Effect of Vapor Lock on Root Canal Debridement by Using a Side-vented Needle for Positive-pressure Irrigant Delivery

Franklin R. Tay, BDSc (Hons), PhD, Li-sha Gu, DDS, MS,† G. John Schoeffel, DDS, MMS,‡ Courtney Wimmer, BS, MS,§ Lisiane Susin, DMD,* Kai Zhang, DDS, MS, PhD,* Senthil N. Arun, BDS, PhD,‖ Jongryul Kim, DDS, PhD,¶ Stephen W. Looney, PhD,§ and David H. Pashley, DMD, PhD#*

Abstract

Introduction: This study examined the effect of vapor lock on canal debridement efficacy by testing the null hypothesis that there is no difference between a "closed" and an "open" system design in smear layer and debris removal by using a side-vented needle for irrigant delivery. **Methods:** Roots in the closed system were sealed with hot glue and embedded in polyvinylsiloxane to restrict fluid flow through the apical foramen during cleaning and shaping. For the open system, the apical foramen was enlarged and connected to the external environment via a channel within the polyvinylsiloxane to permit unrestricted fluid flow. Smear and debris scores were evaluated by using scanning electron microscopy and analyzed by using Cochran-Mantel-Haenszel statistic. **Results:** No difference in smear scores was detected between the 2 systems at all canal levels. Significant differences in debris scores between the 2 systems were found at each canal level: coronal ($P < .001$), middle ($P < .001$), and apical ($P < .001$). **Conclusions:** The null hypothesis was rejected; presence of an apical vapor lock effect adversely affects debridement efficacy. Thus, studies with unspecified or questionable mechanisms to restrict fluid flow through the apical foramen have to be interpreted with caution. *(J Endod 2010;■:1–6)*

Key Words

Debris, irrigation, root canal, side-venting syringe delivery, smear layer, vapor lock

Thorough debridement is crucial for long-term success in root canal treatment (1–4). The mechanical debridement efficacy of an irrigation delivery/agitation system is dependent on its ability to deliver the irrigant to the apical and noninstrumented regions of the canal space and to create a strong enough current to carry the debris away from the canal walls (5–9). Because the root is enclosed by the bone socket during *in vivo* cleaning and shaping (10–12), the canal behaves as a closed-end channel, which results in gas entrainment at its closed end (13–15), producing a vapor lock effect during irrigant delivery (16, 17). Studies that were designed to simulate such a closed system by embedding the root in a polyvinylsiloxane impression material (PVS) to restrict fluid flow through the apical foramen demonstrated incomplete debridement from the apical part of the canal walls with the use of a syringe delivery technique (18–20).

If not optimally designed or meticulously executed, a closed system behaves as an open system that challenges the creditability of the results. For example, a hypothetical closed system that consists of stabilizing the longitudinal bottom half of a completely demineralized root in soft silicone and covering the top half with methyl salicylate to prevent the cleared root from opacifying functions as an open system, even when the apex remains covered by silicone. This permits flow of a dye-containing irrigant through the lateral canals and apical foramen when it is delivered under positive pressure. Likewise, a hypothetical scenario that consists of postextraction flushing of an irrigant through an unsealed apical foramen to remove blood that enters the canal space during tooth extraction bleaches the original *in vivo* vapor lock and revokes the goal of examining debridement efficacy in a closed system.

Because the debridement quality between a closed versus an open system design has not been evaluated simultaneously in a single study, it is dubious whether conclusions derived from studies with unspecified or ambiguous mechanism to restrict fluid flow through the apical foramen are as clinically relevant as those that adopted a robust closed system design. This study attempted to resolve this issue by testing the null hypothesis that there is no difference between a closed and an open system design in smear layer and debris removal by using a side-vented needle for irrigant delivery.

Materials and Methods

Twenty-eight extracted human single-rooted teeth were radiographed to ensure that each tooth contained 1 canal, and that an equal number of narrow (33%) and

From the *Department of Endodontics, School of Dentistry, Medical College of Georgia, Augusta, Georgia; †Department of Operative Dentistry and Endodontics, Guanghua School of Stomatology, Sun Yat-sen University, Guangzhou, China; ‡Retired from private practice and consultant to Discus Dental; §Department of Biostatistics, Medical College of Georgia, Augusta, Georgia; ‖School of Dental Medicine, University of Pennsylvania, Philadelphia, Pennsylvania; ¶Department of Conservative Dentistry, School of Dentistry, KyungHee University, Seoul, Republic of Korea; and #Department of Oral Biology, School of Dentistry, Medical College of Georgia, Augusta, Georgia.

Address requests for reprints to Dr Franklin Tay, Department of Endodontics, School of Dentistry, Medical College of Georgia, Augusta, GA 30912-1129. E-mail address: ftay@mcg.edu.

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wide canals (67%) were present in the 2 experimental groups. Each tooth was decoronated at 17 mm from the anatomic apex. Canal patency was achieved with a size 10 K-file. Working length was established at 1 mm short of the apical foramen.

Experimental Design

Experimental setups are depicted in Fig.1*A–D*. For the closed system, the cementum of each root was coated with tray adhesive. The root apex was covered with hot, flexible glue that was allowed to solidify before the root was inserted into a clear PVS-filled Plexiglas tube. This setup permitted recapitulation of canal patency but prevented fluid extrusion from the apical foramen during canal preparation. For the open system, the apical foramen was enlarged by establishing apical patency to a size 30 file (21). A straw segment was attached with glue to the external root surface to permit unrestricted communication between the apical foramen with the external environment.

Each root was instrumented to size 50/0.04 taper with a crown-down approach. The canal was irrigated with 1.3% NaOCl as the initial irrigant, delivered with a 30-G Max-i-Probe needle (Dentsply-Rinn, Elgin, IL) placed to 1 mm short of working length. Each canal was filled with irrigant during instrumentation. One milliliter of 1.3% NaOCl was used to irrigate the canal between each instrument. For the open system, free flow of irrigant through the straw was confirmed before using larger rotary instruments to working length.

BioPure MTAD (Dentsply-Tulsa, Tulsa, OK) was selected as the final active irrigant on the basis of its ability to remove smear layers consistently from all regions of the canal walls without causing dentin erosion (21). One milliliter of Biopure MTAD was delivered with the Max-i-Probe needle and left in the canal for 5 minutes. This was followed by irrigation of the canal with 4 mL of BioPure MTAD. Irrigants were delivered at the rate of 5 mL/min. Each canal was subsequently irrigated with 5 mL of deionized water and dried with paper points. A temporary dressing was placed over the canal orifice before the root was retrieved from the PVS.

Gas Entrapment

Two teeth from each group were prepared up to the stage shown in Fig. 1*B* (before insertion into the PVS). After cleaning and shaping, an 8 M cesium chloride (CsCl) contrasting medium (22) was delivered to the canal via the Max-i-Probe needle placed to 1 mm short of working length. The needle was removed, and each tooth was placed inside a Skyscan 1174 micro-CT scanner (Micro Photonics, Allentown, PA). Snapshots of the liquid-filled canals were taken at 50 kV and 800 μA.

Scanning Electron Microscopy

Ten roots each from the closed system and open system groups were prepared for scanning electron microscopy (SEM). Two longitudinal grooves were prepared in each root without perforating the canal to facilitate splitting of each root into 2 longitudinal halves. The root halves were fixed in 2% glutaraldehyde, dehydrated in ascending ethanol and hexamethyldisilazane (23), sputter-coated, and examined with a field emission SEM at 5 KeV. Five representative micrographs were taken at 2000× magnification from the apical (0–5 mm), middle (5–10 mm), and coronal (11–15 mm) portions of each root half. Only images from instrumented canal walls were taken, yielding 100 images/portion/group.

Images were examined in a blind manner by 2 investigators other than the one who prepared the canals. The efficacy of smear layer removal was evaluated by using a 5-level scoring system based on the order of severity of smear layer retention. Canal cleanliness was evaluated by using a 5-level debris scoring system based on the order of severity of debris remaining on the instrumented canal wall. Criteria for these scoring systems are listed in the figure legend of Fig. 2*A* (smear score) and Fig. 2*C* (debris score). When discrepancies existed during the course of evaluation, a forced agreement between the 2 examiners was used so that both examiners agreed on the smear and debris scores for each image taken from each canal level.

Smear and debris scores were treated as ordinal data. The median was used to summarize the respective scores of the 10 micrographs taken at each level of each root to account for the clustered nature of the data. The Cochran-Mantel-Haenszel method was used to test for significant differences among treatment groups (closed system versus open system) separately at each canal level (coronal, middle, apical) and for all levels combined if there appeared to be no interaction between treatment group and level ($\alpha = 0.05$).

Light Microscopy

Because the limited area from the apical 0.5–1 mm of the canal walls precluded sufficient SEM images to be taken for this region to be treated as a separate "level", light microscopy was used to qualitatively examine canal cleanliness (debris retention) from this region. The remaining 2 roots from each group were cleaned and shaped as previously described, fixed in 10% formaldehyde, completely demineralized, and embedded in paraffin wax. Serial sections prepared at 0.5–1 mm coronal to the anatomic apex were stained with Masson trichrome and examined at 40× magnification.

Results

The CsCl contrasting medium did not reach the root apex when the apical foramen was prevented from fluid and gaseous exchange with the external environment (Fig. 1*E*). Conversely, no vapor lock existed when the apical foramen remained open to permit fluid flow (Fig. 1*F*).

For the closed system, the effect of a vapor lock was most conspicuous along the apical 0.5–1 mm of the canal, with gross retention of debris and smear layer remnants along the demineralized sclerotic dentin surface (Fig. 3*A*, *C*). For the open system, complete smear layer removal and debris clearance were seen (Fig. 3*B*, *D*). Although dentinal tubules were mostly patent along the middle and coronal thirds of the canal walls in both the closed system (Fig. 3*E*) and open system (Fig. 3*F*) groups, sparsely distributed smear layer remnants and isolated debris conglomerates were observed in the closed system specimens (Fig. 3*E*).

Smear scores for the closed system and open system are shown in Fig. 2*A* and *B*, respectively. Examination of the 2 × 4 contingency tables at each canal level (not shown) indicated no interaction between treatment group and level. The contingency tables were identical at each canal level, indicating no differences in smear scores between the 2 systems ($P = 1.000$). Debris scores for the closed system and the open system are shown in Fig. 2*C* and *D*, respectively. There appeared to be interaction between treatment group and canal level, particularly for the pattern of debris scores among the 3 levels in the closed system. Therefore, separate analyses with the Cochran-Mantel-Haenszel test were performed for each level. Significant differences between the 2 systems were found at each canal level: coronal ($P < .001$), middle ($P < .001$), and apical ($P < .001$).

Stained sections from the apical 0.5–1 mm of the roots from the closed system group showed that debris was incompletely cleared from the canal walls (Fig. 2*E*), in contrast with the clean canal space observed in the open system group (Fig. 2*F*).

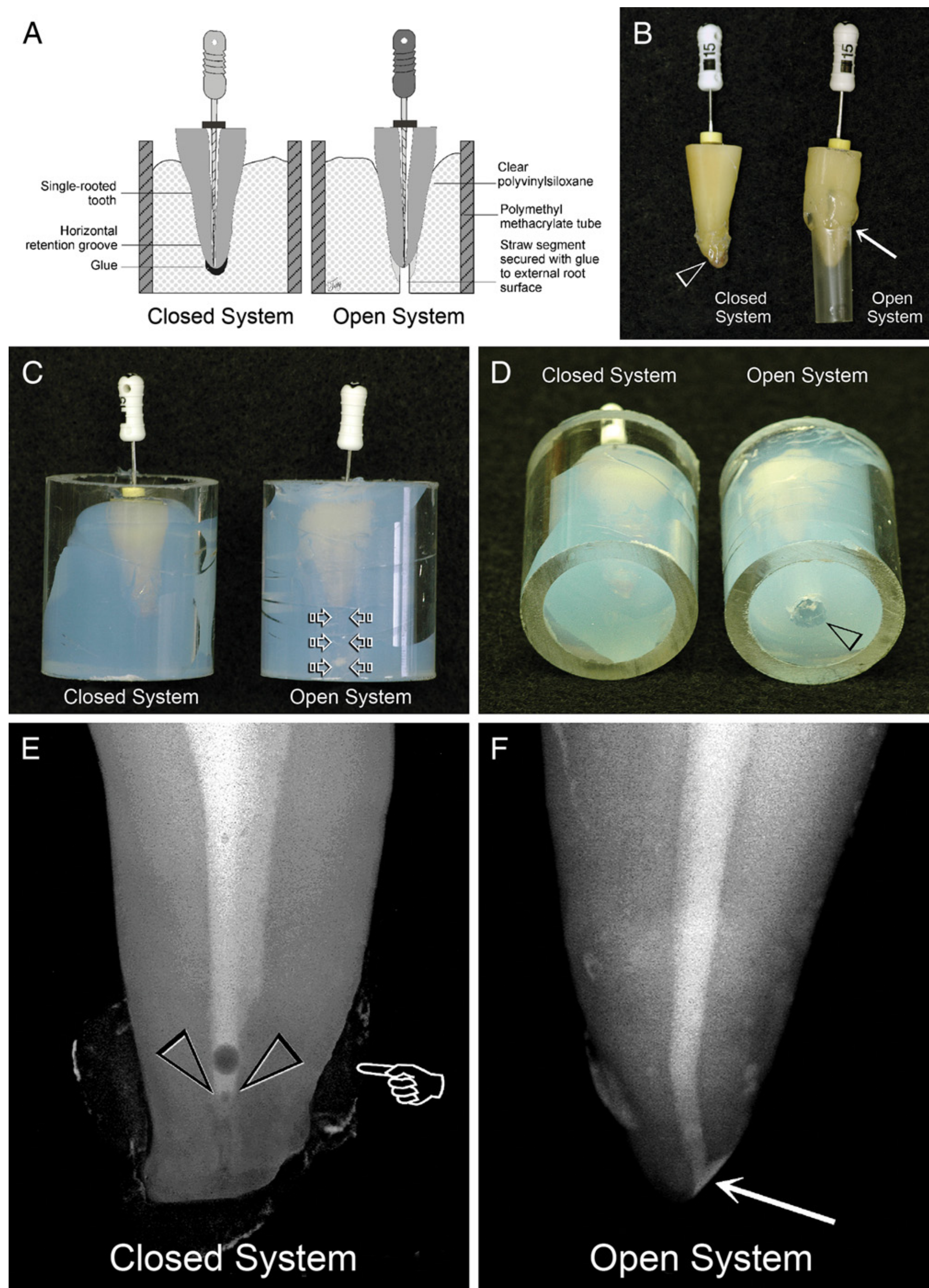

Figure 1. (*A*) A schematic depicting the setups for the closed system and open system groups. (*B*) The apical foramen was covered with hot flexible glue for the closed system group, whereas a straw segment was secured with glue to the external root surface (arrow) for the open system control group. (*C*) Roots shown in (*B*) were stabilized with clear PVS in Plexiglas tubes. For the control group, a piece of cotton was placed inside the straw (open arrows) before the insertion of the assembly into PVS. (*D*) The straw opening in the control group was cleared of PVS to expose the fluid escape channel (open arrowhead). (*E*) A micro-CT snapshot of a shaped canal from the closed system group after delivery of CsCl. Radiopaque carbon paint was applied over the solidified glue surface to enhance the contrast (pointer). A vapor lock with an air bubble on top was produced along the apical end of the canal space (open arrowheads). (*F*) A micro-CT snapshot of a shaped canal from the open system group after the canal was filled with CsCl. The solution was able to reach the apical 0–2 mm of the canal space when the apical foramen remained open (arrow).

Discussion

The null hypothesis has to be rejected because differences in debris debridement were detected at all canal levels between the 2 systems. For positive-pressure irrigation with a needle delivery system, irrigant replacement is limited to 1–1.5 mm beyond the needle tip, and a high flow rate is required to generate turbulent fluid flow for effective agitation (6–9). The apical seat also has to be enlarged to at least size 35–40 for needle placement to within 1–2 mm of the apical seat (10, 24–27). To simplify computer-simulated evaluation of fluid dynamics, hypothetical canals were assumed to be completely

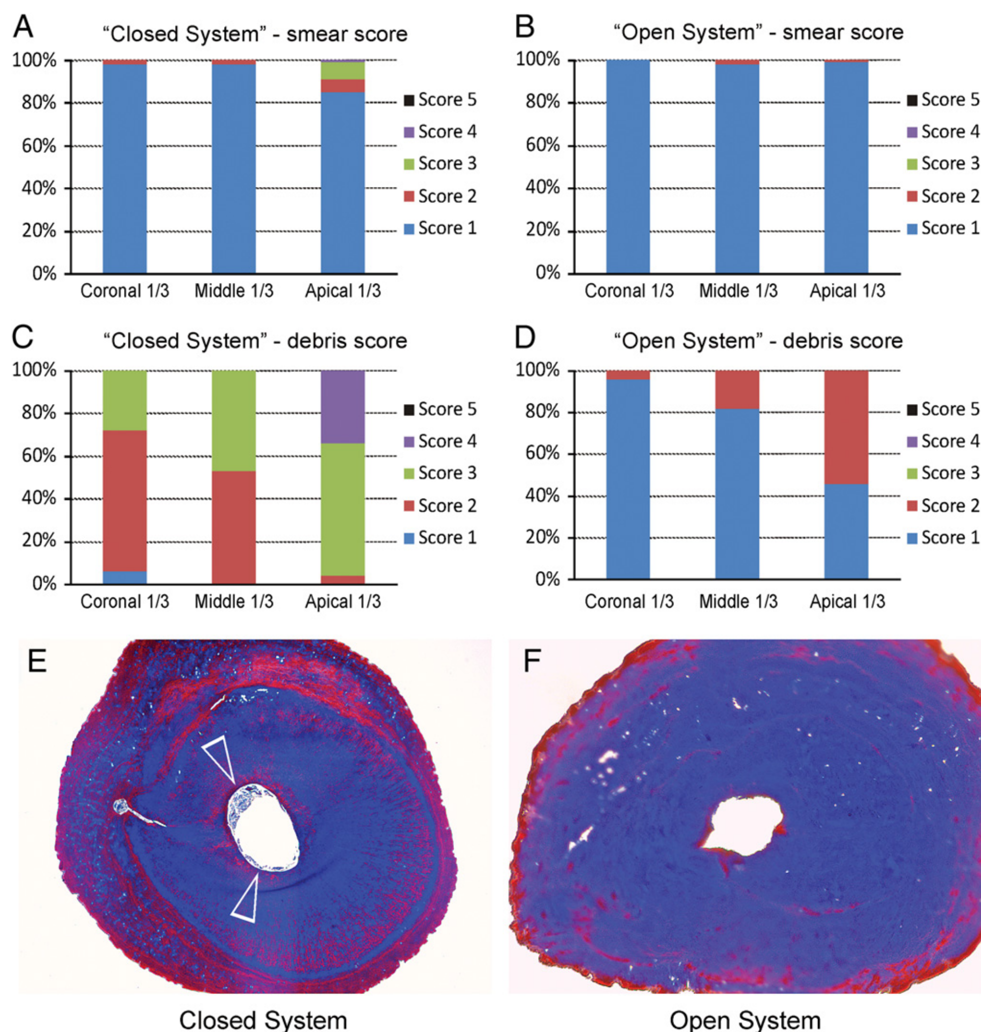

Figure 2. These effects could be seen from the summary of the smear score and debris score from different regions of the canal walls (*A–D*). (*A*) Descriptive statistics of the distribution of smear scores from the coronal third, middle third, and apical third of the canal wall in the closed system group. For the apical third category, scores reflect the overall condition of the apical 0–5 mm part of the canal wall. A 5-level scoring system was used for evaluating the efficacy of smear layer removal: 1: Smear layer is completely absent. Most tubules are patent and debris-free (coronal third and middle third) or occluded with sclerotic casts (apical third); 2: smear layer covering less than 25% of the canal wall and dentinal tubules; 3: smear layer evident in 25%–50% of the canal surface and tubules; 4: smear layer evident in 50%–75% of the canal surface and tubules; 5: smear layer covering 75%–100% of the canal surface and tubules. (*B*) Descriptive statistics of the distribution of smear scores in the open system group. (*C*) Descriptive statistics of the distribution of debris scores in the closed system group. For the apical third category, scores reflect the overall condition of the apical 0–5 mm part of the canal wall. A 5-level scoring system was used for evaluating the efficacy of debris removal: 1: clean canal wall, only very few debris particles; 2: few small conglomerations; 3: many conglomerations, less than 50% of the canal wall covered; 4: more than 50% of the canal wall covered with conglomerations; 5: complete cover of the canal walls with conglomerations. (*D*) Descriptive statistics of the distribution of debris scores in the open system group. (*E*) Masson trichrome–stained, light microscopy image of fixed, demineralized roots taken from 0.5–1 mm coronal to the anatomic apex. The periphery of the canal space in the closed system group was filled with stained, demineralized debris (open arrowheads). (*F*) Masson trichrome–stained light microscopy section taken from a similar region of a root canal in the open system group revealed a clean canal with no stained, demineralized debris.

filled with irrigants (8, 9). Although the use of small-diameter needles and their insertion to within 1 mm of the working length appeared to be logical conclusions from those simulation studies, the contribution of the apical vapor lock to canal debridement had not been appropriately addressed.

In the closed system, irrigant extrusion beyond 1–1.5 mm of a side-venting needle could have generated a liquid film along the air bubble–canal wall interface (28). This probably accounted for the observation of demineralized sclerotic intertubular dentin at the apical 0.5–1 mm of the canals. Nevertheless, fluid stagnation in this "dead-water zone" failed to provide adequate irrigant replacement, resulting in gross debris retention in this region. Significantly more debris could also be detected from all parts of the canal walls in the closed system group. Irrigation with an acidic or calcium-chelating agent created a demineralized collagen matrix on the surface of radicular dentin on removal of the smear layer (29). In the absence of strong turbulent fluid flow, debris particles could be trapped by this porous interlacing fibrillar network as they were displaced by the irrigant toward the canal orifice.

The results of the present study indicate that unless the use of an open system was explicitly stated for the purpose of maximizing the cleaning potential of an irrigant (21), conclusions derived from

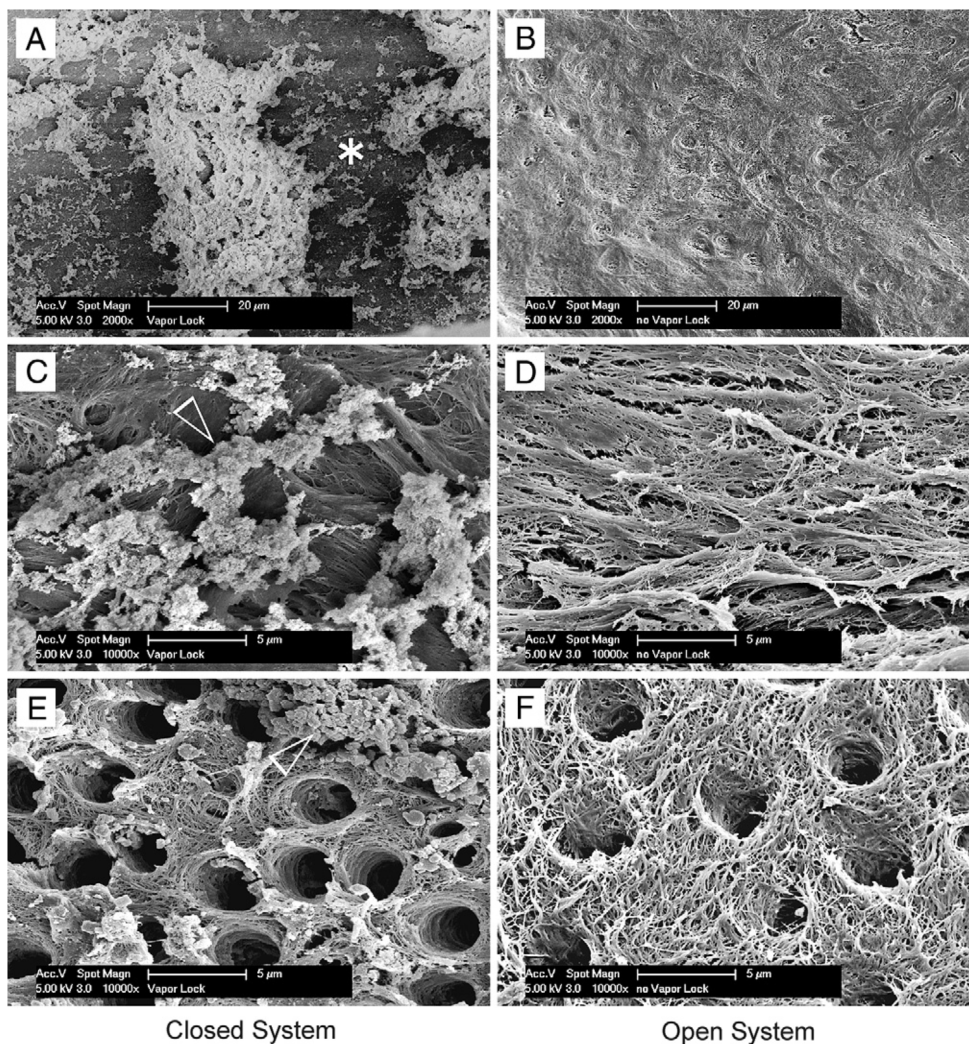

Figure 3. Representative scanning electron micrographs taken from different parts of the cleaned and shaped canal walls. Micrographs arranged on the left (*A*, *C*, and *E*) and right (*B*, *D*, and *F*) sides of the plate were derived from the closed system and open system groups, respectively. (*A*) Along the apical 2 mm zone, the canal wall was sclerotic with minimal tubules (asterisk). For the closed system, this zone was heavily covered with loose debris and some smear layer remnants. (*B*) For the open system, the apical 2 mm zone was sclerotic but devoid of the smear layer and had minimal debris. (*C*) A high magnification view of the region marked by the asterisk in (*A*). Particulate smear layer remnants (open arrowhead) were attached to the surface of the demineralized collagen matrix. (*D*) A high magnification view of (*B*) showing a clean, smear layer–free and debris-free fibrous collagen matrix. No sign of dentinal tubules could be seen in this image. (*E*) A high magnification image representative of the middle and coronal thirds of the canal wall in the closed system. The dentinal tubules were mostly patent and devoid of smear plugs. However, smear layer remnants and particulate debris conglomerates (open arrowhead) could be seen adhering to the fibrous collagen matrix. (*F*) A high magnification image in the middle and coronal thirds of the canal wall in the control group. Tufted collagen fibrils could be identified from the surface of the smear layer–depleted, BioPure MTAD–demineralized intertubular dentin. Minimal debris was present.

studies with unspecified or questionable apical fluid movement mechanisms (eg, reassembling a split tooth embedded in a silicone mold) have to be interpreted with caution. It must be emphasized that the current results are applicable only to side-vented needle delivery and cannot be extrapolated to other irrigation/agitation systems (30) such as sonic (17), ultrasonic (11, 31), or negative-suction devices (32–34) that have the potential to create more forceful currents. The ability of these devices to displace the apical vapor lock has to be validated in future studies that incorporate both closed and open system designs. It appears that dynamic mechanical agitation (the use of a well-fitting gutta-percha cone for manual agitation of an irrigant-filled canal) (27, 35) has the potential to displace the apical gas entrapment from a closed system. Because the material cone is closely adapted to the canal, it would be of interest to see whether this manual agitation technique can effectively displace debris away from the collagen matrix created by acidic/chelating irrigants in a closed canal system that is totally sealed from apex to the cementoenamel junction.

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