

# The EndoVac Method of Endodontic Irrigation

## *Safety First*



G. John Schoeffel, DDS, MMS

This is the first of a 3-part series that will explain the safety, efficacy, and clinical application of the EndoVac (Discus Dental), the endodontic irrigation system that produces apical negative pressure (ANP) to debride and disinfect the root canal system.

### BACKGROUND

A recent study by Clegg, et al<sup>1</sup> comparing the efficacy of sodium hypochlorite, chlorhexidine, and Bio-Pure (DENTSPLY Tulsa) demonstrated that 6% sodium hypochlorite was the only root canal irrigant that could completely remove biofilm from the root canal system and prevent microbial growth. Despite this finding, fear of a sodium hypochlorite accident (Figures 1 to 3)<sup>2</sup> still compels researchers to seek endodontic irrigants comparable to sodium hypochlorite in efficacy but without the risk of tissue destruction beyond the apical foramen.<sup>3</sup>

Although many other irrigants compare favorably with sodium hypochlorite's antimicrobial characteristics,<sup>4</sup> "It is still an open question which of these irrigants is preferable with respect to clinically important properties such as antibacterial activity and tissue dissolution."<sup>5</sup> Ironically, the key to the dilemma was identified, yet not pursued, by Walton and Torabinejad almost 20 years ago. They stated that, "Perhaps the most important factor is the delivery system and not the irrigating solution per se."<sup>6</sup> After reading this reference, this author began developing an irrigation system capable of delivering abundant quantities of sodium hypochlorite to full working length (WL) in conservatively prepared canals and without the danger of extrusion into the periradicular vasculature.

A literature review revealed a basically ignored paper by Chow<sup>7</sup> from 1989, in which he determined



Figure 1. Sodium hypochlorite accident following positive pressure irrigation of a maxillary posterior tooth. Note the panfacial vasculature effect. This is not typical of an inadvertent injection of sodium hypochlorite into the maxillary sinus when the patient only reports the taste of "bleach" at the back of the throat. (Mehra P, Clancy C, Wu J. Formation of a facial hematoma during endodontic therapy. *J Am Dent Assoc.* Jan 2000;131:67-71. Copyright 2000 American Dental Association. All rights reserved. Reprinted by permission.)

*Fear of the sodium hypochlorite accident touches upon every aspect of endodontic treatment, from patient safety to dreaded years of litigation. What causes this phenomenon? All maxillary posterior teeth are capable of direct communication with the maxillary sinus...*

that traditional positive pressure irrigation had virtually no effect apical to the orifice of the irrigation needle in a *closed* root canal system (Figure 4). Fluid exchange and debris displacement were minimal. Equally important to his primary findings, Chow<sup>7</sup> set forth an infallible paradigm for endodontic irrigation: "For the solution to be mechanically effective in removing all the particles, it has to: (a) reach the apex; (b) create a current (force); and (c) carry the particles away."

More recent *in vitro* studies, using traditional positive pressure irrigation techniques<sup>8-10</sup> and scanning electron microscope (SEM) validation, seem to contradict Chow<sup>7</sup> by demonstrating excellent irrigation results in the *apical third* of the root canal. However, SEM validation gives rise to confusion and misinterpretation because dentinal tubular anatomy and distribution differ greatly between the coronal and apical areas of the *apical third*. Mjor, et al<sup>11</sup> demonstrated that (a) "the tubules tended to fade away toward the cementum," (b) "in the most apical part of the teeth, the tubules were irregularly arranged," and (c) "no tubules could be discerned in the dentine bordering the cementum in demineralized histological sections."

Unlike the homogeneous distribution of tubules found coronal to the terminal 2 mm, the apical-most area is almost devoid of tubules, and those present have an irregular distribution (Figures 5 to 7). The left-hand images in Figures 5 to 7 show a longitudinal section of the apical 3 mm of a lower incisor treated with the EndoVac method of ANP under *in vivo* conditions (sealed apex). The 4 round dots are reference points placed 1 mm apart, and in each figure the "x" on the image marks the area shown on the magnified right-

*continued on page 94*

### The EndoVac Method...

continued from page 92

hand SEM image. It can clearly be seen that the number of tubules and their pattern varies depending on the location within the apical third. Accordingly, SEM examinations should not be limited only to those areas rich with tubules coronal to the apical 2 mm; however, in studies they all are, as confirmed by the tubular patterns.

Another technical flaw occurs in in vitro irrigation studies when the examiner fails to seal the apical termination during testing.<sup>12</sup> While such studies

seem to demonstrate excellent apical debridement and disinfection using positive pressure, the lack of apical seal allows free flow of irrigant through the apical foramen (Figure 8). Most irrigation study designs contain this flaw, ignoring the findings of Chow discussed earlier in this article, and thus resulting in a false representation of the irrigant(s) true action at the apical termination. Under in vivo conditions this extrusion would result in a catastrophic sodium hypochlorite accident. Studies that did/do properly seal the apex during irrigation technique testing

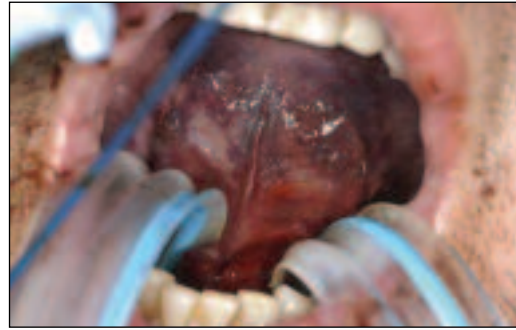


Figure 2. Sodium hypochlorite accident in the mandibular region. Note the widespread diffusion of sodium hypochlorite sublingually.



Figure 3. Widespread diffusion of sodium hypochlorite into the soft palate.

(Figures 2 and 3 were originally featured in the article Review: the use of sodium hypochlorite in endodontics—potential complications and their management [*Br Dent J.* 2007;202: 555-559], with reprint permission by Stephen Hancocks, OBE, Editor-in-Chief of the *British Dental Journal*.)

have failed to produce favorable results when using traditional positive pressure techniques.<sup>13-15</sup>

**THE SODIUM HYPOCHLORITE ACCIDENT**  
Fear of the sodium hypochlorite accident touches upon eve-

ry aspect of endodontic treatment, from patient safety to dreaded years of litigation. What causes this phenomenon? All maxillary posterior teeth are capable of direct communication with the maxillary sinus, and sometimes even the Schneiderian membrane is absent (Figure 9). Direct communication between the maxillary sinus and the root canal systems of these teeth offers virtually no resistance to fluid escaping from the root canal space,<sup>16,17</sup> and may be the most frequent cause of a sodium hypochlorite accident. However, these accidents also happen in the mandibular region, sometimes with even more devastating consequences<sup>18</sup> (Figures 2 and 3).

Although the exact mechanism for the sodium hypochlorite accident has never been elucidated, the capillary blood pressure in the pulp is about 25-mm Hg or 0.48 psi,<sup>19</sup> and the pulpal and periapical capillaries would seem to be a logical portal of entry to the immediate vasculature once endodontic irrigation pressure exceeds the normal regional blood pressure. In 2002, Bradford, et al<sup>20</sup> explored several needle factors to determine which could produce the safest air pressure method to dry the root canal system. They explored open-ended versus side-venting needle designs, placement relative to binding point, and size. Although this study used positive air pressure in the root canal, the results apply equally to irrigation fluids, since "Fluid mechanics is the subdiscipline of continuum mechanics that studies fluids, that

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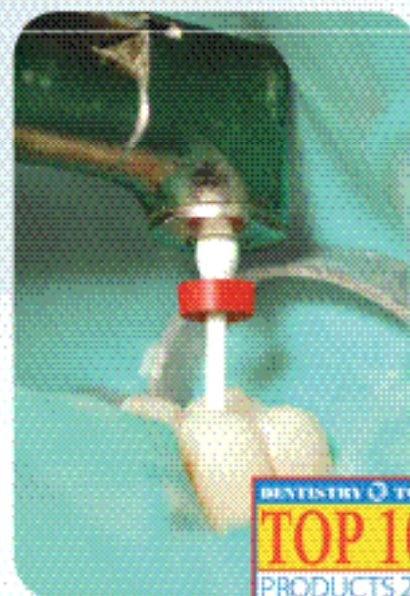
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## The EndoVac Method...

continued from page 94

is, liquids and gases.”<sup>21</sup> Bradford, et al<sup>20</sup> concluded 2 disturbing facts: first, “No needle design proved safe to use in either round or ovoid canals, regardless of stage of instrumentation.” Second, “The clinical significance of these results is that there is no way to ensure complete safety when drying canals with pressurized air.” Given that the principles of fluid mechanics apply to both gases and liquids, there is also no way to ensure complete safety when delivering canal irrigants under positive pressure. Bradford, et

al<sup>20</sup> further concluded (again applicable to canal irrigation) that “Vacuum, rather than air under pressure, may be a superior means for canal drying.” The operative word is *vacuum*.

The EndoVac (endodontic vacuum) was designed to overcome the dangers of pushing irrigants into the capillary beds or the maxillary sinus by creating an apical negative pressure at full WL. The key component of the EndoVac system is a microcannula with an external diameter of 0.32 mm, a spherically sealed end used for guidance, and a population of 12 microholes radially arranged in the last 0.7

mm (Figure 10). The microholes serve 2 functions: to pull endodontic irrigants directly and abundantly to the last 0.2 mm of WL (Figure 11), and to serve as a micro filtration system to prevent clogging of the lumen (internal diameter) of the microcannula.

Other manufacturers also claim endodontic irrigation via “negative pressure,” but not “apical negative pressure.” *Apical* is the operative word. True ANP *only* occurs if the needle/cannula is used to aspirate irrigants from the apical termination of the root canal space (Figure 11). If the needle/cannula is used to discharge

irrigants *into* the root canal system (Figure 4), it is a positive pressure device. Two simple metaphors best help describe the differences: the *fire hose* and the *sewer pump*. If irrigants are pushed out of the needle/cannula, which is how a fire hose discharges water, this is positive pressure. If the irrigants are sucked into the needle/cannula, which is how a sewer pump cleans a septic tank, this is apical negative pressure.

The apical suction effect of pulling (not pushing) endodontic irrigants down and along the walls of the root canal system creates a rapid turbulent cascading effect as the irrigants are

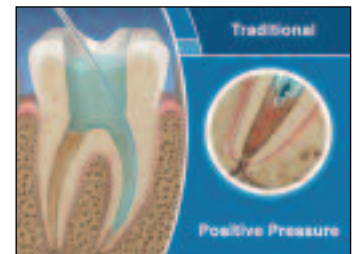


Figure 4. Positive pressure irrigation. Little or no irrigant reaches the apical 2 mm in a closed system. (Illustration courtesy of Discus Dental.)

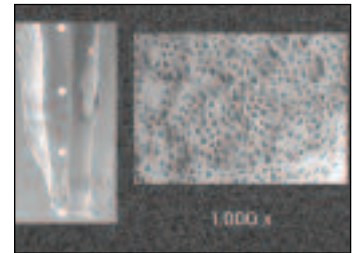


Figure 5. SEM 2.6 mm from WL. The tubules are consistent for tubular distribution and frequency. By definition these tubules are in the apical third, but they are not in the apical 2 mm.

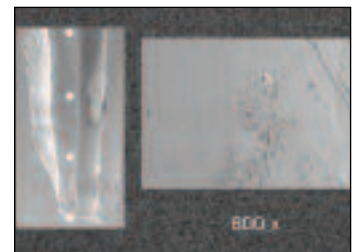


Figure 6. Less than 1 mm from WL. The area is almost devoid of tubules. The only tubules present in the magnification are irregular and almost nonexistent. This arrangement of tubules is never shown in SEM studies that seemingly prove cleanliness of the most critical portion of the apical third.

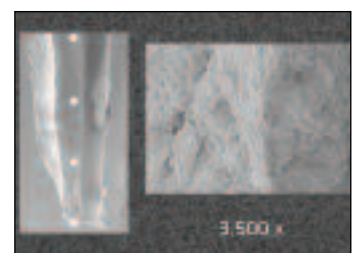


Figure 7. Shown above is 0.5 mm from the apical termination. The area has no dentinal tubules because this is cementum—where it belongs—0.5 mm from the apical termination. This area was examined using energy dispersive spectroscopy—virtually no carbon was detected, indicating a surface devoid of organic material.

forced to flow between the canal walls and the external surface of the microcannula. This turbulent action creates a current force, while the position of the microholes directs this fast-flowing stream of irrigant as close as 0.2 mm from full WL

continued on page 98

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Dr. Schoeffel:

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# The Endo Vac Method of Endodontic Irrigation, Part 2—Efficacy



G. John Schoeffel, DDS, MMS

Since sodium hypochlorite (NaOCl) has the capacity to cause catastrophic tissue damage when extruded into the periradicular vasculature<sup>1-3</sup>, several new, exotic, and often very expensive endodontic irrigants have been marketed in order to replace this time proven endodontic irrigant. However, recent studies by Clegg<sup>4</sup> and Dunavant<sup>5</sup> have demonstrated that NaOCl alone is the only endodontic irrigant capable of significantly eliminating the biofilm associated with endodontic infections. Dunavant studied NaOCl, SmearClear (SybronEndo), BioPure (DENTSPLY Tulsa Dental), chlorhexidine, and REDTA (Roth International), and reported: "Within the parameters of this study, both 1% NaOCl and 6% NaOCl were more efficient in eliminating *E. faecalis* biofilm than the other solutions tested."

Why abandon NaOCl, now that it can safely be delivered to full working length

*Another example of drawing the wrong conclusion from correct data occurs when an investigator fails to duplicate the complete clinical conditions in an in vitro study.*

via apical negative pressure that draws the irrigants down the canal and simultaneously away from the apical tissue?<sup>6,7</sup> The answer is simply because previous irrigation investigations have drawn the wrong conclusions from correct data. Will Rogers, Jr. said it best: "It ain't what you know that gets you in trouble, it's what you know that ain't so."

Consider Senia, et al's classic 1971 in vitro study<sup>8</sup> in which he demonstrated that sodium hypochlorite did not extend any closer than 3 mm from working length even after the apex was opened to a No. 30 size instrument. Contrast this study with Salzgeber's in vivo study<sup>9</sup> in which he used Hypaque (a radiopaque solution with virtually the same viscosity, surface tension, and specific gravity as 5.25% NaOCl) to delineate canal and apical irrigant penetration. Salzgeber<sup>9</sup> concluded that by increasing the apical preparation size past a No. 30 and

tapering the walls, the irrigant would be carried completely down the canals and into the apical tissue (Figure 1). Both of these findings are accurate, and when viewed together it would seem as though the critical size necessary to insure complete penetration of the irrigant to the apical termination is a No. 35 with an increased taper. Salzgeber<sup>9</sup> wrote: "The study by Senia, Marshall and Rosen showed that little or no sodium hypochlorite reached the apical 3 mm when the root canals were enlarged to a no. 30 instrument. The current study showed that the irrigant reaches the apex when the canals are opened larger than a no. 30 file." This also agrees with current research by Zehnder<sup>10</sup> who, using transparent plastic blocks, demonstrated that only after the apical size reaches a No. 35 can one colored irrigant successfully mix with another during instrumentation.

The critical error in the Salzgeber<sup>9</sup> study is that although Hypaque has many of the same physical characteristics of NaOCl, it does not chemically react with organic material and liberate abundant quantities of ammonia and carbon dioxide, as does NaOCl. Under in vivo conditions the gaseous mixture of ammonia and carbon dioxide is trapped in the apical region and quickly forms an apical vapor lock, similar to the same problem encountered in petroleum powered engines, into which further fluid penetration is impossible (Figures 2 to 7). Extending instruments into this vapor lock does not reduce or remove the gas bubble (Figures 8a and 8b). In 1971, Senia<sup>8</sup> wrote: "The solution [NaOCl] in the canal was stirred and carried apically every 5 minutes by means of a No. 10 reamer." The dichotomy is that even though he thought he was carrying the NaOCl to the apex, his own research proved him wrong!

Another example of drawing the wrong conclusion from correct data occurs when an investigator fails to duplicate the complete clinical conditions in an in vitro study. In 1971, Senia<sup>8</sup> duplicated the clinical endodontic condition by successfully sealing the apical termination with green stick compound, thus allowing the apical vapor lock to form. However, some current endodontic irrigation studies<sup>11,12</sup> fail to seal the apical

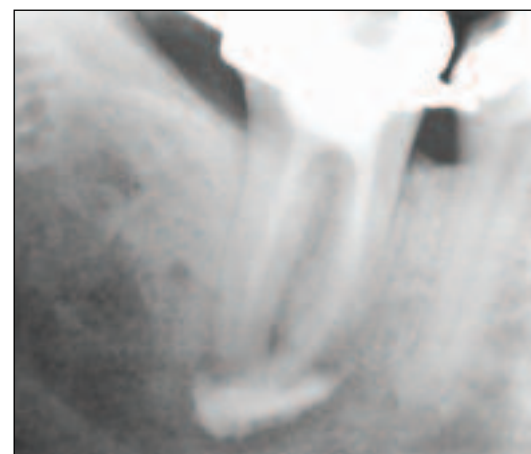
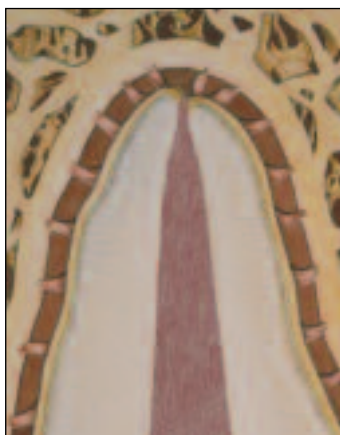


Figure 1. In 1971, Senia, et al<sup>8</sup> demonstrated that sodium hypochlorite could not enter the critical apical area; however, Salzgeber<sup>9</sup> demonstrated that Hypaque (photo at XXXX) could transcend the apical one third and enter the periapical tissues. The problem with the Salzgeber<sup>9</sup> study is that Hypaque does not hydrolyze tissue, produce gases, and thus cannot create an apical vapor lock, see Figures 2 to 7. (Originally published as Figure 11 on page 397 in: Salzgeber RM, Brilliant JD. An in vivo evaluation of the penetration of an irrigating solution in root canals. *J Endod.* 1977;3:394-398. Copyright Elsevier [1977]. Reprinted by permission.)

termination, thus preventing formation of the apical vapor lock and allowing irrigants to flow freely through the apex.

This "open system" error in methods produces results that most certainly skew in favor of the irrigant being tested (Figure 8c). Interestingly, in one of these "open system" studies the examiners who demonstrated superior in vitro canal cleanliness using a revolutionary endodontic irrigant admitted that leaving open the apical termination during testing might have flawed the study.<sup>11</sup> Many in vitro SEM, light microscopy, and microbiological studies<sup>13-20</sup> that did seal or "close" the apical termination before testing irrigation regimes have universally failed to demonstrate clean canal walls in the apical one third, or complete microbiological control. In 1983 Chow<sup>21</sup> convincingly demonstrated the inability for endodontic irrigants to be carried much past the termination of the irrigation needle in a "closed canal" system (Figure 8d). In the discussion of his study,

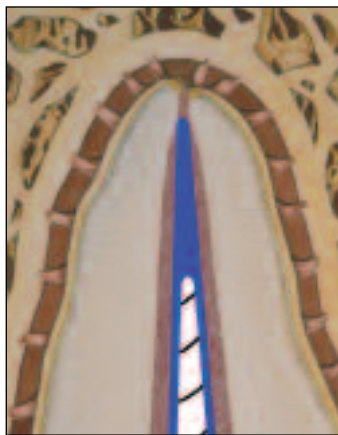
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**Figure 2.** Prior to initiating endodontic therapy there is always some organic material (vital pulp, necrotic pulp, liquefied necrotic pulp) in the root canal system.



**Figure 3.** If sodium hypochlorite is used as an irrigant during instrumentation, it is put in the pulp chamber and then instruments are placed to the apex. When the instrument works its way apically, it forces an "empty space" or cavity within the organic material—the desired effect of instrumentation.



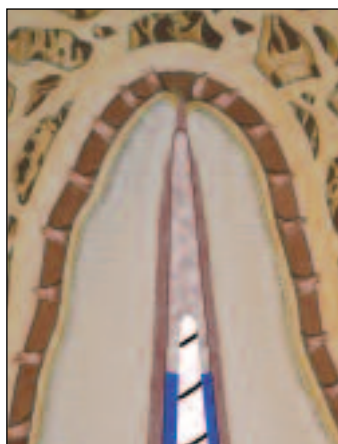
**Figure 4.** When the endodontic instrument is withdrawn from the cavity it just created, sodium hypochlorite (shown as blue) is immediately drawn from the pulp chamber into the now empty cavity created by the instrument. This principle of fluid displacement/replacement was discovered by Archimedes in the 1st century BC when King Hiero II asked him to determine the gold content of his crown.



**Figure 5.** Once the sodium hypochlorite enters the cavity surrounded by organic material, the tissue hydrolysis reaction begins immediately forming small gas bubbles of ammonia and carbon dioxide.



**Figure 6.** When the next larger endodontic instrument is placed apically, it displaces the microbubbles coronally.



**Figure 7.** When the endodontic instrument is withdrawn coronally, the gasses, which are closer to the apical termination than the sodium hypochlorite, replace the endodontic instrument, thus forming the apical vapor lock. Nothing can physically displace this apical vapor lock or gas pocket—see Figure 8, nor can acoustic microstreaming or cavitation dissolve the gas pocket since its composition is gaseous, not liquid.

he defined the 3 criteria necessary for successful mechanical endodontic irrigation. The irrigants must: (1) reach the apex, (2) create a current flow, and (3) carry particles away.

Still another example of drawing the wrong conclusions is not applying correct scientific principles to a specific situation. Consider the erroneous idea that acoustic microstreaming or cavitation can clean any part of the apical portion filled with gas (apical vapor lock). *Acoustic microstreaming* is defined as the movement of fluids along cell membranes,

which occurs as a result of the ultrasound energy creating mechanical pressure changes within the tissue. *Cavitation* is defined as the formation and collapse of gas and vapor filled bubbles or cavities in a fluid. This process ("cavitation") results from the creation and collapse of microbubbles in the liquid.<sup>22</sup> Acoustic microstreaming or cavitation is only possible in fluids/liquids, not gases. Once a sonic or ultrasonically activated tip leaves the irrigant and enters the apical vapor lock, acoustic microstreaming and/or cavitation

becomes physically impossible. This would be like trying to fly a submarine above the water.

Since every clinical endodontic situation is a "closed system" (except those terminating directly in the maxillary sinus and not covered by the Schneiderian membrane), how does a clinician remove an apical vapor lock? How does a clinician achieve a safe current force of irrigant at full working length? How does the clinician remove debris from the apex? The answer to each of these questions is the same—place a small

cannula, attached to the office HiVac, at the apex and aspirate out the gas and canal debris while by drawing fresh sodium hypochlorite to and simultaneously away from the apical vasculature (Figure 9). The efficacy of this method of endodontic irrigation will be demonstrated by reviewing histological and biological studies and a SEM examination of the apical 3 mm.

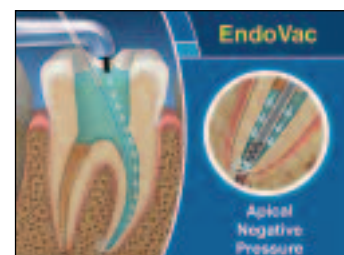
#### HISTOLOGICAL STUDY<sup>23</sup>

This study examined matched pairs of single rooted teeth from the same person that were caries-free and did not have previous restorations. Each pair was randomly divided into 2 groups: one group was treated via traditional needle irrigation delivery, and the other was treated via apical negative pressure delivery (EndoVac, Discus Dental). The root canal system(s) were closed by imbedding the teeth in polyvinyl siloxane impression material, and all teeth were shaped using Gates Glidden drills and Profile series 29 .04 taper rotary instruments (DENTSPLY Tulsa Dental) using a crown-down, continuous taper technique (Figure 10). Final irrigation for the traditional group was performed using a 30-gauge ProRinse side port needle (aka, Max-i-Probe, DENTSPLY) 2 mm from working length to express sodium hypochlorite or EDTA. Final irrigation for the EndoVac group employed the use of a 30-gauge micro cannula attached to the office HiVac and placed at full working length. In this group, irrigants were added coronally and pulled to full working length, and then simultaneously back out through the micro cannula and into the HiVac system. The teeth were prepared histologically, cross-sectioned at 1 mm and 3 mm (see red lines in Figure 10) from working length, and examined for remaining debris. The residual intracanal debris was quantified and statistically analyzed.

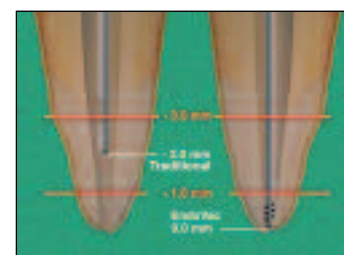
This study demonstrated that the EndoVac group (Figure 11a) produced statis-



**Figures 8a to 8d.** A plastic block with a simulated root canal instrumented to a No. 35/4% taper communicating with a cross drilled hole, sealed with tissue in sections a, b, and d, demonstrates several fluid dynamic issues. First, endodontic instruments cannot displace an apical vapor lock or circulate irrigants into the gas bubble: "a" shows an endodontic file attempting to carry irrigant into the apical vapor lock and "b" shows the same file withdrawn, clearly demonstrating that no irrigant has entered the apical vapor lock as per Senia<sup>8</sup>. Second, "c" demonstrates that if the canal system is not sealed apically (no tissue present in block "c"), that irrigant is easily forced through the termination. This is a common defect in irrigation studies where the examiner fails to seal the apex during experimentation, thus skewing any results in favor of the irrigant. Finally, "d" illustrates a positive pressure sideport needle attempting to circulate irrigant into the apical vapor lock; although coronal flow is evident, no apical circulation occurs as per Chow.<sup>21</sup>



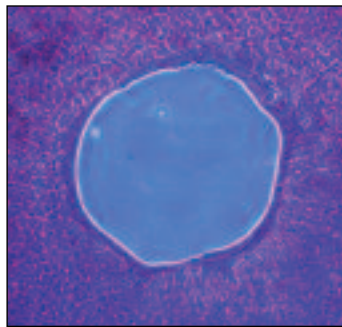
**Figure 9.** The EndoVac endodontic irrigation delivery system produces negative pressure directly at the apical termination via a micro cannula attached to the office HiVac. Twelve radially arranged micro holes (only 6 shown in this view) populate the last 0.7 mm of end of the micro cannula and serve to direct the irrigant flow and as a micro filter. As soon as the irrigant is drawn down the canals, it is sucked away from the apical tissue and into the HiVac system.



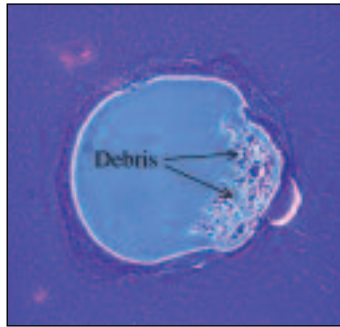
**Figure 10.** The Nielsen, et al study<sup>23</sup> incorporated matched pairs of teeth imbedded in polyvinyl siloxane impression material. The traditional needle was placed at WL—2 mm, which placed its exit portal directly at WL—3 mm, the exact point of the coronal section. The EndoVac was placed at full working length, below both sectioning points. The red lines indicate the points of cross section.

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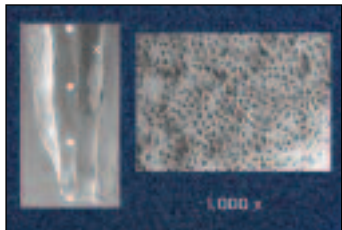
**Figure 11a.** EndoVac Irrigation: This is the companion to the section shown in Figure 11b. It is the matched tooth from the same patient at the same level of cross section. It demonstrates a canal clean and free of either loose or adherent debris after using EndoVac irrigation.



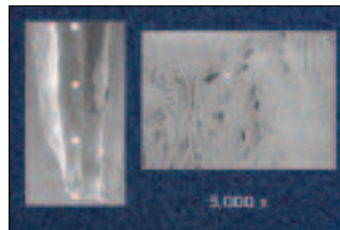
**Figure 11b.** Traditional Irrigation: This cross section taken 1 mm from working length after using traditional techniques, demonstrates significant loose debris in the canal (arrows) as well as debris still adhering to the walls to the right of the loose debris.

Type of Irrigation	EndoVac (Apical Neg. Pressure)			Traditional Positive Pressure		
Irrigate for 2 minutes	2.5%	5.25%	Saline	2.5%	5.25%	Saline
CFU before instrumentation	3.60	3.60	3.48	3.48	3.48	3.56
CFU after instrumentation	2.10	2.58	2.34	2.51	2.26	2.43
CFU after Macro debride	0.00	0.00	2.45	0.60	1.08	2.32
CFU after Micro debride	0.00	0.00	0.00	N/A	N/A	N/A

**Figure 12.** *E. faecalis* study demonstrates no growth in EndoVac samples after Macro Irrigation, while traditional irrigation still produced positive growth. More interesting is the fact that zero growth was realized in the positive control after abundant saline circulated through the apical region. Note: This study only produced a planktonic *E. faecalis* growth, not a biofilm, thus the explanation for producing zero growth via saline alone.



**Figure 13a.** SEM with white dots at 1 mm increments was obtained by splitting a tooth following EndoVac irrigation of an apically sealed tooth. SEM (1,000x) is taken from a region 2.75 mm from the apical termination. Note the homogenous arrangement of clean noninstrumented calcospherites in this area. The tubular pattern at this level is consistent with normal tubular anatomy.



**Figure 13b.** SEM (3,000x) taken at 0.75 mm from the apical termination demonstrates completely clean walls at this level. Although the tubular pattern is irregular, yet normal as described by Mjor, et al<sup>25</sup> the tubules are clear of organic debris or smear layer.

tically significant cleaner canals at 1 mm from working length than traditional irrigation (Figure 11b). However at the 3 mm level (the exact level where irrigant is expressed from the ProRinse needle), there was no significant difference. To the untrained researcher, it is easy to interpret the results as no difference at 3 mm above the WL, and then continue down the wrong logic path and propose that there would be also no difference if the ProRinse could reach WL.

Upon more careful analysis, the reason for the statistical result of no difference is due to the extremely

large variability of the ProRinse, as indicated by the large standard deviations (Percent of Debris in Field: Mean = 2.285%, Std. Deviation = 6.26). In contrast, the EndoVac system produced highly consistent results and therefore tight standard deviations (Percent of Debris in Field: Mean = 0.421%, Std. Deviation = 0.86). So, the statistical analysis used in the Nielsen, et al<sup>23</sup> study paper is not able to discern the obvious difference. There is also the practical safety issue of expressing irrigants under positive pressure immediately adjacent to the periapical vasculature.

#### BIOLOGICAL STUDY<sup>24</sup>

Siquera demonstrated the difficulty in obtaining post-preparation zero growth cultures with sealed root canal systems infected with *E. faecalis*, and sometimes shaped to extremely large 12% tapers.<sup>20</sup> Before deciding to proceed with development of the EndoVac system, a pilot study was designed to examine the possibility of obtaining zero growth cultures using the above cited Siquera protocol to produce a closed root canal system and proper *E. Faecalis* inoculation; however, the test teeth were prepared only to conservative 4% tapered preparations. Since this was a pilot study, it lacked a negative control and the sample sizes were too small to derive definitive statistical data, yet the data is consistent, and when combined with SEM examination, the study demonstrated the merits of proceeding with full development of the EndoVac system of apical negative pressure.

Figure 12 shows that 2.5% and 5.25% concentrations of NaOCl were used for 2 minutes and delivered via either apical negative pressure or traditional positive pressure. It demonstrates that all specimens were successfully and consistently inoculated, and a consistent drop in CFU occurred during the instrumentation phase in both groups. The first apparent difference occurs at the termination of the traditional technique, which corresponds to macro evacuation with the EndoVac method of endodontic irrigation. At the macro phase the EndoVac system produced zero CFU using either dilution of NaOCl. A remarkable difference occurred at the termination of the micro cannula phase of irrigation, when no CFU were recovered from the saline positive control. Why? Since the *E. faecalis* was only grown for 24 hours, biofilm could not form, and because the microorganisms were simply planktonic, the abundant and rapid exchange of saline alone cleared the apical area, thus demonstrating each of Chow's<sup>21</sup> require-

ments for successful mechanical endodontic irrigation: reach the apex, create a current flow, and carry particles away.

This leaves open the question of removing biofilm, and these studies are currently in progress. However, biofilm does not differ chemically from other organic components found in the root canal. As a preview of upcoming results consider Figures 13a and 13b. This specimen was prepared according to the EndoVac instrumentation and irrigation protocol described by Nielsen, et al<sup>23</sup> but was split longitudinally for SEM examination. Figures 13a and 13b are consistent with normal dentinal tubular anatomy in the apical 3 mm<sup>25</sup>, and in both areas there is no evidence of organic debris or smear layer along the walls, and the tubules themselves are free of debris.

#### CONCLUSION

Since the dawn of contemporary endodontics dentists have been squirting sodium hypochlorite into the root canal space and then proceeding to place endodontic instruments down the canal in the errant belief that they were carrying the irrigant to the apical termination. Biological, SEM, light microscopy, and other studies have proven this belief to be invalid. Sodium hypochlorite reacts with organic material in the root canal and quickly forms micro gas bubbles at the apical termination that coalesce into an apical vapor lock with subsequent instrumentation. Since the apical vapor lock cannot be displaced via mechanical means, it prevents further sodium hypochlorite flow into the apical area. Injecting irrigants is limited near to the tip of the injection needle, and the closer the needle tip is positioned to the apical tissue the greater are the chances of apical extrusion. Acoustic microstreaming and cavitation are limited to liquids and have no effect inside the vapor lock. The only method yet discovered to eliminate the apical vapor lock is to evacuate it via api-

cal negative pressure. This method has also been proven to be safe because it always draws irrigants to the source of the vacuum—down the canal and simultaneously away from the apical tissue in abundant quantities. When properly used, the EndoVac is capable of producing the efficient and effective results described herein. ♦

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continued on page #

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*Disclosure: The author holds 2 United States patents on the EndoVac and receives a royalty from Discus Dental based on sales.*