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ORIGINAL ARTICLE

An *in vitro* comparison of apically extruded debris using three rotary nickel-titanium instruments

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Background/purpose: The aim of this *in vitro* study was to compare the amount of extruded debris using three rotary nickel-titanium (NiTi) instruments (ProTaper Universal, Mtwo, and BioRaCe).
Materials and methods: Sixty freshly extracted human single-rooted mandibular premolars were randomly assigned into three groups of 20 teeth each. The root canals were instrumented using ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland), Mtwo (VDW, Munich, Germany), or BioRaCe (FKG Dentaire, La-Chaux-de-Fonds, Switzerland) NiTi instruments. Debris and liquid extruded from the apical foramen during instrumentation were collected into tubes. Then, the liquid inside the tubes was removed by lyophilization, and the mean weight of the remaining debris was calculated for each group and compared. Data were then statistically analyzed using one-way ANOVA and post-hoc Tukey's tests.
Results: There were significant differences in the amount of debris extruded among all groups ($P<0.01$). The greatest amount of apical debris was extruded by the ProTaper Universal group and the least by the BioRaCe group.
Conclusion: According to this study, all instrumentation techniques apically extruded debris through the apical foramen. However, the BioRaCe instruments induced less extruded debris than the ProTaper Universal and Mtwo rotary systems.

Introduction

Root canal preparation is one of the most important stages in endodontic treatment. It includes mechanical cleansing by instruments and the use of irrigants. During the procedure, there is always the possibility of pulp tissue fragments, dentine chips, necrotic tissue, microorganisms, and intracanal irrigants being extruded beyond the apical foramen even when the WL is controlled.[1] The apical extrusion of infected debris may have the potential to disrupt the balance between microbial aggression and host defense, resulting in incidents of acute inflammation and flare-ups.[2] Moreover, it is well documented in the literature that both uncontaminated and contaminated dentine and pulp tissue can trigger an inflammatory reaction when forced periapically during instrumentation.[3] The immunological aspects of postoperative flare-ups were assessed by a number of researchers who concluded that antigens originating in the root canal result in the formation of an antigen–antibody complex when forced beyond the apical foramen, which can lead to a severe inflammatory response.[4–6] Therefore, it might

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be assumed that minimizing the amount of apically extruded material should minimize postoperative reactions.

All preparation techniques and instruments are reported to be associated with the extrusion of intracanal debris, irrigants, and bacteria even when the preparation is maintained short of the apical terminus.[6–12] Vande Visse and Brilliant[13] first quantified the amount of debris apically extruded during instrumentation. Ruiz-Hubard et al.[3] found that a significantly greater amount of debris was forced through the apices of both straight and curved canals when the step-back technique was used. Procedures using a push–pull motion tended to produce more apical debris than instrumentation techniques incorporating rotational force.[7,10,11] This led to the hypothesis that rotary nickel-titanium (NiTi) instruments may produce less apically extruded debris than hand instruments. Generally, rotary instruments have a tendency to pull dentinal debris into the flutes of the file and direct it toward the coronal aspect of the canal.[14]

During the last decade, root canal preparations with rotary NiTi instruments have become popular. Because canal instrumentation with rotary NiTi systems remains significantly more centered in the root canal, this results in less transport of materials than hand filing with stainless steel files.[15,16] Also, this type of instrumentation is more comfortable for patients and operators. Nowadays, advanced instrument designs including specific tip geometries, alternating cutting edges, varying tapers, changing pitch lengths, and surface treatments have been developed to improve efficacy and safety. Progressively tapered NiTi rotary instruments, e.g., ProTaper, have a convex triangular cross-sectional design with different shafts. A variation of ProTaper instruments, ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland), was recently marketed. It was reported that the main changes in ProTaper Universal instruments were an increase in flexibility of S1 and F1, a decrease in flexibility of F2 and F3, and an increase in the torsional strength of S2, F2, and F3 instruments.[17] Mtwo endodontic instruments (VDW, Munich, Germany) are a new generation of NiTi rotary instruments. The transverse section of the Mtwo is in the shape of an italicized "S" with two blade-cutting surfaces resembling that of an S-file.[18] More recently, BioRaCe (FKG Dentaire, La-Chaux-de-Fonds, Switzerland) was introduced into the market as a new rotary system that is a modification of the RaCe (FKG Dentaire). According to the manufacturer, BioRaCe instruments present the same physical characteristics as RaCe instruments; however, they differ from standard RaCe instruments with regard to the instrument tapers (BR0 and BR1) and sequences.

The aim of this *in vitro* study was to compare the amount of extruded debris using three rotary NiTi instruments (ProTaper Universal, Mtwo, and BioRaCe).

Materials and methods

Selection of specimens

Sixty freshly extracted human single-rooted mandibular premolars with mature apices and curvature of 0–10° were selected. The degree of root curvature was determined by the method described by Schneider.[19] All teeth were examined with digital radiographs in the buccal and proximal directions to confirm that there was only a single canal. Teeth with calcification and open apices were excluded. The teeth were cleaned of debris and soft-tissue remnants and were stored in physiological saline at 4°C until used in the study.

Endodontic access cavities were prepared with an Endo Access Bur (Dentsply Maillefer) in a high-speed handpiece, and pulpal remnants were extirpated using a broach, with care taken not to push the broach through the apical foramen. Only root canals with an apical diameter of sizes 15–20 were used. To determine the apical diameter, a #15 K-file (Dentsply Maillefer) was placed into the root canal and advanced until the tip of the file appeared from the apical foramen. In this way, a standard size of the foramen and apical patency was achieved. After the working length (WL) was established 1 mm short of this length, the teeth were decoronated in order to obtain root segments approximately 15 mm long and were randomly assigned to three groups of 20 teeth each.

Instrumentation and debris collection

A previously described method was used for debris collection.[10] Briefly, the roots were fixed onto the removable tops of polyethylene tubes with self-curing acrylic in order to create a hermetic seal. A bent 27-gauge needle was forced into the tube's top to use as a drainage cannula to balance the air pressure inside and outside the tube. These tubes acted as collectors for the debris evacuated through the foramen of the root during instrumentation. Specimens prepared in this manner were randomly numbered. The numbers were carved on both the polyethylene tubes and the tops. The tops were removed and the empty tubes without tops were weighed three times on a precision electronic microbalance (Sartorius CP2P; DWS, Chicago, IL, USA) to an accuracy of 0.001 mg, and the average value was recorded. Two coats of nail varnish were applied to the external surface of all roots. Tops with

the attached roots were fixed onto the preweighed tubes so that the root was suspended within the tube. Before the experiment, a hole was created in the nail varnish that covered the apical foramen using a size 15 K-file. During this procedure, only 1 mm of instrument was extruded. In this way, a standard size of the foramen and apical patency was achieved.[9,11,12] The tooth and polyethylene tubes were shielded from the operator by a rubber-dam during the instrumentation process.

Group 1 (ProTaper Universal Instruments; Dentsply Maillefer): all instruments were used in a 16:1 gear reduction handpiece powered by a torque-controlled electric motor (X-Smart; Dentsply Maillefer) at a consistent rotation speed of 300 rpm. Shapers (S1, S2, and SX) were used with a brushing action. The S1 file (taper 2–11%, size 17) was advanced to resistance, but no more than two-thirds of the canal depth. The SX file (taper 3–19%, size 19) was then introduced until resistance was encountered. This was followed by the reintroduction of the S1 file to the full WL. Other files were then inserted to the full WL in the following sequence: S2 (taper 4–11.5%, size 20), F1 (taper 5.5–7%, size 20), F2 (taper 5.5–8%, size 25), F3 (taper 5–9%, size 30), and F4 (taper 6%, size 40), to achieve #40 for the apical preparation. Finishers (F1–F4) were used with an in-and-out action.

Group 2 (Mtwo Instruments; VDW): Mtwo instruments were set into permanent rotation with the torque-limited rotation handpiece, Mtwo Direct (Dental Systems GmbH, Bensheim, Germany), at a maximum speed of 280 rpm. According to the manufacturer, the Mtwo instruments should be used in a single length technique with a gentle in-and-out motion. Therefore, all files of the instrumentation sequence were used to the full WL of the root canal. Seven rotary instruments were used: Mtwo 4% taper, size 10; Mtwo 5% taper, size 15; Mtwo 6% taper, size 20; Mtwo 6% taper, size 25; Mtwo 5% taper, size 30; Mtwo 4% taper, size 35; and Mtwo 4% taper, size 40.

Group 3 (BioRaCe Instruments; FKG Dentaire): the canals were instrumented at a speed of 500 rpm using the same handpiece and electric motor as in Group 1. The BioRaCe instruments were used with "four gentle strokes" according to the recommendations of the manufacturer. BR0 (8% taper, size 25) was only used in the coronal third. BR1 (5% taper, size 15), BR2 (4% taper, size 25), BR3 (6% taper, size 25), BR4 (4% taper, size 35), and BR5 (4% taper, size 40) were used in the full WL of the canal.

Regardless of the technique used, all canals were irrigated with 2 mL of a 2.5% sodium hypochlorite (NaOCl) solution after the use of each instrument. The irrigant was delivered by a disposable plastic syringe with an attached 27-gauge stainless-steel needle. The tip of the needle was never allowed to bind to the root canal walls. Each instrument was used three times before being replaced. All of the instrumentation procedures were performed by a single operator.

Once the instrumentation was completed, the debris adhering to the root was scraped off with the inside surface of the tube. The collector tubes were taken to a lyophilizer (Cryodos; Telstar SA, Terrassa, Spain), and the debris was freeze-dried. Following lyophilization, the tops with the attached teeth were removed from the collector tubes. Tubes with the remaining debris were weighed three times on a precision electronic microbalance, and the average value was recorded. The net weight of the dry debris was determined by subtracting the original weight of the empty collector tube from the gross weight. The mean weight of the extruded debris was then calculated for each group.

Statistical analysis

Statistical tests were performed using SPSS version 9.0 (SPSS Inc., Chicago, IL, USA). Data were statistically analyzed using one-way analysis of variance and post-hoc Tukey's tests.

Results

The mean extruded debris values (minimum and maximum) and standard deviation for each group are presented in Table 1. The results indicated that all of the instruments tested caused measurable apical debris extrusion. Comparisons of the mean amounts of extruded debris among the three groups showed statistically significant differences

Table 1. Extruded debris weights (mg) with the three rotary nickel-titanium instruments

Instrumentation system	*n*	Mean ± SD	Minimum	Maximum
ProTaper Universal	20	1.958 ± 0.346*	0.760	2.305
Mtwo	20	0.984 ± 0.279*	0.335	1.915
BioRaCe	20	0.538 ± 0.193*	0.140	0.960

*Statistically significant difference among the groups ($P < 0.01$). SD = standard deviation.

($P<0.01$). A statistically significant difference was found between the ProTaper Universal and each of the other two groups ($P<0.01$). The most apical debris extruded was seen in the ProTaper Universal group. The lowest mean weight of debris was in the BioRaCe group, which significantly differed from the Mtwo and ProTaper Universal groups ($P<0.01$).

Discussion

A major objective of root canal treatment is to obtain a clean root canal system. Debris such as dentine chips, necrotic pulp tissue, microorganisms, and irrigants may be extruded into the periradicular tissue during canal instrumentation. This debris can lead to postoperative pain and discomfort. Using an instrumentation technique that minimizes apical extrusion would be advantageous to both practitioners and patients.[14] Therefore, this aspect should be investigated for newly developed root canal instrumentation techniques/systems. The present study showed that all of the current instrumentation systems tested produced apically extruded debris *in vitro*.

Many factors affect the amount of extruded intracanal materials, such as the instrumentation technique, instrument type and size, preparation endpoint, and irrigation solution.[6–8,13,14] Even though all instrumentation techniques extrude some debris apically, there are differences among them. Ruiz-Hubard et al.[3] found that less debris was apically extruded using a crown-down pressureless technique in curved and straight canals when compared to the step-back technique. Al-Omari and Dummer[6] reported that techniques involving a linear filing motion, such as step-back techniques, create a greater mass of debris than those involving some sort of rotational action. In previous studies, rotary NiTi systems were mostly associated with less apical extrusion than manual instrumentation. Zarrabi et al.[20] compared ProFile, RaCe and FlexMaster rotary instruments with the step-back technique using manual files and reported that the step-back technique extruded greater amounts of debris than did the rotary instruments. Similarly, Reddy and Hicks,[14] and Ferraz et al.[7] noted that manual instrumentation produced significantly more debris than did rotary NiTi techniques and the balanced-force technique. It was speculated that rotation during instrumentation, with both the rotary and balanced-force techniques, tended to pull dentinal debris into the flutes of the file and direct it toward the coronal aspect of the canal.[7,14] On the other hand, in other studies, the amount of debris extruded by handpiece-driven techniques was found to be comparable to those with a manual technique. Hinrichs et al.[21] compared the amount of apically extruded debris of three handpiece-driven rotary techniques (Light-Speed, Profile .04 Taper Series 29, and NT's McXIM) with Flex-R using the balanced-force technique. There were no statistically significant differences among the groups with respect to the total extruded debris. Also, Azar and Ebrahimi,[22] and Kustarci et al.[11] reported that NiTi rotary systems were associated with less apical extrusion, but were not significantly better than hand-file instrumentation.

The results of the present study agree with previous studies by Tanalp et al.[10] and Logani and Shah[23] in that the ProTaper system caused a significantly larger amount of extruded debris compared to ProFile. It can be speculated that a faster, aggressive system with its characteristic design features, which removes a substantial amount of dentine in a shorter period of time, is unable to coronally displace the debris with the same efficiency as it cuts, and thus poses a risk of increased apical extrusion of debris.[23] Also, the long pitch design of the ProTaper instruments may cause a greater amount of debris to be extruded.[24] It was reported that the RaCe system induced less extruded debris than the manual technique and the FlexMaster system.[20] According to the present results, the amount of extruded debris with BioRaCe was significantly lower compared to the Mtwo and ProTaper Universal systems, presumably due to its non-convex triangular cross-sectional design and smaller core diameter, which allows more space to carry debris out toward the orifice, thus avoiding its compaction in the root canal. S1, S2, F1 and F2 ProTaper Universal instruments, like BioRaCe, possess three sharp cutting edges, but because of a convex triangular cross-section, their debris space is smaller than that of BioRaCe. In a recently published scanning electron microscopy study,[17] it was found that there was an increase in the cross-sectional area of the F3 ProTaper Universal instrument compared with the same-sized ProTaper instrument. Furthermore, other design features of the BioRaCe, such as its short twisted cutting edges alternating with straight edges, may give rise to favorable debris-transporting spaces.

In this study, regardless of the technique used, all canals were irrigated with 2 mL of a 2.5% NaOCl solution after the use of each instrument to reflect the clinical irrigation protocol. Therefore, the number of instruments used in rotary systems may affect the amounts of extruded solution and debris. However, we used an instrument sequence according to the manufacturer's recommendations. Also, NaCl crystals that occurred after lyophilization of the NaOCl were neglected.

It must be emphasized that the results of this study should not be directly extrapolated to clinical situations. No attempt was made to simulate the presence of vital pulp or periapical tissues, and an

in vivo model might give different results, as periapical tissues may serve as a natural barrier, inhibiting debris extrusion. Results may also differ because of positive and negative pressure at the apex,[25] and with normal or pathological periapical tissues. Furthermore, this study was limited to teeth with a mature root morphology. The observed results should not be generalized to teeth with immature root development and open apices.

Under the conditions of this *in vitro* study, it was concluded that all instrumentation techniques produced measurable apical extrusion of debris. However, the BioRaCe instruments resulted in significantly less debris extrusion compared to the ProTaper Universal and Mtwo rotary systems.

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