Irrigation in Endodontics

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The success of endodontic treatment depends on the eradication of microbes (if present) from the root-canal system and prevention of reinfection. The root canal is shaped with hand and rotary instruments under constant irrigation to remove the inflamed and necrotic tissue, microbes/biofilms, and other debris from the root-canal space. The main goal of instrumentation is to facilitate effective irrigation, disinfection, and filling. Several studies using advanced techniques such as microcomputed tomography (CT) scanning have demonstrated that proportionally large areas of the main root-canal wall remain untouched by the instruments,1 emphasizing the importance of chemical means of cleaning and disinfecting all areas of the root canal (Figs. 1 and 2). There is no single irrigating solution that alone sufficiently covers all of the functions required from an irrigant. Optimal irrigation is based on the combined use of 2 or several irrigating solutions, in a specific sequence, to predictably obtain the goals of safe and effective irrigation. Irrigants have traditionally been delivered into the root-canal space using syringes and metal needles of different size and tip design. Clinical experience and research have shown, however, that this classic approach typically results in ineffective irrigation, particularly in peripheral areas such as anastomoses between canals, fins, and the most apical part of the main root canal. Therefore, many of the compounds used for irrigation have been chemically modified and several mechanical devices have been developed to improve the penetration and effectiveness of irrigation. This article summarizes the chemistry, biology, and procedures for safe and efficient irrigation and provides cutting-edge information on the most recent developments.

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GOALS OF IRRIGATION

Irrigation has a central role in endodontic treatment. During and after instrumentation, the irrigants facilitate removal of microorganisms, tissue remnants, and dentin chips from the root canal through a flushing mechanism (Box 1). Irrigants can also help prevent packing of the hard and soft tissue in the apical root canal and extrusion of infected material into the periapical area. Some irrigating solutions dissolve either organic or inorganic tissue in the root canal. In addition, several irrigating solutions have antimicrobial activity and actively kill bacteria and yeasts when introduced in direct contact with the microorganisms. However, several irrigating solutions also have cytotoxic potential, and they may cause severe pain if they gain access into the periapical tissues. An optimal irrigant should have all or most of the positive characteristics listed in Box 1, but none of the negative or harmful properties. None of the available irrigating solutions can be regarded as optimal. Using a combination of products in the correct irrigation sequence contributes to a successful treatment outcome.

IRRIGATING SOLUTIONS

Sodium Hypochlorite

Sodium hypochlorite (NaOCl) is the most popular irrigating solution. NaOCl ionizes in water into Na⁺ and the hypochlorite ion, OCl⁻, establishing an equilibrium with
Hypochlorous acid (HOCl). At acidic and neutral pH, chlorine exists predominantly as HOCl, whereas at high pH of 9 and above, OCl⁻ predominates. Hypochlorous acid is responsible for the antibacterial activity; the OCl⁻ ion is less effective than the undissolved HOCl. Hypochloric acid disrupts several vital functions of the microbial cell, resulting in cell death.

NaOCl is commonly used in concentrations between 0.5% and 6%. It is a potent antimicrobial agent, killing most bacteria instantly on direct contact. It also effectively dissolves pulpal remnants and collagen, the main organic components of dentin. Hypochlorite is the only root-canal irrigant of those in general use that dissolves necrotic and vital organic tissue. It is difficult to imagine successful irrigation of the root canal without hypochlorite. Although hypochlorite alone does not remove the smear layer, it affects the organic part of the smear layer, making its complete removal possible by subsequent irrigation with EDTA or citric acid (CA). It is used as an unbuffered solution at pH 11 in the various concentrations mentioned earlier, or buffered with bicarbonate buffer (pH 9.0), usually as a 0.5% (Dakin solution) or 1% solution. However, buffering does not seem to have any major effect on the properties of NaOCl, contrary to earlier belief.

There is considerable variation in the literature regarding the antibacterial effect of NaOCl. In some articles hypochlorite is reported to kill the target microorganisms in seconds, even at low concentrations, although other reports have published considerably longer times for the killing of the same species. Such differences are a result of confounding factors in some of the studies. The presence of organic matter during the killing experiments has a great effect on the antibacterial activity of NaOCl. Haapasalo and colleagues showed that the presence of dentin caused marked delays in the killing of Enterococcus faecalis by 1% NaOCl. Many of the earlier studies were performed in the presence of an unknown amount of organic matter (eg, nutrient broth) or without controlling the pH of the culture, both of which affect the result. When the confounding factors are eliminated, it has been shown that NaOCl kills the target microorganisms rapidly even at low concentrations of less than 0.1%. However, in vivo the presence of organic matter (inflammatory exudate, tissue remnants, microbial biomass) consumes NaOCl and weakens its effect. Therefore, continuous irrigation and time are important factors for the effectiveness of hypochlorite.

Byström and Sundqvist studied the irrigation of root canals that were necrotic and contained a mixture of anaerobic bacteria. These investigators showed that using

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**Box 1**

**Desired functions of irrigating solutions**

- Washing action (helps remove debris)
- Reduce instrument friction during preparation (lubricant)
- Facilitate dentin removal (lubricant)
- Dissolve inorganic tissue (dentin)
- Penetrate to canal periphery
- Dissolve organic matter (dentin collagen, pulp tissue, biofilm)
- Kill bacteria and yeasts (also in biofilm)
- Do not irritate or damage vital periapical tissue, no caustic or cytotoxic effects
- Do not weaken tooth structure
0.5% or 5% NaOCl, with or without EDTA for irrigation, resulted in considerable reduction of bacterial counts in the canal when compared with irrigation with saline. However, it was difficult to render the canals completely free from bacteria, even after repeated sessions. Siqueira and colleagues\textsuperscript{15} reported similar results using root canals infected with \textit{E faecalis}. Both studies failed to show a significant difference in the antibacterial efficacy between the low and high concentrations of NaOCl. Contrary to these results, Clegg and colleagues\textsuperscript{16} in an ex vivo biofilm study, demonstrated a strong difference in the effectiveness against biofilm bacteria by 6% and 3% NaOCl, the higher concentration being more effective.

The weaknesses of NaOCl include the unpleasant taste, toxicity, and its inability to remove the smear layer (Fig. 3) by itself, as it dissolves only organic material.\textsuperscript{17} The limited antimicrobial effectiveness of NaOCl in vivo is also disappointing. The poorer in vivo performance compared with in vitro is probably caused by problems in penetration to the most peripheral parts of the root-canal system such as fins, anastomoses, apical canal, lateral canals, and dentin canals. Also, the presence of inactivating substances such as exudate from the periapical area, pulp tissue, dentin collagen, and microbial biomass counteract the effectiveness of NaOCl.\textsuperscript{11} Recently, it has been shown by in vitro studies that long-term exposure of dentin to a high concentration sodium hypochlorite can have a detrimental effect on dentin elasticity and flexural strength.\textsuperscript{18,19} Although there are no clinical data on this phenomenon, it raises the question of whether hypochlorite in some situations may increase the risk of vertical root fracture.

In summary, sodium hypochlorite is the most important irrigating solution and the only one capable of dissolving organic tissue, including biofilm and the organic part of the smear layer. It should be used throughout the instrumentation phase. However, use of hypochlorite as the final rinse following EDTA or CA rapidly produces severe erosion of the canal-wall dentin and should probably be avoided.\textsuperscript{20}

\textbf{EDTA and CA}

Complete cleaning of the root-canal system requires the use of irrigants that dissolve organic and inorganic material. As hypochlorite is active only against the former, other substances must be used to complete the removal of the smear layer and dentin debris. EDTA and CA effectively dissolve inorganic material, including hydroxyapatite.\textsuperscript{21–24} They have little or no effect on organic tissue and alone they do not have antibacterial activity, despite some conflicting reports on EDTA. EDTA is most commonly

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\textbf{Fig. 3.} Cross section of root dentin covered by the smear layer created by instrumentation. Notice smear plugs in dentin canals.
used as a 17% neutralized solution (disodium EDTA, pH 7), but a few reports have indicated that solutions with lower concentrations (eg, 10%, 5%, and even 1%) remove the smear layer equally well after NaOCl irrigation. Considering the high cost of EDTA, it may be worthwhile to consider using diluted EDTA. CA is also marketed and used in various concentrations, ranging from 1% to 50%, with a 10% solution being the most common. EDTA and CA are used for 2 to 3 minutes at the end of instrumentation and after NaOCl irrigation. Removal of the smear layer by EDTA or CA improves the antibacterial effect of locally used disinfecting agents in deeper layers of dentin. EDTA and CA are manufactured as liquids and gels. Although there are no comparative studies about the effectiveness of liquid and gel products to demineralize dentin, it is possible that the small volume of the root canal (only a few microliters) contributes to a rapid saturation of the chemical and thereby loss of effectiveness. In such situations, the use of liquid products and continuous irrigation should be recommended.

**Chlorhexidine Digluconate**

Chlorhexidine digluconate (CHX) is widely used in disinfection in dentistry because of its good antimicrobial activity. It has gained considerable popularity in endodontics as an irrigating solution and as an intracanal medicament. CHX does not possess some of the undesired characteristics of sodium hypochlorite (ie, bad smell and strong irritation to periapical tissues). However, CHX has no tissue-dissolving capability and therefore it cannot replace sodium hypochlorite.

CHX permeates the microbial cell wall or outer membrane and attacks the bacterial cytoplasmic or inner membrane or the yeast plasma membrane. In high concentrations, CHX causes coagulation of intracellular components. One of the reasons for the popularity of CHX is its substantivity (ie, continued antimicrobial effect), because CHX binds to hard tissue and remains antimicrobial. However, similar to other endodontic disinfecting agents, the activity of CHX depends on the pH and is also greatly reduced in the presence of organic matter.

Several studies have compared the antibacterial effect of NaOCl and 2% CHX against intracanal infection and have shown little or no difference between their antimicrobial effectiveness. Although bacteria may be killed by CHX, the biofilm and other organic debris are not removed by it. Residual organic tissue may have a negative effect on the quality of the seal by the permanent root filling, necessitating the use of NaOCl during instrumentation. However, CHX does not cause erosion of dentin like NaOCl does as the final rinse after EDTA, and therefore 2% CHX may be a good choice for maximized antibacterial effect at the end of the chemomechanical preparation.

Most of the research on the use of CHX in endodontics is carried out using in vitro and ex vivo models and gram-positive test organisms, mostly *E faecalis*. It is therefore possible that the studies have given an overpositive picture of the usefulness of CHX as an antimicrobial agent in endodontics. More research is needed to identify the optimal irrigation regimen for various types of endodontic treatments. CHX is marketed as a water-based solution and as a gel (with Natrosol). Some studies have indicated that the CHX gel has a slightly better performance than the CHX liquid but the reasons for possible differences are not known.

**Other Irrigating Solutions**

Other irrigating solutions used in endodontics have included sterile water, physiologic saline, hydrogen peroxide, urea peroxide, and iodine compounds. All of these except iodine compounds lack antibacterial activity when used alone, and they do not
dissolve tissue either. Therefore there is no good reason for their use in canal irrigation in routine cases. In addition, water and saline solutions bear the risk of contamination if used from containers that have been opened more than once. Iodine potassium iodide (eg, 2% and 4%, respectively) has considerable antimicrobial activity but no tissue-dissolving capability\(^{38,39}\) and it could be used at the end of the chemomechanical preparation like CHX. However, some patients are allergic to iodine, which must be taken into consideration.

**Interactions Between Irrigating Solutions**

Hypochlorite and EDTA are the 2 most commonly used irrigating solutions. As they have different characteristics and tasks, it has been tempting to use them as a mixture. However, EDTA (and CA) instantaneously reduces the amount of chlorine when mixed with sodium hypochlorite, resulting in the loss of NaOCl activity. Thus, these solutions should not be mixed.\(^{40}\)

CHX has no tissue-dissolving activity and there have been efforts to combine CHX with hypochlorite for added benefits from the 2 solutions. However, CHX and NaOCl are not soluble in each other; a brownish-orange precipitate is formed when they are mixed (Fig. 4). The characteristics of the precipitate and the liquid phase have not been thoroughly examined, but the precipitate prevents the clinical use of the mixture. Atomic absorption spectrophotometry has indicated that the precipitate contains iron, which may be the reason for the orange development.\(^{41}\) Presence of parachloroani-line, which may have mutagenic potential, has also been demonstrated in the precipitate.\(^{42,43}\)

Mixing CHX and EDTA immediately produces a white precipitate (Fig. 5). Although the properties of the mixture and the cleared supernatant have not been thoroughly studied, it seems that the ability of EDTA to remove the smear layer is reduced.

Many clinicians mix NaOCl with hydrogen peroxide for root-canal irrigation. Despite more vigorous bubbling, the effectiveness of the mixture has not been shown to be

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**Fig. 4.** Orange precipitate formed by mixing chlorhexidine with sodium hypochlorite.
better than that of NaOCl alone.\textsuperscript{32} However, combining hydrogen peroxide with CHX in an ex vivo model\textsuperscript{32,44} resulted in a considerable increase in the antibacterial activity of the mixture compared with the components alone in an infected dentin block. However, there are no data concerning the use or effectiveness of the mixture in clinical use.

**Combination Products**

Although some of the main irrigating solutions cannot be mixed without loss of activity or development of potentially toxic by-products, several combination products are on the market, many with some evidence of improved activity and function. Surface-active agents have been added to several different types of irrigants to lower their surface tension and to improve their penetration in the root canal. In the hope of better smear-layer removal, detergents have been added to some EDTA preparations (eg, SmearClear (Fig. 6))\textsuperscript{45} and hypochlorite (eg, Chlor-XTRA (Fig. 7) and White King). Detergent addition has been shown to increase the speed of tissue dissolution by hypochlorite.\textsuperscript{46} No data are available on whether dentin penetration is also improved. Recently, a few studies have been published in which the antibacterial activity of a chlorhexidine product with surface-active agents (CHX-Plus; see Fig. 7) has been compared with regular CHX, both with 2% chlorhexidine concentrations. The studies\textsuperscript{47,48} have shown superior killing of planktonic and biofilm bacteria by the combination product. There are no studies about whether adding surface-active agents increases the risk of the irrigants escaping to the periapical area in clinical use.

MTAD (a mixture of tetracycline isomer, acid, and detergent, Biopure, Tulsa Dentsply, Tulsa, OK, USA) and Tetraclean are new combination products for root-canal irrigation that contain an antibiotic, doxycycline.\textsuperscript{49–51} MTAD and Tetraclean are
designed primarily for smear-layer removal with added antimicrobial activity. Both contain CA, doxycycline, and a detergent. They differ from each other in CA concentration and type of detergent included. They do not dissolve organic tissue and are intended for use at the end of chemomechanical preparation after sodium hypochlorite. Although earlier studies showed promising antibacterial effects by MTAD, recent studies have indicated that an NaOCl/EDTA combination is equally or more effective.

Fig. 6. SmearClear is a combination product containing EDTA and a detergent.

Fig. 7. Chlor-XTRA and CHX-Plus are combination products whose tissue dissolution or antibacterial properties have been improved by specific surface-active agents.
than NaOCl/MTAD.\textsuperscript{54,55} Comparative studies on MATD and Tetraclean have indicated better antibacterial effects by the latter.\textsuperscript{56} Although a mixture containing an antibiotic may have good short-term and long-term effects, concerns have been expressed regarding the use of tetracycline (doxycycline) because of possible resistance to the antibiotic and staining of the tooth hard tissue, which has been demonstrated by exposure to light in an in vitro experiment.\textsuperscript{57} However, no report of in vivo staining has been published.

**CHALLENGES OF IRRIGATION**

**Smear Layer**

Removal of the smear layer is straightforward and predictable when the correct irrigants are used. Relying on EDTA alone or other irrigants with activity against the inorganic matter only, however, results in incomplete removal of the layer. Therefore, use of hypochlorite during instrumentation cannot be omitted (**Fig. 8**). The smear layer is created only on areas touched by the instruments. Delivery of irrigants to these areas is usually unproblematic, with the possible exception of the most apical canal, depending on canal morphology and the techniques/equipment used for irrigation. However, careless irrigation, with needles introduced only to the coronal and middle parts of the root canal, is likely to result in incomplete removal of the smear layer in the apical root canal.

**Dentin Erosion**

One of the goals of endodontic treatment is to protect the tooth structure so that the physical procedures and chemical treatments do not cause weakening of the dentin/root. Erosion of dentin has not been studied much; however, there is a general consensus that dentin erosion may be harmful and should be avoided. A few studies have shown that long-term exposure to high concentrations of hypochlorite can lead to considerable reduction in the flexural strength and elastic modulus of dentin.\textsuperscript{19} These studies have been performed in vitro using dentin blocks, which may allow artificially deep penetration of hypochlorite into dentin. However, even short-term irrigation with hypochlorite after EDTA or CA at the end of chemomechanical preparation causes strong erosion of the canal-wall surface dentin (**Fig. 9**).\textsuperscript{20} Although it is not known for sure whether surface erosion is a negative issue or if, for example, it could improve dentin bonding for posts, it is the authors’ opinion that hypochlorite irrigation after

![Fig. 8. Instrumented canal wall after removal of the smear layer by NaOCl and EDTA.](image-url)
demineralization agents should be avoided. Instead, chlorhexidine irrigation could be used for additional disinfection at the end of the treatment.

**Cleaning of Uninstrumented Parts of the Root-canal System**

Irrigation is most feasible in the instrumented areas because the irrigation needle can follow the smooth path created by the instruments. Cleaning and removing of necrotic tissue, debris, and biofilms from untouched areas rely completely on chemical means, and sufficient use of sodium hypochlorite is the key factor in obtaining the desired results in these areas (Fig. 10). A recent study showed that untouched areas, in particular anastomoses between canals, are frequently packed with debris during instrumentation. Visibility in micro-CT scans indicates that the debris also contain a considerable proportion of inorganic material (Fig. 11). Although at present it is not known how these debris can best be removed (if at all), it is likely that physical agitation (eg, ultrasound) and the use of demineralizing agents are needed in addition to hypochlorite.

**Biofilm**

Biofilm (Fig. 12) can be removed or eliminated through the following methods: mechanical removal by instruments (effective only in some areas of the root canal);

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**Fig. 9.** Considerable erosion of canal-wall dentin occurs when hypochlorite is used after EDTA or CA.

**Fig. 10.** Canal-wall dentin in an uninstrumented area after hypochlorite irrigation has removed (dissolved) tissue remnants and predentin, revealing the large calcosphereites that have already joined mineralized dentin.
dissolution by hypochlorite; and detachment by ultrasonic energy. Other chemical means, such as chlorhexidine, can kill biofilm bacteria if allowed a long enough contact time. However, as they lack tissue-dissolving ability, the dead microbial biomass stays in the canal if not removed mechanically or dissolved by hypochlorite. Any remaining organic matter, microbes, or vital or necrotic tissue jeopardizes the integrity of the seal of the root filling. Therefore the goal of the treatment is not only to kill the microbes in the root canal but also to remove them as completely as possible.

Safety versus Effectiveness in the Apical Root Canal

Irrigation must maintain a balance between 2 important goals: safety and effectiveness. This point is particularly true with the most important irrigant, sodium hypochlorite, but other irrigants can also cause pain and other problems if they gain access to the periapical tissues. Effectiveness is often jeopardized in the apical root canal by restricting anatomy and valid safety concerns. However, the eradication of the microbes in the apical canal should be of key importance to the success of endodontic

Fig. 11. An anastomosis between 2 joining canals has been packed with debris during rotary instrumentation.

Fig. 12. Bacteria growing on dentin surface; early stages of biofilm formation.
treatment. Sufficient exchange of hypochlorite and other irrigants in this area while keeping the apical pressure of the solutions minimal is the obvious goal of irrigation of the apical root canal. A better understanding of fluid dynamics and the development of new needle designs and equipment for irrigant delivery are the 2 important areas to deal with in the challenges of irrigating the most apical part of the canal. These areas are discussed in the following sections.

**COMPUTATIONAL FLUID DYNAMICS IN THE ROOT-CANAL SPACE**

Computational fluid dynamics (CFD) is a new approach in endodontic research to improve our understanding of fluid dynamics in the special anatomic environment of the root canal. Fluid flow is commonly studied in 1 of 3 ways: experimental fluid dynamics; theoretic fluid dynamics; and computational fluid dynamics (Fig. 13). CFD is the science that focuses on predicting fluid flow and related phenomena by solving the mathematical equations that govern these processes. Numerical and experimental approaches play complementary roles in the investigation of fluid flow. Experimental studies have the advantage of physical realism; once the numerical model is experimentally validated, it can be used to theoretically simulate various conditions and perform parametric investigations. CFD can be used to evaluate and predict specific parameters, such as the streamline (Fig. 14), velocity distribution of irrigant flow in the root canal (Fig. 15), wall flow pressure, and wall shear stress on the root-canal wall, which are difficult to measure in vivo because of the microscopic size of the root canals.

In CFD studies, no single turbulence model is universally accepted for different types of flow environments. The use of an unsuitable turbulence model may lead to potential numerical errors and affect CFD results. Gao and colleagues found that CFD analysis based on a shear stress transport (SST) $\kappa-\omega$ turbulence model

![Particle tracking during irrigation simulated by a CFD model.](image)
was in close agreement with the in vitro irrigation model. CFD based on an SST $k-\omega$ turbulence model has the potential to serve as a platform for the study of root-canal irrigation.

The irrigant velocity on the canal wall is considered a highly significant factor in determining the replacement of the irrigant in certain parts of the root canal and

![Image](image1.png)

**Fig. 14.** Streamline provides visualization of the irrigant flow in the canal.

![Image](image2.png)

**Fig. 15.** Velocity contour and vectors colored by velocity magnitude in an SST $k-\omega$ turbulence model. High-velocity flow seen in the needle lumen and in the area of the side vent.
in the flush effect, therefore directly influencing the effectiveness of irrigation. In a turbulent flow, there is a viscous sublayer that is a thin region next to a wall, typically only 1% of the boundary-layer thickness, in which turbulent mixing is impeded and transport occurs partly or, as the limit of the wall is approached, entirely by viscous diffusion. From turbulent structure measurements of pipe flow, the regions of maximum production and maximum dissipation are just outside the viscous sublayer. Hence, the fastest flow is found in the turbulent boundary, whereas the minimum velocity is observed on the wall of all root-canal irrigations. Some of the goals of CFD studies in endodontics are to improve needle-tip design for effective and safe delivery of the irrigant and to optimize the exchange of irrigating solutions in the peripheral parts of the canal system.

IRRIGATION DEVICES AND TECHNIQUES

The effectiveness and safety of irrigation depends on the means of delivery. Traditionally, irrigation has been performed with a plastic syringe and an open-ended needle into the canal space. An increasing number of novel needle-tip designs and equipment are emerging in an effort to better address the challenges of irrigation.

Syringes

Plastic syringes of different sizes (1–20 mL) are most commonly used for irrigation (Fig. 16). Although large-volume syringes potentially allow some time-savings, they are more difficult to control for pressure and accidents may happen. Therefore, to maximize safety and control, use of 1- to 5-mL syringes is recommended instead of the larger ones. All syringes for endodontic irrigation must have a Luer-Lok design. Because of the chemical reactions between many irrigants, separate syringes should be used for each solution.

Needles

Although 25-gauge needles were commonplace for endodontic irrigation a few years ago, they were first replaced by 27-G needles, now 30-G and even 31-G needles are taking over for routine use in irrigation. As 27 G corresponds to International Standards

Fig. 16. Plastic syringes for irrigation.
Organization size 0.42 and 30 G to size 0.31, smaller needle sizes are preferred. Several studies have shown that the irrigant has only a limited effect beyond the tip of the needle because of the dead-water zone or sometimes air bubbles in the apical root canal, which prevent apical penetration of the solution. However, although the smaller needles allow delivery of the irrigant close to the apex, this is not without safety concerns. Several modifications of the needle-tip design have been introduced in recent years to facilitate effectiveness and minimize safety risks (Figs. 17 and 18). There are few comparative data about the effect of needle design on irrigation effectiveness; it is hoped that ongoing CFD and clinical studies will change this situation.

**Gutta-percha Points**

The recognition of the difficulty of apical canal irrigation has led to various innovative techniques to facilitate the penetration of solutions in the canal. One of these includes the use of apically fitting gutta-percha cones in an up-and-down motion at the working length. Although this facilitates the exchange of the apical solution, the overall volume of fresh solution in the apical canal is likely to remain small. However, the benefits of gutta-percha point assisted irrigation have been shown in 2 recent studies.64,65

**EndoActivator**

EndoActivator (Advanced Endodontics, Santa Barbara, CA, USA) is a new type of irrigation facilitator. It is based on sonic vibration (up to 10,000 cpm) of a plastic tip in the root canal. The system has 3 different sizes of tips that are easily attached (snap-on) to the handpiece that creates the sonic vibrations (Fig. 19). EndoActivator does not deliver new irrigant to the canal but it facilitates the penetration and renewal of the irrigant in the canal. Two recent studies have indicated that the use of EndoActivator facilitates irrigant penetration and mechanical cleansing compared with needle irrigation, with no increase in the risk of irrigant extrusion through the apex.66,67

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**Fig. 17.** Four different needle designs, produced by computerized mesh models based on true and virtual needles.
Vibringe

Vibringe (Vibringe BV, Amsterdam, The Netherlands) is a new sonic irrigation system that combines battery-driven vibrations (9000 cpm) with manually operated irrigation of the root canal (Fig. 20). Vibringe uses the traditional type of syringe/needle delivery but adds sonic vibration. No studies can be found on Medline.

RinsEndo

The RinsEndo system (Durr Dental Co) is based on a pressure-suction mechanism with approximately 100 cycles per minute.68 A study of the safety of several irrigation systems reported that the risk of overirrigation was comparable with manual and RinsEndo irrigation, but higher than with EndoActivator or the EndoVac system.67 Not enough data are available to draw conclusions about the benefits and possible risks of the RinsEndo system.

EndoVac

EndoVac (Discus Dental, Culver City, CA, USA) represents a novel approach to irrigation as, instead of delivering the irrigant through the needle, the EndoVac system is based on a negative-pressure approach whereby the irrigant placed in the pulp chamber is sucked down the root canal and back up again through a thin needle with a special design (Fig. 21). There is evidence that, compared with traditional needle irrigation and some other systems, the EndoVac system lowers the risks associated with irrigation close to the apical foramen considerably.67 Another advantage of the reversed flow of irrigants may be good apical cleaning at the 1-mm level and a strong antibacterial effect when hypochlorite is used, as shown by recent studies.69,70

Fig. 18. Flexiglide needle for irrigation also easily follows curved canals.

Fig. 19. (A) EndoActivator with the large (blue) plastic tip. (B) Same tip in sonic motion.
The use of ultrasonic energy for cleaning of the root canal and to facilitate disinfection has a long history in endodontics. The comparative effectiveness of ultrasonics and hand-instrumentation techniques has been evaluated in several earlier studies. Most of these studies concluded that ultrasonics, together with an irrigant, contributed to a better cleaning of the root-canal system than irrigation and hand-instrumentation alone. Cavitation and acoustic streaming of the irrigant contribute to the biologic-chemical activity for maximum effectiveness. Analysis of the physical mechanisms of the hydrodynamic response of an oscillating ultrasonic file suggested that stable and transient cavitation of a file, steady streaming, and cavitation microstreaming all contribute to the cleaning of the root canal. Ultrasonic files must have free movement in the canal without making contact with the canal wall to work effectively. Several studies have indicated the importance of ultrasonic preparation for optimal

**Fig. 20.** Vibringe irrigator creates sonic vibrations in the syringe and needle.

**Ultrasound**

The use of ultrasonic energy for cleaning of the root canal and to facilitate disinfection has a long history in endodontics. The comparative effectiveness of ultrasonics and hand-instrumentation techniques has been evaluated in several earlier studies. Most of these studies concluded that ultrasonics, together with an irrigant, contributed to a better cleaning of the root-canal system than irrigation and hand-instrumentation alone. Cavitation and acoustic streaming of the irrigant contribute to the biologic-chemical activity for maximum effectiveness. Analysis of the physical mechanisms of the hydrodynamic response of an oscillating ultrasonic file suggested that stable and transient cavitation of a file, steady streaming, and cavitation microstreaming all contribute to the cleaning of the root canal. Ultrasonic files must have free movement in the canal without making contact with the canal wall to work effectively. Several studies have indicated the importance of ultrasonic preparation for optimal

**Fig. 21.** EndoVac system uses negative pressure to make safe and effective irrigation of the most apical canal possible. The irrigant in the pulp chamber is sucked down the root canal and back up again via the needle, opposite to the classic method of irrigation.
debridement of anastomoses between double canals, isthmuses, and fins. The effectiveness of ultrasonics in the elimination of bacteria and dentin debris from the canals has been shown by several studies. However, not all studies have supported these findings.

Van der Sluis and colleagues suggested that a smooth wire during ultrasonic irrigation is as effective as a size 15 K-file in the removal of artificially placed dentin debris in grooves in simulated root canals in resin blocks. It is possible that preparation complications are less likely to occur with an ultrasonic tip with a smooth, inactive surface.

SUMMARY

Irrigation has a key role in successful endodontic treatment. Although hypochlorite is the most important irrigating solution, no single irrigant can accomplish all the tasks required by irrigation. Detailed understanding of the mode of action of various solutions is important for optimal irrigation. New developments such as CFD and mechanical devices will help to advance safe and effective irrigation.

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