Histologic Evaluation of Canal and Isthmus Debridement Efficacies of Two Different Irrigant Delivery Techniques in a Closed System

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Abstract

Introduction: This study compared canal and isthmus debridement efficacies between side-vented needle irrigation (SNI) and continuous ultrasonic irrigation (CUI) in the mesial root of mandibular first molars with narrow isthmuses using a closed-canal design. **Methods:** Micro–computed tomography scanning was used to select 20 teeth, each containing a narrow isthmus. Each root was sealed at the apex; embedded in polyvinylsiloxane to simulate a closed-canal system; and instrumented to size 40, 0.04 taper. Final irrigation was performed with either SNI or CUI (N = 10). Masson trichrome-stained sections were prepared from demineralized roots at 10 canal levels between 1.0 and 2.8 mm from the anatomic apex. The areas and debris occupied by the canals and isthmus were measured using ImageJ software (National Institutes of Health, Bethesda, MD) and statistically analyzed using repeated-measures analysis. **Results:** Overall, a significant difference was identified between SNI and CUI in the amount of debris remaining in the isthmus (P = .006) but not in the canal (P = .940). There was significantly more debris in the most apical three canal levels (1.0–1.4 mm) regardless of the irrigation technique (P < .001). The isthmus harbored significantly less debris in the CUI group between isthmus levels 1.0 to 2.2 mm when compared with SNI (P < .001 and P = .029). Neither technique removes debris completely from the canal or isthmuses. **Conclusions:** Compared with SNI, CUI removes significantly more debris from narrow isthmuses of mandibular mesial roots. *(J Endod 2011;37:544–548)*

Key Words

Canal, closed system, continuous ultrasonic irrigation, debris, isthmus, side-vented needle irrigation

Successful endodontic treatment requires eradication of bacterial biofilm from the entire canal system (1, 2). Current instrumentation techniques are incapable of reaching all surfaces and irregularities within the canal (3). Practitioners must rely on the delivery of irrigants to noninstrumented areas to debride the remaining debris and bacteria (4, 5). Posterior teeth with isthmuses connecting multiple canals (6) make it difficult for irrigant penetration, resulting in ineffective dissolution of hard-/soft-tissue remnants and microorganism destruction. A closed canal system may also produce gas entrapment that compromises optimal irrigant delivery to the apical 2.0 mm of the canal space (7).

Different irrigation delivery devices are available for enhancing irrigant distribution and flow (8). Side-vented needle irrigation (SNI) has been proposed to improve the hydrodynamic action of irrigant flow. However, this technique produces irrigant exchange no further than 1.0 mm beyond the needle tip (9, 10) and is ineffective in flushing debris from the apical third of the canal without adjunctive agitation methods (7).

Ultrasonic irrigation shows better canal debridement efficacy over the use of needle irrigation alone (11). ProUltra PiezoFlow (Dentsply Tulsa Dental Specialties, Tulsa, OK) uses continuous ultrasonic irrigation (CUI) for simultaneous continuous irrigant delivery and ultrasonic activation (12), unlike passive ultrasonic irrigation, which requires intermittent replenishment of irrigant between ultrasonic file activation (11). Agitation of sodium hypochlorite (NaOCl) enhances tissue dissolution (13), and its continuous replenishment provides an uninterrupted supply of nascent chlorine for organic tissue dissolution (14).

Previous *in vitro* and *in vivo* studies that examined the debridement efficacy of ultrasonic irrigation in the apical 1 to 3 mm of the canal reported significantly cleaner isthmuses (15–22) and a greater reduction in bacteria colony-forming units (4). However, some studies failed to take into account the contribution of a closed-system design on canal/isthmus debridement efficacy. In other studies, the criteria for mesiodistal isthmus width selection appeared to be loosely defined (23). A wide isthmus is more readily accessible to irrigants than a narrow or “partial” isthmus (24, 25) that is occluded by sclerotic dentin (23). Thus, the purpose of the present study was to compare the canal and isthmus debridement efficacies between SNI and CUI techniques by testing the null hypothesis that there is no difference between SNI and CUI in cleaning the mesial root of mandibular first molars with narrow isthmuses in a closed-canal system.

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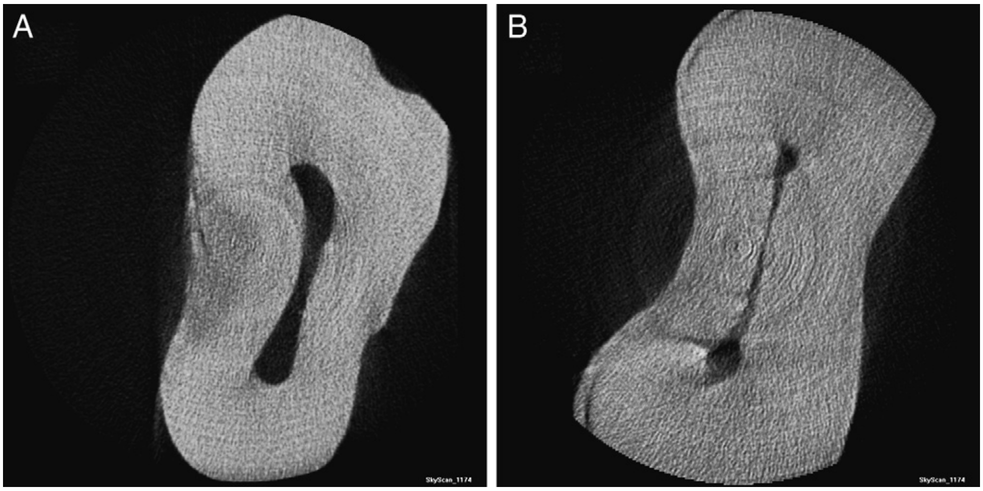

Figure 1. A micro–computed tomography scan was used for nondestructive screening of the apical third of the mesial root of mandibular molars (1–3 mm from the anatomic apex). Roots with mesiodistal isthmus widths wider than one quarter of the diameter of the unshaped canals anywhere along the scanned regions were excluded from the study. (*A*) A representative image from a root that had an isthmus width wider than the set selection criteria. This root was not included in the study. (*B*) A representative image from a root that had an acceptable isthmus width. This root was included in the study.

Materials and Methods

Extracted mandibular first molars were collected with patient's consent and stored in 0.9% sodium chloride (NaCl) containing 0.02% sodium azide (NaN_3) to prevent bacterial growth. Tooth selection and root preparation were performed according to Susin et al (26). Briefly, only teeth with narrow isthmuses were used. Criteria for tooth selection required the mesiodistal isthmus width to be less than one quarter the diameter of the unshaped canals. The teeth were examined with a micro–computed tomography scan (SkyScan 1174; SkyScan, Aartselaar, Belgium) along root levels from which histological sections were subsequently prepared (Fig. 1). Twenty selected teeth were randomly divided into two groups (N = 10). A custom-fabricated fixture was used to produce a closed system that permitted canal irrigation and suction to be performed by a single operator (26) while preventing fluid and gases from escaping to the external environment (27).

Experimental Groups

Each canal was instrumented to a size 40, 0.04 taper (28) with ProFile Vortex rotary nickel-titanium instruments (Dentsply Tulsa Dental Specialties). The pulp chamber was flooded with 6% NaOCl and replenished with 1.0 mL after each instrument. Recapitulation was performed with a size 10 K-file to improve irrigant penetration (29). The two experimental groups represent the two different irrigation techniques performed after the last rotary instrument used. Each group received the same postinstrumentation final irrigation volume.

In the SNI group, the final irrigation consisted of irrigant delivered 1.0 mm from the working length (9, 10, 30, 31) with a 30-G side-vented needle. The irrigants used were 6% NaOCl (15 mL) followed by 17% EDTA (15 mL) as the final rinse. The irrigation volumes were chosen so that they were similar to those used for group 2. Each irrigant was delivered at a flow rate of 15 mL/min for 1 minute each.

In the CUI group, the ProUltra PiezoFlow system uses a rigid, 25-G (0.5-mm) needle embedded in an adapter allowing attachment to an ultrasonic handpiece. The needle is activated while the irrigant is delivered through tubing connected to a syringe. This study inserted the needle into the canal 1.0 mm short of binding, the ultrasonic unit was set to a power level of 5, and the irrigant was delivered at 15 mL/min as recommended by the manufacturer. Fifteen milliliters of 6% NaOCl was delivered followed by 15 mL of 17% EDTA as the final rinse. Simultaneous ultrasonic activation was performed during irrigant delivery for a total of 2 minutes. Upon completion of the active irrigation regimen, each root was rinsed with sterile saline, dried with paper points, temporized, removed from the experimental setup, and stored in 10% formaldehyde.

Light Microscopy

All roots were completely demineralized in formic acid/sodium formate, histologically prepared, sectioned in 0.2-mm increments beginning at 1.0 to 2.8 mm from the anatomic apex, and digitally recorded (26). Images taken from the 10 root levels were analyzed using ImageJ software (National Institutes of Health, Bethesda, MD). Outlines of the mesiobuccal and mesiolingual canals and the isthmus were traced to determine the surface area of the respective regions. Areas occupied by stained debris in the corresponding regions were also determined. For each canal and isthmus level, the percentage area occupied by debris was calculated by dividing the area of debris by the sum of either the corresponding canals or isthmus area.

Statistical Analyses

Data from the canals and isthmuses were analyzed separately using repeated-measures analysis to answer the following questions: (1) Was there a difference between the irrigation techniques in terms of overall cleanliness? (2) Were differences found among the 10 root levels in the ability of the two techniques to clean the canal and isthmus? and (3) Were the canals cleaner than the isthmus for either technique? Because of the highly skewed nature of the data, rank-based methods incorporating rank transform were used for all analyses (31).

To address questions 1 and 2, a repeated-measures analysis with one within factor (root level) and one between factor (irrigation technique) was used for the canal and isthmus data to test for significant interactions among the factors. If no significant interactions were found, a main effects analysis was performed to test the null hypothesis that there is no difference among factor levels, ignoring the effects of the other factor. If a significant interaction was found, a simple-effects analysis was performed. Bonferroni adjustments were made so that the family-wise error rate for the tests of each factor could be controlled

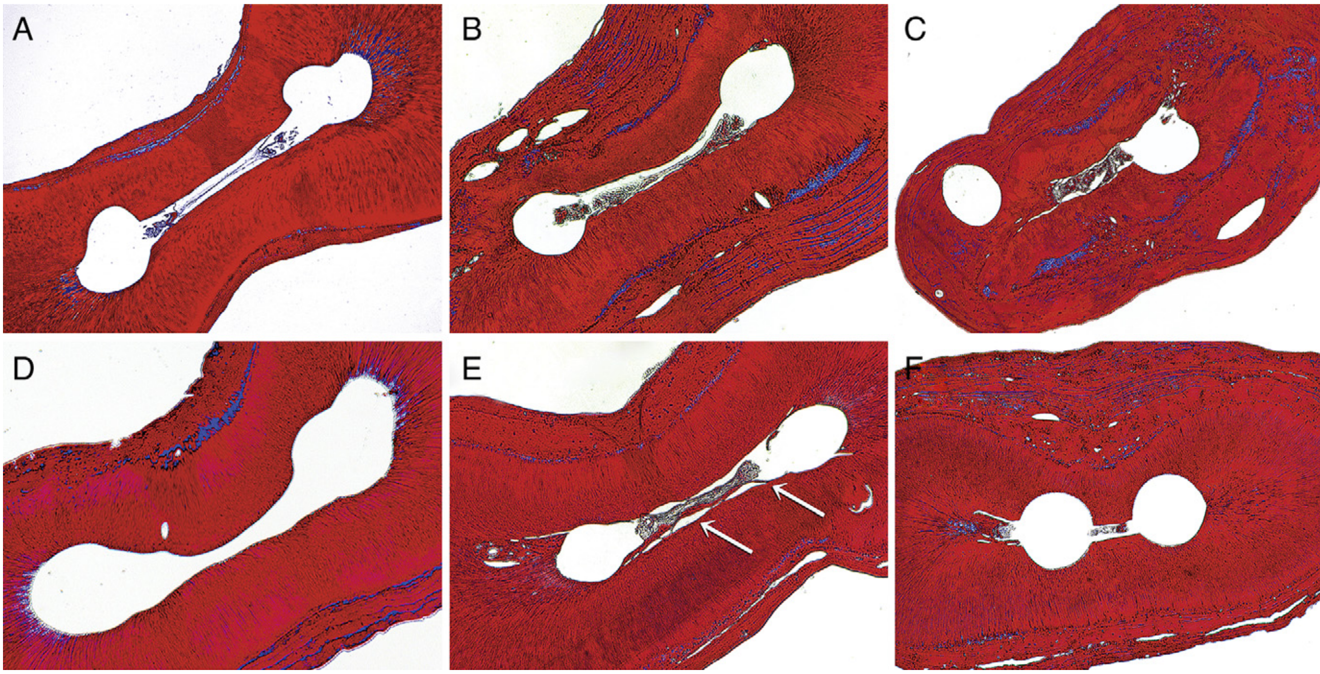

Figure 2. Light microscopy images of Masson's trichrome-stained cross-sections of root specimens that were irrigated using either SNI or CUI. (*A–C*) The SNI group at the (*A*) 2.8-mm level, (*B*) the 2.0-mm level, and (*C*) the 1.0-mm level. (*D–F*) The CUI group at the (*D*) 2.8-mm level (note that the isthmus was completely free of debris); (*E*) the 2.0-mm level (note that a portion of the isthmus separated from the isthmus proper during sectioning, resulting in an artifactual space (arrows); and (*F*) the 1.0-mm level (original magnifications 20–40×).

at the 0.05 level (32). Tukey-Kramer multiple comparisons for repeated measures were used to perform all pair-wise comparisons. Two-tailed tests with a significance level of 0.05 were used for all comparisons.

To address question 3, the area under the curve was used to calculate a measure of overall cleanliness over all levels for each specimen (33). A repeated-measures analysis with one within factor (root level) and one between factor (irrigation technique) was performed at $\alpha = 0.05$.

Results

Figure 2A through F are examples showing canal and isthmus cleanliness achieved by SNI or CUI at different root levels. Figure 3 summarizes the percentage area occupied by debris in the canals and isthmus of the two experimental groups.

For the first two questions, analysis of data from the canals indicated that SNI and CUI were not significantly different in overall cleanliness between 1.0 and 2.8 mm from the anatomic apex ($P = .757$), but there was a significant effect at specific root levels ($P < .001$). Significantly more debris was identified in the most apical three root levels (1.0–1.4 mm) regardless of the irrigation technique. Analysis of the data from the isthmuses indicated significant differences between SNI and CUI at every root level until the level of 2.4 mm was reached ($P \leq .001$–.029).

With respect to whether the canals were cleaner than the isthmus for either technique, a significant difference was found between SNI and CUI in the isthmus ($P = .006$) but not in the canal ($P = .940$). A detailed report on the statistical analyses is included as supporting data (supplemental information and Tables 1–5 are available at www.jendodon.com).

Discussion

Remaining debris can harbor bacteria, resulting in treatment failure (1–4, 34). Two clinically relevant irrigation techniques were selected to compare their canal and isthmus debridement efficacies in the mesial root of mandibular molars. The use of an *in vitro* closed-end canal design more closely replicates *in vivo* scenarios (7, 27, 28) in which the apical foramen is enclosed within alveolar bone and the periodontal ligament (4, 20–22).

Canal cleanliness for SNI ranged from 93.55% to 100%, whereas canal cleanliness for CUI ranged from 94.66% to 100%, resulting in no significant difference at any canal level between the two irrigation techniques. However, isthmus cleanliness for SNI ranged from 52.14% to 99.32%, and for CUI it ranged from 87.53% to 99.93%. CUI removed significantly more debris in noninstrumented isthmuses than SNI at levels 1.0 to 2.2 mm. This trend is in agreement with results reported by previous *in vivo* (17, 20–22) and *in vitro* studies (15, 16, 18, 19).

Previous *in vivo* studies (21, 22) found significantly cleaner canals and isthmuses with ultrasonic irrigation when compared with hand/rotary instrumentation. These studies used 60 seconds of activation and made no mention of depth of irrigant delivery; they also used second and third molars in addition to first molars and made no attempt in determining isthmus width prior to tooth selection. Both studies reported debris in only "very narrow isthmuses." Although *in vivo* studies are obviously clinically relevant models, incorporating an approach that examines isthmus width before specimen selection allows for examination of the effect of irrigation technique from a more objective perspective.

The CUI device has a rigid irrigant delivery needle with an outside diameter of 0.5 mm (equivalent to a size 50 file) (12). Previous studies (4, 21, 22) finished apical preparations to a size 30 file and indicated that the ultrasonic needle was not able to reach further than within 4 to 5 mm of the working length. Ahmad et al (35) reported that in order for ultrasonic acoustic streaming to occur, the apical preparation must be finished to at least size 40. The canals in the present study were finished to a size 40, 0.04 taper; in a completely straight canal, this ultrasonic needle would be incapable of reaching further than within 3 mm of the working length. This distance from the working length will increase

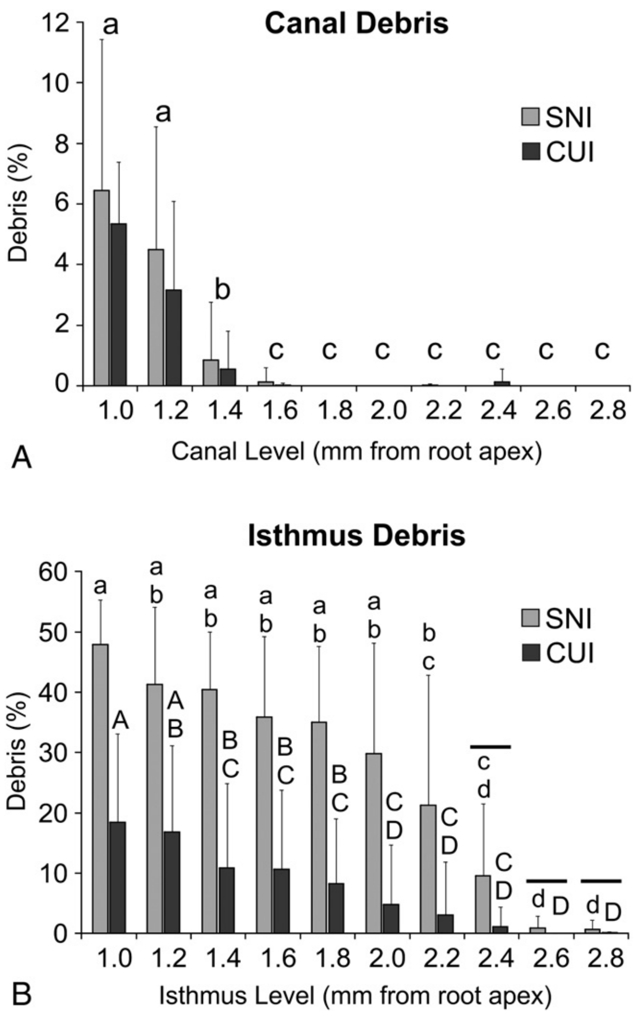

Figure 3. A bar chart summarizing remaining debris expressed as a percentage of the total canal area or isthmus area (mean ± standard deviation) at each canal level of the two irrigation groups. Factor levels marked with the same letter were not significantly different ($P > .05$).

as the curvature of the canal increases because of the rigidity of the ultrasonic needle and the manufacturer's recommendation to prevent canal wall contact during ultrasonic activation. Although canal curvature was not assessed in the present study, some specimens (9/20) prevented penetration of the ultrasonic needle beyond 1 to 2 mm into the orifice before canal wall contact. Although it is anticipated that the ultrasonically activated irrigant possesses cavitation and acoustic streaming qualities, we opined that the lack of this significant needle penetration into the canal hindered the true potential of ultrasonic irrigation to remove debris completely from the apical part of narrow isthmuses. Such a scenario may be more pronounced in the narrower canals of maxillary molars (24) or in the presence of partially isthmuses in maxillary and mandibular molars (23, 25).

Within the limitations of this study, the null hypothesis that there is no difference between SNI and CUI in cleaning the mesial root of mandibular first molars with narrow isthmuses in a closed-canal system has to be rejected. It may be concluded that there is no difference in the canal debridement efficacy between SNI and CUI at any root level from the apical third of the canal. Both irrigation techniques left a small but significant amount of debris in the apical 1.0 to 1.4 mm of the canal when compared with other root levels. However, CUI produced significantly cleaner isthmuses than SNI at root levels 1.0 to 2.2 mm, whereas both techniques produced equally clean isthmuses at the 2.4- to 2.8-mm root levels. Neither technique was capable of completely removing all debris in the canals or isthmus.

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The authors deny any conflicts of interest related to this study.

Supplementary Material

Supplementary material associated with this article can be found in the online version at www.jendodon.com (doi:10.1016/j.joen.2011.01.006).

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