치의학박사 학위논문

Root canal cleansing efficacy of various irrigant activation systems during non-surgical retreatment

재근관치료 시 수 종의 irrigant activation system의 근관 세척 효능 비교

2021년 2월

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2020년 12월

서울대학교 대학원

치의과학과 치과보존학 전공

박 성 연

박성연의 박사학위논문을 인준함

2021년 1월

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Abstract

Root canal cleansing efficacy of various irrigant activation systems during non-surgical retreatment

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Objectives.

Complete removal of obturation material can be a challenge in non-surgical root canal retreatment. Insufficient removal of obturation materials is a reason for root canal retreatment failure. The purpose of this study was *in vitro* comparison of the cleaning efficacy of various root canal irrigant activation systems on debris and smear layer removal in the apical and middle portions of root canals during non-surgical retreatment.

Methods.

Sixty-six distal roots of the freshly extracted mandibular molars were divided randomly into six groups: (1) primary root canal treatment with Ni-Ti instrumentation but no obturation (negative control); (2) retreatment with Ni-Ti instrumentation and syringe irrigation (positive control); (3) retreatment with additional ultrasonic irrigation using the Piezon Master 700; (4) ultrasonic irrigation with the ENDOSONIC Blue; (5) sonic irrigation with the EDDY; and (6) multisonic irrigation with GentleWave System. Roots were split and prepared for scanning electron microscopy (SEM) evaluation. SEM images acquired in the apical and middle regions were assessed to quantify the amount of debris and smear layer remaining using a 5-step scale. Differences between groups were compared using the Kruskal-Wallis test followed by Tamhane T2 test at $P < 0.05$.

Results.

Among the treatment groups, only Gentlewave System had a significantly lower debris score than positive control group in both the middle and apical regions ($P < 0.05$). All treatment groups had significantly lower smear scores than negative and positive control groups in the apical regions and significantly lower smear scores than positive control group in the middle regions ($P < 0.05$). The GentleWave multisonic System showed lower debris and smear scores but did not differ significantly with the tested passive ultrasonic or sonic irrigation system ($P > 0.05$).

Conclusion.

The additional use of root canal irrigant activation systems such as passive ultrasonic irrigation, sonic irrigation, and GentleWave System during non-surgical retreatment improved cleaning efficacy in the apical and middle root canals compared to the positive control group. GentleWave System showed higher cleaning efficacy but did not differ significantly with the tested passive ultrasonic or sonic irrigation system.

Keywords : debris, smear layer, non-surgical retreatment, irrigation, GentleWave System, passive ultrasonic irrigation, sonic irrigation, scanning electron microscopy

Student Number : 2013-31192

Contents

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Ⅰ. Introduction

In a survey conducted by the American Association of Endodontics, 46% of all endodontic treatments were non-surgical retreatments (1). The objective of a non-surgical root canal retreatment is to restore healthy periapical and periradicular tissue (2). Healthy periapical tissue can be restored only when the root canal system is free of any organic tissue, bacteria/biofilm, and inorganic dentinal debris and obturation material. According to Schirrmeister *et al.* (3), the complete removal of previous obturation materials is especially important because necrotic tissue and bacteria embedded in the remaining gutta-percha and sealer may be responsible for post treatment disease. However, removing the previously obturated material from a root canal system remains a challenge (4, 5). The removal of gutta-percha using hand instruments is a slow and difficult process, especially when the filling material is well compacted. Thus, nickel-titanium (Ni-Ti) rotary instruments are recommended for reducing clinical time and facilitating removal. However, many studies showed that, even after using Ni-Ti rotary instruments, filling material was not completely removed from the root canal walls (6-9). Peters *et al.* (10) showed that more than 35% of the canal walls are untouched during mechanical instrumentation, therefore, it is critical to rely on adjunctive measures such as chemical irrigation and adjunctive irrigant activation to eliminate residual obturation material. In a previous study (11), the efficacy of ultrasonic irrigation to reduce the amount of remaining filling material following non-surgical retreatment was compared to those of conventional needle irrigation and instrumentation and the results showed that none of the roots were free of gutta-percha and sealer.

Recently, several new irrigant activation systems and techniques have been developed. ENDOSONIC Blue (Maruchi, Chuncheon, Kangwon, Korea) is a passive ultrasonic irrigation (PUI) system that consists of a Ni-Ti file without superelasticity at temperatures below 55 °C. At the temperature of NaOCl used for root canal treatment, the file has no superelasticity and is easily bent. Therefore, loss of ultrasonic energy could be reduced even if the file is in the curved root canal wall, and ultrasonic energy can be transmitted well into the apical region.

A novel passive sonic irrigation (PSI) system, EDDY (VDW, Munich, Germany), is powered to a high frequency up to 6,000 Hz by an air scaler. The vibration produced is transferred to the polyamide tip, which is moved in an oscillating motion at high amplitude. This three-dimensional movement triggers cavitation and acoustic streaming.

Another endodontic device, the GentleWave System (Sonendo Inc., Laguna Hills, CA, USA), delivers endodontic irrigants to root canals with minimal instrumentation using a combination of acoustics and advanced fluid mechanics (12). The high-speed, degassed endodontic irrigants are delivered into the pulp chamber of the tooth by a treatment instrument on the occlusal surface of an accessed tooth. The endodontic irrigants reach the entire root canal system while built-in suction within the treatment instrument removes the excess fluid (13, 14). The GentleWave System has been shown to greatly remove tissue debris and biofilm from complex anatomical areas such as the isthmi (15, 16).

The purpose of this study was *in vitro* comparison of the cleaning efficacy of various root canal irrigant activation systems, such as passive ultrasonic irrigation, sonic irrigation, and GentleWave System on debris and smear layer removal in the apical and middle portions of root canals during non-surgical retreatment.

II. Materials and Methods

Specimen preparation

This study was approved by the Seoul National University human research ethics committee (IRB No. S-D20160011). A total of 66 freshly extracted human mandibular molars that were visually and radiographically examined were stored in phosphate-buffered solution at 4 °C. Any teeth with large caries or fractures, internal or external root resorption, open apices, calcification of the root canals, or previous root canal therapy were excluded. The average distal root length was 12.3 ± 1.67 mm, and average angle of curvature determined by Schneider's method was 14.3° ± 7.7° (17).

When present, caries were removed. Missing coronal tooth structure was restored using etchant (Etch-Rite; Pulpdent, Watertown, MA, USA), bonding agent (Optibond; Kerr, Orange, CA, USA), and Virtuoso flowable light-cure composite (Denmat, Lompoc, CA, USA). Following endodontic access, all teeth were firmly secured using an adhesive (McMaster-Carr, Los Angeles, CA, USA) and sealed within a water-saturated porous medium to simulate blood-saturated periapical tissue. After endodontic access preparation, reproducible glide paths and working lengths (WLs) were established using #10 K files (MANI Inc., Tochigi, Japan). WL was defined as 1 mm short from the radiographic apex.

Root canal preparation

Conventional Ni-Ti rotary instrumentation was performed with ProTaper shaping files (SX, S1, S2) and finishing files (F1 and F2 files) (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) spun at a speed of 300 rpm (18). During instrumentation, 2 mL 3% NaOCl (diluted with distilled water; Clorox, Oakland, CA, USA) was delivered between use of each instrument. RC Prep (Patterson Dental, Saint Paul, MN, USA) was used. Final conventional irrigation was performed with 3% NaOCl solution using a 30G Max-i-Probe irrigation needle (Dentsply Rinn, Elgin, IL, USA) and a syringe for 1 minute at a flow rate of 5 mL/min followed by a 2-minute rinse with 17% EDTA (Pulpdent, Watertown, MA, USA) at 5 mL/min and a final rinse with 1 mL saline solution. During irrigation, irrigation needle was placed 1 mm short of the WL and was moved with a 1 to 2 mm up and down motion to prevent locking in the canal. Canals were dried with sterile paper points (Dentsply). Eleven samples were randomly selected as negative controls (Group 1).

Root canal obturation

Canals were obturated using a lateral condensation technique with gutta-percha cones (Dentsply) corresponding to final file size and accessory cones (Diadent, Burnaby, BC, Canada) along with AH Plus sealer (Dentsply). Radiographs were acquired after obturation. Cotton plugs were placed in pulp chambers, and the access opening was covered with Cavit (3M ESPE, Seefeld, Germany). Roots were wrapped in sterile, moistened cotton, placed in a vial labeled with the specimen number, and stored in an incubator at 37 °C for two weeks. Teeth were maintained in a moist environment throughout incubation.

Retreatment procedure

Cavit and cotton plugs were removed from pulp chambers and replaced with 100 μL chloroform (Patterson Dental) to soften the gutta-percha. ProTaper Universal Retreatment files D1, D2, and D3 (Dentsply) at a 500 - 700 rpm were used to remove gutta-percha (18). Between instrument changes and during removal of gutta-percha, canals were irrigated with 2 mL 3% NaOCl. When necessary, #10 K-file was used to confirm patency.

After removing obturation material, canals were shaped further with Ni-Ti rotary instrumentation comprised of the ProTaper shaping files (SX, S1, and S2) and finishing files (F1, F2, and F3 files) at a speed of 300 rpm. Canals were irrigated with 2 mL 3% NaOCl between use of each instrument. Radiographs were acquired after removal of obturation material. Eleven samples were randomly selected as positive controls and used to establish baseline values for debris (Group 2). The other samples underwent additional irrigation to form Groups 3, 4, 5, and 6.

Group 1: Negative control

After primary root canal treatment with Ni-Ti instrumentation and syringe irrigation, eleven samples were randomly selected as negative controls before root canal obturation.

Group 2: Positive control

After retreatment with Ni-Ti instrumentation and syringe irrigation, eleven samples were randomly selected as positive controls and used to establish baseline values for debris.

Group 3: Passive ultrasonic irrigation system

After retreatment, eleven samples underwent additional passive ultrasonic irrigation. A Piezon Master 700 with ESI tip (DT-011; size 15, taper 0.02) (EMS, Nyon, Switzerland) was set to low power Endo Mode with medium-to-high irrigation flow rate, as recommended by the manufacturer. One reservoir of the Piezon Master 700 was filled with 3% NaOCl and another with 8% EDTA. The Piezon Master 700 with ESI tip was used to irrigate 3 mL/min for 10 seconds per canal and activate each canal for 3 times of 20 seconds with 3% NaOCl. Similar activation was performed for 3 times of 20 seconds with 8% EDTA. The 8% EDTA solution was selected based on recommendations in the instructions for the GentleWave System. Each canal was irrigated with 2 mL distilled water. All canals were dried with sterile paper points.

Group 4: Passive ultrasonic irrigation system

After retreatment, eleven samples underwent additional passive ultrasonic irrigation. An ENDOSONIC Blue ultrasonic system with Ni-Ti file (size 15, taper 0.02) was set to maximum power, and 3% NaOCl was delivered to each canal by syringe needles per 10 seconds. Activation of each canal with the ENDOSONIC

Blue was for 5 times of 10 seconds, as recommended by the manufacturer. Root canals were flushed with 3% NaOCl. Similar activation was performed for 5 times of 10 seconds with 8% EDTA. Each canal was irrigated with 2 mL distilled water. All canals were dried with sterile paper points.

Group 5: Passive sonic irrigation system

After retreatment, eleven samples underwent additional passive sonic irrigation. EDDY (size 25, taper 0.04) was set to power 2, as recommended by the manufacturer. Each canal was activated with EDDY for 3 times of 20 seconds with 3% NaOCl and 3 times of 20 seconds with 8% EDTA. Each canal was irrigated with 2 mL distilled water. All canals were dried with sterile paper points.

Group 6: GentleWave System

After retreatment, eleven samples underwent additional multisonic irrigation with GentleWave System. For GentleWave treatments, the tip of the treatment instrument was placed inside the pulp chamber of the molar. Treatment consisted of 3% NaOCl for 5 minutes, distilled water for 30 seconds, 8% EDTA for 2 minutes, and distilled water for 15 seconds as recommended by the manufacturer (15). All canals were dried with sterile paper points.

Scanning electron microscopy processing

Each tooth was filled with 1 mL 4% buffered formalin for overnight fixation at 4 °C. The roots from the six groups were separated from their crowns with a diamond disc (NTI-Kahla GmbH, Kahla, Germany). The roots were split longitudinally, and representative specimens were sectioned horizontally at 5 mm from the anatomic apex. Samples underwent standard dehydration processing with ascending grades of ethanol (50%, 70%, 80%, 100%) for 10 minutes with further dehydration in 100% ethanol for 30 minutes. Samples were mounted on tabs with carbon conductive tape and sputter coated with Au-Pd at 20 mA for 1 minute. All the treatment flows are illustrated in Figure 1.

Scoring of debris and smear layer

For each root half, SEM images were acquired in the apical (0 – 3 mm from apex) and middle (3 – 6 mm from apex) regions. Images were acquired at 40×, 150×, and 600× at 15 kV using a SEM (Tabletop Microscope TM3010; Hitachi, Tokyo, Japan). For analysis, debris was defined as the residual filling material and dentinal mud in the canal area. A 5-step scale method as in previous studies (19, 20) was used to assess the amount of debris and smear layer.

For debris score:

0 : clean canal wall, very few debris particles; < 10%

1 : few small residual debris; 10 – 25%

2 : many residual debris, < 50% of the canal wall covered; 25 – 50%

3 : > 50% of the canal wall covered; 50 – 75%

4 : complete or nearly complete covering of the canal wall by debris; 75 – 100%

For smear score:

0 : no smear layer, orifice of dentinal tubules patent; 90% or more open dentinal tubules

1 : small amount of smear layer, some open dentinal tubules; 50 – 90% open dentinal tubules

2 : homogeneous smear layer along most of the canal wall, few open dentinal tubules; 25 – 50% open dentinal tubules

3 : entire root canal wall covered with a homogeneous smear layer, very few open dentinal tubules; < 25% open dentinal tubules

4 : thick inhomogenous smear layer covering the entire root canal wall. 0% open dentinal tubules

Debris scoring was performed at 150× magnification and smear scoring at 600×. All images were saved in a digital file (TIF format) and loaded into the Microsoft PowerPoint software (Microsoft Corp., Redmond, WA, USA). To quantify the debris and smear layer, the images were divided into 100 squares by using a digital grid. Two examiners, previously calibrated and blind to the study, evaluated acquired images in the apical and middle regions for each root.

Data analysis

Average debris and smear scores were calculated for each root. Statistical analysis was performed with nonparametric test by using Kruskal-Wallis test. Differences between groups were analyzed with the Tamhane T2 test at $P < 0.05$. The data were analyzed using IBM SPSS Statistics for Windows, Version 26 (IBM Corp., Armonk, NY, USA).

Ⅲ. Results

Representative SEM images of the six groups at 150× magnification and 600× are shown in Figure 2. Group 1 showed less debris but large amounts of smear layer. Group 2 showed large amounts of debris and smear layer. Groups 3, 4, and 5 showed less debris and smear layer, and Group 6 showed the smallest amounts of debris and smear layer.

Evaluation of each root half provided similar semi-quantitative results (Figure 3, Table 1). According to debris score analysis, Group 2 had the highest overall average debris score in the apical and middle regions. Group 1 demonstrated the lowest debris score in the middle regions. Group 6 had the lowest debris score in the apical regions. Among the treatment groups, only Group 6 had a significantly lower debris score than positive control group (Group 2) in both the middle (P = 0.004) and apical regions (P = 0.012).

Following an analysis of smear score, the highest smear score was for Group 2 in the middle and apical regions. Group 6 had the least amount of smear layer in the middle and apical regions. In the middle regions, Group 6 had a significantly lower smear score than negative and positive control group (Group 1 and Group 2) ($P < 0.001$). In the apical regions, all treatment groups (Groups 3, 4, 5, and 6) had significantly lower smear scores than negative and positive control group (Group 1 and Group 2) (P = 0.005). All treatment groups showed significantly lower smear scores than positive control group (Group 2) in the middle and apical regions ($P < 0.05$). Group 6 had the lowest debris and smear scores in the apical regions. Table 1 provides the summary of the average debris and smear scores in the apical and middle regions for the six groups.

Figure 4 shows representative cross-sectional SEM images for the six groups. Cross-sectional images for Group 1 were similar to that of Group 6. SEM images of Groups 2, 3, 4, and 5 showed the presence of residual filling material in root canals and dentinal tubules.

Ⅳ. Discussion

During non-surgical endodontic retreatment, complete removal of endodontic filling materials has been proven to be challenging (4, 5). In this study, various irrigant activation protocols used after conventional non-surgical retreatment were examined to determine their efficacy on the removal of debris and smear layer. This study showed that the amount of debris removed in the apical and middle regions of root canal systems was greater with the GentleWave System than with ultrasonic or sonic activation. However, the differences were not significant. The positive control, for which additional activated irrigation was not performed, showed a similar debris score to PUI/PSI groups. These findings agree with a study by Da Rosa, in which the greatest reduction of filling material was observed after using ProTaper Universal Retreatment files ($P < 0.05$), and PUI did not improve the removal of filling material after using rotary files for root canal preparation ($P > 0.05$) (21). The lack of improvement in debris score after using passive ultrasonic or sonic irrigation system was probably because of the high bond strength of AH Plus sealer to root dentin (22), and its adhesion was likely higher than the forces generated by acoustic microstreaming and cavitation. Overall, relatively clean canal walls were found among all groups. These results may be attributed to the root canal preparation size (F3), which allowed sufficient debris transportation coronally.

All treatment groups showed significantly lower smear scores than control groups (Group 1 and Group 2) in the apical regions (P = 0.005). In the middle regions, only GentleWave System showed significantly lower smear score than the control groups (Group 1 and Group 2) ($P < 0.001$). The results in this study indicate that the use of activated irrigation is beneficial for removing smear layer in the apical regions. These results are similar to those reported by Urban *et al.* (23) and Haupt *et al.* (24) who demonstrated a similar effectiveness regarding smear layer removal for PUI and PSI, and both activation techniques performed significantly better than syringe irrigation. Nevertheless, further studies are required to assess root canal cleanliness after canal preparation and subsequent activation of irrigants with flexible tips in curved canals, as the influence of sonic and ultrasonic activation in severely curved root canals is controversial (24-26).

Sonic irrigation differs from ultrasonic irrigation because it operates at a lower frequency. For sonic application, frequencies range from 1000 to 6000 Hz. Consequently, the streaming velocity of the irrigant is lower. Moreover, the oscillating patterns of the sonic instruments are different, with one node near the attachment of the file and one antinode at the tip of the file. When the movement of the sonic file is constrained, the sideways movement disappears, while longitudinal vibration is produced (27). Two studies reported that PUI removed more dentin debris from root canals than sonic irrigation (28, 29), and the positive relationship between streaming velocity and frequency is thought to explain the higher efficiency of PUI versus sonic irrigation. However, recent studies showed that EDDY tips activated by an air scaler at 6,000 Hz performed equal to or better than PUI (23, 24), in agreement with our study. Although EDDY generates lower frequencies than ultrasonic devices (25 – 30 kHz), it was equally effective in cleaning debris and smear layer. This result might be because the effect of cavitation is dependent on the frequency of the instrument inside the root canal and on the amplitude of the swinging instrument. Thus, cavitation might occur at lower frequencies (30). Measurements showed an amplitude of 11 μm for an ultrasonic instrument and 346 μm ± 41 μm for EDDY (30).

A significant difference was seen for debris scores between GentleWave System and positive control, as observed in SEM images. Moreover, in the apical regions, the GentleWave System showed lower debris score than negitive control, which had no obturation materials. Consequently, GentleWave System was shown to provide more effective debris removal especially in the apical regions. The GentleWave System disperses different endodontic irrigants from the tip of the handpiece into the pulp chamber. When the endodontic irrigant is in contact with stagnant fluids in the pulp chamber, because of shear forces, hydrodynamic cavitation occurs, forming thousands of microbubbles called a cavitation cloud. The bubbles subsequently implode and create sound waves that cover a broad frequency spectrum (multisonic ultracleaning spectra) that reverberate and contribute to the cleaning throughout the root canal system. The presence of multisonic ultracleaning energy in combination with advanced fluid dynamics loosens the obturation material and sealer when engaged in the dentinal wall and leads to a low debris score. According to a recent study, the GentleWave System was effective in retrieving separated instruments while conserving the dentinal structure (31).

The GentleWave System showed slightly cleaner canals among the treatment groups. However, the differences between the treatment groups were not statistically significant. Previous study by Wright *et al.* showed similar result that GentleWave removed more residual obturation material than the side-vented needle and EndoVac, but the differences between GentleWave and the other 2 groups were not statistically significant (32). The effectiveness of the PUI and GentleWave System in endodontic retreatment was recently reported (33). The use of PUI and GentleWave significantly reduced the volume of remaining filling material after initial instrumentation. However, none of these techniques was able to render canals free from filling materials. When comparing the cleanliness of the middle and apical thirds by SEM analysis, there were no significant differences between ultrasonic instruments and GentleWave System, which is in agreement with the present study.

Results from this study should be interpreted with caution because of the large standard deviation observed. One possible explanation is the challenge of standardizing the amount of residual obturation material after conventional retreatment. In this study design of using extracted teeth, the difference in the anatomy of root canal might have the influence on the differences in the amount of debris formed on the root canal surface.

In addition, representative specimens in this study were sectioned horizontally and analyzed at 5 mm from the anatomic apex (34, 35). The results showed that the GentleWave System removed the sealer even from the dentinal tubules, while the presence of sealer at least 100 μm deep into the tubules was observed when teeth were treated with an ultrasonic or sonic irrigation system. However, penetration of the sealer after obturation was not always 100 μm into all tubules. This penetration into tubules may result from a cold lateral condensation technique and primary cleaning of the root canals using conventional needle syringe irrigation (35). Previously, the ability of the GentleWave System to penetrate approximately 450 μm into dentinal tubules was shown (36). The results from our study support this penetration into the dentinal tubules. More studies are needed to confirm this finding.

Although SEM allows the highly detailed observation of dentinal tubules and filling material, a 3D view of the entire root canal system cannot be achieved by this method. Thus, this method did not allow measurement of the thickness of either residue. Furthermore, SEM evaluations allow assessment of only limited areas of the canal wall. Most of the studies assessed root canal filling materials removal efficacy by means of micro-computed tomography (micro-CT) (32, 33, 37-39). Further investigation, which may include the use of other assessment techniques such as micro-CT, may provide a 3D analysis of the removal of obturation materials. Energy dispersive X-ray spectroscopy (EDX) may be used for microchemical analysis of root canal surface thus it can be possible to identify the chemical elements included in the composition of gutta-percha and sealer debris (9).

This study presented the efficacy of root canal irrigant activation systems such as passive ultrasonic irrigation, sonic irrigation, and GentleWave System on debris and smear layer removal during non-surgical retreatment. Under the conditions of the present *in vitro* study, the additional use of various irrigant activation systems improved cleaning efficacy in the apical and middle root canals compared to the positive control group. GentleWave System showed higher cleaning efficacy but did not differ significantly with the tested passive ultrasonic or sonic irrigation system.

Ⅴ. References

1. Lin S, Sabbah W, Sedgley CM, Whitten B. A survey for endodontists in today's economy: exploring the current state of endodontics as a profession and the relationship between endodontists and their referral base. J Endod 2015;41(3):325-332.
2. Crozeta BM, de Sousa-Neto MD, Leoni GB, Mazzi-Chaves JF, Silva-Sousa YT, Baratto-Filho F. A micro-computed tomography assessment of the efficacy of rotary and reciprocating techniques for filling material removal in root canal retreatment. Clin Oral Investig 2016;20(8):2235-2240.
3. Schirrmeister JF, Wrbas KT, Meyer KM, Altenburger MJ, Hellwig E. Efficacy of different rotary instruments for gutta-percha removal in root canal retreatment. J Endod 2006;32(5):469-472.
4. Jiang S, Zou T, Li D, Chang JW, Huang X, Zhang C. Effectiveness of sonic, ultrasonic, and photon-induced photoacoustic streaming activation of NaOCl on filling material removal following retreatment in oval canal anatomy. Photomed Laser Surg 2016;34(1):3-10.
5. Kfir A, Tsesis I, Yakirevich E, Matalon S, Abramovitz I. The efficacy of five techniques for removing root filling material: microscopic versus radiographic evaluation. Int Endod J 2012;45(1):35-41.
6. Pirani C, Pelliccioni GA, Marchionni S, Montebugnoli L, Piana G, Prati C. Effectiveness of three different retreatment techniques in canals filled with compacted gutta-percha or Thermafil: a scanning electron microscope study. J Endod 2009;35(10):1433-1440.

7. Mollo A, Botti G, Prinicipi Goldoni N, Randellini E, Paragliola R, Chazine M, Ounsi HF, Grandini S. Efficacy of two Ni-Ti systems and hand files for removing gutta-percha from root canals. Int Endod J 2012;45(1):1-6.
8. Azim AA, Wang HH, Tarrosh M, Azim KA, Piasecki L. Comparison between single-file rotary systems: part 1-efficiency, effectiveness, and adverse effects in endodontic retreatment. J Endod 2018;44(11):1720-1724.
9. Prati C, Zamparini F, Spinelli A, Pelliccioni GA, Pirani C, Gandolfi MG. Secondary root canal treatment with Reciproc Blue and K-File: radiographic and ESEM-EDX analysis of dentin and root canal filling remnants. J Clin Med 2020;9(6):1902.
10. Peters OA, Schönenberger K, Laib A. Effects of four Ni - Ti preparation techniques on root canal geometry assessed by micro computed tomography. Int Endod J 2001;34(3):221-230.
11. Grischke J, Muller-Heine A, Hulsmann M. The effect of four different irrigation systems in the removal of a root canal sealer. Clin Oral Investig 2014;18(7):1845-1851.
12. Haapasalo M, Shen Y, Wang Z, Park E, Curtis A, Patel P, Vandrangi P. Apical pressure created during irrigation with the GentleWave system compared to conventional syringe irrigation. Clin Oral Investig 2016;20(7):1525-1534.
13. Charara K, Friedman S, Sherman A, Kishen A, Malkhassian G, Khakpour M, Basrani B. Assessment of apical extrusion during root canal irrigation with the novel GentleWave System in a simulated apical environment. J Endod 2016;42(1):135-139.
14. Ma J, Shen Y, Yang Y, Gao Y, Wan P, Gan Y, Patel P, Curtis A, Khakpour M, Haapasalo M. *In vitro* study of

calcium hydroxide removal from mandibular molar root canals. J Endod 2015;41(4):553-558.
15. Molina B, Glickman G, Vandrangi P, Khakpour M. Evaluation of root canal debridement of human molars using the GentleWave System. J Endod 2015;41(10):1701-1705.
16. Choi HW, Park SY, Kang MK, Shon WJ. Comparative analysis of biofilm removal efficacy by multisonic ultracleaning system and passive ultrasonic activation. Materials (Basel) 2019;12(21):3492.
17. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32(2):271 - 275.
18. Colaco AS, Pai VA. Comparative evaluation of the efficiency of manual and rotary gutta-percha removal techniques. J Endod 2015;41(11):1871-1874.
19. Peters OA, Barbakow F. Effects of irrigation on debris and smear layer on canal walls prepared by two rotary techniques: a scanning electron microscopic study. J Endod 2000;26(1):6-10.
20. Hülsmann M, Rummelin C, Schafers F. Root canal cleanliness after preparation with different endodontic handpieces and hand instruments: a comparative SEM. J Endod 1997;23(5):301 - 306.
21. Da Rosa RA, Santini MF, Cavenago BC, Pereira JR, Duarte MA, So MV. Micro-CT evaluation of root filling removal after three stages of retreatment procedure. Br Dent J 2015;26(6):612-618.
22. Vilanova WV, Carvalho-Junior JR, Alfredo E, Sousa-Neto MD, Silva-Sousa YT. Effect of intracanal irrigants on the bond strength of epoxy resin-based and methacrylate

resin-based sealers to root canal walls. Int Endod J 2012;45(1):42-48.
23. Urban K, Donnermeyer D, Schafer E, Burklein S. Canal cleanliness using different irrigation activation systems: a SEM evaluation. Clin Oral Investig 2017;21(9):2681-2687.
24. Haupt F, Meinel M, Gunawardana A, Hulsmann M. Effectiveness of different activated irrigation techniques on debris and smear layer removal from curved root canals: a SEM evaluation. Aust Endod J 2020;46(1):40-46.
25. Van der Sluis LW, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: a review of the literature. Int Endod J 2007;40(6):415-426.
26. Rodig T, Dollmann S, Konietschke F, Drebenstedt S, Hulsmann M. Effectiveness of different irrigant agitation techniques on debris and smear layer removal in curved root canals: a scanning electron microscopy study. J Endod 2010;36(12):1983-1987.
27. Lumley PJ, Blunt L, Walmsley AD, Marquis PM. Analysis of the surface cut in sonic files. Endod Dent Traumatol 1996;12(5): 240-245.
28. Sabins RA, Johnson JD, Hellstein JW. A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. J Endod 2003;29(10):674-678.
29. Stamos DE, Sadeghi EM, Haasch GC, Gerstein H. An *in vitro* comparison study to quantitate the debridement ability of hand, sonic, and ultrasonic instrumentation. J Endod 1987;13(9):434 - 440.
30. Baars S. Development and analysis of a sonically activated instrument for cleaning dental root canals (in German) [PhD

thesis]. Munich, Germany: Technical University of Munich 2014.
31. Wohlgemuth P, Cuocolo D, Vandrangi P, Sigurdsson A. Effectiveness of the GentleWave System in removing separated instruments. J Endod 2015;41(11):1895-1898.
32. Wright CR, Glickman GN, Jalali P, Umorin M. Effectiveness of Gutta-percha/Sealer Removal during Retreatment of Extracted Human Molars Using the GentleWave System. J Endod 2019;45(6):808-812.
33. Crozeta BM, Chaves de Souza L, Correa Silva-Sousa YT, Sousa-Neto MD, Jaramillo DE, Silva RM. Evaluation of passive ultrasonic irrigation and GentleWave System as adjuvants in endodontic retreatment. J Endod 2020;46(9):1279-1285.
34. Bolles JA, He J, Svoboda KK, Schneiderman E, Glickman GN. Comparison of Vibringe, EndoActivator, and needle irrigation on sealer penetration in extracted human teeth. J Endod 2013;39(5):708-711.
35. Xu LL, Zhang L, Zhou XD, Wang R, Deng YH, Huang DM. Residual filling material in dentinal tubules after gutta-percha removal observed with scanning electron microscopy. J Endod 2012;38(3):293-296.
36. Vandrangi P. Evaluating penetration depth of treatment fluids into dentinal tubules using the GentleWave System. Dentistry 2016;6(3):1000366.
37. Rodig T, Hausdorfer T, Konietschke F, Dullin C, Hahn W, Hulsmann M. Efficacy of D-RaCe and ProTaper Universal Retreatment NiTi instruments and hand files in removing gutta-percha from curved root canals - a micro-computed tomography study. Int Endod J 2012;45(6):580-589.

38. Machado AG, Guilherme BPS, Provenzano JC, Marceliano-Alves MF, Goncalves LS, Siqueira JFJ, Neves MAS. Effects of preparation with the Self-Adjusting File, TRUShape and XP-endo Shaper systems, and a supplementary step with XP-endo Finisher R on filling material removal during retreatment of mandibular molar canals. Int Endod J 2019;52(5):709-715.
39. Yilmaz F, Koc C, Kamburoglu K, Ocak M, Geneci F, Uzuner MB, Celik HH. Evaluation of 3 different retreatment techniques in maxillary molar teeth by using micro-computed tomography. J Endod 2018;44(3):480-484.

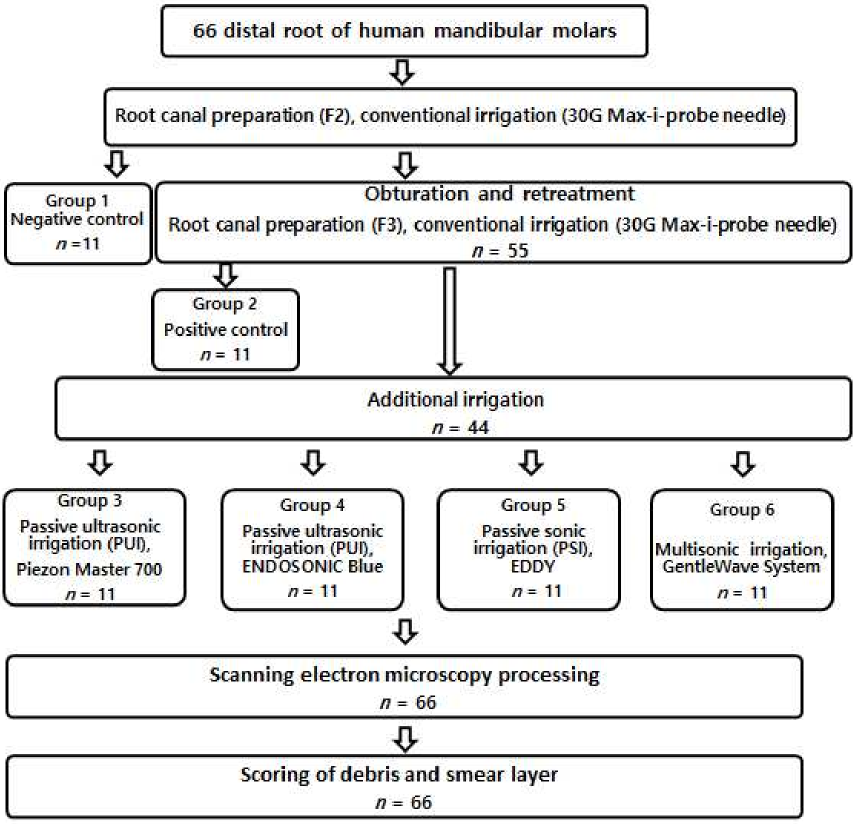
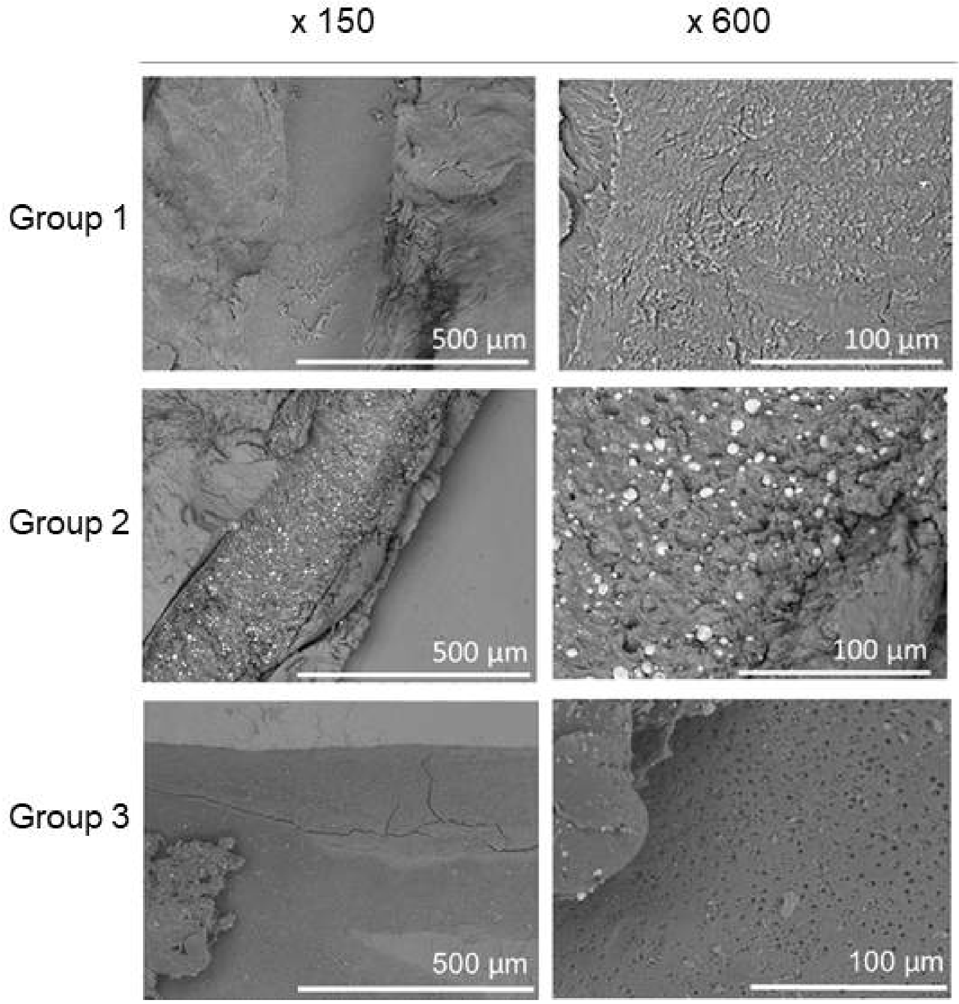


Figure 1. Flowchart of the experimental procedure.


x 150
x 600
Group 1
Group 2
Group 3
500 µm
100 µm
500 µm
100 µm
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100 µm

(continued)

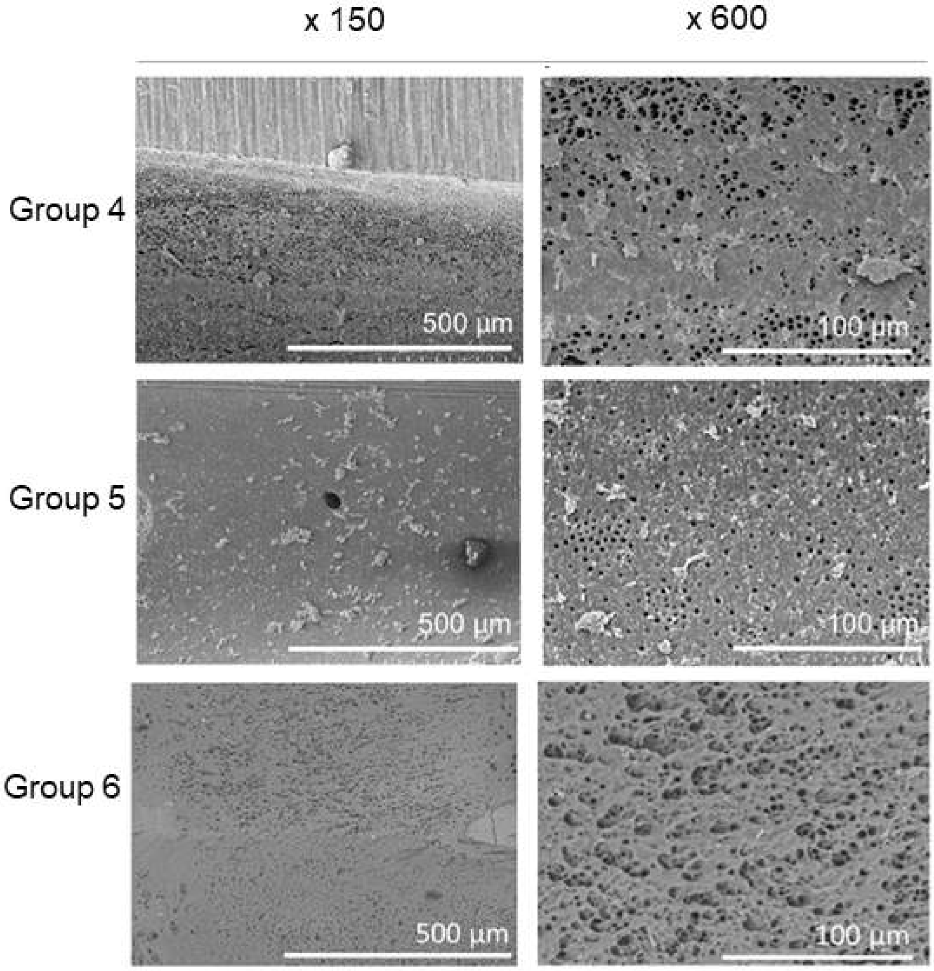


Figure 2. Representative scanning electron microscopy (SEM) images of apical regions of root canals from the six groups. SEM images are low (150×) and high (600×) magnifications of root canals showing debris and smear layer. Debris scoring was performed at 150× magnification and smear scoring at 600×. For analysis, debris was defined as the residual filling material and dentinal mud in the canal area. Smear score was assigned according to the percentage of open dentinal tubules.

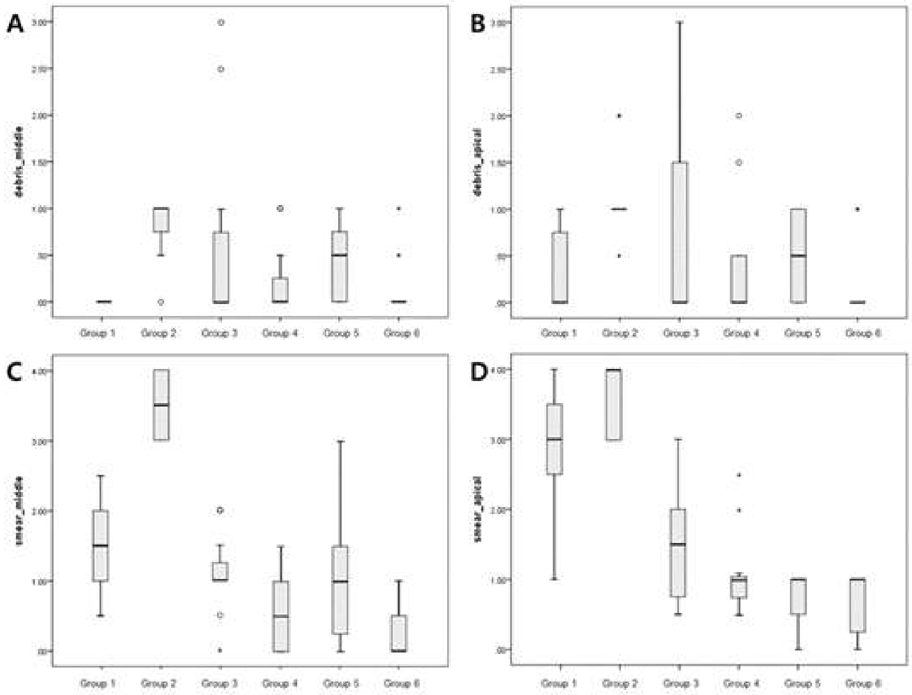
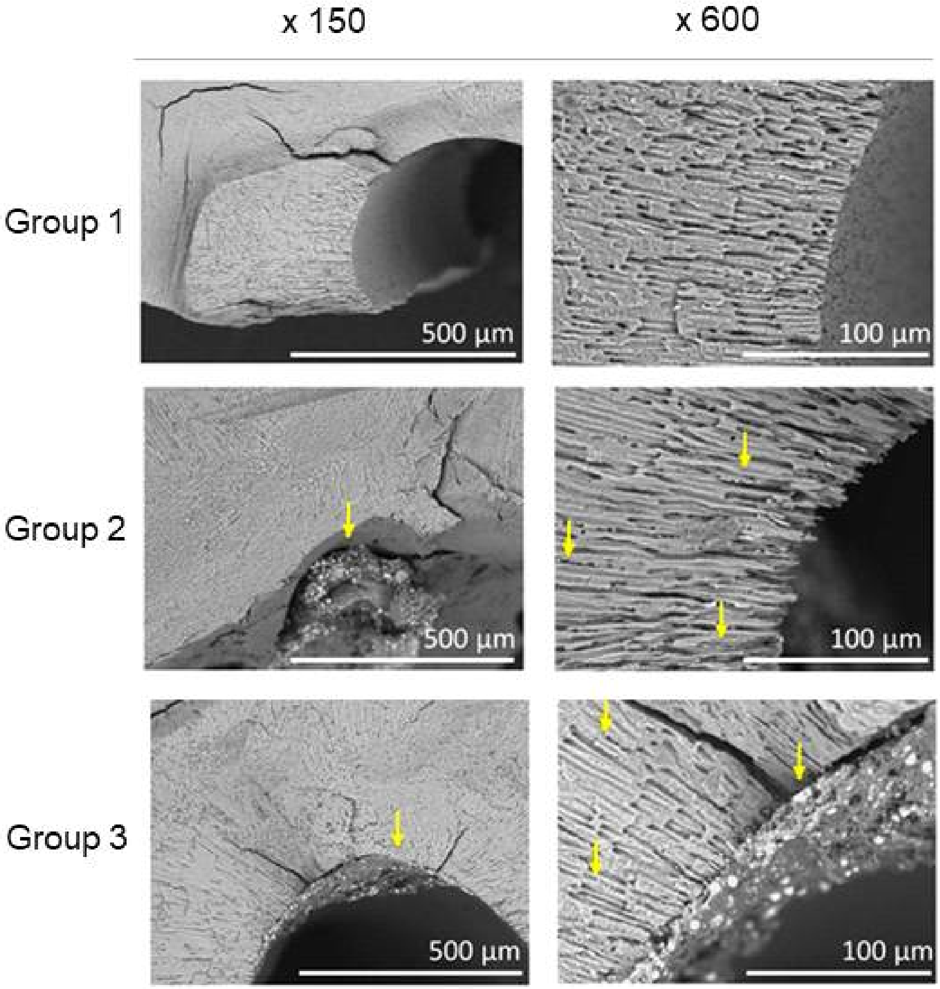


Figure 3. Box plots showing the distribution of values for the groups. (A) and (B) show debris scores for middle and apical regions, respectively. (C) and (D) show smear scores for middle and apical regions, respectively. Small circles, mild outliers; asterisks, extreme outliers (individual values more than 1.5 interquartile range).

Table 1. Debris and smear scores at apical and middle regions of the six groups in mean (SD)

	Debris		Smear	
Activation method	middle	apical	middle	apical
Group 1 (Negative control)	0.00[a] (0.00)	0.32[a] (0.46)	1.50[b] (0.67)	2.82[b] (0.93)
Group 2 (Positive control)	0.82[b] (0.34)	1.14[b] (0.45)	3.45[c] (0.47)	3.55[b] (0.52)
Group 3 (Piezon Master 700)	0.68[a,b] (1.08)	0.82[a,b] (1.12)	1.09[b] (0.58)	1.41[a] (0.80)
Group 4 (ENDOSONIC Blue)	0.23[a] (0.41)	0.45[a,b] (0.69)	0.64[a,b] (0.60)	1.10[a] (0.62)
Group 5 (EDDY)	0.45[a,b] (0.42)	0.50[a,b] (0.45)	0.95[a,b] (0.91)	0.73[a] (0.41)
Group 6 (GentleWave System)	0.14[a] (0.32)	0.18[a] (0.40)	0.27[a] (0.41)	0.64[a] (0.45)

Different superscript letters indicate statistically significant differences between groups ($P < 0.05$)


x 150
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Group 1
Group 2
Group 3
500 µm
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(continued)

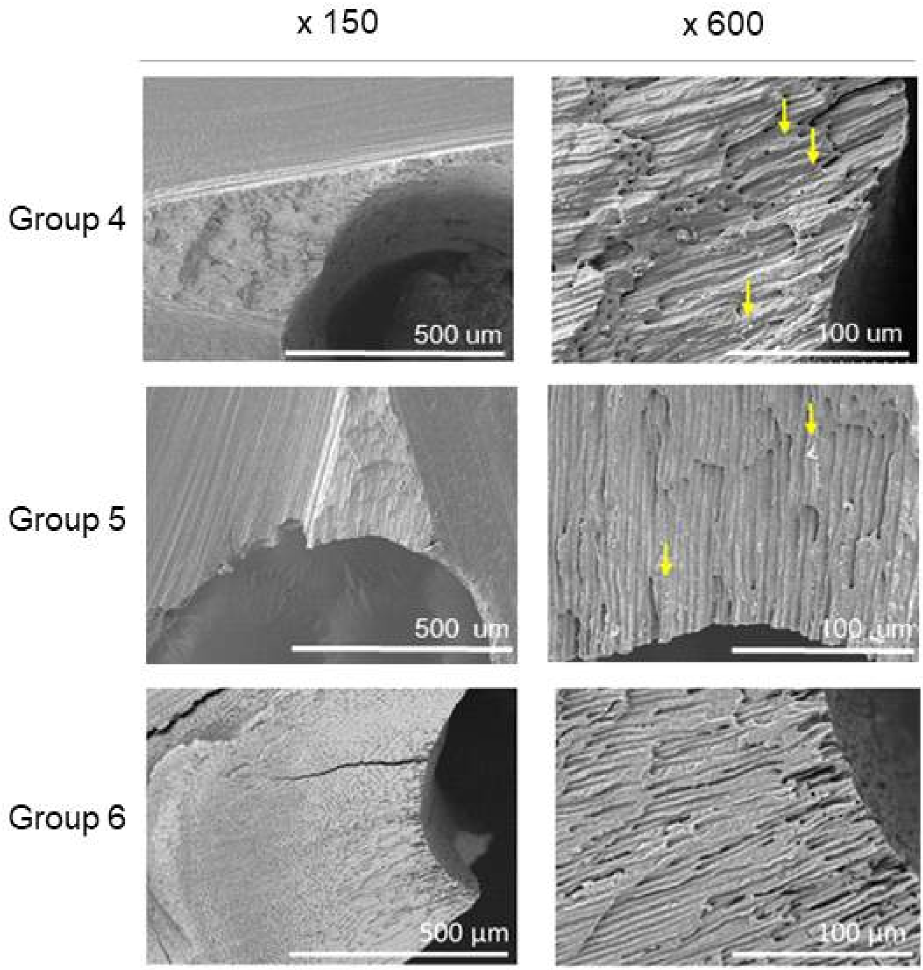

Figure 4. Representative SEM images of cross-sections of the six groups. SEM images show low (150×) and high (600×) magnifications of root canals. Note residual filling material remaining in root canals and dentinal tubules (arrows).

국문초록

재근관치료 시 수 종의 Irrigant activation system의 근관 세척 효능 비교

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(지도교수 손 원 준)

1. 목 적

본 연구의 목적은 재근관치료 시 수 종의 irrigant activation system 사용에 따른 치근단 부위와 치근 중앙 부위에서의 잔사와 도말층 제거 정도를 평가하여 다양한 irrigant activation system의 근관 세척 효능을 비교 평가하는 것이다.

2. 방 법

발거된 건전한 하악 대구치 66개의 단일 원심 근관을 대상으로 ProTaper file을 사용하여 근관 형성 후 치아를 무작위로 11개씩 6

개의 군으로 나누었다. 제 1군: 근관 형성 후 근관 충전을 하지 않은 음성 대조군, 제 2군: 근관 충전 후 Ni-Ti file과 syringe irrigation을 사용하여 재근관치료를 시행한 양성 대조군, 제 3군: 재근관치료 후 초음파 세척 장비인 Piezon Master 700을 사용하여 추가적인 근관 세척을 시행, 제 4군: 초음파 세척 장비인 ENDOSONIC Blue를 사용하여 추가적인 근관 세척을 시행, 제 5군: 음파 세척 장비인 EDDY를 사용하여 추가적인 근관 세척을 시행, 제 6군: GentleWave System을 사용하여 multisonic irrigation을 시행.

모든 시편을 통상의 방법에 따라 처리한 후 주사전자현미경을 통하여 치근단과 치근 중앙 부위에서 획득한 이미지를 두 명의 평가자가 독립적으로 맹검 평가하여 5단계로 smear score와 debris score를 평가하였고 결과는 Kruskal-Wallis test와 Tamhane T2 test를 이용하여 분석하였다. 통계적 유의 수준은 P = 0.05로 설정하였다.

3. 결 과

실험군 중에서는 GentleWave System이 치근 중앙과 치근단 부위에서 양성 대조군에 비해 유의성 있게 낮은 debris score를 나타내었다 (P < 0.05). 모든 실험군이 치근단 부위에서 음성 및 양성 대조군에 비해 유의성 있게 낮은 smear score를 나타내었고 치근 중앙 부위에서 양성 대조군에 비해 유의성 있게 낮은 smear score를 나타내었다 (P < 0.05). GentleWave System이 초음파 또는 음파 세척에 비해 낮은 debris score와 smear score를 나타내었으나 통계적으로 유의한 차이는 없었다 (P > 0.05).

4. 결 론

재근관치료 시 근관 세척 과정에서 초음파 근관 세척, 음파 근관 세척, GentleWave System과 같은 irrigant activation system의 추가적인 사용은 양성 대조군에 비해 치근단 부위와 치근 중앙 부위에서 세척 효능을 향상시켰다. GentleWave System의 세척 효능이 가장 우수하였으나 초음파 또는 음파 세척에 비해 통계적으로 유의한 차이는 없었다.

주요어 : 도말층, 잔사, 비외과적 재근관치료, 근관 세척, GentleWave System, 초음파 근관 세척, 음파 근관 세척, 주사전자현미경

학 번 : 2013 - 31192