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Influence of Root Canal Curvature on Wall Cleanliness in the Apical Third during Canal Preparation

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ABSTRACT

Objective: The aim of this study was to evaluate the influence of root canal curvature (curved and straight root canals), prepared using reciprocating and rotary files, on wall cleanliness during root canal treatments.
Methods: Thirty curved and 30 straight human root canals were prepared using ProTaper (Dentsply), ProTaper Next (Dentsply) and Reciproc files (Dentsply) (n=20/group). The roots were split longitudinally and observed using a scanning electron microscope. Six micrographs were obtained at 1, 3 and 5 mm from the working length (WL). Two blinded observers scored the amount of debris. Mean debris scores were compared using a non-parametric the Mann-Whitney U test or Kruskal-Wallis test, and a Bonferroni correction was used for multiple comparisons.
Results: Considering all the shaping systems together, the debris scores were lower in curved root canals ($P<0.05$). Reciproc and ProTaper Next performed better than ProTaper in straight canals ($P<0.05$). No difference was found between ProTaper Next and Reciproc regardless of the canal curvature or distance from the WL. Considering all the shaping systems together, cleanliness increased when pulling away from the WL.
Conclusion: The anatomical configuration of the root canal influences the quality of cleaning by shaping instruments regardless of the instrument kinematics during endodontic procedures. In every circumstance, the last millimetres of the apical third remain the most difficult area to clean.
Keywords: Debris, reciprocating motion, root canal preparation, rotary nickel-titanium instruments, smear layer

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HIGHLIGHTS

- The influence of root canal curvature on wall cleanliness during endodontic procedures has not been described yet.
- The initial anatomical configuration of the tooth can influence the quality of the cleanliness during root canal preparation.
- Curved canals have better cleanliness than straight canals, regardless of the endodontic instrumentation kinematics (rotary/reciprocation).
- The last milimeters of the root canal always remain the most difficult to clean despite the root canal curvature and tested instruments.

INTRODUCTION

Chemomechanical preparation is essential for endodontic success and consists of cleaning and shaping the root canal (1). Shaping allows irrigation solutions (mainly sodium hypochlorite and ethylenediaminetetraacetic acid) to reach the apical area, which permits the removal of bacteria, organic and inorganic debris and the smear layer produced during instrumentation from the canal space (2). The debris and smear layers inhibit the penetration of disinfectants and root canal sealer into the porous structure of the dentin (3, 4). The use of engine-driven nickel-titanium (NiTi) instruments has become the gold standard of shaping procedures (5). Indeed, instruments driven by rotary motion improve the cleaning of the root canal walls compared to manual files in straight and curved canals (6). Recently, reciprocating files have shown good shaping ability and cleaning efficiency in straight and curved canals, which makes them a suitable alternative to rotary files (7, 8). However, no system motion has shown better results with respect to smear layer or debris removal, and previous studies have demonstrated that the apical third cannot be completely cleaned with any instrumentation or irrigation protocol (9-12). Although this parameter has been independently evaluated in straight and curved canals, no data on the influence of the canal curvature on cleanliness with different instrumental motions are available (13, 14).

ProTaper F2 finishing files (Dentsply, York, Pennsylvania, USA), which are rotary NiTi instruments with a convex triangular cross-section and a taper that decreases from the tip to the median section (apical 0.0-0.08), are widely investigated in previous studies (15). The ProTaper Next X2 is a rotary file with an offset centred rectangular cross-section that provides a 'swaggering' motion in the root canal and has a 0.06 taper (16). Reciproc R25 files (Dentsply) are used in reciprocation. They have an S-shaped cross-section with a 0.08 taper in the first 3 mm (0.08) (7). ProTaper Next ([PTN] Dentsply) and Reciproc (R) are both composed of the same NiTi M-Wire alloy, which permits a comparison between the shaping systems.

The aim of this study was to evaluate the influence of the root canal curvature prepared with different instrumental kinematics (ProTaper [PT], PTN and Reciproc) on the cleanliness of the apical third of the root canal walls.

METHODS

Specimen Preparation

A total of 60 mature permanent upper premolars, which were freshly extracted for periodontal disease or orthodontic reasons, were selected, numbered and preserved in an aqueous solution of 0.5% chloramine before and after preparation (protocol conducted with the approval of the ethics committee no: DC-2008-642). The teeth were non-carious and had either straight or curved root canals, which were visually standardised. A pre-operative radiograph was obtained in the buccolingual and mesiodistal directions using a digital technique to measure the root curvature according to the Schneider method (17). The curvature was determined by measuring the angle between a line parallel to the long axis of the root canal and a second line that passes through a set of 2 points: the start curvature and apical foramen. The similarity of the anatomy was verified, and only those teeth with a root canal width close to the terminus presenting a size of approximately 15 and intact root apices were included. This parameter was verified with a size 15 K file (Dentsply). The teeth were decoronated using a diamond bur to standardise the working lengths (WL) to 15 mm. Teeth with oval or excessively tapered (no instrument-wall contact) canals were excluded from the study. Two groups of 30 root canals (30 curved [$\alpha>20°$]; 30 straight) were randomly divided into 3 groups (PT, PTN [Dentsply] and R [Dentsply]) of 10 teeth each (n=10) (6) using a random number generator (Intemodino group, Prague, Czech Republic) to provide a total of 6 ex-

Figure 1. Sample mounted on a Protrain device (Simit, Mantua, Italy)

perimental groups based on the shaping system used. The samples were mounted on an endodontic trainer (Protrain, Simit, Mantua, Italy) with the root canal curvature oriented to the right of the operator, and the wax was positioned at the apices of the teeth to simulate the periodontal ligament (Figure 1). Only one canal per tooth was prepared. The glide path was verified with a size 10 K file (Dentsply), and the WL was determined by measuring the length of a manual K file (size 10) at the apical foramen-1 mm. Each canal was then prepared according to the assigned experimental group. All the files were new, mounted on an X-Smart Plus motor (Dentsply) and used as per the manufacturer's instructions with adapted individual torque, speed and kinematics.

PT Group

In this group, the roots were prepared at a speed of 300 rpm with the use of SX (3 $N.cm^{-1}$), S1 (3 $N.cm^{-1}$), S2 (1 $N.cm^{-1}$), F1 (1.5 $N.cm^{-1}$) and F2 (2 $N.cm^{-1}$) files (PT, Dentsply). The files were used sequentially to the WL to reach an apical size of 25 and a taper of 0.08.

PTN Group

The roots were sequentially instrumented to obtain an apical size of 25 and a taper of 0.06 by using PTN (Dentsply) X1 and X2 shaping files under permanent rotation (300 rpm; 2 $N.cm^{-1}$).

R group

The canals were prepared using the Reciproc (Dentsply) R25 single file with a taper of 0.08 to obtain the same apical diameter as the roots in the PT and PTN groups.

The apical diameter was verified with a size 25 manual file (Dentsply) at the WL. The apical patency was verified between each instrument by means of a manual K file (size 10) inserted beyond the apical foramen. To permit a comparison between experimental groups and to avoid any influence of irrigation

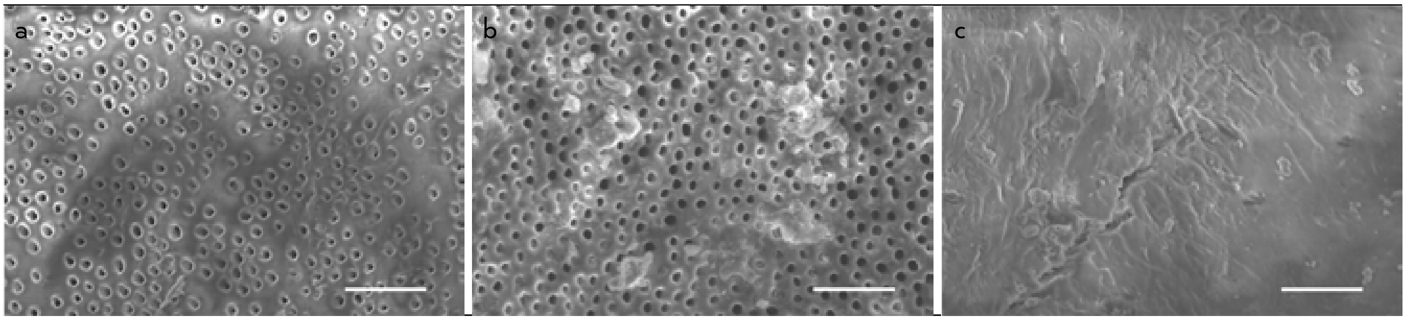

Figure 2. a-c. Score 1 root canal wall (a), score 2 root canal wall (b) and score 3 root canal wall (c). Scanning electron micrographs show a clean root canal surface (a), partially covered tubules (b) and completely covered tubules (c) *(bars=50 μm)*

on the results of this study, the irrigation protocol was standardised and simplified with only sodium hypochlorite as follows: a 2 mL sodium hypochlorite solution at a concentration of 5.25% was delivered between each instrument using a plastic syringe with needle of size 30 (Ultradent Products Inc., South Jordan, Utah, USA) progressively to 1 mm from the WL (15, 18).

Specimen Observation

The roots were immediately coded for the blinded analysis, and a groove was formed longitudinally with a diamond bur. Special care was taken to avoid penetration of the canal with the bur, and the roots were split longitudinally to allow observations of the canal walls. The split roots were placed in a scanning electron microscope (SEM; Neoscope II, JEOL, Tokyo, Japan). Six micrographs were obtained at each distance (1, 3 and 5 mm) from the WL using high vacuum, 10 kV and 1000× magnification parameters, thus providing a total of 18 micrographs per tooth and a 360° circular view of the canal walls.

Two experienced endodontists, blinded to the experimental groups, independently graded the amount of debris and the smear layer on each micrograph using Mayer's semi-quantitative score on a scale of 1 to 3 (1: no or a small amount of debris/smear layer, 2: many conglomerations/smear layer amounts and 3: completely covered canal walls) (11) (Figure 2).

Statistical Analysis

The inter-observer agreement at each WL was measured by the Kappa coefficient using 360° pictures (6 micrographs per tooth for 60 teeth). The agreement was excellent if Kappa was >0.80, satisfactory if 0.61<Kappa≤0.80, moderate if 0.41<Kappa≤0.60, low if 0.21<Kappa≤0.40 and very low if Kappa≤0.20. The Mann-Whitney U test was used to assess comparisons of the amount of debris and the smear layer at each distance from the WL (average values of 12 debris and smear layer scores) between the curved and straight root. Differences in the amount of debris and the smear layer scores at each distance from the WL between the 3 experimental groups were assessed using the Kruskal-Wallis test followed by *post hoc* pairwise comparisons with the Mann-Whitney U test (and applying the Bonferroni correction for multiple comparisons). Statistical testing was conducted at the 2-tailed α level of 0.05, and the data were analysed using the Statistical Analysis System (SAS) software package version 9.3 (SAS Institute Inc.; Cary, NC, USA).

TABLE 1. Mean value (standard deviation) of the debris and smear layer scores in different areas regarding the root canal curvature

Distance from WL	Straight root canals (n=30/group)	Curved root canals (n=30/group)	P
1 mm	2.79 (0.27)	2.61 (0.45)	0.1000
3 mm	2.53 (0.46)	2.12 (0.62)	0.0088
5 mm	1.97 (0.60)	1.58 (0.51)	0.0075

WL: working length

TABLE 2. Mean value (standard deviation) of the debris and smear layer scores in different areas regarding the shaping system used

Distance from WL	Straight+curved root canals (n=20/group)			P
	PT	PTN	R	
1 mm	2.93 (0.12)*†	2.54 (0.43)	2.59 (0.42)	0.0003
3 mm	2.66 (0.39) *†	2.21 (0.64)	2.10 (0.55)	0.0027
5 mm	2.25 (0.67) *†	1.45 (0.35)	1.63 (0.38)	0.0006

PT: ProTaper; PTN: ProTaper Next; R: Reciproc; WL: working length; *: significant difference with PTN; †: significant difference with R

RESULTS

The inter-observer agreement for grading the amount of debris and the smear layer was acceptable, with a weighted Kappa coefficient (95% confidence interval [CI]) of 0.59 (0.50-0.68) for micrographs at the WL of 1 mm, 0.68 (0.63-0.74) at the WL of 3 mm and 0.66 (0.61-0.73) at the WL of 5 mm.

No group showed perfectly clean root canal walls; however, the amount of debris/smear layer decreased as the distance from the WL increased. Considering the root canal curvature as shown in Table 1, straight roots demonstrated a larger amount of debris/smear layer than did the curved root canals at 3 mm (2.53±0.46 and 2.12±0.62, respectively) and 5 mm (1.97±0.60 and 1.58±0.51, respectively) from the WL (P<0.01). Regarding the shaping system used (Table 2), the PT group presented the worst scores at 1, 3 and 5 mm from the WL (2.93±0.12, 2.66±0.93 and 2.25±0.67, respectively) compared to the PTN (2.54±0.43, 2.21±0.64 and 1.45±0.35, respectively), and R (2.59±0.42, 2.10±0.55 and 1.63±0.38, respectively)

TABLE 3. Mean value (standard deviation) of the debris and smear layer scores in different areas regarding the root canal curvature and the shaping system used

	Straight root canals (n=10/group)				Curved root canals (n=10/group)			
Distance from WL	PT	PTN	R	P	PT	PTN	R	P
1 mm	3.00 (0.00)*†	2.70 (0.18)	2.63 (0.36)	0.0004	2.86 (0.13)	2.40 (0.53)	2.56 (0.48)	0.1069
3 mm	2.85 (0.20)*†	2.42 (0.41)	2.33 (0.56)	0.0107	2.48 (0.45)	2.00 (0.77)	1.88 (0.46)	0.0725
5 mm	2.49 (0.68)*	1.54 (0.28)	1.89 (0.33)	0.0049	2.01 (0.59)	1.37 (0.40)	1.38 (0.21)	0.0179

PT: ProTaper; PTN: ProTaper Next; R: Reciproc; WL: working length
*significant difference with PTN
†significant difference with R

groups (P<0.01). No difference was found between the PTN and R groups (P>0.05). Considering the root canal curvature and each shaping system used (Table 3), differences between the experimental groups in the straight roots were similar when all roots were considered together (P<0.05), except between PT and R at 5 mm from the WL (straight roots: 2.49±0.68 and 1.89±0.33, respectively). In the curved roots, no significant difference was observed after correction for multiple tests between the shaping systems, regardless of the distance from the WL.

DISCUSSION

The aim of this study was to investigate the influence of the root canal curvature on the cleanliness by comparing the amount of debris/smear layer in straight and curved root canals.

Removing infected dentin, vital/necrotic pulp and microorganisms from the root canal is one of the main goals of endodontic procedures (19). The amount of debris is generally measured by SEM observations, and even though this method has been widely described and optimised, some drawbacks persist (6, 20-23). Indeed, debris/smear layer quantification is generally based on a small number of photomicrographs and offers only a selective appreciation of the root canal wall cleanliness. Moreover, the magnification used is generally debated on the use of high magnification (1000×) that permits detailed observation but reduces the observer's field of view (23, 24). These limitations were avoided in the present study by considering the whole circumference of the root walls at a specified distance from the WL, which allows both general appreciation and detailed observations that were possible owing to the high magnification (11, 12). Previous experimental protocols do not allow to precisely differentiate smear layer formation and removal during instrumentation of the root canal, because the same shaping instrument both produces and removes it. Therefore, the final cleanliness of the root canal was considered.

Different elements were standardised to ensure the comparability of the experimental groups. Therefore, to reduce the influence of natural variations in the morphology between the included teeth, apical diameters, WLs, canal curvatures and NiTi alloys composing the investigated instruments were standardised. The PTN and R systems, both composed of M-Wire alloy, were selected to provide both reciprocating and rotary instruments, while avoiding any influence of variations in the alloy metallurgy. Moreover, according to the main objective of this study, a simplified irrigation protocol with only sodium hypochlorite was used, without irrigation activation devices and chelating agents (15, 18). This permitted non-interference with the real cleaning efficiency of the evaluated instruments.

Since no instrumentation or irrigation protocol can completely clean the apical third, contrary to the coronal and middle thirds, we thus decided to focus this investigation on the apical third by gathering extra measurements at 3 mm from the WL (6, 9-12). The PT group was used in the present study to compare our results with those of previous studies (6, 23). Generally, Reciproc resulted in better cleaning of canal walls than PT-shaped canals (15). Mancini et al. (21) obtained similar PT results regarding cleanliness that showed the ability to compare instrumental motion in straight versus curved canals similar to our study.

The results of this investigation are not surprising and are in agreement with those of previous studies, which confirm that the cleaning efficiency decreases when approaching the WL within the apical third for all the investigated systems (13-15). Thus, differences between the apical third and the two coronal thirds shown in previous studies can be observed within the apical third.

Interestingly, we noted lower cleaning scores in the straight canals for all the groups and observed no influence of the motion of the instrument on the cleanliness of the curved canals, as shown previously (15). To our knowledge, no studies comparing the cleaning efficiency of the instruments between straight and curved canals have been published. However, it is a well-known fact that instrumental strains in the curved canals result in apically higher dentin removal at the outer side of the curvature (25). Thus, higher strains between instruments and root canal walls in the curved canals could explain the better cleaning at the expense of the increased risk of apical root canal transportation. However, these conclusions require comparative studies on the cleaning of the internal and external sides of the root curvatures separately.

Regarding the influence of the investigated instruments, the cleaning efficiency of PTN and R was higher than that of PT at each distance from the WL in the straight canals. This difference was not found in the curved canals. Nonetheless, the inferior results observed in the PT group could be explained by less contact between the root canal walls and the PTN instrument, which improved debris removal compared to the PT system (26). Regarding the superior cleaning obtained in the R group compared to the PT group, our results are in agreement with those of Çapar et al. (27), who demonstrated a better cut of dentine with the R than with the PT system. Generally, the high chip space of an instrument improves its debris removal capacity (15). Previous researches have shown that instruments with active cutting-edge blades had superior cleaning efficiency compared to radial lands (6, 28, 29). Thus, lower PT results could be explained by the presence of the convex flutes of the triangular cross-section that are not found on the PTN and R instruments (Figure 1).

Moreover, our results suggest that there was no influence of instrumentation kinematics on the root canal cleaning. This is confirmed by previous SEM observation studies and bacterial removal studies, which show no differences in the cleaning efficiency of reciprocation or rotary files (8, 15, 30). Hence, we can hypothesise that to improve the cleaning of the root canal walls, the file design was more decisive than the number and kinematics (rotation/reciprocation) of instruments used. However, these conclusions have to be tempered due to the differences in the sections and tapers of the investigated instruments and in previous works. Furthermore, smear layer width and compaction can influence its removal difficulty. These parameters should be precisely investigated in further studies to assess their influence on cleanliness in curved and straight root canals. In addition, no formal size calculation was performed to determine the appropriate sample size needed. The fixed size of 30 straight roots and 30 curved roots was set *a priori* to provide a first estimation of the effect of root canal curvature. We therefore caution that we cannot exclude a lack of adequate statistical power and that our study should be considered only as exploratory. *A posteriori*, we calculated the smallest significant difference between the straight *versus* curved roots (expressed as the standardised mean difference) that our study sample size (30 per groups) allowed us to detect at 80% power. With a 2-tailed test and a significance level of 5%, we could detect an effect size of 0.74, which was interpreted as a large effect size.

CONCLUSION

In summary, on the basis of the parameters of this *in vitro* study, we conclude that within the apical third, the root canal cleanliness was higher in curved root canals, with ProTaper Next and Reciproc compared to ProTaper and when pulling away from the WL. Cleaning of the apical third was not influenced by instrumentation kinematics (rotary/reciprocation) but depended on the root canal curvature and the instrument design.

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