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ORIGINAL ARTICLE

Geometric Analysis of Maxillary First Premolar Prepared by Two Nickel-Titanium Rotary Instruments

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ABSTRACT

Aim: The present study was conducted with the aim of evaluating and comparing the shaping ability of two Nickel-titanium rotary instruments, with two disparate design features, on root canal geometry of extracted human maxillary first premolars using microcomputed tomography.

Study design: Twenty four bifurcated maxillary first premolars were divided into two groups and embedded in a rubber-based impression material. Both groups were submitted to microcomputed tomography before and after canal preparation (buccal and palatal) with either ProFile Vortex or Revo-S rotary instruments. Images were reconstructed and cross-sections corresponding to a distance 1, 2, 3, 4, 5, 6, and 7 mm from the anatomical apex were selected for canal transportation analysis. Volume changes were also measured.

Results: The degree and direction of canal transportation were non-significant for both instruments. Statistically significant differences were observed only between levels in the buccal canal in both groups. There was no significant difference between the two rotary systems in regards to the volume of dentin removed.

Conclusion: Our findings showed that ProFile Vortex and Revo-S instruments respected the original root canal anatomy and behaved similarly. ProFile Vortex rotary systems produced with innovative process were concluded to shape the upper maxillary premolar by leading minimal canal transportation, similar to Revo-S, rotary systems produced from traditional process.

Keywords: Maxillary first premolar, Micro-CT, Nickel-Titanium, Rotary instrument.

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INTRODUCTION

Intra-radicular microbial infection has been shown to be the main cause of apical periodontitis.[1-3] Therefore, the goal of root canal treatment is to eliminate or reduce the number of microorganisms to a level that will allow healing of the periapical tissues[4] and to prevent microbial reinfection. This process involves chemomechanical cleaning and shaping as well as obturation of the root canal system.

Root canal preparation is essential for removing necrotic pulp tissue, microorganisms, heavily infected dentin and debris, and for creating a root canal shape that will improve irrigation, placement of intracanal medications and facilitate the root canal filling at a high technical standard.[5] However, many studies have reported undesirable effects after root canal preparation using stainless steel files, such as zips, elbows, loss of working length, instrument fractures and perforations.[6-9]

Nickel-titanium instruments (NiTi) have been introduced to avoid errors associated with stainless steel instruments.[10] Instruments made of such alloys show improved physical properties, including super-elasticity and the shape memory effect, which drastically improves canal preparation efficiency and reduces iatrogenic errors.[11,12]

Over the last decade, advancements in the manufacturing of nickel-titanium instruments have led to new concepts in instrument design and canal preparation.[13] However, two design features have had a strong impact on the instrument shaping potential: the cross-sectional design and tip configuration.[9,14]

Recently, more focus has been directed toward improving the alloy properties. One of the metallurgical advancements is the use of a special thermomechanical process to modify the nickel-titanium raw material, such as the M-wire used in the production of the ProFile Vortex (Dentsply Tulsa Dental Specialties, Tulsa, Oklahoma, USA), or in the manufacturing of files such as the twisted file (TF group; SybronEndo, Orange, CA, USA).[13] This type of treatment has been reported to increase flexibility and the resistance to cyclic fatigue.[13]

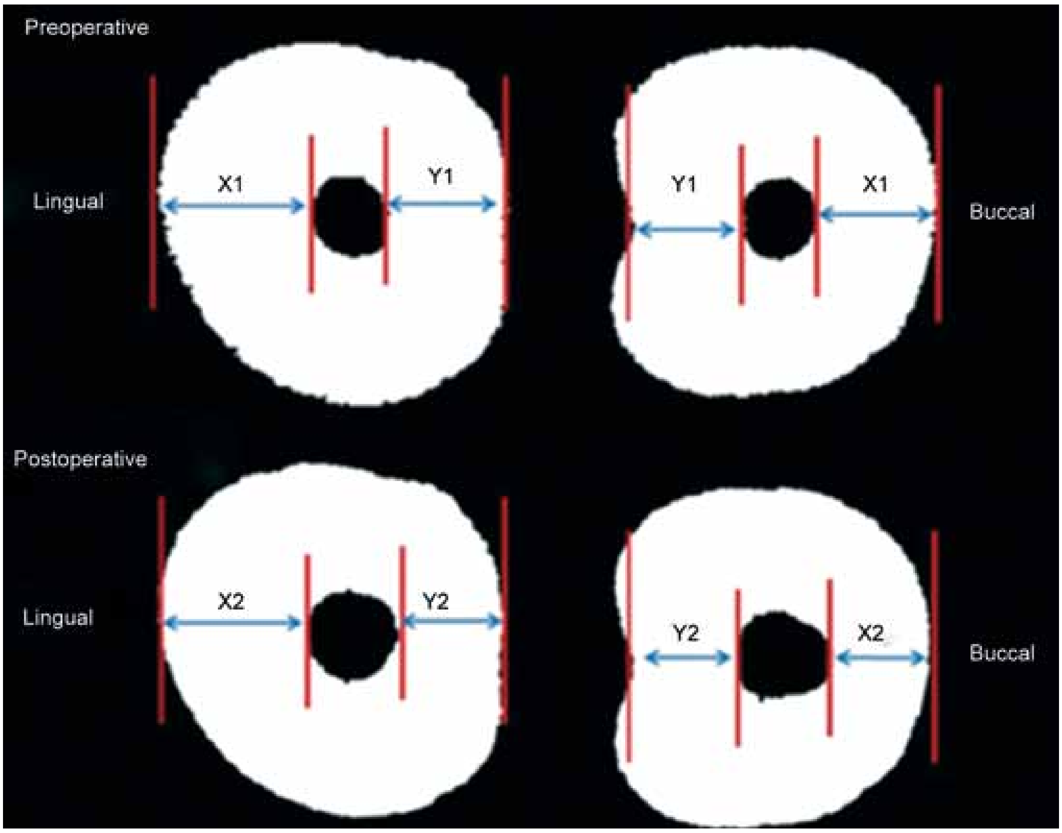


Fig. 1: Representative cross section before and after instrumentation showing how transportation was measured

Despite the different instrument designs and metallurgical advancements, root canal preparation is negatively influenced by the anatomical variation of root canals.[14] The root form and canal anatomy of maxillary first premolars are highly variable. The most common anatomical features include two roots, narrow furcation entrances, deep mesial concavities and multiple canals.[15] A very unique anatomical feature characterizing only the maxillary first premolar is the palatal furcation groove of the buccal root, which is a developmental depression located at the palatal aspect of the buccal root (Fig. 1), the prevalence of the palatal groove ranges from 62 to 100%.[16-18] Lack of knowledge about the extent and thickness of the dentin in this area might lead to excessive thinning or perforation of the dentinal wall during either endodontic or restorative procedures, thereby increasing the possibility of vertical root fractures.[19-21]

Recently, new generations of NiTi rotary instruments with higher flexibility and greater cutting efficiency have been introduced. Revo-S (RS; Micro-Mega, Besancon Cedex, France), another NiTi rotary system, was developed with a distinctive asymmetric cross-section, and the manufacturer claims that this particular instrument geometry facilitates canal penetration and the upward removal of debris.[22] The ProFile Vortex files (Dentsply, Tulsa Dental Specialties) made of M-Wire were introduced in 2009. These files have a triangular cross section, no radial lands, a variable pitch, and a noncutting tip, which is similar in design to the EndoSequence files. However, they are slightly different because the ProFile Vortex files are composed of M-Wire NiTi, have a novel design with helical angles, and are not electropolished.[23]

With the recent progress in the manufacturing of endodontic rotary instruments, a detailed analysis of their shaping ability and safety is required to understand how design features affect performance. A variety of methodologies have been developed and described to compare the shaping and cleaning ability of different instrumentation techniques and instruments in preparing root canals. Recently, microcomputed tomography (μCT) has emerged in the field of endodontic research. This technique is a highly accurate and nondestructive method for evaluating changes in the root canal geometry after root canal preparation. This analytical procedure permits a three-dimensional evaluation of the root canal geometry before and after preparation.[24-26] Linear and volumetric changes can be analyzed from such scans, including the volume of dentin removed, canal 'thickness' (diameter), prepared surface, cur-vature, canal transportation, structure model index (SMI), and canal centering ratio.[14,27]

The purpose of this study was to evaluate, *in vitro*, the volume of removed dentin, and canal transportation in bifurcated maxillary first premolars after root canal preparation using two different rotary endodontic instruments with two disparate design features.

MATERIALS AND METHODS

Twenty-four extracted bifurcated premolars were selected based on the following criteria: closed apices, obvious palatal groove of buccal root, and the absence of caries, anomalies, restorations and canal obstructions. Each root had 20° to 40° according to Schneider's technique. The teeth were stored in a 10% buffered formalin solution (Baxter Scientific Products, IL).

An access cavity was prepared using #2 and #4 high-speed round carbide burrs (Meisinger, Hager & Meisinger, GMBH, Germany). To determine the working length, a K-file # 10 (Dentsply-Maillefer, Ballaigues, Switzerland) was placed inside the canal until its tip was visible at the apical foramen when examined using an operating microscope. The final working length was calculated using a digital radiograph of the instrument in this position and then subtracting 1 mm. The same radiographic images were used to assess the degree of root canal curvature according to the criteria described by Schneider (1971).[28] Before initial scanning, a customized jig was fabricated and each tooth was mounted such that it could be placed in the same position before and after preparation. Teeth were scanned using a μCT scanner (1172 scanner; SKYSCAN, Kontich, Belgium) at 100 kV and 100 μA with a resolution of 18.6 μm using an AL + 0.5 mm thick aluminum filter and 54% beam-hardening reduction. Using NRecon software (SKYSCAN, Kontich, Belgium), these images were reconstructed, producing two-dimensional cross-sectional slices of the tooth structure. To reach the required resolution, a scanning time of 3.5 houre was required for each scan.

The teeth were distributed into two groups. Each group consisted of twelve teeth, as follows:

Group I: Teeth were instrumented with a nickel-titanium ProFile Vortex (Dentsply Tulsa, USA).

Group II: Teeth were instrumented with a nickel-titanium Revo-S (MICRO-MEGA, France).

Canals were instrumented using a crown-down technique following the manufacturer's instructions and were irrigated with 1.0 ml of 1% sodium hypochlorite (Master –X Bleach, Portland, OR) after each instrumentation using a 27-gauge needle attached to a 10 ml syringe. The preparation with each system was considered complete when a # 30 instrument of 0.06 taper was passively introduced to working length. Teeth were scanned again using the same machine and procedure as mentioned above. Images were evaluated using CT-Analyzer software (SKYSCAN, Kontich, Belgium). The top of the selected images was set at the point just below the furcation, and the bottom was set at the apex of each root. Then, each root was saved and analyzed separately. To assess the volume of the pulp space, a custom processing set of actions were used to binarize the root and pulp space, including threshold adjustment, morphological operation (to remove any particles inside the pulp space), despeckle (to remove speckle from the pulp space and to also remove pores), and bitwise operation (to copy the region of interest to the image). For the two-dimensional and three-dimensional analyses, the following parameters were obtained:

I. Volume Changes

The preoperative volume of the canal was determined by the voxel number (volumetric pixel), which is automatically converted to (3 mm) by the CT-Analyzer. The volume of removed dentin was calculated by subtracting the volume of the canal before preparation from the volume of the canal after preparation.

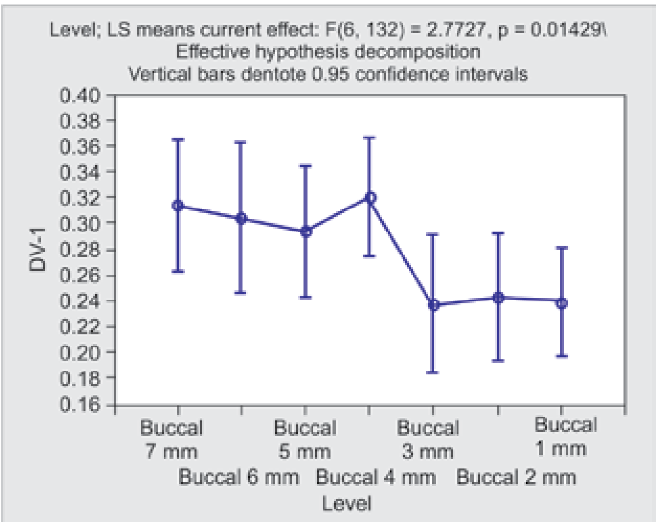
II. Canal Transportation

Canal transportation was measured before and after instrumentation at 1 to 6 and 7 mm from the apex of each root according to the following formula [(X1 - X2) - (Y1 - Y2)], as suggested by a previous study;[24] where X1 is the distance between the buccal portion of the buccal root or the lingual portion of the palatal root and the uninstrumented canal, X2 is the distance between the buccal portion of the buccal root or the lingual portion of the palatal root and the instrumented canal, Y1 is the distance between the lingual portions of the buccal root or the buccal portion of the palatal root and the uninstrumented canal, and Y2 is the distance between the lingual portions of the buccal root or the buccal portion of the palatal root and the instrumented canal (see Fig. 1).

The degree of transportation was measured in millimeters by calculating the absolute values that resulted from the above formula. A positive value obtained from the formula indicates that transportation has occurred from the buccal to the curvature, whereas a negative value indicates that transportation has occurred in the direction facing the furcation.

STATISTICAL ANALYSIS

A two-way analysis of variance test was used to compare the changes in root canal transportation and volume changes before and after the instrumentation ($p < 0.05$). To analyze different cross-sectional level effects on canal transportation, a pair-wise comparison was used. A chi-squared test was used to compare the direction of canal transportation between groups, whereas a Cochran Q test was used to compare the differences in the direction of canal transportation between levels.



Graph 1: Buccal canal transportation (Square root transformed data)

Table 1: The means and standard of deviations of volume changes

Changes in volume		*Buccal canal*		*Palatal canal*	
		Mean	*SD*	*Mean*	*ST*
GI	Pre	1.49	± 0.75	1.20	± 0.55
	Post	2.1	± 0.83	1.79	± 0.5
	Changes	0.62 (41.6%)	± 0.31	0.59 (49%)	± 0.29
GII	Pre	1.96	± 1.06	1.78	± 1.07
	Post	3.03	± 1.29	2.68	± 1.19
	Changes	1.07 (54.6%)	± 0.53	0.89 (50%)	± 0.44

Table 2: Means and standard of deviations of buccal canal transportation at different levels

Cross-section (mm)	*Canal Transportation*			
	GI		*GII*	
	Mean	*SD*	*Mean*	*SD*
7	0.09	± 0.05	0.13	± 0.09
6	0.11	± 0.06	0.11	± 0.10
5	0.09	± 0.05	0.12	± 0.08
4	0.10	± 0.06	0.13	± 0.057
3	0.08	± 0.05	0.07	± 0.06
2	0.07	± 0.05	0.07	± 0.06
1	0.08	± 0.05	0.05	± 0.04

RESULT

I. Volume Changes

No significant difference was observed between the groups ($p = 0.11$). However, a significant difference between pre- and postinstrumentation was demonstrated ($p < 0.001$).The pre- and postinteraction between groups was significant ($p = 0.026$), which means that the group effect and the 'Pre-Post' effect cannot be generalized. The highest volume gain was 54.6%, while the lowest was 41% (Table 1).

II. Transportation

Buccal Root

The mean scores (Table 2) indicated that canal transportation was highest coronally. No significant difference was observed between groups ($p = 0.79$). However, a significant level effect was demonstrated ($p = 0.014$). The level-group interaction was not significant ($p = 0.51$), which means that the level effect could be generalized for the two groups. Square root transformed data (Graph 1) were further analyzed with pair-wise comparisons, which showed significant differences between different cross-sectional levels, as demonstrated in Table 3.

The analysis of the cross-sectional level effect revealed that cross sections 7 and 4 promoted significantly greater amounts of canal transportation than cross sections 1, 2 and 3. Generally, there were more canal transportations toward the outer curve of the canal than the inner curve (Table 4). However, no significant differences between groups or levels were demonstrated.

Palatal Root

The mean score of palatal canal transportations were between 0.04 and 0.14 mm (Table 5), with the least mean shown at level 5 for GI (0.05 mm) and level 4 for GII (0.04 mm). There were no significant differences between groups ($p = 0.84$), and no significant level effect could be demonstrated; $p = 0.12$. The level-group interaction was not

Table 3: Analysis of cross-sectional level effect with Post hoc test

Level	*7 mm*	*6 mm*	*5 mm*	*4 mm*	*3 mm*	*2 mm*	*1 mm*
(mm)	*(0.31361)*	*(0.30481)*	*(0.29468)*	*(0.32035)*	*(0.23737)*	*(0.24332)*	*(0.23938)*
7	—	0.78207	0.552246	0.832268	0.017799*	0.028651*	0.020969*
6	0.78207	—	0.750426	0.625374	0.035651*	0.055090	0.041427*
5	0.55224	0.750422	—	0.420465	0.073526	0.108358	0.084083
4	0.832268	0.625374	0.420465	—	0.010043*	0.016674*	0.011956*
3	0.017799*	0.035651*	0.073526	0.010043*	—	0.851686	0.949623
2	0.028651*	0.055090	0.108358	0.016674*	0.851868	—	0.901477
1	0.020969*	0.041427*	0.084083	0.011956*	0.949623	0.901477	—

*Significant difference

Table 4: Direction of buccal canal transportation at different cross-sectional levels

Cross-section(mm)	*GI*		*GII*	
	Inward(%)	*Outward(%)*	*Inward(%)*	*Outward(%)*
7	75	25	75	25
6	50	50	58.33	41.67
5	41.67	58.33	58.33	41.67
4	50	50	33.33	66.67
3	50	50	41.67	58.33
2	41.67	58.33	33.33	66.67
1	41.67	58.33	41.67	58.33

Table 5: Means and standard of deviations of palatal canal transportation

Cross-section (mm)	*Canal transportation*			
	GI		*GII*	
	Mean	*SD*	*Mean*	*SD*
7	0.08	± 0.05	0.09	± 0.09
6	0.09	± 0.07	0.14	± 0.10
5	0.05	± 0.04	0.08	± 0.05
4	0.09	± 0.10	0.04	± 0.05
3	0.07	± 0.05	0.07	± 0.06
2	0.08	± 0.05	0.08	± 0.05
1	0.07	± 0.05	0.09	± 0.09

Table 6: Direction of palatal canal transportation at different cross-sectional

Cross-section (mm)	*GI*		*GII*	
	Inward(%)	*Outward(%)*	*Inward(%)*	*Outward(%)*
7	75	25	83.33	16.67
6	58.33	41.67	66.67	33.33
5	58.33	41.67	58.33	41.67
4	41.67	58.33	50	50
3	41.67	58.33	33.33	66.67
2	25	75	53.38	41.67
1	25	75	41.67	58.33

significant ($p = 0.61$), which means that the level effect could be generalized for the two groups. The directions of palatal canal transportation showed the same behavior observed with the buccal canal (Table 6). No significant differences can be demonstrated between groups or levels.

DISCUSSION

Several studies have reported that the presence of grooves on the furcation aspects of the buccal roots of MFPs varied between 62 and 100% based on different evaluation methods, thereby supporting the results of the current investigation. Lack of knowledge about the extent and thickness of the dentin in this area might lead to excessive thinning or perforation of the dentinal wall during either endodontic or restorative procedures, increasing the possibility of vertical root fractures.[19,20]

The advantages of using NiTi instruments in root canal preparation are well documented; however, their cutting ability is a complex interrelationship of different parameters, such as the cross-sectional design, chip-removal capacity, helical and rake angles, metallurgical properties, and surface treatment of the instrument.[14,29]

The Revo-S and ProFile Vortex are lately introduced file systems that are distinctly different in their geometric design and manufacturing methods. The new features of the ProFile Vortex files, such as their triangular cross section, variable pitch, variable helical angle and the noval M-wire, have shown better cyclic fatigue resistance. MICRO-MEGA, France, has introduced the Revo-S sequence with only 3 nickel-titanium instruments. This new design has an asymmetrical cross section that gives the instrument 'snake-like' movement, as claimed by the company. Hence, in this study, we compared the shaping ability of two endodontic instruments with two disparate design features in the maxillary first premolar using a well-established technique.[25] Two parameters were used in this comparison, volume changes and canal transportation, before and after preparation using CBCT scanning, which was used because it provides an accurate, reproducible, 3-dimensional evaluation of changes in both dentin thickness and root canal volume before and after preparation without the destruction of specimens.[24-26]

Root canal instrumentation in both groups resulted in a significant increase in canal volume with no significant difference between the groups. The greatest gain in the buccal root canal volume was 1.54 mm^3, while the palatal root gained 0.89 mm^3 in volume. It is not possible to compare our results to other studies because there is lack of consensus regarding tooth type and the boundaries of the region of interest. However, when percent volume changes were calculated, our data were in agreement with earlier studies resulting in a mean volume gain between 26 and 58%.[30]

Once transportation occurs, the rest of the shaping steps will be affected, thereby leading to the formation of ledges, perforations, or zipping. These shaping errors will lead to improper sealing that might adversely influence the root canal treatment prognosis. It has been suggested that 0.15 mm apical transportation is acceptable.[14,31] However, if apical transportation exceeds 0.3 mm, it will have a negative impact on root canal filling. In this study, the transportation values did not reach this critical level, and the maximum value of 0.14 mm was considered to be within the acceptable limit.

Apart from factors related to the access cavity design and operator's experience, the canal anatomy, instrument design, and alloy have the greatest impact on the direction and degree of canal transportation. Independent of the instrument type, it has been shown that a noncutting tip instrument has a better centering ability than a cutting tip instrument.[9,14,32,33] Our results revealed nonsignificant differences between the two instruments, and the use of the ProFile Vortex, which has a different production process, was found to lead to transportation that did not differ from the use of Revo-S conventional NiTi rotary instrument systems. These results are in agreement with results from other studies by Çelik (2013)[34] and also correspond to the study by Yamamura (2012),[35] who found that both EndoSequence and ProFile Vortex files performed similarly with regards to transportation. In addition, the manufacturer claims that the Revo-S except SC2 was designed with 3 different diameters of asymmetrical cutting edges to provide more flexibility by decreasing the core diameter of the instruments, allowing them to fit in the original canal. However, this system has been shown to lead to similar transportation with other NiTi rotary instrument used in the study; this result is in agreement with the recent study by Çelik (2013),[34] in which they found that the Revo-S showed the same degree of transportation when compared to other NiTi rotary instruments Revo-S.

Interestingly, the direction of transportation was unpredictable. The majority of our samples showed transportation at the inner curvature coronally, while apically, the direction was more toward the outer curvature. It was expected that the noncutting tip of both instruments would result in less canal transportation toward the inner curvature at the middle level and may even predispose transportation toward the outer curvature, which is in agreement with previous results.[36] However, in the buccal root, there were more canal transportations toward the outer curve of the canal than toward the inner curve. Analysis of the cross-sectional level effect indicated that cross sections 7 and 4 promote a significantly greater amount of canal transportation than cross sections 1, 2 and 3. This result could be attributed to the canal anatomy, as the palatal furcation groove concavity of the buccal root of the upper premolars starts at the bifurcation level and reaches a maximum depth of 0.18 to 0.46 mm at a mean distance of 1.18 mm from the bifurcation, with a maximum value of 0.89 mm in the middle third.[16-18] Therefore, the shaping quality was primarily influenced by the canal anatomy. In our study, both in conclusion, Revo-S and ProFile Vortex files performed similarly when comparing transportation and volume changes. This result could be attributed to the similarity in design of the two file systems. The raw material has little or no impact on the performance of the instruments, and the shaping quality was primarily influenced by the canal anatomy. However, both instruments allowed for the safe preparation of root canals of maxillary first premolars.

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