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Efficacy of Controlled Memory and Shape Memory Nickel Titanium Instruments in Removing Filling Material from Severely Curved Root Canals: An *Ex Vivo* Study

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ABSTRACT

Introduction: The aim of the present study was to compare the efficacy of four NiTi instruments with different properties (shape memory and control memory), in both rotary and reciprocating motions, during retreatment procedures. **Methods and Materials**: Mesial canals of thirty-two mandibular molars were instrumented, obturated, and then scanned with" Cone-beam Computed Tomography" (CBCT). Teeth were randomly divided into 4 groups (n=8) according to each system: "Shape Memory" (SM) instruments including Reciproc (R25 file) and ProTaper Next (X3 and X2 file), "Controlled Memory" (CM) instruments including WaveOne Gold (Primary file) and Hyflex (30.06 and 25.06 file). The specimens were rescanned after retreatment procedures. The volume of the residual material left inside the canals, the operating time and the fractured files were analyzed. ANOVA and student t-tests were used for statistical analysis. **Results**: There were no significant differences in the percentage of the residual filling material or requiring time amongst different groups of instruments (P>0.05). However, CM instruments presented the highest frequency of fractured files [2 SM instruments (12.5%) and 7 CM instruments (43.75%)] with a significant difference (P=0.023). **Conclusions**: This *ex vivo* study showed that CM and SM instruments can remove filling materials from mandibular mesial root canals during retreatment procedures; nonetheless the CM instruments had a higher frequency of fractured files. No system was able to completely remove the filling materials. Therefore, additional procedures and techniques are needed to improve root canal cleanliness.

Keywords: Endodontics; Retreatment; Root Canal Preparation; Tooth Root

Introduction

When an endodontic treatment fails, the microbiota is different from a primary treatment. In such conditions, bacteria have been able to survive the initial treatment and now, are immersed in the root canal filling materials [1]. Therefore, it is necessary to remove as much root canal filling materials as possible to access and clean the engaged root canal system again [2].

Lower molar retreatments are difficult because their mesial roots have a complicated anatomical root canal system; with enough variability in their internal [3] and external anatomy [4].

Nickel Titanium (NiTi) instruments facilitate cleaning and shaping of severely curved root canals [5, 6]. The NiTi instruments have two crystallographic phases: austenite and martensite. In the austenite phase, the metal is more rigid, whereas in the martensite phase, the metal is soft and ductile and can be easily deformed [7].

Previous studies have employed NiTi files to remove root canal filling materials [8-10]. However, when strained, these files can generate fractures inside the root canals [11]. This problem has been studied to evaluate the fracture resistance of NiTi files [12].

The superelastic property of a NiTi instrument allows it to return to its original shape after a substantial deformation, a property known as "Shape Memory" (SM) [7, 13]. As the M-Wire, heat-treated NiTi instruments provide several benefits; including higher fracture resistance while keeping same SM characteristics [14]. New NiTi instruments, with special thermo mechanical processes, can change to a martensite phase when used clinically, by being able to control the memory of the file. This feature which is known as "Control Memory" (CM) [15], makes them more flexible and resistant to fracture [16-18].

Different methods, in combination with NiTi rotary and reciprocating systems, were not able to remove all the filling materials from root canals [8-10]. However, there are few studies which evaluate SM and CM properties of NiTi instruments for endodontic retreatments [19, 20].

The aim of this study was to use cone-beam computed tomography (CBCT) in order to a) evaluate the percentage of the remaining filling materials, b) the time and the file fractures of SM and CM instruments in rotary and reciprocating motions during retreatment procedures in mesial canals of lower molars with severely curved roots.

Materials and Methods

Sample size

The total sample size for this study was calculated using Stata/SE 11.1 statistical software (StataCorp, TX, USA); based on the following pre-established parameters from a pilot study: Minimum detectable difference between means was 0.20. The level of significance was determined at 0.05, and 3 groups were considered. With these parameters, the estimated minimum sample was found to be 4 specimens per group. In this study, we decided to duplicate the minimum sample size to 8 specimens per group according to Martins *et al.* [10].

Specimen preparation

This study was reviewed and approved by Cayetano Heredia Peruvian University Ethics Committee (214-09-17). Same operator conducted the protocols followed in the study. The mesial roots of freshly human mandibular molars, which were extracted for reasons not related to this study and kept in physiological saline, were examined under 3.5× magnification. Then, we chose the ones with intact mesial roots and fully formed apices, and with lengths more than 15 mm. In selected teeth, an endodontic access was drilled and radiographic examinations were done so as to choose only those with two separated mesial canals. Roots classified as Vertucci´s type IV [3] were included in the study. Teeth with previous endodontic treatments, pulp calcification, internal resorption, or double curvature in mesial canals were excluded. Only mesial canals with curvature angles more than 35° [4] were chosen using Image J software version 1.50i (Wayne Rasband National Institute of Health, USA). The mean angle was 37.35°.

Sample preparation

The crowns were sectioned using a diamond bur; to achieve a standardized root length of 15 mm. The glide path was established by using a # 8 K-type file (Maillefer, Ballaigues, Switzerland). The working length (WL) was established 1 mm short from the apical foramen, and cleaning and shaping of the canal was done using UnicOne 20.06 (UnicOne, Medin, Nové Město na Moravě, Czech Republic). The pulp chamber was irrigated with 1 mL 4% sodium hypochlorite (NaOCl) with an endodontic tip; Navitip (Ultradent Products Inc, South Jordan, UT, USA). The file was introduced into the root canal until resistance was felt in pecking motion with slight apical pressure. The canal was irrigated with 4% NaOCl and the file was cleaned with a sponge. These steps were repeated until the file reached the WL.

The smear layer was removed using 2 mL 17% EDTA and 4% NaOCl; activated by an ultrasonic device with 3 cycles of 20 sec each. Obturation was performed using a modified hybrid Tagger`s technique [21]; a tapered gutta-percha cone 20/0.06 was coated with sealer (AH-Plus, Dentsply DeTrey, Konstanz, Germany) and adjusted to the root canal. An engine plugger was placed 4-5 mm into the canal for thermomechanical compaction. A final cold vertical compaction with stainless steel Machtou plugger (VDW, München, Germany) in the orifice was

Table 1. Time and mean percent volume of residual filling materials in root canals after retreatment procedures

Instrument	Mean percent volume of residual filling materials				Time in seconds	*P*-value
	Excluding fractured files		Including fractured files			
	Mean (SD)	*P*-value	Mean (SD)	*P*-value	Mean (SD)	
Reciproc	29.246 (13.6)	0.89*	29.32 (13.71)	0.26*	138.98 (32.93)	0.91*
Protaper Next	24.43 (13.445)		29.87 (15.31)		113.81 (20.2)	
Wave One Gold	20.208 (11.208)		34.99 (26.03)		133.63 (33.71)	
Hyflex CM	25.39 (12.404)	0.57**	48.82 (27.36)	0.11**	120.65 (24.36)	0.99**
Control memory	27.18 (13.24)		29.56 (13.99)		128.76 (30.36)	
Shape memory	22.51 (11.31)		41.9 (26.77)		127.86 (28.94)	

** Statistical analysis with ANOVA test (P>0.05); ** Statistical analysis with Student´s T-test (P>0.05)*

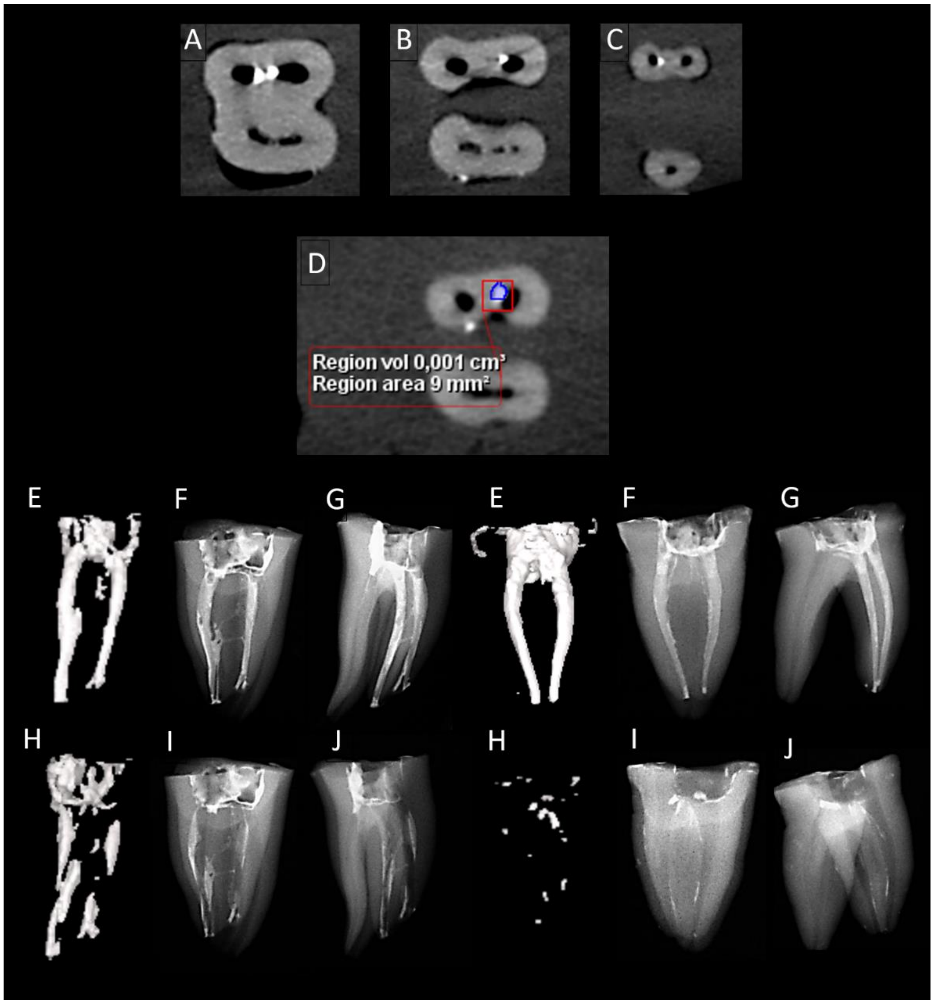

Figure 1. *A)* Residual filling materials in the cervical third from CBCT; *B)* Residual filling materials in the medial third from CBCT; *C)* Residual filling materials in the apical third from CBCT; *D)* CBCT Measure of the residual filling material volume; *E)* CBCT Reconstructions of the initial filling materials; *F)* Proximal X-ray views of the initial filling materials; *G)* X-ray in an angle view of the initial filling materials; *H)* CBCT Reconstructions of the remaining filling materials; *I)* Proximal X-ray views of the residual filling materials; *J)* X-rays in an angle view of the residual filling materials

done. Buccolingual and Mesiodistal radiographies of the teeth were taken to evaluate the quality of the obturation. The crowns were sealed with a temporary filling material (Coltosol, Coltène/Whaledent, Altstätten, Canton of St. Gallen, Switzerland) and then stored in an incubator (Precision Scientific Company, Chicago Illinois, USA) at 37°C and 100% humidity for 15 days. All specimens were mounted on silicone models, and blind randomisation was performed via writing a new coded name for each specimen in the model.

CBCT scanning

A Pre-operative scan was performed after the obturation of canals using a Planmeca promax 3D CBCT scanner (Planmeca, Helsinki, Finland); which allows scanning of an isotropic voxel size 75 µm and 0.5 mm copper+2.5 mm aluminum filter. Other parameters included x-ray voltage of 90 kVp, FOV of 5 cm and 6.3 mA, 15 sec of exposure time, 360° rotation and 0.5° rotation step. The images were reconstructed with Planmeca Roemexis v. 4.4.1 software (Planmeca, Helsinki, Finland) using the modified Feldkamp cone-beam reconstruction algorithm. The original grayscale images were processed for noise reduction, using a low metal artifact reduction algorithm.

Removal of obturation material

Four experimental groups were evaluated: Reciproc (REC), ProTaper Next (PTN) which represented Shape Memory instruments (SM) WaveOne Gold (WOG), and Hyflex CM (HYF) which represented Controlled Memory instruments (CM). Mesiobuccal and mesiolingual canals were balanced and randomly distributed between the groups (www.random.org).

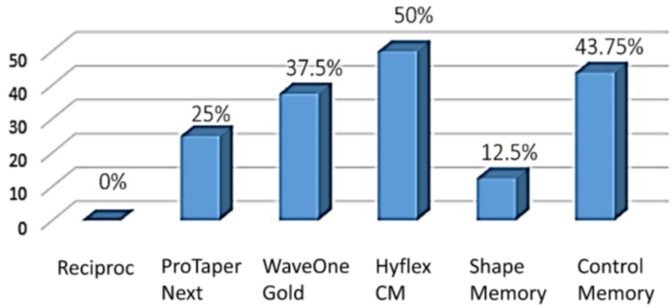

Figure 2. Percentage of fractured instruments during the retreatment procedures. CM instruments presented the highest frequency of fractured files with statistical significance (*P*=0.023)

Obturation was removed using R25 file (25/0.08) for the Reciproc group and Primary (25/0.08) for the WaveOne Gold Group. The removal of the filling materials followed the same protocol used in the canal instrumentation; with an endodontic motor (VDW silver, Munich, Germany) in Reciproc motion and WaveOne motion, respectively.

In PTN group, X3 (30/0.07) was used in the cervical and middle thirds and X2 (25/0.06) in the apical third. In HYF group, 30/0.06 file was used in the cervical and middle thirds and 25/0.06 in the apical third. These files were used with an endodontic motor (VDW silver, Munich, Germany) at 500 rpm and 300 g/cm torque in a continuous rotary motion with light apical pulses of pressure until the WL was reached. A total of 20 mL of 4% NaOCl in each canal was used for irrigation. Removal of obturation was considered complete when the obturation materials were no longer visualized between the cutting blades, and the brushing motion could not remove any more materials in all groups. No solvent was used in any group to avoid any interference with each system. For each sample, the total time needed for the instruments to remove the obturation material, was counted in seconds. Time taken to irrigate, change and clean instruments was excluded. Each set of files was used in a single canal. When the files fractured, the operator stopped removing filling materials.

Evaluation of the remaining filling materials

A postoperative CBCT scan was performed to allow evaluation of the remaining obturation materials. A second blind was performed by changing the IDs of the subjects in the dataset, to prevent the operator from knowing what specimen was being evaluated. The calibration was performed by a radiologist (ICC=0.909). The resulting images of the remaining root canal filling materials from pre-operative and post-operative scans were compared.

The integrity of the files was evaluated using a microscope (D. F. Vasconcellos, Sao Paulo, Brasil) to determine if the file was fractured. The teeth were radiographed buccolingually and mesiodistally to assess the residual filling materials in the x-rays and then, the images were compared (Figure 1).

Statistical analysis

Using ANOVA and *t*-test, the time needed for retreatment procedures was analysed (*n*=4), excluding the samples with fractured instruments. The mean percentage of the residual filling materials in canals with (*n*=8) and without (*n*=4) fractured files was analysed, also using ANOVA and *t*-test. The fractured CM instruments and SM instruments (*n*=16) were analysed using Fisher exact test. The calculations were performed by SPSS software v.20 (SPSS inc., Chicago, Il, USA). The type-one error of the test was set at 0.05 and a power of 80%.

Results

The root curvature of the teeth ranged between 35° and 44° (mean 37.5°±2.65) with no statistically significant difference between groups (*P*=0.561). There was no significant difference in time between systems (*P*>0.05) (Table 1). There was no statistically significant difference in residual filling materials between systems (*P*>0.05) (Table 1). The percentage of fractured files were determined in Figure 2. No REC file was fractured, and files fractures were: 2 PTN files (25%), 3 WOG files (37.5%) and 4 HYF files (50%), 2 SM instruments (12.5%) and 7 CM instruments (43.75%). CM instruments presented the highest frequency of fractured files with statistical significance (*P*=0.023).

Discussion

In the present study, the CM instruments presented higher percentage of fractures with statistical significance. However, there were no differences in the capacity of root-filling-material removal or the time needed during this performance.

The aim of endodontic retreatments is to remove as much fillings material as possible to improve cleanliness. Nevertheless, none of the used techniques was able to completely remove the filling materials from root canal walls, which was in agreement with literature [19, 20, 22-26].

There was no statistically significant difference in the effective time employed for retreatment procedures between groups. This result was in accordance with what was reported in previous studies when PTN and REC were used [8, 9]. PTN, REC and WOG have also shown similar effective time employed in initial treatments [27].

In order to obtain an even distribution of the specimens in the groups and minimize the effect of root canal anatomy, the selected roots had two separated canals; from the pulp chamber to the apex.

The distribution of the groups regarding canal curvature angles was well-balanced. The curved canals of mesial roots have been previously used for retreatment in the literature [24-26, 28-31].

Micro-CT [8, 10, 19, 31-33] and CBCT [20, 34-37] were used to evaluate the remaining filling materials. The CTshey were noninvasive techniques and could provide precise quantitative evaluation of residual volume material. ProMax 3D Scanner (Planmeca OY, Helsinki, Finland) and Romexis software (Planmeca OY, Helsinki, Finland) have been used in a previous similar study [37]. CBCT showed larger root canal volume compared to micro-CT examination, since the latter generated artifacts [38]. In CBCT, lower FOV, lower mA, lower voxel size and high kVp are preferable to achieve fewer volumetric distortion artifacts [39]. A 75 µm voxel size and a small 5 cm FOV were used in the present study.

We employed a single use of files; since we considered that when they were used repeatedly, they could lose their cutting capacity and thus, it could be a cause of bias. However, and in the literature, files were used multiple times during retreatment procedures [22-24, 29, 40]. The files in our study were not submitted to improvement resistance procedures such as deep cryogenic treatment [41].

In the PTN group, X3 was used in the cervical middle thirds, and X2 was used for the apical third. The files were calibrated at 500 rpm and at 3 Ncm of torque in a continuous rotary motion as described in previous studies [8-10]. We used Hyflex CM files with the same torque and speed so that they were in the same conditions of use.

Prodesign Logic® and Prodesign R® both CM systems showed better performance compared to WaveOne Gold in resistance to cyclical fatigue [42]. Hyflex EDM® has been used for retreatments of straight roots with a better performance than WOG [20]. Achieving cleaning and shaping of the apical third in a curved canal is complicated, therefore, our results cannot be extrapolated to straight roots. The use of conventional superelastic NiTi files during retreatments in curved canals might lead to fracture; unlike in straight canals where these procedures are more predictable [22].

The results of our remaining filling materials stood with previous studies; with similar methodology when PTN (X3 and X2), REC (R25) [8, 26] and WOG [20] were used for retreatment procedures. There is a need to improve cleanliness and shaping to a greater size [19, 23, 26, 29].

The M Wire (REC) and CM Wire (ProDesign Logic) instruments (SM and CM respectively) have been previously evaluated for retreatment procedures in curved canals [19]. CM Wire was equally effective as M Wire because they could follow the curvature and remove filling materials. Hyflex EDM and WOG (both CM instruments) were evaluated for retreatment procedures in straight canals, with Hyflex EDM being more efficient than WOG [20]. Also, one WOG file suffered fracture and was reported.

We found that CM instruments had the most file fractures with statistical significance in rotary motion (HYF) as well as in reciprocating motion (WOG). CM instruments are more flexible because they are in martensite phase and do not have enough strength to penetrate gutta-percha, unlike SM instruments that can follow the canal curvature retaining some rigidity [8-10].

The NiTi files normally has an average of 55% nickel and 45% titanium, whereas the Hyflex CM have a lower percentage of Nickel (52.1%). This is statistically significant for its low amount of Nickel in comparison with other conventional NiTi files [43].

Previous studies showed that during initial treatment cases, CM instruments had better results when shaping curved roots canals since these instruments are more flexible and less prone to fracture in comparison to SM instruments[16, 17, 44]. They were more resistant to cyclic flexural deformation and had a low torsional resistance [45]. The aforementioned may be the reason for high numbers of fractured files during retreatment procedures in our study.

Fractured files are considered procedural errors in the literature [22, 24, 29]. When they occur, either the total study sample decreases or the samples are replaced. We included the file fracture to measure the efficacy performance of SM and CM instruments.

Conclusions

CM and SM instruments could remove root canal filling materials from mandibular mesial root canals with severe curvature. However, CM instruments had a higher frequency of fractured files. Generally, none of the investigated systems was able to completely remove the filling materials. Therefore, supplemental procedures and techniques are needed to improve root canal cleanliness.

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Conflict of Interest: 'None declared'.

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