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Research Article

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Buckling resistance, torque, and force generation during retreatment with D-RaCe, HyFlex Remover, and Mtwo retreatment files

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ABSTRACT

Objectives: This study compared the buckling resistance of 3 nickel-titanium (NiTi) retreatment file systems and the torque/force generated during retreatment.
Materials and Methods: The buckling resistance was compared among the D-RaCe (DR2), HyFlex Remover, and Mtwo R25/05 retreatment systems. J-shaped canals within resin blocks were prepared with ProTaper NEXT X3 and obturated by the single-cone technique with AH Plus. After 4 weeks, 4 mm of gutta-percha in the coronal aspect was removed with Gates-Glidden drills. Retreatment was then performed using DR1 (size 30, 10% taper) followed by DR2 (size 25, 4% taper), HyFlex Remover (size 30, 7% taper), or Mtrwo R25/05 (size 25, 5% taper) (15 specimens in each group). Further apical preparation was performed with WaveOne Gold Primary. The clockwise torque and upward force generated during retreatment were recorded. After retreatment, resin blocks were examined using stereomicroscopy, and the percentage of residual filling material in the canal area was calculated. Data were analyzed using 1-way analysis of variance with the Tukey test.
Results: The HyFlex Remover files exhibited the greatest buckling resistance ($p < 0.05$), followed by the Mtwo R25/05. The HyFlex Remover and Mtwo R25/05 files generated the highest maximum clockwise torque and upward force, respectively ($p < 0.05$). The DR1 and DR2 files generated the least upward force and torque ($p < 0.05$). The percentage of residual filling material after retreatment was not significantly different between file systems ($p > 0.05$).
Conclusions: NiTi retreatment instruments with higher buckling resistance generated greater clockwise torque and upward force.

Keywords: Buckling resistance; Root canal retreatment; Torque; Upward force

INTRODUCTION

During root canal retreatment, several instruments are used to remove the existing root canal filling material. Nickel-titanium (NiTi) rotary instruments are preferred to hand files because they are more efficient and cause less extrusion of debris [1,2]. NiTi retreatment instruments must have the ability to penetrate gutta-percha and the rigidity to resist deformation during retreatment. Buckling is defined as a sudden sideways deflection of an instrument when the compressive load exceeds the instrument's resistance [3]. NiTi retreatment instruments

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should therefore have adequate buckling resistance to prevent deformation. However, the buckling resistance of NiTi retreatment instruments has not yet been studied.

NiTi instruments possess 2 different phases: austenite and martensite [4]. Martensite is more flexible than austenite, whereas austenite is stiffer and harder than martensite or R-phase [5]. Because NiTi retreatment instruments are required to penetrate the root-filling material, austenitic instruments with higher hardness and stiffness are preferable. The ProTaper Universal Retreatment system (Dentsply Maillefer, Ballaigues, Switzerland), D-RaCe (FKG Dentaire, La Chaux-de-Fonds, Switzerland), R-Endo (Micro-Mega, Besançon, France), and Mtwo retreatment system (VDW, Munich, Germany) are manufactured using a traditional NiTi alloy and are composed of austenite at room temperature. A previous study reported the superior effectiveness of D-RaCe files in removing gutta-percha from curved root canals compared to ProTaper Universal Retreatment system and Hedström files [6]. D-RaCe and Mtwo retreatment files have comparable performance in removing gutta-percha and require less time than R-Endo and Hedström files [7].

In recent years, NiTi retreatment instruments manufactured using heat treatment, such as the HyFlex Remover file (Coltene/Whaledent AG, Altstätten, Switzerland), have become available. HyFlex Remover was made using C-wire, which was used for One Curve (Micro-Mega) [8]. One Curve exhibited superior cyclic fatigue resistance compared to One Shape, a predecessor of One Curve, which was made with a conventional NiTi alloy. According to the manufacturer, the C-wire consists of initial electropolishing and a subsequent heat treatment [8]. While the ProTaper Universal Retreatment system, D-RaCe, and R-Endo consist of 2 to 4 instruments for the removal of root canal filling materials, the HyFlex Remover system comprises a single instrument to remove canal filling materials up to 3 mm short of the apex. The effectiveness of the HyFlex Remover compared with that of the traditional NiTi retreatment instruments requires further investigation.

NiTi retreatment files typically have a large taper, and they continuously touch the root canal wall and/or the filling material during use. Torque is defined as the force generated when the NiTi file rotates [9]. An upward force means an apical driving force, generated by the binding of the instrument's blade in the root dentin due to its spiral configuration, which causes the screw-in effect [10]. An excessive screw-in force can increase torque and may cause the NiTi file to fracture [11]. The torque and force generated during the removal of gutta-percha might contribute to the formation of dentinal defects during retreatment [12]. The study aimed to compare 3 retreatment NiTi file systems based on their buckling resistance, the stress/torque generated during the removal of gutta-percha in an artificial root canal, and the amount of residual filling material after retreatment.

MATERIALS AND METHODS

Three types of retreatment NiTi file systems were used: D-RaCe (DR1 and DR2, FKG Dentaire), HyFlex Remover, and Mtwo (R25/05, VDW) (**Table 1**). *A priori* analysis of variance (ANOVA) (fixed effects, omnibus, 1-way) was selected from the F test family using an alpha-type error of 0.05 and a power ($1 - \beta$) of 0.85 in G*Power 3.1.9.7 software (Heinrich Heine, Universität Düsseldorf, Germany) based on a previous study with similar methodology [13]. In total, 36 specimens ($n = 12$, per group) were indicated as the appropriate sample size required to observe significant differences in torque and force values.

Table 1. Nickel-titanium (NiTi) retreatment instruments used in this study

NiTi file	Manufacturer	ISO tip size, taper	Length (mm)	Speed (rpm)	Maximum torque (N·cm)
DR1	FKG Dentaire, La Chaux-de-Fonds, Switzerland	Size 30, 10% taper	15	800	1.5
DR2		Size 25, 4% taper	25	400	1.5
HyFlex Remover	Coltene/Whaledent AG, Altstätten, Switzerland	Size 30, 7% taper	19	400	2.5
Mtwo R25/05	VDW, Munich, Germany	Size 25, 5% taper	21	300	1.2

Buckling resistance test

Buckling resistance was evaluated using a universal testing machine (UTM; Universal Mechanics Analyzer, IB Systems, Seoul, Korea), which consisted of a stainless-steel jaw operated by a reversible geared motor, a staging platform connected to a load cell, and a torque gauge. Lopes *et al.* [14] measured the buckling resistance as the force generated when an axial force caused a lateral elastic displacement of 1 mm of a NiTi file. In the present study, a NiTi file was compressed in the axial direction at 1.2 mm/s, while the tip of the file was placed in a small dimple prepared on a ceramic block (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) (**Figure 1A**). The force generated by the 2 mm axial movement was recorded as the buckling resistance. During the buckling resistance test, the DR1 file did not bend following the application of a downward force, and therefore, its buckling resistance could not be measured. The test was performed on 15 new instruments of DR2, HyFlex Remover, and Mtwo R25/05.

Retreatment techniques

Forty-five J-shaped canals in resin blocks (Endo shaping block, Diadent, Cheongju, Korea) with a working length of 14 mm were prepared using ProTaper Next (Dentsply Maillefer) up to X3 (tip size 30, apical 7.5% taper). The canals were obturated with matched gutta-percha points (Dentsply Maillefer) and AH Plus (Dentsply Sirona, Ballaigues, Switzerland) using the single-cone technique. The specimens were then stored in a humidifier at 37°C to allow the sealer to set. After 4 weeks, retreatment was performed. First, Gates-Glidden drills of sizes 3 and 2 were used at 800 rpm to remove root filling materials in the coronal 4 mm of the canal. Then, the specimens were allocated to 1 of the 3 groups, and further retreatment was conducted using 1 of the 3 retreatment file systems. X-Smart Plus (Dentsply Sirona) was

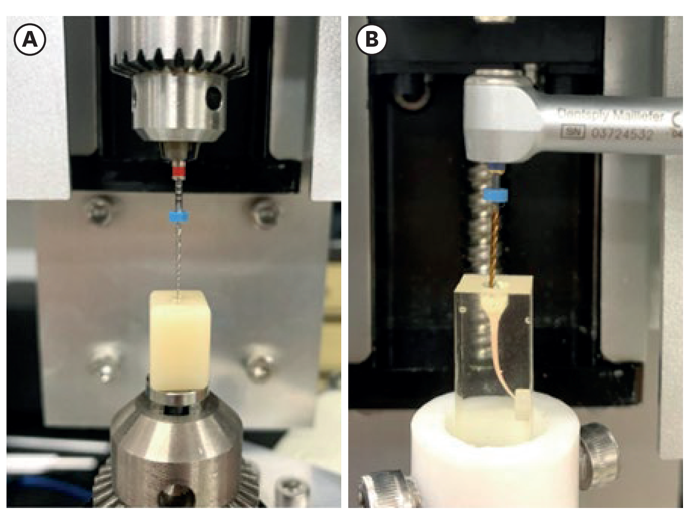

Figure 1. Experimental setup for the (A) buckling resistance test and (B) retreatment.

used to operate the NiTi instruments. During retreatment, the resin blocks were affixed on the UTM staging platform (**Figure 1B**). The torque and screw-in force (force generated in the upward direction) were recorded in real-time. The artificial canals were irrigated with saline during retreatment, and no solvent was used. Both root canal filling and retreatment were performed by the same operator.

1. Group DR: D-RaCe file system (DR1 and DR2; n = 15)

The root filling materials in the coronal 8 mm of the canal were removed by DR1 (tip size 30, 10% taper) at 800 rpm. Then, DR2 (tip size 25, 4% taper) was inserted into the canal in 2 parts, 11 mm and 14 mm, at 400 rpm. Three dynamic pecking motions were applied to each part. After preparation of the first part, the file was removed, debris was wiped off, and the canal was irrigated with saline. During the removal of gutta-percha in the second part, the DR2 was inserted up to the complete working length (14 mm) in accordance with the manufacturer's instructions [15]. Each DR1 and DR2 file was used for only 1 canal.

2. Group HY: HyFlex Remover (n = 15)

HyFlex Remover (tip size 30, 7% taper) file was used to remove the filling materials until 3 mm short of the apex, according to the manufacturer's instructions [16]. Three pecking motions were performed up to a depth of 11 mm at 400 rpm. Only 1 instrument was used for each canal.

3. Group MT: Mtwo retreatment file (n = 15)

Mtwo R25/05 (tip size 25, 5% taper) was used to remove the filling materials until the file was 3 mm short of the apex according to the manufacturer's instructions [17]. Three pecking motions were performed up to a depth of 11 mm at 300 rpm. Only 1 instrument was used for each canal.

In all 3 groups, further apical preparation was performed with WaveOne Gold Primary (Dentsply Maillefer) in WaveOne Gold mode with an X-Smart Plus motor. Canal shaping with WaveOne Gold Primary was performed for the complete working length. During instrumentation, the canal was irrigated with saline solution. After apical preparation, the resin canals were examined using a stereomicroscope at ×20 magnifications, and the residual filling materials in the canals were assessed. Photographs of the resin blocks were taken in the lateral views using a digital camera connected to the stereomicroscope. The area with residual filling materials and the total canal areas were measured using ImageJ software (National Institute of Health, Bethesda, MD, USA). The percentage of residual filling material in the canal was calculated using the following equation: (Area of Residual Filling Material/Canal Area) ×100 (%).

Normal distributions of data for buckling resistance, maximum clockwise torque, maximum upward force, and the percentage of residual filling material after retreatment were verified with the Shapiro-Wilk test and compared using 1-way ANOVA with the Tukey honestly significant difference test. Pearson correlation analysis was performed to analyze the relationship between the buckling resistance and the maximum clockwise torque, maximum upward force, and the percentage of residual filling material. Statistical analysis was performed with SPSS version 25 (IBM, Armonk, NY, USA) and the *p* value was set at 0.05.

RESULTS

The HyFlex Remover file showed the highest buckling resistance (950.22 ± 27.75 gf), followed by the Mtwo R25/05 (712.81 ± 25.64 gf) and DR2 (365.0 ± 56.05 gf) files ($p < 0.05$) (**Table 2**, **Figure 2A**).

The D-RaCe system, which included DR1 and DR2 files, generated the least upward force and torque (**Table 2**, **Figure 2B** and **2C**). The HY group demonstrated the highest maximum clockwise torque ($p < 0.05$), followed by the MT group (**Table 2**, **Figure 2B**). The MT group had the highest maximum upward force, followed by the HY group (**Table 2**, **Figure 2C**). Representative graphs of the torque and upward forces during retreatment are presented in **Figure 3**.

The buckling resistance and maximum upward force had a moderate positive relationship ($p < 0.001$, Pearson $r = 0.601$). Buckling resistance and maximum clockwise torque had a strong positive relationship ($p < 0.001$, Pearson $r = 0.798$). The percentage of residual filling material in the canal in the DR, HY, and MT groups was 10.58, 12.43, and 7.60%, respectively, without significant inter-group differences ($p > 0.05$). Representative stereomicroscopic images are shown in **Figure 4**. The relationship between buckling resistance and the percentage of residual filling material was not significant ($p > 0.05$).

DISCUSSION

In the present study, HyFlex Remover and Mtwo R25/05 generated higher maximum clockwise torque and upward force. The D-RaCe system consisted of 2 instruments, while HyFlex Remover and Mtwo R25/05 were each operated by 1 instrument. Therefore, the force and torque in the DR group would be distributed into 2 instruments. Since DR2 was instrumented to the full working length, the canal filling material posed few apical obstacles.

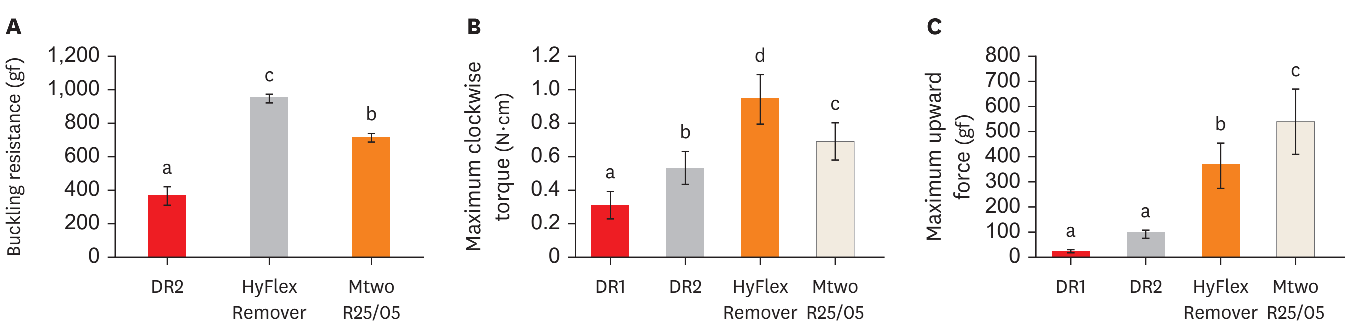

Figure 2. Results of tests for (A) buckling resistance, (B) maximum clockwise torque, and (C) maximum upward force.
The different lowercase letters in each figure indicate significant differences between nickel-titanium retreatment instruments.

Table 2. Buckling resistance, maximum screw-in force, and clockwise torque generated during instrumentation of the nickel-titanium retreatment instruments, and percentage of residual filling material

Characteristic	DR1	DR2	HyFlex Remover	Mtwo R25/05
Buckling resistance (gf)		365.0 ± 56.05[a]	950.22 ± 27.75[c]	712.81 ± 25.64[b]
Maximum clockwise torque (N·cm)	0.310 ± 0.084[a]	0.534 ± 0.097[b]	0.948 ± 0.153[d]	0.696 ± 0.113[c]
Maximum upward force (gf)	20.77 ± 9.68[a]	92.49 ± 16.58[a]	364.71 ± 89.45[b]	539.78 ± 132.20[c]
Percentage of residual filling material (%)	10.58 ± 8.03		12.43 ± 7.60	7.60 ± 4.45

Values are presented as mean ± standard deviation.
Different lowercase letters in each row indicate significant differences between groups ($p < 0.05$).

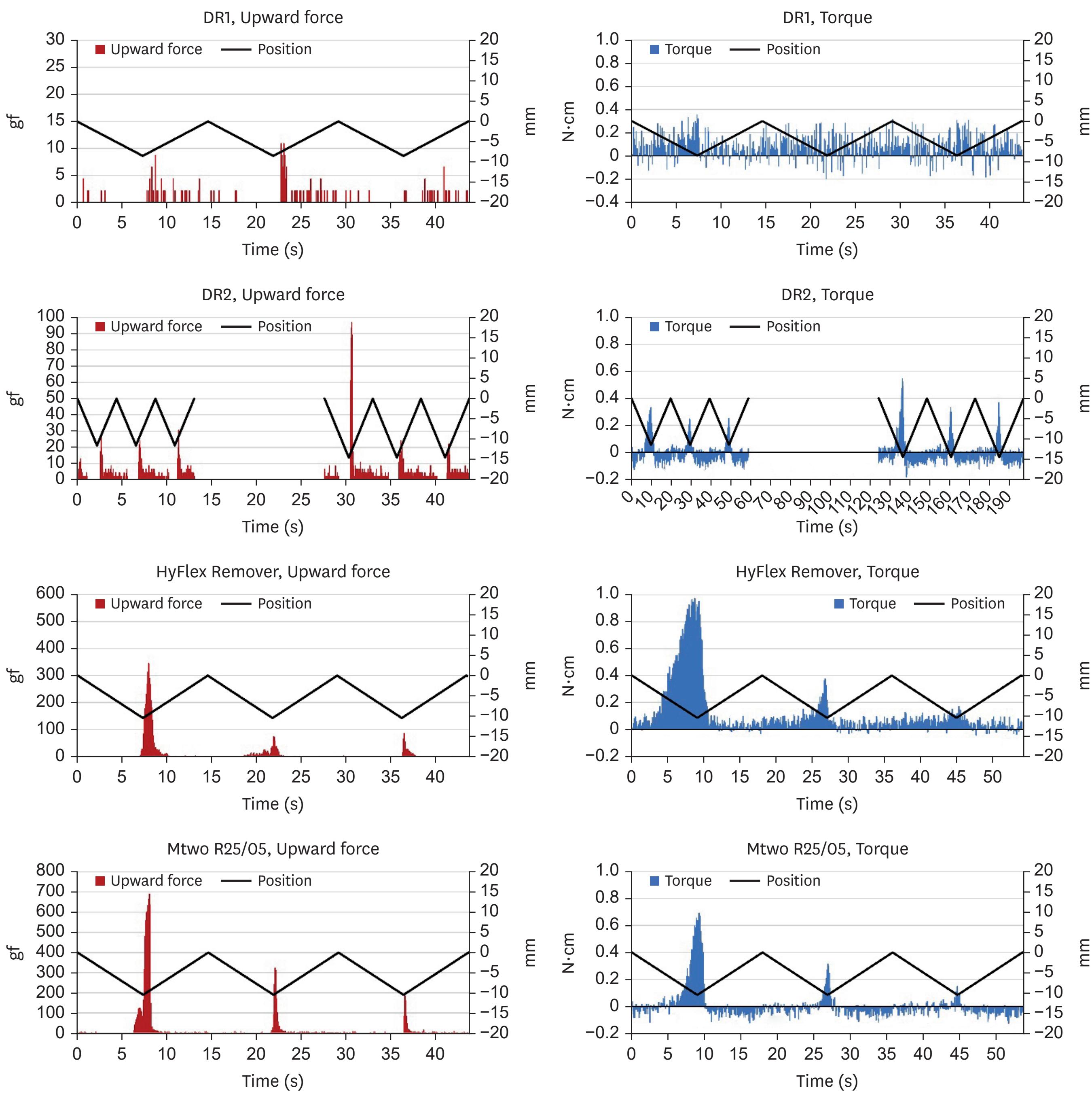

Figure 3. Representative graphs of the upward force and torque generated during retreatment. The upward force is presented as a positive value in the graph for force vs. time. Clockwise torque is shown as a positive value in the graph for torque vs. time. The coronal level of the resin block was considered point zero, and downward movement toward the apex was described as a negative value in the vertical direction.

However, instrumentation with HyFlex Remover and Mtwo R25/05 was performed 3 mm short of the working length; therefore, gutta-percha was encountered apically during shaping. Apical blockage by filling material seems to generate more torque and upward force. The clockwise torque increased as the instrument approached the apical point (**Figure 3**). The maximum torque generated by retreatment was 0.310–0.948 N·cm in this study, which was similar to a previous study recorded during retreatment with XP-endo Shaper (0.74–1.13 N·cm).

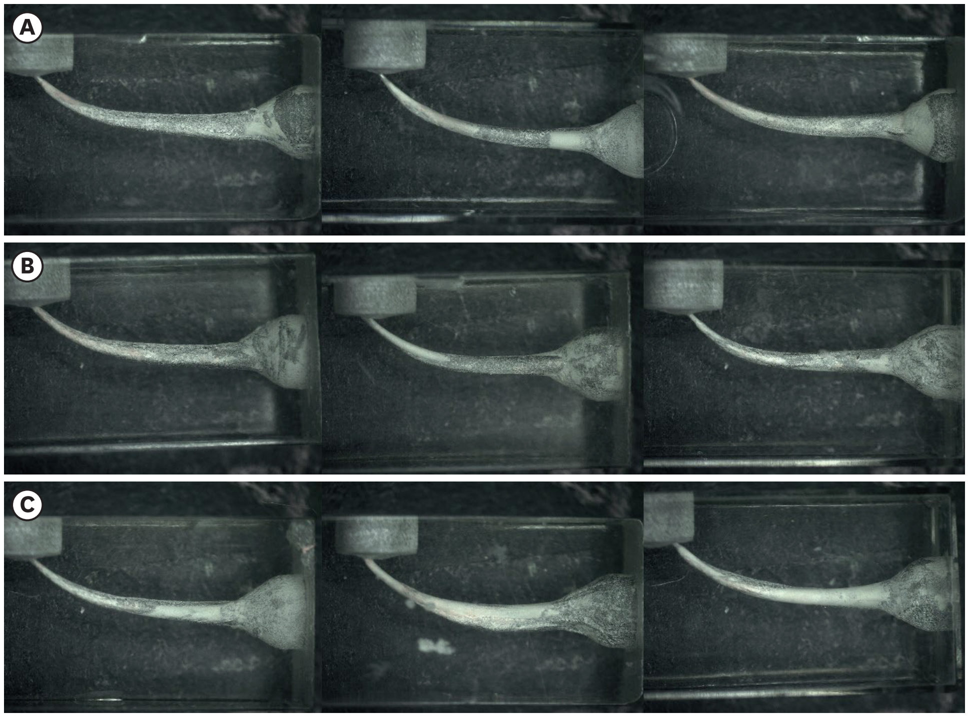

Figure 4. Representative stereomicroscopic images of resin blocks after retreatment. (A) Retreatment using DR1, DR2, and WaveOne Gold Primary. (B) Retreatment using HyFlex Remover and WaveOne Gold Primary. (C) Retreatment using Mtwo R25/05 and WaveOne Gold Primary.

NiTi files with a greater taper and larger cross-sectional area generated higher torque during canal shaping [18,19]. The HyFlex Remover generated the greatest maximum clockwise torque, exceeding that produced by the DR2 and Mtwo R25/05 files. Conversely, DR1 has a 10% taper and generated the least clockwise torque. DR1 was inserted within the gutta-percha in the coronal 8 mm region, and intimate contact with the canal wall was avoided. Therefore, DR1 did not result in severe torque during retreatment.

HyFlex Remover, which had the largest cross-sectional area, demonstrated the highest buckling resistance. Previous studies reported that NiTi instruments with larger cross-sectional areas had higher buckling resistance [20,21]. Both buckling resistance and clockwise torque were affected positively by the cross-sectional area [19]. The buckling resistance and the maximum upward force had a positive relationship. A high buckling resistance indicated superior resistance to deflection during pecking motion. A NiTi retreatment instrument with higher buckling resistance could penetrate inside gutta-percha, and a greater reactional upward force might be generated by a downward movement toward gutta-percha.

The greatest upward force was observed when the instrument reached the most apical level and then moved toward the coronal region (**Figure 3**). The upward and downward forces that occurs during retreatment might influence the risk of NiTi retreatment files being embedded within the gutta-percha and fracturing [6]. During retreatment using NiTi rotary instruments, the additional use of a hand instrument, which facilitates pathfinding and removal of gutta-percha, is recommended [22].

Although the 3 kinds of NiTi retreatment file systems demonstrated different buckling resistance, clockwise torque and upward force, the percentage of residual filling material was not significantly

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different among the file brands. DR1 and Mtwo R25/05 have active working tips [6,15,17], whereas HyFlex Remover possesses a non-cutting tip [16]. DR1 and Mtwo R25/05 could penetrate gutta-percha due to the active cutting tip. Mtwo has an S-shaped cross-section, D-RaCe has a triangular cross-section, and HyFlex Remover possesses a modified triangular cross-sectional shape [6,15-17]. It is speculated that the combined effect of the cross-sectional shape, cutting ability of the file tip, and alloy characteristics influenced the efficacy of removing filling materials.

The sizes of DR2, HyFlex Remover, and Mtwo R25/05 were size 25/04, size 30/07, and size 25/05. The final apical preparation was performed with WaveOne Gold Primary, which has a tip size of 25 and variable taper with an apical 7% taper. Because the dimensions of ProTaper NEXT were larger than those of WaveOne Gold Primary, the mean percentage of residual filling materials after retreatment was 7.60%–12.43%. During retreatment, the resin blocks were fixed with a stainless-steel jig and connected to a staging platform of the UTM. The insertion direction of the NiTi retreatment instruments was consistent with the longitudinal axis of the canal without inclination. The effect of inclination on the efficacy of removing previous filling material needs to be investigated.

In this study, resin blocks with J-shaped canals were used to standardize canal dimensions. The root canal sealer penetrates the dentinal tubules and facilitates micromechanical retention [23]. The epoxy ring of AH Plus and the amine group of dentinal collagen fibers form a covalent bond [24]. The removal of root canal filling materials from human root canals is more difficult and time-consuming than that from resin blocks. Therefore, the results of our study cannot be extrapolated to clinical scenarios.

CONCLUSIONS

NiTi retreatment instruments with higher buckling resistance generated greater clockwise torque and upward force. There was no significant difference in the efficacy of the removal of filling material between the 3 tested NiTi retreatment file systems.

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