9 Apical Negative Pressure: Safety, Efficacy and Efficiency

Gary Glassman and Karine Charara

Abstract

The objective of dentistry is to prevent oral disease and retain the natural dentition, hopefully for the lifetime of the patient. The objective of endodontic treatment is to prevent and/or treat apical periodontitis. In order for an endodontic irrigant delivery system to be mechanically effective and satisfy the objective of endodontics, it must reach the apical terminus, create a current along the root canal wall and have the ability to remove debris, tissue and bacterial contaminants. Currently, the irrigant of choice to achieve this objective is full-strength sodium hypochlorite (NaOCl).

During endodontic irrigation, the organic component of pulpal tissue consumes NaOCl rapidly as the reaction of hydrolysis occurs forming water and releasing ammonia and carbon dioxide as the by-products. In very short order, a column of gas develops at the apical one third of the root canal (apical vapour lock). The conundrum that the clinician faces is to safely and effectively deliver the irrigants to the apical terminus, break the apical vapour lock and allow constant exchange of irrigant and thereby continual hydrolysis of pulpal tissue by the NaOCl, without the risk of apical extrusion.

This chapter will outline the scientific evidence surrounding apical negative pressure as a safe and reliable method to deliver irrigants to the apical terminus, thereby satisfying the objectives of endodontic treatment.

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The Challenge of Endodontic Debridement

Adequate debridement of the apical one third of the root canal can be very challenging and must not be discounted from providing high-quality endodontic care. Successful endodontic treatment depends on a number of factors, including proper instrumentation, successful irrigation and decontamination of the root canal system to the apices and in areas such as isthmuses and lateral and accessory canals [1]. After traditional nickel–titanium instrumentation and syringe-assisted irrigation, inaccessible areas such as isthmuses, fins, accessory canals and the root canal terminus may remain filled with residual debris and microorganisms [2, 3]. The presence of persistent microbes and their by-products could result in persistent periradicular inflammation [4]. Delivering an endodontic irrigant with a needle and a syringe may be unpredictable, thereby not allowing the irrigant to reach root canal anastomoses and the apical one third of the principal canals. Unless the needle of a positive-pressure delivery system is placed close to the apex, the portion of the canal from the apex to the end of the needle may not be reached by the irrigant [5]. When the needle is placed to a depth that allows the irrigation solution to reach the apex, it is possible the solution may enter the periapical tissues [6]. This can be a source of post-operative pain, and if a significant quantity of a toxic irrigant such as NaOCl is injected into the periapical tissue, the potential to experience a NaOCl accident increases [7]. With debris and bacteria frequently surviving the cleaning and shaping procedures, adjuvant techniques, to the traditional syringe and needle commonly used, may result in superior root canal cleaning [3, 8].

Manual and Machine-Assisted Irrigation Techniques

Root canal irrigation systems can be divided into two categories: manual irrigation techniques and machine-assisted irrigation techniques [9]. Manual irrigation techniques include the positive-pressure syringe fitted with a variety of needle designs and the manual-dynamic agitation using a gutta-percha point. Machine-assisted irrigation techniques include sonics and ultrasonics, as well as newer systems such as the EndoVac, based on apical negative pressure (SybronEndo); the GentleWave (Sonendo), based on multisonic pressure wave formation; the plastic rotary F File (Plastic Endo); the Vibringe (Vibringe); the Rinsendo (Air Techniques); and the EndoActivator (Dentsply Tulsa Dental Specialties). Two important factors that should be considered during the process of irrigation are whether the irrigation systems can deliver the irrigant to the apical terminus and whether the irrigant is capable of debriding areas that could not be reached with mechanical instrumentation, such as lateral/accessory canals, isthmuses and deltas.

Continuous and Intermittent Flushing Techniques

Two flushing methods are currently employed to irrigate root canal systems: the continuous and intermittent. With the intermittent flush technique, the irrigant is injected in the root canal space with a syringe and the irrigant solution can then be activated; the canal is filled several times after each activation cycle. Inversely, the continuous flush techniques provide an uninterrupted supply of fresh irrigation solution into the root canal. This technique can provide more effective results and reduce the time required for final irrigation when compared with intermittent irrigation devices. Taking into consideration that chloride (responsible for dissolving the organic tissues and NaOCl's antibacterial property) is unstable and quickly consumed, a continuous flow of irrigant would make intuitive sense.

Apical Negative Pressure

Pressure is defined as a force per unit area. During root canal treatment, pressure is exerted against the root canal wall when the irrigant solution is delivered into the root canal space. Negative pressure refers to a situation in which an enclosed volume has lower pressure than its surroundings.

Many people use a negative-pressure device on a fairly frequent basis when they use a vacuum cleaner. Negative pressure is also seen in medical quarantine situations where an isolation room will have negative pressure so the outflow of contaminated air is through an opened door or window. This prevents microorganisms from escaping and makes it safer for patients and medical personnel. Oil pipelines also employ negative pressure to prevent the contamination of the environment in the event of a rupture.

In a situation where the pipeline is under the sea and the pipeline's wall breaks off, seawater will flood the pipeline. If the pipeline were positively pressurised, their contents would explode and leak into the ocean, creating a potentially hazardous spill. This chapter will provide a comprehensive review of an apical negative-pressure system for endodontic irrigation, the EndoVac system.

The EndoVac System

The EndoVac system was developed to safely and predictably deliver irrigant to the apical terminus, thereby allowing a better penetration of the irrigation solution into the inherent anatomy and morphology of the root canal system, such as isthmuses, inter-canal and intra-canal communications, curvatures and oval-shaped canals. All these anatomic irregularities make disinfection of the root canal extremely challenging [10] (Fig. 9.1). Apical negative-pressure systems for irrigation have the ability to suction, thereby drawing and delivering the irrigant passively to the apex [9]. The EndoVac system delivers the chosen irrigant passively to the apex [5, 10] and positively addresses the problem of irrigation penetration past the apex into the periapical tissue which may result in treatment complications [6, 11, 12].

The EndoVac apical negative-pressure irrigation system has three active component parts (Fig. 9.2): the Master Delivery Tip (MDT) (Fig. 9.3), the macrocannula and the microcannula. The MDT accommodates a syringe of irrigant, which is expressed through a 20-gauge needle. There is also a plastic suction hood attached around the 20-gauge needle which is connected to clear plastic tubing which inserts into a multiport adaptor which in turn is inserted into the high-volume suction [13]. As such, the MDT can simultaneously deliver and evacuate any excess irrigant that may flow over from the pulp chamber. The macrocannula is used to draw irrigant by way of suction from the chamber to the coronal and middle segments of the canal, while irrigant is simultaneously delivered to the pulp chamber directed towards an axial wall and never towards a canal orifice. The macrocannula or microcannula is connected via clear plastic tubing to the high-speed suction of the dental unit via the multiport adaptor. The plastic macrocannula (Fig. 9.4) has an external diameter of ISO size of 0.55 mm and an internal diameter of ISO size of 0.35 mm. It is made of blue translucent plastic, has a 0.02 taper and is meant for single use only. It is attached snugly

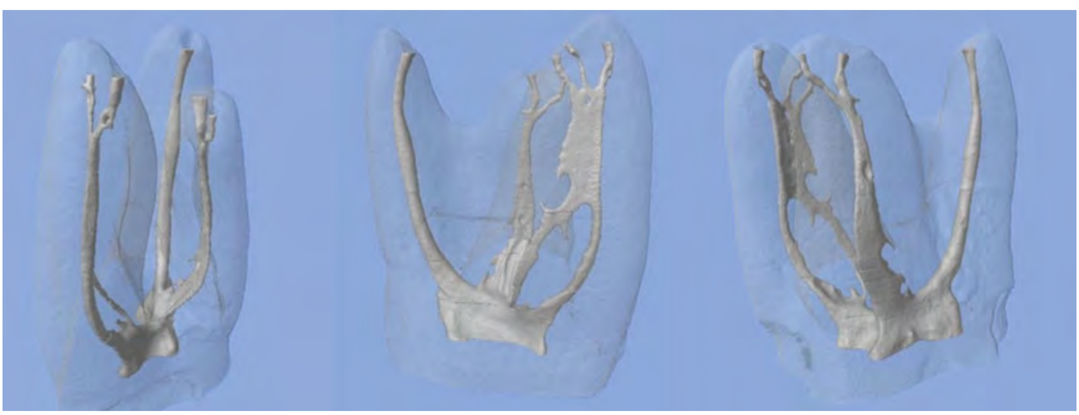

Fig. 9.1 Micro-CT images of a maxillary molar demonstrate the root canal complexity (Courtesy Dr. Ronald Ordinala Zapata)

Fig. 9.2 The components of the EndoVac system: the Master Delivery Tip (MDT) accommodates different sizes of syringes filled with irrigant, the macrocannula is attached to the autoclavable aluminium handpiece and the microcannula is attached to an autoclavable aluminium fingerpiece. The macrocannula, the microcannula and the MDT are connected via clear plastic tubing. The tubes are connected to the high-volume suction of the dental chair via the multiport adaptor (Courtesy Dr. John Schoeffel)

to an autoclavable aluminium hand piece (Fig. 9.5) and is used in an up-and-down pecking motion, while irrigant is simultaneously delivered passively to the pulp chamber in the manner mentioned above. It is used to remove the gross debris and tissue left behind during instrumentation. The microcannula (Fig. 9.6) contains 12 microscopic holes and is capable of evacuating debris to full working length [14]. The size of 0.32-mm-external-diameter stainless-steel microcannula of zero taper has four sets of three laser-cut, laterally positioned offset holes adjacent to its closed end, 100 μ in diameter and spaced 100 μ apart. These holes act as filters to prevent the clogging of the internal lumen of the microcannula which has an internal diameter of ISO size of 0.20 mm. The microcannula is attached to an autoclavable aluminium fingerpiece and is used for irrigation of the apical part of the canal when it is positioned at working length. The microcannula has a closed end and should be taken to the full working length to aspirate irrigants and debris. The microcannula can be used in canals that are enlarged with endodontic files to ISO size 35 with 0.04 taper or larger. A non-tapered preparation can also be considered; in this situation the manufacturer recommends an enlargement of the root canal to 40/0.02.

During irrigation, the MDT delivers irrigant to the pulp chamber and siphons off the excess irrigant to prevent overflow. Both the macrocannula and microcannula exert negative pressure that pulls fresh irrigant from the chamber, down the canal to the tip of the cannula, into the cannula and out through the suction hose. Thus, a constant flow of fresh irrigant is delivered by negative pressure to working length, allowing the reaction of hydrolysis to continually occur.

Fig. 9.3 Master Delivery Tip (MDT) composed of a 20-gauge needle and luer lock connectors to connect to the syringe and the high-volume suction of the dental chair (Courtesy Kerr Endodontics (SybronEndo). Orange, California)

Method of Use

Irrigation begins during rotary instrumentation. The MDT delivers fresh irrigant to the access opening when each instrument is changed in the hand piece. Using the MDT is optional during access and the instrumentation phases of root canal treatment. A normal Monoject syringe may be used to replenish the irrigant in the pulp chamber during instrumentation. This removes instrumentation debris and exchanges irrigant deep within the pulp chamber as subsequent files are brought closer and then finally to

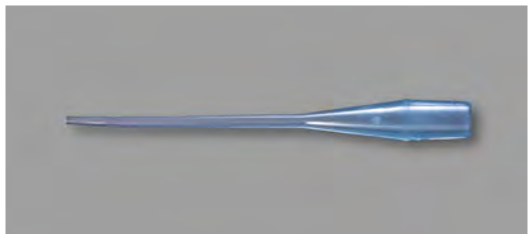

Fig. 9.4 The macrocannula is made of blue translucent plastic and it is attached to an autoclavable aluminium handpiece (Fig. 9.5) (Courtesy Kerr Endodontics (SybronEndo). Orange, California)

Fig. 9.5 Autoclavable handpiece for the macrocannula (Courtesy Kerr Endodontics (SybronEndo). Orange, California)

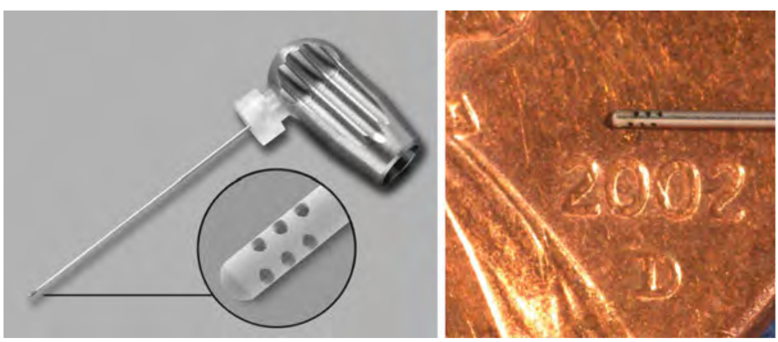

Fig. 9.6 The ISO size of 0.32-mm-external-diameter stainless-steel microcannula of zero taper has four sets of three laser-cut, laterally positioned offset holes adjacent to its closed end, 100 µ in diameter and spaced 100 µ apart (Courtesy Dr. John Schoeffel)

working length. When using the MDT, always direct the irrigant flow against a chamber wall; never direct the flow of irrigant towards a canal's orifice as the pressure of irrigant expression has the potential of causing an irrigation accident in straight and wide canals even when the needle is not placed directly in the orifice or canal.

Following complete instrumentation, the macrocannula is used in each canal for 30 s in a short up-and-down pecking motion as close as possible to working length. Continue to deliver copious NaOCl with the MDT while the macrocannula is moving up and down the canal. Observe the macrocannula for continuous flow and that it does not become blocked with debris. If it does, then remove the plastic tubing from the aluminium handle, place a syringe of water tightly at the end and express the water through the handle and macrocannula to dislodge the blockage. This is carefully done over the sink and not over the patient. This step can also be performed with the microcannula should it get blocked. The use of the macrocannula in the final irrigation protocol will remove the gross debris and tissue left behind during instrumentation. If a shortcut is made and this step is not completed for the full 30 s in each canal, then the microcannula used in the next step may get blocked and slow down the irrigation process.

The next step involves three micro cycles. They are called micro cycles because the microcannula is now used at full working length to remove debris from the canal lumen and isthmus areas. Use a ruler to position the rubber stopper that is placed on the microcannula or score the microcannula with an indelible marker (Fig. 9.7). Delicately guide the microcannula to full working length by holding the fingerpiece. The fingerpiece is then released and the tubing is stabilised. The NaOCl is added with the MDT to the pulp chamber for 10 s (Fig. 9.8). After 10 s the irrigant flow is stopped for just a couple of seconds to allow the gas bubbles formed by hydrolysis to be purged from the canal. The NaOCl is added for another 10 s after which the irrigant flow is stopped again to allow the gas bubbles to be purged from the canal. The NaOCl is then added for the third and final time for another 10 s, but at the end of this time period, the microcannula is removed by the fingerpiece as the MDT continues to deliver NaOCl to the pulp chamber as to not allow its removal from the canal just being treated. This allows the canal to be charged (soaked) with fresh NaOCl for 60 s. The first micro cycle allows the organic com-

Fig. 9.7 Remove the cap of the microcannula. Use the provided rubber stopper or a marker to indicate working length (Courtesy Kerr Endodontics (SybronEndo). Orange, California)

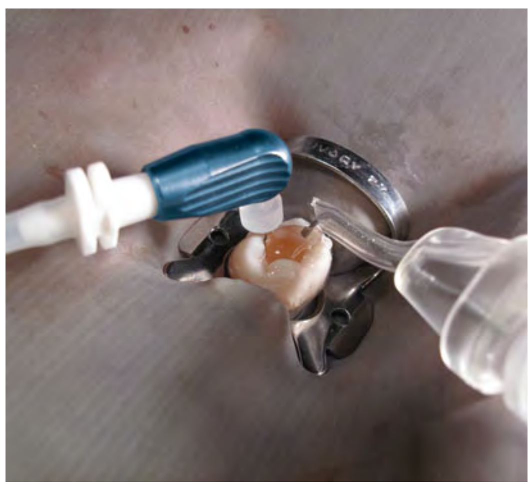

Fig. 9.8 Once the microcannula is placed at full working length, the clinician may leave it in place and proceed with irrigant delivery via the MDT. Put a slight bend on the microcannula if it won't stay in the canal on its own (Courtesy Kerr Endodontics (SybronEndo). Orange, California)

ponent of the smear layer to be removed in addition to any fine debris left behind during instrumentation. The second micro cycle using EDTA removes the inorganic component of the smear layer. The microcannula is again delicately guided to full working length. EDTA is added for 10 s, and then the microcannula is removed allowing the canal to be charged for 60 s. As mentioned, this will remove the inorganic component of the smear layer and expose the dentinal tubules in preparation for the third micro cycle. The third micro cycle is the same as the first micro cycle, two purges and a charge for 60 s. Now that the smear layer has been removed from the root canal walls by the first two micro cycles, this third micro cycle will allow the NaOCl to enter the dentinal tubules via osmosis and dissolve the remaining tissue and microbiota [15]. There is no better way to dry the root canals than to delicately guide the microcannula to full working length for just a moment. This is followed by one or two paper points. The canal(s) is now ready for obturation. Refer to Fig. 9.9 for a flow chart illustrating the final irrigation protocol using the EndoVac system.

Debris Removal

Several studies were carried out to evaluate the EndoVac system's ability to remove debris within the root canal system after instrumentation with rotary files [16–21]. Debridement is a principal objective of root canal treatment and remains a challenge especially in the apical portion of the canal and within the isthmuses and lateral and accessory canals. Debridement is the elimination of organic and inorganic substances as well as microorganisms from the root canal by mechanical and/or chemical means [22]. When compared to traditional syringe and side-vented needle irrigation, the EndoVac system has demonstrated better control to reach the last millimetre of the root canal.

Some in vitro and in vivo studies have demonstrated greater removal of debris from the apical walls and a statistically cleaner result using apical negative-pressure irrigation in closed root canal systems with sealed apices. In an in vivo study of 22 teeth by Siu and Baumgartner, less debris remained at 1 mm from working length using apical negative pressure compared to the use of traditional needle irrigation, while Shin

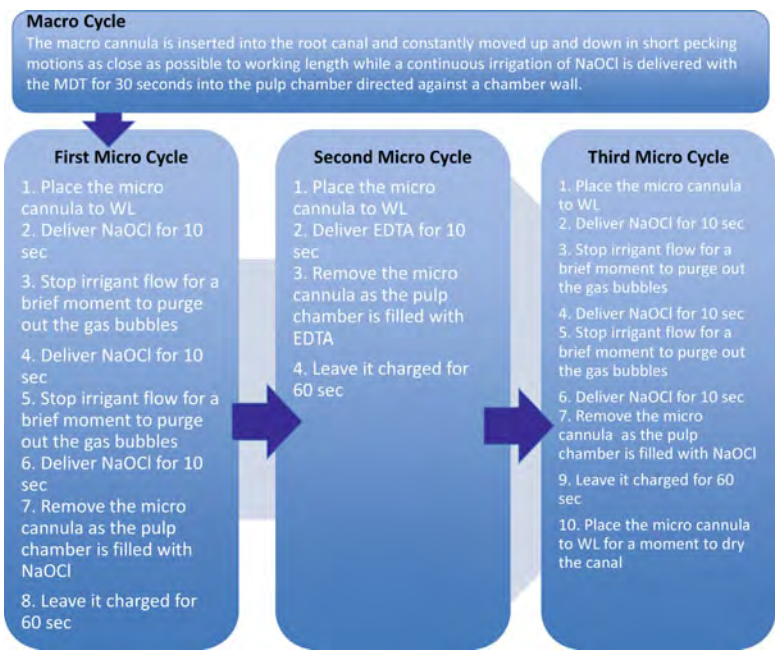

Fig. 9.9 Final irrigation protocol using EndoVac system

et al. found in an in vitro study of 69 teeth comparing traditional needle irrigation with apical negative pressure that these methods both resulted in clean root canals but that apical negative pressure resulted in less debris remaining at 1.5 and 3.5 mm from working length [18, 23, 24]. When comparing root canal debridement using manual-dynamic agitation (using a well-fitted gutta-percha cone in an up-and-down motion in the canal) or the EndoVac system for final agitation in a closed system and an open system, it was found that the presence of a sealed apical foramen adversely affected debridement efficacy when manual-dynamic agitation was used, but did not adversely affect results when the EndoVac system was used. Apical negative-pressure irrigation is an effective method to overcome the fluid-dynamic challenges inherent in closed root canal systems [25, 26]. The ability of the EndoVac system to significantly clean more debris from a mechanically inaccessible recess of the curved in vitro root canal model may be caused by robust bubble formation during irrigant delivery, creating higher wall shear stresses by a two-phase air–liquid flow phenomenon that is well known in other industrial debridement systems [27]. Less debris remained with the EndoVac system at 1 mm from the working length and in isthmuses [18, 20, 21]. To enhance cleanliness of the root canal system, EndoVac system has the ability to safely deliver irrigant to working length [18] by pulling the irrigant into the canal and removing it by negative pressure [18]. This vacuum action enhances the volume of solution and the circulation of the irrigation solution in the apical end of the root canal. Moreover, the negative pressure avoids air entrapment in the apical third [21] and promotes a regular replenishment of the irrigant apically [21]. A recent study demonstrated that the volume of irrigant delivered apically was significantly higher than the volume delivered by conventional syringe needle irrigation within the same period [18] and resulted in significantly more debris removal at 1 mm from working length than did needle irrigation.

One study is not in agreement with those positive outcomes discussed above. Jiang et al. ran a study and evaluated the EndoVac system's ability to remove dentin debris from artificially made grooves in standardised root canals. The model was made of a single tooth root in which an apical groove comparable to an ovoid apical canal was created and packed with dentin debris. They compared several devices to activate the irrigation solution. Once the irrigation regimen was completed, they viewed the grooves through a stereomicroscope to evaluate the residual dentin debris. A score between 0 and 3 was given to each specimen: 0 = the groove is empty, 1 = less than half of the groove is filled with debris, 2 = more than half of the groove is filled with debris and 3 = the complete groove is filled with debris. The specimens irrigated with the EndoVac system had their groove completely filled with debris (score 3) 65 % of the time, while 35 % had less than half filled with debris [17]. It is important to note that Jiang et al. failed to follow the manufacturer's instructions by failing to use the critical macrocannula, an error that could easily cause the microcannula to clog and become ineffective. When the microcannula is blocked by debris, the clinician will experience decreased or complete arrest of irrigant flow. To rectify the situation, the microcannula can be wiped with a 2 × 2 gauze or air and water can be blown into it to unclog it. This can also be done with the macrocannula should it also become clogged during its use (Fig. 9.10). Complete clogging of the microcannula happens very rarely, if the macrocannula is used according to the manufacturer's instructions. The microcannula will continue to work even if several holes are blocked. However, its effectiveness will decrease. To avoid this complication, the macrocannula's main purpose is to remove as much debris as possible before the smaller microcannula is introduced. This will reduce the incidence of it clogging as long as the macrocannula is used according to the manufacturer's recommendation. A weaker capacity of the EndoVac system to remove apical debris could be attributed to the minimal turbulence intensity produced within the canal by the microcannula [28]. This evidence of low wall shear stress values causes a minimum physical interaction between the irrigant and the root canal walls [29]. This absence of

Fig. 9.10 If either cannula becomes clogged, try unclogging it by attaching the back end of either the fingerpiece or handpiece onto a syringe filled with water. Push the plunger; in most instances the hole(s) is immediately cleared (Courtesy Kerr Endodontics (SybronEndo). Orange, California)

interaction may explain the difficulty of the irrigation solution to reach the root canal's lateral canals and anastomoses [5].

Microbial Control

The effective removal of organic and inorganic tissues would logically allow better access and elimination of endodontic pathogens, responsible of apical periodontitis, localised in the root canal system.

Hockett et al. tested the ability of apical negative-pressure irrigation to remove a thick biofilm of *E. faecalis* in mesial roots of mandibular molars, finding that these specimens rendered negative cultures after 48-h incubation, while some of those irrigated using traditional positive-pressure irrigation were positive at 48 h [29]. One in vivo dog study found that apical negative-pressure irrigation with 2.5 % NaOCl resulted in similar bacterial reduction than the use of apical positive-pressure irrigation combined with seven days of intra-canal medication which was the triple antibiotic paste [30]. The triple antibiotic Trimix (metronidazole, ciprofloxacin and minocycline) has been utilised for pulpal regeneration/revascularisation in teeth with incompletely formed apices [31]. The antibiotic medication is applied in regeneration cases to safely kill bacteria. Since the triple antibiotic versus the use of EndoVac with NaOCl was statistically equivalent for mineralised tissue formation and the repair process [30], the study [30] suggests that EndoVac may overcome the need for intra-canal medication. Further research is required to evaluate this potential. Using apical negative pressure with NaOCl also decreases the risk of drug resistance, tooth discoloration and allergic reactions often seen with the administration of antibiotics [32, 33]. A recent randomised controlled clinical trial [34] compared the antimicrobial effectiveness of EndoVac system and the traditional positive-pressure syringe and needle for irrigation. From the 16 mandibular molar treated with the conventional method, negative culture was found in 67 % compared to 100 % among the apical negative-pressure irrigation group. A second clinical study [35] demonstrated a higher frequency of obtaining negative culture with EndoVac system compared to a syringe with regular needle. Unlike Cohenca et al. [34], Pawar et al. [35] did not reach significance between the two clinical groups. However, Pawar et al. added an overriding codicil in their discussion: "The original EndoVac protocol recommends using a concentration of 5.25 % NaOCl. Almost all studies investigating the efficacy of EndoVac have used NaOCl at concentrations ranging from 2.5 to 6 %. The use of 0.5 % NaOCl [a 1,000 % dilution from the manufacturer's instructions] in this study could be considered responsible for the lack of significant differences in antimicrobial efficacy between EndoVac irrigation and standard irrigation" [35].

Smear Layer Removal

The smear layer is created when the dentinal walls of the root canal system interact with endodontic instruments [36]. The smear layer is comprised of inorganic and organic material such as dentin filings and pulp tissue remnants [37]. This deposit can be penetrated by bacteria and may offer protection to biofilms adhering to the root canal walls [38]. Furthermore, the smear layer interferes with the tight adaptation of currently used root canal sealers to dentinal walls and may therefore promote microleakage [39]. Torabinejad et al. [40] suggested that the removal of the smear layer decreases bacteria and improves adaptation of obturation materials to the canal walls. Another study showed that the smear layer produced during root canal preparation promotes adhesion and colonisation of *P. nigrescens* [41] to the dentin matrix and might increase the likelihood of canal reinfection. Removing the smear layer reduces the potential for microleakage [19, 42] and improves sealer penetration in dentinal tubules [43]. When manufacturer's recommendations are followed, EndoVac system delivers a sufficient volume of irrigants which enables to remove smear layer [19, 44, 45] (Fig. 9.11).

Compared to passive ultrasonic irrigation, apical negative-pressure irrigation and manual-dynamic irrigation are more efficient in removing the smear layer in the apical one third [45]. A possible explanation for this is that both techniques reach full working length of instrumented canals, eliminate the apical vapour lock at the apex and hence allow adequate irrigant replacement [44, 45]. When evaluating irrigation of the apical one third, the phenomenon of apical vapour lock should be considered [26, 46, 47].

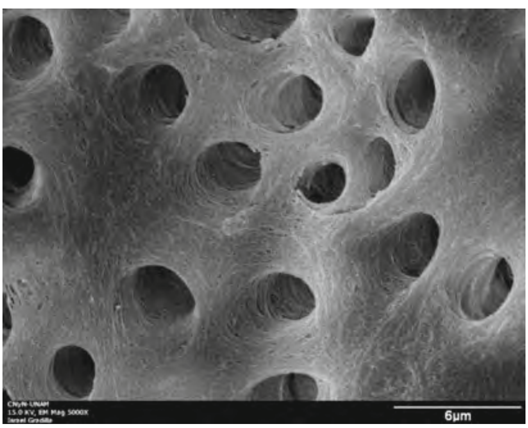

Fig. 9.11 SEM of a clean root canal wall where the smear layer has been removed (Courtesy Dr. Arianna Gomez-Perez)

Apical Vapour Lock

Since roots are surrounded by the periodontium, unless the root canal foramen is open, the root canal behaves like a close-ended channel. This produces an apical vapour lock that resists displacement during instrumentation and final irrigation, thus preventing the flow of irrigant into the apical region and adequate debridement of the root canal system [48, 49]. Apical vapour lock also results in gas entrapment at the apical one third [9]. During irrigation, NaOCl reacts with organic tissue in the root canal system, and the resulting hydrolysis liberates abundant quantities of ammonia and carbon dioxide [50]. This gaseous mixture is trapped in the apical region and quickly forms a column of gas into which further fluid penetration is impossible. Extension of instruments into this vapour lock does not reduce or remove the gas bubble [13], just as it does not enable adequate flow of irrigant.

The phenomenon of apical vapour lock has been confirmed in studies in which roots were embedded in a polyvinyl siloxane impression material to restrict fluid flow through the apical foramen, simulating a close-ended channel [26]. The results in these studies were found to be an incomplete debridement of the apical part of the canal walls with the use of a positive-pressure syringe delivery technique [26]. Micro-CT scanning and histological tests conducted by Tay et al. have also confirmed the presence of apical vapour lock [26]. In fact, studies conducted without ensuring a close-ended channel cannot be regarded as conclusive on the efficacy of irrigants and the irrigant system [51–53]. The apical vapour lock may also explain why in a number of studies investigators were unable to demonstrate a clean apical third in sealed root canals [54–56].

In a paper published in 1983, Chow determined that traditional positive-pressure irrigation had virtually no effect apical to the orifice of the irrigation needle in a closed root canal system [57]. Fluid exchange and debris displacement were minimal. Equally important to his primary findings, Chow 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" [57]. The apical vapour lock and consideration for the patient's safety have always prevented the thorough cleaning of the apical 3 mm. It is critically important to determine which irrigation system will effectively irrigate the apical third, as well as isthmuses and lateral canals [10], and do it in a safe manner that prevents the extrusion of irrigant.

Calcium Hydroxide Removal

As stated previously, the debridement of the root canal system consists of elimination of organic, inorganic and microbial components, thus accomplished by mechanical instrumentation supported by various irrigation regimens and placement of intra-canal medication. Calcium hydroxide is a commonly used intra-canal medicament [58] that has antimicrobial activity proven to contribute to bacterial endotoxin neutralisation [59] and to periapical repair [60]. However, to provide a maximum interface between the root canal walls and the filling material, calcium hydroxide has to be removed [61]; otherwise, the bond strength [62] of the sealer and its penetration into the dentinal tubules could be reduced [63]. Conventional methods for irrigation have demonstrated limited capacity to remove calcium hydroxide from the apical third of the root canal [64]. A scanning electron microscopic evaluation of longitudinally sectioned canines demonstrated that EndoVac system performs better than the traditional syringe irrigation in removing calcium hydroxide from the apical one third of root canals [65]. The results were similar to another study [66] where EndoVac system was compared to the traditional syringe irrigation and the ProUltra® PiezoFlow™ ultrasonic irrigation needle (Dentsply Tulsa, Tulsa, OK, USA). EndoVac system left significantly less calcium hydroxide compared to the traditional syringe irrigation and provided better results than PiezoFlow™, but the difference was not statistically significant [66]. Although the EndoVac system improves the removal of calcium hydroxide, the apical portion of the canal was not completely free of intracanal medicament. Therefore, the use of the master apical file in combination with the EndoVac system may result in better removal of calcium hydroxide [66].

Sodium Hypochlorite Incidents

In light of the cytotoxicity of the sodium hypochlorite, its extrusion from the root canal will affect the periapical tissue and may cause the patient a series of complications of a variable clinical significance, beginning with the a postoperative pain [7].

Although a devastating endodontic NaOCl incident is rare [67], the cytotoxic effects of NaOCl on vital tissue are well established [68]. The associated sequelae of NaOCl extrusion have been reported to include life-threatening airway obstructions [69], facial disfigurement requiring multiple corrective surgical procedures [70], permanent paraesthesia with loss of facial muscle control [71] and tooth loss [72].

Although the exact aetiology of the NaOCl incident is still uncertain, based on the evidence from actual incidents and the location of the associated tissue trauma, it would appear that an intravenous injection might be the main cause. The patient shown in Fig. 9.12 [73] demonstrates a widespread area of tissue trauma that is in contrast to the characteristics of NaOCl incident trauma reported by Pashley [68]. This extensive trauma, particularly involving the pattern of ecchymosis around the eye, could only have occurred if the NaOCl had been introduced intravenously to a vein close to the root apex through

Fig. 9.12 Clinical aspect of emphysema related to extravasation of the sodium hypochlorite solution during endodontic treatment, with ecchymosis and severe swelling of the right side of the face. These symptoms appeared after a root canal treatment of the upper right canine (Reproduced with permission from Elsevier)

which extrusion of the irrigant occurred and the irrigant then found its way into the venous complex. This would require positive pressure apically exceeding the venous pressure, for which the mean value is 5.88 mmHg [12]. In other words, NaOCl extrusion into the venous system is more susceptible to occur when the apical pressure of irrigant is greater than 5.88 mmHg. One in vitro study, where a positive-pressure needle irrigation technique was used to mimic clinical conditions and techniques, demonstrated that the apical pressure generated easily exceeds the value of normal venous pressure [74]. The results of this study suggested that a combination of factors is necessary for a severe NaOCl accident to occur. The hypothesis that involves intravenous infusion of extruded NaOCl into the facial vein via non-collapsible venous sinusoids within the cancellous bone has been suggested [12].

This does not imply that NaOCl can or should be excluded as an endodontic irrigant; in fact, its use is essential to achieve adequate chemical debridement. What this does imply is that it must be delivered safely.

Safety

With traditional root canal irrigation, clinicians must be careful when determining how far an irrigation needle is placed into the canal. Recommendations for avoiding NaOCl incidents include not binding the needle in the canal, not placing the needle close to working length and using a gentle flow rate when using positive-pressure irrigation [75]. In contrast, the EndoVac system pulls irrigant into the canal to working length and irrigant and debris is removed by negative pressure. Apical negative pressure has been shown to enable irrigants to safely reach the apical one third and help overcome apical vapour lock [18, 20].

Apart from being able to avoid air entrapment, the EndoVac system is also advantageous in its ability to deliver irrigants safely to working length without causing their undue extrusion into the periapex [14, 18, 76], thereby avoiding NaOCl incidents. It is important to note that it is possible to create positive pressure in the pulp canal if the MDT is misused, which would create the risk of a NaOCl incident. The manufacturer's instructions must be followed for correct use of the Master Delivery Tip by never directing towards the orifice of a canal.

In order to compare the safety of six current intra-canal irrigation delivery devices, an in vitro test was conducted using the worst-case scenario of apical extrusion, with neutral atmospheric pressure and an open apex [14]. The study concluded that the EndoVac system did not extrude irrigant even after deep intra-canal delivery and suctioning of the irrigant from the chamber to full working length, whereas other devices did. The EndoActivator extruded only a very small volume of irrigant, the clinical significance of which is not known.

Mitchell and Baumgartner tested irrigant (NaOCl) extrusion from a root canal sealed with a permeable agarose gel [11]. Significantly less extrusion occurred using the EndoVac system compared with positive-pressure needle irrigation. A well-controlled study by Gondim et al. found that patients experienced less post-operative pain, measured objectively and subjectively, when apical negative-pressure irrigation was performed (EndoVac system) than with apical positive-pressure irrigation [7]. Furthermore, PiezoFlow™ showed a greater potential to cause apical extrusion compared with EndoVac system's safety. When positioned within the last 5 mm of the root canal, the ultrasonic activated needle could cause apical extrusion of irrigant solution [76].

Conclusion

Traditional endodontic technique advocated placing NaOCl into the root canal space followed by endodontic instruments in the belief that they were carrying the irrigant to the apical terminus. Biological, scanning electron microscopy, light microscopy and other studies have proven this belief to be in error. NaOCl reacts with organic material in the root canal and quickly forms microbubbles at the apical termination that coalesce into a single large apical vapour bubble with subsequent instrumentation. Since the apical vapour lock cannot be displaced via mechanical means, it prevents further NaOCl flow into the apical area. The safest method yet discovered to provide fresh voluminous amounts of NaOCl safely to the apical terminus to eliminate the apical vapour lock is to evacuate it via apical negative pressure. This method has also been proven to be safe because it always draws irrigants to the source via suction—down the canal and simultaneously away from the apical tissue in abundant quantities. When the proper irrigating agents are delivered safely to the full extent of the root canal terminus, thereby removing most of organic tissue and microbial contaminants, success in endodontic treatment may be taken to levels never seen before.

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