned before and after canals were prepared using stainless steel K-Files, Ni-Ti rotary ProTaper and rotary SafeSiders instruments. Differences in dentin volume removed, the surface area, the proportion of unchanged area and canal transportation were calculated using specially developed software. **Results:** Instrumentation of canals increased volume and surface area. Statistical analysis found a statistically significant difference among the 3 groups in total change in volume ($P = 0.001$) and total change in surface area ($P = 0.13$). Significant differences were found when testing both groups with group III (SafeSiders). Significant differences in change of volume were noted when grouping was made with respect to canal type (in MB and DB) ($P < 0.05$). **Conclusion:** The current study used computed tomography, an innovative and non destructive technique, to illustrate changes in canal geometry. Overall, there were few statistically significant differences between the three instrumentation techniques used. SafeSiders stainless steel 40/0.02 instruments exhibit a greater cutting efficiency on dentin than K-Files and ProTaper. CT is a new and valuable tool to study root canal geometry and changes after preparation in great details. Further studies with 3D-techniques are required to fully understand the biomechanical aspects of root canal preparation.

Keywords: Computed tomography scan, geometry, root canal, surface area, three dimensional, volume

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Introduction

A major cause of treatment failure in endodontics is inability to locate, clean, disinfect and fill properly all root canals. [1] Cleaning and shaping the root canal system is the most important step of the root canal treatment procedure. This includes the removal of organic substrate from the root canal system by chemo-mechanical methods, and the shaping of the root canal system into a continuously tapered preparation. Maintaining the original path of the root canal will ensure adequate irrigation as well as filling of the entire root canal system. [2],[3],[4]

During the last few decades, a number of methodologies have been described to evaluate root canal preparation including plastics models, histological sections, scanning electron microscopic studies, serial sectioning radiographic comparisons and silicone impressions of instrumented canals. [5],[6],[7],[8] Without doubt, these techniques have shown potential for endodontic research and have been used successfully by several investigations over many years. However, some inherent limitations have repeatedly discussed, encouraging the search for new method with improved possibilities. [9] A recently introduced non-destructive method to evaluate changes of root canal geometry after endodontic preparation in more detail is the use of high resolution computed tomography. It is a non invasive technique that possesses the ability to visualize morphological characteristics in detailed and accurate manner without destruction of the tooth. Computed tomography offers reproducible data in all three-dimensions and by comparing data on each tooth before and after root canal treatment. [10]

Different instrument geometry will produce canals with different shapes. Therefore the aim of this study is to assess the effects of three root canal preparation techniques on canal volume and surface area using three-dimensionally reconstructed root canals in extracted human maxillary molars.

Materials and Methods

Preparation of specimens

Thirty extracted Human Maxillary Molars having three separate roots and similar root shape were randomly selected from a pool of extracted teeth for this study and stored in normal saline solution until used. The criteria for selection were the following: Each tooth had to have fully formed apex, three separated roots and slightly to moderate curved roots.

A custom made specimen holder from silicone was made for each tooth to exactly fit the same position in the scanning machine. The analysis of each sample consisted of two stages: Pre-operative scanning and post-operative scanning.

The specimens were divided into three groups of 10 with respect to canal curvatures. Of the 90 canals, 30 canals each were assigned for preparation by either k-files (Dentsply Maillefer, Germany), rotary ProTaper (Dentsply Maillefer, Germany) at speed of 300 rpm, and rotary SafeSiders (Essential Dental systems, South Hackensack, NJ, USA) with flat non-cutting side with reciprocating hand piece according to the manufacturer's instructions.

Root canal treatment

An endodontic access cavity was prepared in each tooth, and the root canal was negotiated using a size 15 k-file. The working length was determined to be 1 mm short of the apical foramen. No attempt was made to prepare the second mesio-buccal (MB2) canals in this study, because they did not always present as separate canals along the entire length of the root. Hand k-files were assigned to prepare Group 1; k-files were used in a balanced-force motion. These canals were stepped-back to a size 80 file and recapitulated with the master apical file after completing the preparation. Rotary Pro-taper were assigned to group 2, canals were prepared with rotary pro-taper in crown down fashion. Rotary SafeSiders were assigned to group 3, canals were prepared with a reciprocating hand-piece strictly according to the manufacturer's instructions. All canals in the three groups were copiously irrigated after each instrument with 3% NaOCl using a side venting endodontic irrigation syringes (Max-I-probe from Dentsply, Germany).

CT measurements and evaluations

A computed tomography scanner (Philips Brilliance CT 64-slice) system with an isotropic nominal resolution of 19.6μm was used at 120 kV to scan the specimens before and after preparation. Typically, 64 slices with a voxel size of 39.2 × 39.2 × 39.2 μm were scanned with each scanning procedure requiring about 1.2 seconds per stack (64 slices).

Volumes of interest were selected extending from the furcation region to the apex of the roots.

These procedures produced binary images of the root canals. The high contrast of dentin to the root canals filled with air after access cavity of the sample yielded excellent segmentation of the specimens which was carried out using (Able 3D-DOCTOR software v.4.0.2). Although the special mounting device ensured almost exact repositioning of the samples (error <2 voxel) with minimal rotational error (<1°), the precision was perfected by superimposing two sets of segmented root canals over each other. An additional time of 8 hours was required for segmentation and reconstruction of each sample outer and inner surfaces. Visualization and editing of reconstructed images was carried out using volume rendering (Autodesk 3D STUDIO Max 2010 32bit-ink) [Figure 1] and [Figure 2].

Figure 1: Reconstructed root canal system

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Figure 2: Reconstructed outer tooth surface

Click here to view

Subsequently, matched root canals were evaluated as follows: Volumes and surface areas of the root canals were determined from triangulated data using the "Marching Cubes" algorithm.

Increases in volume and surface area were calculated by subtracting the scores for the treated canals from those recorded for the untreated counterparts.

Images of the untreated and the instrumented canals were not superimposed when using the CT technique to assess volume and surface area. These parameters were evaluated separately for the exactly matched volumes of interest. However, exact superimposition had to be accomplished, before and after canal preparation, to obtain reproducible results assessed by CT for centres of gravity (CoG) of canal preparation. The data sets were then compared by voxel in each slice. Each slice was defined by a series of coordinated data for the x-, y- and z-axes. The first two axes were parallel to the slice, whilst the z-axis is at right angles to each slice.

CoG of the canals, calculated for each slice, were connected along the z-axis by a fitted line. Matched images of the surface area of the canals, before and after preparation, were examined to evaluate the amount of surface area instrumented. It was assumed that surface voxels remaining in the same place, before and after treatment represented un-instrumented parts of the canal walls.

The amount of instrumented surface could be calculated by subtracting the number of static surface voxels from the total number of surface voxels. Finally, average canal transportations were calculated by comparing cross section images before and after treatment for the apical 4 mm of the canals [Figure 3]. Statistical analysis with 2-way ANOVA and Tukey HSD test were used to analyze the data.

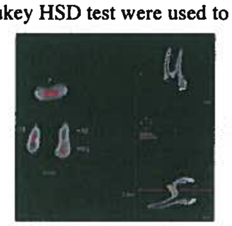

Figure 3: Cross-section evaluation of root canal transportation. Super imposition of canals pre-operative and post-operative. Red color represents canal shape before preparation; Green color represents canal shape after preparation

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Results

Volume rendering revealed detailed images of outer root contours, as well as root canal systems. Gross canal anatomy was studied using volume rendered images of isolated root canals. Disto-buccal (DB) roots were found to have one root canal in all cases. In contrast, mesio-buccal (MB) and palatal (P) canals presented with complicated canal systems.

The majority of MB and P canals were classified according to Vertucci [11] as type V [Figure 4]. In total, 29 cases (7) had a second MB2 canal present. Finally, lateral canal was found in mesio-buccal root in one case of the total sample [Figure

5].

Figure 4: CT- slice showing Type V palatal canal

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Figure 5: CT-slice showing lateral canal

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Instrumentation of canals increased volume and surface area. Prepared canals were significantly more rounded, had greater diameters and were straighter than unprepared canals.

A statistically significant difference among the 3 groups in total change in volume (P = .001) and total change in surface area (P = 0.13) represented in [Table 1] and [Figure 6].

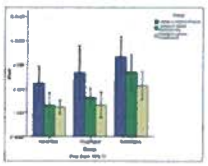

Figure 6: Diagrams showing total change in volume and surface area between all the groups

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Tukey HSD test indicates that there were no statistically significant difference when testing group I and II (k-files, ProTaper) respectively. Significant differences were found when testing both groups with group III (SafeSiders). Significant differences in change of volume were noted when grouping was made with respect to canal type (in MB and DB) ($P < 0.05$).

Procedural errors

Only one file (shaping File S1) fractured with the ProTaper instruments. Furthermore, the k-files system produced one specimen with fractured instrument (file No 25) and perforation in disto-buccal canal illustrated in [Figure 7] and [Figure 8] those canals were excluded from the study.

Figure 7: CT- scan slice showing the perforation

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Figure 8: Three-D reconstructed model showing perforation

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Discussion

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 cut-planes were viewed to evaluate canal transportation, as well as the cross-sectional cut-planes to evaluate pre-and postoperative canal transportation. The CT scans were an improvement over the technique designed by Bramante *et al.* [12] 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 cut-plane 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. Micro-computed 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. [13] The trend to tapered canal shapes for cleaning efficacy and obturation mechanics has been a slow and measured conversion in the last two decades. [14] Step-back and/or crown-down strategies for shaping have been the established paradigm for creating tapered shapes in the last 20 years. [3],[15] 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. [16] Research also showed improved clockwise and counter-clockwise torsion over stainless steel instruments, making them more resistant to fracture. [13],[17] SafeSiders instruments were recently introduced to prepare root canals less aggressively than previous endodontic instrumentation systems, while allowing for more complete shapes of oval cross-sections. No previous reports have evaluated the shaping ability of SafeSiders instruments using CT. In the present study, SafeSiders instruments, pro-taper and hand k-files were used in maxillary molars to allow comparisons to the data of previous studies performed under the same technical conditions. [9],[18],[19] Results of this study have demonstrated the complex shape of root canal systems not detectable by 2D radiographs. Because CT is noninvasive, it is possible to visualize the root canal before, during and after instrumentation without altering the sample. [20]

In our study Rendered 3D images, viewed as a full screen on the computer, gave excellent detail of the tooth and root canal in 3D. These images were viewed from many angles. It was also possible to magnify areas of interest. Canal systems were rendered separately and with dentin superimposed showing the orientation of root canals within a tooth. By rotating and viewing the canal system through 360 it was possible to make a qualitative assessment of the effect of root canal instrumentation on molar root canals. The results of our study revealed that there were statistically significantly difference in total change in volume and surface area between all three groups. While there were no statistically significantly difference when tests were made between pro-taper instruments and hand k-files. When grouping was made in respect to the root type statistically significantly difference in volume and surface area were found in MB and DB canals. These results may seem somewhat unexpected when using a greater taper instruments like pro-taper. The explanation for this outcome must lie on the influence of canal anatomy, diameter and cross section on the shaping ability of the instruments.

Peters *et al.*[9] compared the effects of NiTi and K-Files preparation techniques on canal volume and surface area using three-dimensionally reconstructed root canals in extracted human maxillary molars. The results showed that there were no statistically significant differences between the four experimental groups. By contrast, significant differences were noted when grouping was made with respect to canal type.

The effect of ProTaper rotary root canal preparation on Extracted human maxillary molars, employing micro computed tomography (μCT) was studied by Peters *et al.* [21] The results of this study showed that preparation significantly increased canal volumes and surface areas. They found that canal anatomy had an insignificant impaction preparation indicating that ProTaper instruments were able to shape constricted 'canals. In contrast, wide canals were less well prepared by ProTaper.

The root canal preparation using RaCe and ProTaper rotary Ni-Ti instruments was compared by Paque *et al.*[22] They showed that both Ni-Ti systems maintained curvature well. Both systems respected original root canal curvature well and were safe to use but the cleanliness was not satisfactory for both systems.

Hand and nickel-titanium root canal instrumentations performed by dental students were compared using a micro-computed tomographic. [23] A significant difference was found at the coronal and mid-root thirds. In addition, the modified double flared technique produced a significantly larger canal area than system GT and ProTaper. There was no significant difference between the three groups in the apical third.

The cutting efficiency of 3 different instrument designs used in reciprocation (k-files, SafeSiders and reamers) was evaluated by Wan *et al.* [24] Their results showed a statistically significant difference among the 3 instrument types. They concluded that the SafeSiders stainless steel 40/0.02 instruments exhibit a greater cutting efficiency on dentin than K-Files and K-Reamers of the same size and taper.

Musikant *et al.*[25] measured the time required to instrument and shape canals by conventional reamers and files compared with a newly introduced reamer and file system. They found that the non interrupted flat-sided design (EZ-Fill SafeSider reamers) produced the fastest times for comparably shaped canals because of reduced engagement of the instrument with the walls of the canal compared with conventional instruments. In addition, the conventional designs for both reamers and files results in slower, less efficient instrumentation to the apex compared with their EZ-Fill SafeSider counterparts.

Conclusion

The current study used computed tomography, a nondestructive technique, to illustrate changes in canal geometry. Overall, there were few statistically significant differences between the three instrumentation techniques used. SafeSiders stainless steel 40/0.02 instruments exhibit a greater cutting efficiency on dentin than K-Files and ProTaper. K-Files and ProTaper display a similar cutting efficiency. Canal anatomy had a strong influence, indicating that ProTaper instruments were able to shape constricted canals. In contrast, wide canals were less well prepared by ProTaper, suggesting that these instruments might be better suited for curved and constricted canals than wide canals. CT is a new and valuable tool to study root canal geometry and changes after preparation in great details. Further studies with 3D-techniques are required to fully understand the biomechanical aspects of root canal preparation.

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Figures

[Figure 1], [Figure 2], [Figure 3], [Figure 4], [Figure 5], [Figure 6], [Figure 7], [Figure 8]

Tables

[Table 1]

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