In Vivo Debridement Efficacy of Ultrasonic Irrigation Following Hand-Rotary Instrumentation in Human Mandibular Molars

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Abstract

This study histologically compared the in vivo debridement efficacy of hand/rotary canal preparation versus a hand/rotary/ultrasound technique in mesial root canals of vital mandibular molars. Group 1 consisted of 16 teeth prepared with a hand/rotary technique whereas group 2 consisted of 15 teeth prepared in similar fashion but followed by 1 min of ultrasonic irrigation, per canal, utilizing an ultrasonic needle in a MiniEndo unit. Five uninstrumented mandibular molars served as histologic controls. After extraction and histologic preparation, 0.5 μm cross-sections, taken every 0.2 mm from the 1- to 3-mm apical levels, were evaluated for percentage of tissue removal. Nonparametric analysis revealed mean percent canal and isthmus cleanliness values to be significantly higher for group 2 at all levels evaluated, except one. In conclusion, the 1 min use of the ultrasonic needle after hand/rotary instrumentation resulted in significantly cleaner canals and isthmuses in the mesial roots of mandibular molars.

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Success in endodontic treatment depends on adequate preparation of the root canal space (1–3). Related factors in achieving this success, such as reduction in the number of organisms and obturation of the root canal system, are dependent on thorough root canal debridement (4, 5). The goal of cleaning and shaping is the removal of all vital or necrotic tissue, microorganisms, and their by-products.

The intricate nature of root canal anatomy has complicated the cleaning and shaping procedure (6–12). Small isthmuses and irregularities within the root canal system harbor tissue, microbes, and their by-products (8–10). These areas have been shown to be inaccessible to conventional hand and rotary instrumentation (13–23).

The use of ultrasonics as a primary cleaning and shaping technique has not been shown to result in better canal debridement as compared to hand instrumentation alone (24–29). These results have been attributed to constraint of the ultrasonic file within the nonflared root canal space (30).

Other researchers have studied the effectiveness of an ultrasonically activated file after hand instrumentation. The results showed greater canal and isthmus cleanliness values (13–16, 23, 31). For example, in vivo studies by Haidet et al. (16) and Archer et al. (23) histologically compared the tissue removal of step-back versus step-back/ultrasound (3 min using an ENAC piezoelectric unit) in the mesial roots of mandibular molars. Haidet et al. (16) reported that at the apical 1-mm level, canals and isthmuses were both significantly cleaner with the combination method. Archer et al. (23) found canal and isthmus cleanliness values to be significantly higher at the 1-, 2-, and 3-mm apical levels when the step-back/ultrasound method was used.

Clinicians have been slow to adopt ultrasound as an addition to endodontic cleaning and shaping. The major reasons for this are the need for three additional minutes per canal for adequate debridement, and file breakage at high levels of ultrasound activation.

We have developed an ultrasonically activated irrigating needle as an adjunctive device for canal debridement. The irrigating needle, when connected to a MiniEndo piezoelectric ultrasonic unit, can be activated at the highest power setting without needle breakage. Additionally, sodium hypochlorite can be delivered apically through the needle rather than adding the irrigating solution to the coronal access. Because more energy is produced at a higher power setting, perhaps the time of ultrasound treatment can be reduced from 3 min to 1 min. A 1-min treatment time per canal is more acceptable clinically.

Therefore, the purpose of this in vivo, prospective, randomized, single-blinded study was to histologically compare debridement efficiency of a hand/rotary cleaning and shaping technique versus a hand/rotary cleaning and shaping /ultrasound technique in the mesial roots of human mandibular molars.

Materials and Methods

Thirty-six healthy, adult volunteer subjects participated in this study. The Human Subjects Review Committee of The Ohio State University approved the study, and we obtained written informed consent from each subject.

Pulp vitality of the 36 test teeth was initially established with Green Endo-Ice refrigerant spray (Hygenic Corp., Akron, OH) and a Kerr Vitality Scanner (Kerr Dental, West Collins Orange, CA) digital electric pulp tester. Only vital teeth were included in this

study. All patients' teeth used in this study were treatment planned for extraction before we recruited the patients into the study. Teeth were scheduled for extraction because of nonrestorability or patient refusal of endodontic treatment when they presented to the emergency clinic.

Before the initiation of the study, random six-digit numbers were recorded on a master code list corresponding to the experimental treatment groups. The master code was used to randomly assign the teeth to each treatment group after the hand/rotary instrumentation had been completed. Therefore, operator bias was eliminated because it was not known which group would receive ultrasonic irrigation until the hand/rotary cleaning and shaping was complete. Both canals of the mesial root of the experimental tooth received the same treatment.

The 36 experimental teeth were randomly divided into three groups. Group 1 consisted of 16 teeth prepared using a manual hand-file/rotary cleaning and shaping technique but with no ultrasonic irrigation. Group 2 consisted of 15 teeth prepared with a manual hand-file/rotary cleaning and shaping technique, immediately followed by 1 min of ultrasonic irrigation per canal. Group 3 consisted of five uninstrumented teeth, which served as histologic controls. These five teeth were freshly extracted mandibular molars with vital pulps. Initial radiographs of the experimental teeth in Groups 1 and 2 were taken with a parallel film holder and were analyzed using Schneider's method (32) to determine the curvature of the mesial roots. For the three groups, only the mesial roots were used.

After achieving adequate pulpal anesthesia, the experimental teeth were isolated with a rubber dam. A standard access opening was made using a #4 round bur in a high-speed handpiece. The presence of pulpal hemorrhage was noted as a confirmation of pulpal vitality.

Group 1: Root Canal Preparation

New K-type hand files (Dentsply Maillefer, Tulsa, OK) and rotary ProFile GT files (Dentsply Tulsa Dental, Tulsa, OK) were used for canal preparation of each tooth. Working length was established with a Root ZX (J. Morita Mfg. Corp., Irvine, CA) and radiographically to within 1 mm of the radiographic apex for each mesial canal. Each canal orifice was enlarged with #5 Gates Glidden bur and the canals initially cleaned and shaped to a #20 hand file. A crown down technique was then used to enlarge the coronal portion, then the mid root, and finally the apical third of the canal with rotary files. The sequence of Profile GT rotary instrumentation was: 30/.10, 30/.08, 30/.06, 30/.04, 70/.12, 50/.12, 35/.12. Each canal was irrigated with approximately 2 ml of 6.0% sodium hypochlorite by weight (Chlorox, The Chlorox Co., Oakland, CA) following the use of every third hand file, rotary file and #5 Gates-Glidden bur. Each rotary file was used with EndoGel lubricant (Jordco Inc., Beaverton, OR) during instrumentation of each canal. A size #30 K-file was then inserted and a radiograph exposed to confirm that the initial working length was maintained. When indicated, instrumentation adjustments were made to ensure adequate preparation and establishment of an apical preparation 1 mm from the radiographic apex. After completion of instrumentation, each mesial canal was flushed with 15 ml of 6.0% sodium hypochlorite at a rate of 15 ml/min. The canals were dried using coarse and medium sterile paper points.

Group 2: Root Canal Preparation Plus 1 Min of Ultrasonic Irrigation

The teeth in this group were prepared in an identical method to those teeth in Group 1 with the addition of an ultrasonically energized needle used after completion of the hand/rotary preparation. The ultrasonic unit used was a MiniEndo (Spartan EIE Inc., San Diego, CA). The power adjustment on the unit was set at full power. A new 1.5 inch, 25-gauge, irrigating needle (Becton Dickinson & Company, Franklin Lakes, NJ) was used for each tooth. A pilot study, using acrylic blocks,

determined that the 25-gauge needle produced cavitation and provided the greatest amount of acoustic streaming compared to 27-and 30-gauge needles. The pilot study also showed that the 25-gauge needle could be used at the full power setting without breaking. An ultrasonic needle was used rather than a file because the irrigating solution could be continuously delivered through the needle. Each needle was inserted through the rear aperture of a specially designed ultrasonic needle holding device (patent applied for) and connected to the MiniEndo handpiece. The needle was secured at a 45° angle to the long axis of the ultrasonic handpiece and 20 mm of the needle was exposed. Luer-Lok IV tubing (Medex, Dublin, OH) connected the needle in the handpiece to a 30 ml Luer-Lok syringe (Becton, Dickinson & Co.) containing 30 ml of 6.0% sodium hypochlorite.

Upon completion of the hand/rotary preparation, each canal was filled with 1 ml of 6.0% sodium hypochlorite. The ultrasonic needle was placed in the canal as far apically as it would go without binding. After activation of the MiniEndo unit, the needle was moved passively in an up and down motion to ensure it did not bind with the root canal walls. The energized ultrasonic needle was used continuously for 1 min in each canal. Six percent sodium hypochlorite was delivered at a rate of 15 ml/min through the ultrasonic needle. High-speed suction was maintained at all times on the distal aspect of the experimental tooth. This procedure was then repeated for the other mesial canal. After completion of the hand/rotary/ultrasonic preparation, the canals were dried with coarse and medium paper points.

In both groups, a sterile cotton pellet was then placed in the pulp chamber of each tooth and the access sealed with Cavit (3M ESPE AG, Seefeld, Germany). The teeth were immediately extracted using a surgical root resection technique to preserve the integrity of the mesial roots. Each mesial canal was irrigated with 1 ml of 6.0% sodium hypochlorite to remove any possible pieces of loose cavit or blood that had entered the canal during the extraction process. Each canal was then irrigated with 1 ml of 10% formalin to allow for fixation of any remaining pulpal tissue. A 0.5 mm vertical groove was placed in the buccal surface of the mesial root with a #1/2 round bur to help maintain root orientation and aid in canal identification. Each tooth was immediately placed into a 20 ml vial of 10% formalin and labeled with the random six-digit number. Teeth remained in these vials until histologic processing was started.

Group 3: Histologic Control

The five teeth in this group were vital mandibular molars that had been extracted by The Ohio State University Oral Surgery Department. Immediately after the teeth were extracted, access openings were made and the presence of pulp tissue confirmed. The pulp chambers were then irrigated with 1 ml of 10% formalin to fix the tissue. The teeth were then marked with a vertical groove on the buccal surface of the mesial root and placed into randomly numbered vials containing 20 ml of formalin. These uninstrumented teeth served as controls for histologic processing and sectioning procedures.

Histologic Preparation

After fixation, all teeth were decalcified in an aqueous solution of equal parts 50% formic acid and 20% sodium citrate for 10 days. Teeth were then dehydrated and infiltrated using methyl salicylate as a clearing agent (33). After infiltration, the teeth were placed in an embedding boat containing Paraplast (Sherwood Medical Ind. Inc., St Louis, MO). The specimens were oriented in two planes to produce perpendicular sections from the same level in both root canals.

After the Paraplast had set, 5 μm sections were obtained using an American Optical Model 820 microtome (American Optical Co., Buffalo, NY). Sections were collected until the external apex of the tooth

TABLE 1. Summary of mean percentage of canal cleanliness ($\pm$SE)

Level (mm)	N	(Group 1) Hand/Rotary No Ultrasound	N	(Group 2) Hand/Rotary Ultrasound	p-Value*
1.0	30	75.1 $\pm$ 28.0	25	99.0 $\pm$ 2.4	0.0010
1.2	30	85.1 $\pm$ 20.9	26	99.2 $\pm$ 2.1	0.0328
1.4	31	83.9 $\pm$ 29.0	26	99.5 $\pm$ 1.5	0.0010
1.6	31	88.7 $\pm$ 22.9	26	99.5 $\pm$ 1.9	0.0402
1.8	30	94.5 $\pm$ 12.9	27	99.3 $\pm$ 3.3	0.0024
2.0	29	96.5 $\pm$ 6.1	28	100 $\pm$ 0.1	0.0010
2.2	29	98.6 $\pm$ 3.0	28	99.9 $\pm$ 0.4	0.0402
2.4	29	98.6 $\pm$ 2.1	27	100 $\pm$ 0.1	0.0056
2.6	28	99.0 $\pm$ 2.0	27	100 $\pm$ 0.0	0.0320
2.8	29	99.6 $\pm$ 1.3	27	100 $\pm$ 0.0	0.0056
3.0	29	99.7 $\pm$ 0.6	28	99.8 $\pm$ 0.5	0.1169

* Bonferroni adjusted p-value.

TABLE 2. Summary of mean percentage of isthmus cleanliness ($\pm$SE)

Level (mm)	N	(Group 1) Hand/Rotary No Ultrasound	N	(Group 2) Hand/Rotary Ultrasound	p-Value*
1.0	8	15.0 $\pm$ 17.6	3	96.5 $\pm$ 3.5	0.0285
1.2	8	27.7 $\pm$ 31.6	5	89.7 $\pm$ 14.1	0.0285
1.4	9	24.8 $\pm$ 29.4	8	82.9 $\pm$ 29.8	0.0144
1.6	8	37.9 $\pm$ 35.4	8	77.2 $\pm$ 31.8	0.0482
1.8	7	34.3 $\pm$ 35.4	8	91.7 $\pm$ 9.5	0.0285
2.0	9	27.8 $\pm$ 32.9	11	73.3 $\pm$ 37.3	0.0412
2.2	10	27.5 $\pm$ 32.2	10	85.4 $\pm$ 30.5	0.0049
2.4	10	30.9 $\pm$ 34.9	10	86.3 $\pm$ 21.8	0.0030
2.6	10	28.0 $\pm$ 34.4	11	81.8 $\pm$ 29.1	0.0010
2.8	12	32.8 $\pm$ 35.8	11	91.8 $\pm$ 15.3	0.0048
3.0	11	34.1 $\pm$ 35.0	11	94.2 $\pm$ 13.3	0.0030

* Bonferroni adjusted p-value.

(external foramen or major diameter) was located. Starting at the 1 mm level (minor diameter) from the external apex, slides were prepared of four sections every 0.2 mm until the 3 mm level was reached. Slides were stained using Gomori's One-Step Trichrome Method (34). The best, technically error-free section was chosen from each stained slide for evaluation. All slides were labeled with the specimen's six-digit random number and sequentially numbered according to the order in which they were taken.

Method of Evaluation

Blinded and mounted sections from all three groups were evaluated by the primary investigator (RG) using a computer (Tangent, Intel Pentium III, Windows 2000) attached to a Nikon Eclipse e600 microscope (Nikon, Melville, NY). Neurolucida Image Analysis Program version 5.0 (MicroBrightField, Inc., Colchester, VT) was used to measure the area of the root canals and isthmuses and all pulp tissue contained within them. The full-color section was projected onto the monitor screen at $40\times$, $100\times$, and $200\times$ magnification. The magnification selected to evaluate cleanliness was determined by the largest magnification in which the entire canal/isthmus could be viewed in its entirety. A computer mouse was used to trace the outline of the root canal. The area of the canal space was calculated (μm^2) by the software. Pulp tissue was identified and the area of remaining tissue was calculated in the same manner just described. If more than one area of remaining pulpal tissue was present within each section being analyzed, the cursor was moved to each separate area the tissue outlined. The total tissue area was calculated by adding together all the separate remaining tissue

areas and subtracting from 100% to determine the percent of canal cleanliness. The isthmuses between canals were traced separately from the primary root canals and their total area and the area of their remaining pulpal tissue recorded as described above. Inherent error and reliability of the single evaluator was controlled by determining the intra-class correlation coefficient.

The Mann-Whitney-Wilcoxon test was used to statistically analyze mean cleanliness values for both canals and isthmuses (Tables 1 and 2). Method of instrumentation and apical level were the factors that were analyzed. The raw P values were then adjusted by the step-down Bonferroni method of Holm. Differences between groups regarding distribution of teeth (1st, 2nd, and 3rd molars), clinical and histologic typing of teeth (type II or III) and curvature of canals were analyzed by Fischer Exact tests. Comparisons were considered significant at p < 0.05.

Results

A comparison of canal and isthmus cleanliness is shown in Tables 1 and 2. The Figures are examples of canal preparation for the hand/rotary group and hand/rotary/ultrasound group. The intra-class correlation coefficient was determined to be 0.989 (95% confidence interval 0.951 [lower limit]; 0.998 [upper limit]) indicating excellent reliability of the evaluator.

For canal cleanliness, there were significant differences at all 10 apical levels between the two techniques. The 3 mm level was not significant (Table 1). Isthmus cleanliness values were significantly differ-
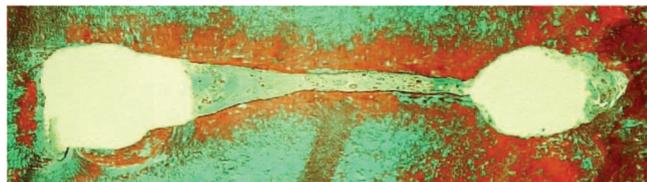
Figure 1. Photomicrograph of representative cross-section at the 1.0 mm level: hand/rotary group (1)—70% mesiolingual canal (right) and 95% mesiobuccal canal (left) cleanliness, isthmus cleanliness 27%, original magnification 40×, Gomori's stain.

Figure 2. Photomicrograph of representative cross-section at the 1.0 mm level: hand/rotary/ultrasound group (2)—100% mesiolingual canal (right) and 100% mesiobuccal canal (left) cleanliness, isthmus cleanliness 99.8% (dentin projection evident in isthmus), original magnification 40×, Gomori's stain.

Figure 3. Photomicrograph of representative cross-section at the 3.0 mm level: hand/rotary group (1)—100% cleanliness in the mesiolingual canal (left) and 100% cleanliness in the mesiobuccal canal (right), with isthmus cleanliness of 51%, original magnification: 100×, Gomori's stain.

Figure 4. Photomicrograph of representative cross-section at the 3.0 mm level: hand/rotary/ultrasound group (2)—100% cleanliness in the mesiolingual canal (left) and 100% cleanliness in the mesiobuccal canal (right), with isthmus cleanliness of 90%, original magnification: 100×, Gomori's stain.

Discussion

The mean canal cleanliness values (Table 1) for the hand/rotary group is similar to those reported by other authors utilizing step-back preparation techniques (14–16). The addition of 1-min of ultrasonically activated irrigation significantly improved the overall mean canal cleanliness values at all 10 apical levels. The addition of ultrasonic irrigation also produced more consistent cleaning of the canals as seen by the low standard errors in the majority of levels in group 2 as compared to group 1 (Table 1). These results were equal or superior to the results reported by previous investigators (14–17, 23), at all levels, using only 1-min of ultrasonic irrigation as compared to 3-min in the previous studies.

Isthmus cleanliness values improved from the 1-mm to 3-mm level within the hand/rotary group; however, the cleanliness values only ranged from 15 to 38%. These results are similar to those reported by Lev et al. (15), Goodman et al. (14), Haidet et al. (16), Metzler et al. (17), and Archer et al. (23) and confirm that complete tissue removal from isthmuses of teeth with vital pulps is impossible with hand or hand/rotary cleaning and shaping alone. The addition of 1-min of ultrasonically activated irrigation following hand/rotary cleaning and shaping significantly increased the cleanliness values (73–96%) at all levels evaluated (Table 2). While increasing cleanliness significantly, complete debridement of the isthmuses was not always attained. We did observe some tissue remaining in the very narrow isthmuses; however, ultrasonic irrigation was significantly better than hand/rotary cleaning and shaping alone.

The finding of no significant differences between the groups for tooth distribution, mesial root typing and root curvature demonstrates that the two groups were of equal difficulty. Clinically, the in vivo nature of this study makes isolation, access, working length determination and cleaning and shaping more relevant than in vitro studies. That is, in vitro studies can control for poor access, determine working lengths accurately by visualizing files at the apical foramen and instrument teeth without regard to difficult access or clinical time constraints. Therefore, in vivo studies may be more clinical relevant than in vitro studies.

The MiniEndo system is a piezoelectric unit that does not require an external cooling source and is more powerful than magnetorestrictive units. Ahmad et al. (28) reported that cleaning within a canal, via

ent between the two treatment groups at all eleven levels examined (Table 2).

The uninstrumented control teeth showed mean cleanliness values ranging from 8.2% at the 1.2 mm level to 29.2% at the 2.6 mm level. Only 1 control tooth revealed an isthmus. It had a value of 0.0% cleanliness at the 2.0 mm level and 21.7% at the 2.2 mm level.

The distribution of teeth was as follows: first molars—56% (9/16) group 1, 40% (6/15) group 2; second molars—38% (6/16) group 1, 60% (9/15) group 2; third molars—6% (1/16) group 1, 0% (0/15) group 2. There were no significant differences between the groups (p = 0.3723, Fisher Exact test).

Clinical and histologic typing of the mesial roots were as follows: type III—81% (13/16) group 1; 73% (11/15) group 2; type II—19% (3/16) group 1, 27% (4/15) group 2. There were no significant differences between the groups (p = 0.6851, Fisher Exact test).

Curvature of the canals, as determined by Schneider's method (32), were as follows: moderate (less than 25 degrees)—56% (9/16) group 1, 47% (7/15) group 2; severe (26 to 52 degrees)—44% (7/16) group 1, 54% (8/15) group 2. There were no significant differences between the groups (p = 0.7244, Fisher Exact test).

cavitation, occurs at the tip of the ultrasonic file and requires apical preparation of the canal to at least a size #40 file. They also reported that high energy is required to allow cavitation to occur. In this study, cavitation was achieved by utilizing the MiniEndo system at full power capacity. Acoustic streaming, on the other hand, occurs on the sides of the ultrasonic file and can occur with either high or low energy (26–28). Apical preparations within this study were never larger than a size #30 file and the 25-gauge ultrasonic needle had an outside diameter of 0.50-mm (size #50 file). Therefore, the ultrasonic needle depth was within 4 to 5 mm of the apical preparation. In this study, the action of the ultrasonically activated irrigation is presumed to have included both cavitation and acoustic streaming. Although the needle was not placed to the complete depth of the preparation, the high energy generated by the ultrasound unit, and use of sodium hypochlorite, resulted in statistically cleaner canals and isthmuses.

The use of an ultrasonic irrigating needle allowed for the continual deposition and renewal of irrigating solution within the canal. This differed from previous studies (14–17, 23) where irrigant was delivered only into the coronal access opening. The delivery of fresh irrigating solution within the root canal may have contributed to the improved cleanliness values. Because canal and isthmus cleanliness values were not 100%, perhaps longer ultrasonic times could be utilized in future studies. However, longer ultrasonic times may increase the time of endodontic treatment and be inconvenient

Littman (35) demonstrated that the operator is more important than the technique in the thoroughness of canal debridement. Therefore, operator performance may have affected the canal cleanliness values in this study. Goodman et al. (14) found that the addition of ultrasound after hand instrumentation helped equalize the debridement results between operators; thereby compensating for poorer debridement by an operator.

Will improving tissue debridement from the root canal and isthmus areas improve clinical success? Empirically, it would make sense that a cleaner canal system should improve the outcome of root canal therapy. In conclusion, the 1-min use of ultrasonically activated irrigation, following hand/rotary cleaning and shaping, has been shown to improve canal and isthmus cleanliness.

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