Review of Contemporary Irrigant Agitation Techniques and Devices

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Abstract

Introduction: Effective irrigant delivery and agitation are prerequisites for successful endodontic treatment. **Methods:** This article presents an overview of the irrigant agitation methods currently available and their debridement efficacy. **Results:**Technological advances during the last decade have brought to fruition new agitation devices that rely on various mechanisms of irrigant transfer, soft tissue debridement, and, depending on treatment philosophy, removal of smear layers. These devices might be divided into the manual and machine-assisted agitation systems. Overall, they appear to have resulted in improved canal cleanliness when compared with conventional syringe needle irrigation. Despite the plethora of *in vitro* studies, no well-controlled study is available. This raises imperative concerns on the need for studies that could more effectively evaluate specific irrigation methods by using standardized debris or biofilm models. In addition, no evidence-based study is available to date that attempts to correlate the clinical efficacy of these devices with improved treatment outcomes. Thus, the question of whether these devices are really necessary remains unresolved. There also appears to be the need to refocus from a practice management perspective on how these devices are perceived by clinicians in terms of their practicality and ease of use. **Conclusions:** Understanding these fundamental issues is crucial for clinical scientists to improve the design and user-friendliness of future generations of irrigant agitation systems and for manufacturers' contentions that these systems play a pivotal role in contemporary endodontics. *(J Endod 2009;35:791–804)*

Key Words

Agitation, debris, irrigation, machine-assisted, manual, smear layer

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Removal of vital and necrotic remnants of pulp tissues, microorganisms, and microbial toxins from the root canal system is essential for endodontic success (1–3). Although this might be achieved through chemomechanical debridement (4–6), it is impossible to shape and clean the root canal completely (7–16) because of the intricate nature of root canal anatomy (17–19). Even with the use of rotary instrumentation (20), the nickel-titanium instruments currently available only act on the central body of the canal, leaving canal fins, isthmi, and cul-de-sacs untouched after completion of the preparation (9–11, 20–24). These areas might harbor tissue debris, microbes, and their by-products (17–19), which might prevent close adaptation of the obturation material (25–27) and result in persistent periradicular inflammation (28, 29). Therefore, irrigation is an essential part of root canal debridement because it allows for cleaning beyond what might be achieved by root canal instrumentation alone (8, 30). Ideal root canal irrigants should meet all the conditions described above for endodontic success (31). However, there is no one unique irrigant that can meet all these requirements, even with the use of methods such as lowering the pH (32–34), increasing the temperature (35–39), as well as addition of surfactants to increase the wetting efficacy of the irrigant (40, 41). Thus, in contemporary endodontic practice, dual irrigants such as sodium hypochlorite (NaOCl) with ethylenediaminetetraacetic acid (EDTA) or chlorhexidine (CHX) (42–44) are often used as initial and final rinses to complement the shortcomings that are associated with the use of a single irrigant. More importantly, these irrigants must be brought into direct contact with the entire canal wall surfaces for effective action (31, 42, 45), particularly for the apical portions of small root canals.

Throughout the history of endodontics, endeavors have continuously been made to develop more effective irrigant delivery and agitation systems for root canal irrigation. These systems might be divided into 2 broad categories, manual agitation techniques and machine-assisted agitation devices (Fig. 1). The objective of this review was to present an overview of contemporary irrigant agitation methods available in endodontics and to provide a critique of their debridement efficacy.

Manual Agitation Techniques

Syringe Irrigation with Needles/Cannulas

Conventional irrigation with syringes has been advocated as an efficient method of irrigant delivery before the advent of passive ultrasonic activation (46). This technique is still widely accepted by both general practitioners and endodontists. The technique involves dispensing of an irrigant into a canal through needles/cannulas of variable gauges, either passively or with agitation. The latter is achieved by moving the needle up and down the canal space. Some of these needles are designed to dispense an irrigant through their most distal ends, whereas others are designed to deliver an irrigant laterally through closed-ended, side-vented channels (47). The latter design has been proposed to improve the hydrodynamic activation of an irrigant and reduce the chance of apical extrusion (48). It is crucial that the needle/cannula should remain loose inside the canal during irrigation. This allows the irrigant to reflux and causes more debris to be displaced coronally, while avoiding the inadvertent expression of the irrigant into periapical tissues. One of the advantages of syringe irrigation is that it allows comparatively easy control of the depth of needle penetration within the canal and the volume of irrigant that is flushed through the canal (46).

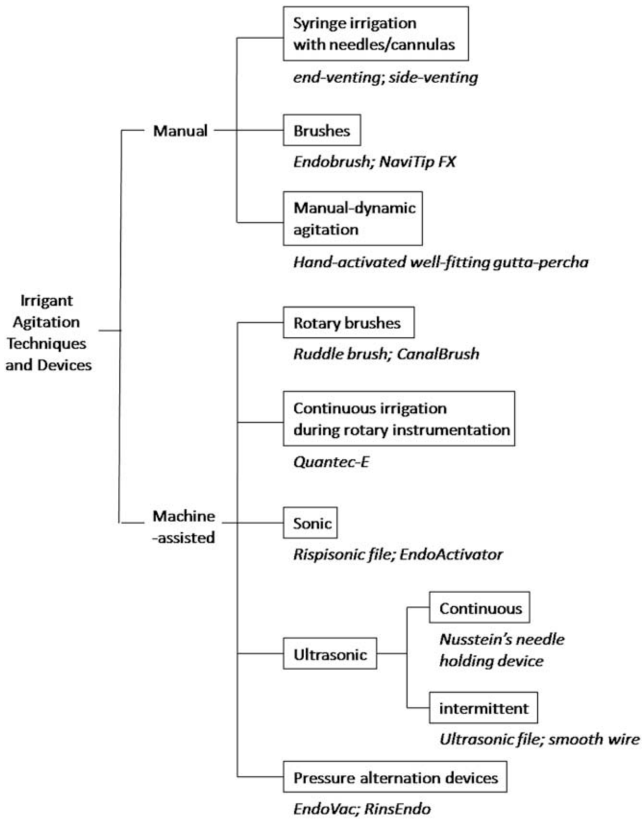

Figure 1. Summary of the types of irrigation agitation techniques and devices available for use in endodontics.

Nevertheless, the mechanical flushing action created by conventional hand-held syringe needle irrigation is relatively weak. After conventional syringe needle irrigation, inaccessible canal extensions and irregularities are likely to harbor debris and bacteria, thereby making thorough canal debridement difficult (21, 49–51). A previous study has shown that when conventional syringe needle irrigation was used, the irrigating solution was delivered only 1 mm deeper than the tip of the needle (52). This is a disturbing issue because the needle tip is often located in the coronal third of a narrow canal or, at best, the middle third of a wide canal (53). The penetration depth of the irrigating solution and its ability to disinfect dentinal tubules are therefore limited. The efficacy of syringe needle irrigation in such canals has been challenged (54–56). A study evaluating the effectiveness of 3 kinds of EDTA salts and NaOCl delivered alternately by using a Monoject syringe with a 27-gauge needle reported that the debridement properties of the solutions were adequate in the coronal two thirds of the canals but were less effective in the apical third (57). Even after EDTA and NaOCl irrigation was performed with a specially developed side-vented, closed-end needle that was placed within 1 mm of the working length, abundant smear layer remained in the apical region of the root canals (58, 59). Indeed, the need for adequate enlargement of the root canal to improve irrigation efficacy was recognized by Grossman (60) as early as 1943. It has been reported that hand-held syringe needle irrigation is less effective when the canal is enlarged to less than size 40 at the apex (61, 62). The data from the study of Falk and Sedgley (62) further showed that the efficacy of irrigation was significantly reduced in canals prepared to size 36 compared with size 60, but with no advantage provided by further enlargement to size 77. Therefore, clinicians need to balance the need for optimizing the mechanical efficacy of irrigation via canal enlargement with the negative consequences of inadvertent reduction in radicular dentin thickness and subsequent weakening of the root structure (63).

Factors that have been shown to improve the efficacy of syringe needle irrigation include closer proximity of the irrigation needle to the apex (53, 59, 64), larger irrigation volume (65), and smaller-gauge irrigation needles (53). Smaller-gauge needles/cannulas might be chosen to achieve deeper and more efficient irrigant replacement and debridement (46, 53, 64). However, the closer the needle tip is positioned to the apical tissue, the greater is the chance of apical extrusion of the irrigant (52, 53). Slow irrigant delivery in combination with continuous hand movement will minimize NaOCl accidents. With careful use, the benefits of deep intracanal irrigation should outweigh its risks (66). Moreover, irrigant flow rate and the exchange of irrigant should also be considered as factors directly influencing fluid flow beyond the needle/cannula (67). However, it is difficult to standardize and control the fluid flow rate during syringe needle irrigation (67). Thus, it would be advantageous to develop new application systems that increase dentin tubular penetration depths. This ensures more thorough debridement of the prepared canals, while minimizing apical extrusion to eliminate the cytotoxic effects of canal irrigants such as NaOCl on the periapical tissues (68, 69). The ultrasonic irrigation systems discussed subsequently in this review have the potential to achieve these goals (70, 71).

Brushes

Strictly speaking, brushes are not directly used for delivering an irrigant into the canal spaces. They are adjuncts that have been designed for debridement of the canal walls or agitation of root canal irrigant. They might also be indirectly involved with the transfer of irrigants within the canal spaces. Recently, a 30-gauge irrigation needle covered with a brush (NaviTip FX; Ultradent Products Inc, South Jordan, UT) was introduced commercially. A recent study reported improved cleanliness of the coronal third of instrumented root canal walls irrigated and agitated with the NaviTip FX needle over the brushless type of NaviTip needle (45). Nevertheless, the differences in the apical and middle thirds were not statistically significant. The results might have been improved if the brush-covered needle was mechanically activated in an active scrubbing action during the irrigation process to increase the efficiency of the brush (45). However, friction created between the brush bristles and the canal irregularities might result in the dislodgement of the radiolucent bristles in the canals that are not easily recognized by clinicians, even with the use of a surgical microscope.

During the early 1990s, similar findings indicating improved canal debridement with the use of canal brushes were reported by Keir et al (72). They used the Endobrush in an active brushing and rotary motion. The Endobrush (C&S Microinstruments Ltd, Markham, Ontario, Canada) is a spiral brush designed for endodontic use that consists of nylon bristles set in twisted wires with an attached handle and has a relatively constant diameter along the entire length. In that study, the brush was advanced to working length with a 90-degree rotary motion combined with a 2- to 3-mm push-pull motion for 1 minute at the conclusion of instrumentation. During debridement, the bristles of the brush were claimed to extend to the noninstrumented canal walls and into the fins, cul-de-sacs, and isthmi of the canal system to remove trapped tissue and debris. Indeed, the results in that study indicated that instrumentation with the Endobrush was significantly better than instrumentation alone in debriding the root canal (72). However, the Endobrush could not be used to full working length because of its size, which might lead to packing of debris into the apical section of the canal after brushing (72).

Manual-Dynamic Irrigation

An irrigant must be in direct contact with the canal walls for effective action. However, it is often difficult for the irrigant to reach the apical portion of the canal because of the so-called vapor lock effect (73, 74). Research has shown that gently moving a well-fitting gutta-percha master cone up and down in short 2- to 3-mm strokes (manual-dynamic irrigation) within an instrumented canal can produce an effective hydrodynamic effect and significantly improve the displacement and exchange of any given reagent (75, 76). This was recently confirmed by the studies of McGill et al (77) and Huang et al (78). These studies demonstrated that manual-dynamic irrigation was significantly more effective than an automated-dynamic irrigation system (RinsEndo; Dürr Dental Co, Bietigheim-Bissingen, Germany) and static irrigation. Several factors could have contributed to the positive results of manual-dynamic irrigation (77): (1) the push-pull motion of a well-fitting gutta-percha point in the canal might generate higher intracanal pressure changes during pushing movements, leading to more effective delivery of irrigant to the "untouched" canal surfaces; (2) the frequency of push-pull motion of the gutta-percha point (3.3 Hz, 100 strokes per 30 seconds) is higher than the frequency (1.6 Hz) of positive-negative hydrodynamic pressure generated by RinsEndo, possibly generating more turbulence in the canal; and (3) the push-pull motion of the gutta-percha point probably acts by physically displacing, folding, and cutting of fluid under "viscously-dominated flow" (79) in the root canal system. The latter probably allows better mixing of the fresh unreacted solution with the spent, reacted irrigant.

Although manual-dynamic irrigation has been advocated as a method of canal irrigation as a result of its simplicity and cost-effectiveness, the laborious nature of this hand-activated procedure still hinders its application in routine clinical practice. Therefore, there are a number of automated devices designed for agitation of root canal irrigants that are either commercially available or under production by manufacturers.

Machine-assisted Agitation Systems

Rotary Brushes

A rotary handpiece–attached microbrush has been used by Ruddle (80) to facilitate debris and smear layer removal from instrumented root canals. The brush includes a shaft and a tapered brush section. The latter has multiple bristles extending radially from a central wire core. During the debridement phase, the microbrush rotates at about 300 rpm, causing the bristles to deform into the irregularities of the preparation. This helps to displace residual debris out of the canal in a coronal direction. However, this product has not been commercially available since the patent was approved in 2001.

CanalBrush (Coltene Whaledent, Langenau, Germany) is an endodontic microbrush that has recently been made commercially available. This highly flexible microbrush is molded entirely from polypropylene and might be used manually with a rotary action. However, it is more efficacious when attached to a contra-angle handpiece running at 600 rpm. A recent report by Weise et al (81) showed that the use of the small and flexible CanalBrush with an irrigant removed debris effectively from simulated canal extensions and irregularities.

Continuous Irrigation During Rotary Instrumentation

The Quantec-E irrigation system (SybronEndo, Orange, CA) is a self-contained fluid delivery unit that is attached to the Quantec-E Endo System. It uses a pump console, 2 irrigation reservoirs, and tubing to provide continuous irrigation during rotary instrumentation (82). Ideally, continuous irrigant agitation during active rotary instrumentation would generate an increased volume of irrigant, increase irrigant contact time, and facilitate greater depth of irrigant penetration inside the root canal. This should result in more effective canal debridement compared with syringe needle irrigation. These speculations, however, were not supported by the work of Setlock et al (83). Compared with needle irrigation, Quantec-E irrigation did result in cleaner canal walls and more complete debris and smear layer removal in the coronal third of the canal walls. However, these advantages were not observed in the middle and apical thirds of the root canal (83). This is also confirmed by Walters et al (82), who found that there was no significant difference between standard syringe needle irrigation and irrigation with the Quantec-E pump.

Sonic Irrigation

Frequency and Oscillating Pattern of Sonic Instrument

Tronstad et al (84) were the first to report the use of a sonic instrument for endodontics in 1985. Sonic irrigation is different from ultrasonic irrigation in that it operates at a lower frequency (1–6 kHz) and produces smaller shear stresses (85). The sonic energy also generates significantly higher amplitude or greater back-and-forth tip movement. Moreover, the oscillating patterns of the sonic devices are different compared with ultrasonically driven instruments. A minimum oscillation of the amplitude might be considered a node, whereas a maximum oscillation of the amplitude represents an antinode. They have 1 node near the attachment of the file and 1 antinode at the tip of the file (86). When the movement of the sonic file is constrained, the sideway oscillation disappears. This results in a pure longitudinal file oscillation. This mode of vibration has been shown to be particularly efficient for root canal debridement, because it is largely unaffected by loading and exhibits large displacement amplitudes (86).

Effect of Sonic Irrigation

Sonic activation has been shown to be an effective method for disinfecting root canals (87). Table 1 is a summary of the research articles on sonic irrigation from 1985–2008 (84, 88–95). Sabins et al (94) and Stamos et al (89) surmised that the more powerful ultrasonic systems removed more dentin debris from the root canal than the less powerful sonic irrigation systems. The positive relationship between acoustic streaming velocity and frequency might explain the superior efficiency of the ultrasonic systems over the sonic systems. In contrast to their findings, Jensen et al (93) found no significant difference in residual debris between these 2 endosonic agitation techniques. However, preshaping of the canals was not mentioned in the study by Jensen et al, which could have accounted for their findings. Another possibility is that the time for sonic irrigation has been set at 3 minutes in the study by Jensen et al, which is longer than the 30 or 60 seconds used in the studies by Sabins et al and Stomas et al. Thus, it is reasonable to assume that when sonic irrigation is applied for a longer time period, there will probably be no difference in the remaining debris between these 2 endosonic agitation techniques. This hypothesis has to be tested in future work.

Conventionally, sonic irrigation is performed by using a Rispisonic file attached to a MM 1500 sonic handpiece (Medidenta International, Inc, Woodside, NY) after canal shaping. The Rispisonic files have a nonuniform taper that increases with file size. Because they are barbed, these files might inadvertently engage the canal wall and damage the finished canal preparation during agitation. The EndoActivator System (Dentsply Tulsa Dental Specialties, Tulsa, OK) is a more recently introduced sonically driven canal irrigation system (95). It consists of a portable handpiece and 3 types of disposable polymer tips of different sizes. These tips are claimed to be strong and flexible and do not break easily. Because they are smooth, they do not cut dentin. The EndoActivator System was reported to be able to effectively clean debris from lateral canals, remove the smear layer, and dislodge

TABLE 1. Research Articles on Sonic Irrigation, in Chronological Order

			Irrigation				Evaluation		
Year	Author (reference no.)	MAF	Irrigation instrument	PSI	Time	Irrigant	Evaluation method	Evaluation criteria	Isthmus
1985	Tronstad et al (84)	—	#20 K-file	No		2.5% NaOCl	SEM	Smear layer, dentin debris	No
1985	Barnett et al (88)	—	#20 K-file, #35 K-file	No		15% EDTA	—	—	No
1987	Stamos et al (89)	—	#25 K-file, #30 K-file	No	—	2.6% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1987	Reynolds et al (90)	—	#15, #20	No	—	Water	Histologic evaluation	Predentin and dentin debris	No
1989	Pugh et al (91)	—	—	No	2–3 min	Tap water	Injection with impression material and clearing	Canal morphology	No
1989	Walker and del Rio (92)	#25	#15, 20 Trisonic file, #15 Endostar file	No	80 s (Trisonic), 3 min (Endostar)	Tap water	Histologic evaluation	Debris	No
1999	Jensen et al (93)	#35/.10	#15 Rispisonic file	Yes	3 min	5.25% NaOCl	Stereomicroscopic evaluation	Dentin debris	No
2003	Sabins et al (94)	#35	#15 Rispisonic file	Yes	30 s, 60 s	5.25% NaOCl	Surgical operating microscope	Dentin debris	No
2008	Ruddle (95)	—	EndoActivator tips	Yes	—	—	—	—	—

MAF, master apical file; PSI, passive sonic irrigation; SEM, scanning electron microscopy.

clumps of simulated biofilm within the curved canals of molar teeth (76). During use, the action of the EndoActivator tip frequently produces a cloud of debris that can be observed within a fluid-filled pulp chamber. Vibrating the tip, in combination with moving the tip up and down in short vertical strokes, synergistically produces a powerful hydrodynamic phenomenon (96). In general, 10,000 cycles per minute (cpm) has been shown to optimize debridement and promote disruption of the smear layer and biofilm (76). A possible disadvantage of the polymer tips used in the EndoActivator system is that they are radiolucent. Although these tips are designed to be disposable and do not break easily during use, it would be difficult to identify them if part of a tip separates inside a canal. Presumably, these tips might be improved by incorporating a radiopacifier in the polymer.

Ultrasonics

Ultrasonic devices had long been used in periodontics before Richman (97) introduced ultrasound to endodontics as a means of canal debridement in 1957. In 1980, an ultrasonic unit designed by Martin et al (98) became commercially available for endodontic use. Compared with sonic energy, ultrasonic energy produces high frequencies but low amplitudes (99). The files are designed to oscillate at ultrasonic frequencies of 25–30 kHz, which are beyond the limit of human auditory perception (>20 kHz). They operate in a transverse vibration, setting up a characteristic pattern of nodes and antinodes along their length (99, 100). Table 2 is a summary of the research articles on ultrasonic irrigation from 1980–2008 (7, 16, 46, 54, 70, 71, 85, 89–94, 98, 101–145).

Two types of ultrasonic irrigation have been described in the literature. The first type is combination of simultaneous ultrasonic instrumentation and irrigation (UI). The second type, often referred to as passive ultrasonic irrigation (PUI), operates without simultaneous instrumentation. Studies on endosonic systems have shown that teeth prepared ultrasonically with UI devices have significantly cleaner canals than teeth prepared by conventional root canal filing alone (16, 89, 98, 103–105, 108, 112, 122, 127, 136, 137). Nevertheless, other studies have failed to demonstrate the superiority of UI as a primary cleaning and shaping technique (85, 90–92, 101, 110, 115–117, 126). These results might be attributed to the constraint of vibratory motion and cleaning efficacy of an ultrasonic file within the nonflared root canal space (85, 95). In addition, it is difficult to control the cutting of dentin during UI and hence the shape of the prepared root canal. Strip perforations as well as highly irregular-shaped canals were frequently produced (128, 146). Therefore, UI is not generally perceived as an alternative to conventional hand instrumentation (101, 125, 139, 147). On the contrary, the endodontic literature supports that it is more advantageous to apply ultrasonics after completion of canal preparation (31). All the ultrasonic irrigation discussed subsequently in this review will be referred to as PUI.

The term *PUI* was first used by Weller et al (101) to describe an irrigation scenario where there was no instrumentation, planing, or contact of the canal walls with an endodontic file or instrument (93). With this noncutting technology, the potential to create aberrant shapes within the root canal was reduced. During PUI, the energy is transmitted from an oscillating file or a smooth wire to the irrigant in the root canal by means of ultrasonic waves. The latter induces acoustic streaming and cavitation of the irrigant (85, 110, 115). The following section serves as a brief overview on PUI. The review by van der Sluis et al (100) provides a more detailed critique on this issue.

Irrigant Application Methods During PUI

Two flushing methods might be used during PUI, namely a continuous flush of irrigant from the ultrasonic handpiece or an intermittent

TABLE 2. Research Articles on Ultrasonic Irrigation, in Chronological Order

Year	Author (reference no.)	MAF	Irrigation: Irrigation instrument	Irrigation: PUI	Irrigation: Flushing method	Irrigation: Time	Irrigation: Irrigant	Evaluation: Evaluation method	Evaluation: Evaluation criteria	Evaluation: Isthmus
1980	Martin et al (98)	#30	K-file	No	Intermittent	3 min	Tap water	Quantification of dentin-cutting efficiency	Weight loss of dental hard tissue	No
1980	Weller et al (101)	#30	#15 finger plugger	Yes/no	Intermittent	20 s	Distilled water	Radioactively labeled debris model	Radioactivity	No
1982	Cameron (102)	—	Smooth broach	Yes	Intermittent	—	3.0% NaOCl	—	—	—
1982	Cunningham et al (103)	#15	#10, #15 endodontic file	No	\—	—	2.5% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1982	Cunningham et al (16)	#15	#10, #15 endodontic file	No	—	—	2.5% NaOCl	SEM	Dentin debris	No
1982	Cunningham (104)	#25	—	No	Intermittent	3 min	Saline; NaOCl	Bacteriologic evaluation	CFUs	No
1982	Martin and Cunningham (105)	—	—	—	—	—	2.5% NaOCl	Patient's subjective evaluation, radiography	Presence of postoperative pain and a radiolucency	No
1983	Cameron (106)	—	Smooth wire	Yes	Intermittent	1, 3, 5 min	3% NaOCl	SEM	Smear layer	No
1983	Cymerman et al (107)	—	#30 K file	No	—	2 min	Sterile saline	SEM	Canal wall cleanliness	No
1985	Goodman et al (108)	#25–#30	#15 finger plugger	Yes	—	3 min	2.62% NaOCl	Histologic evaluation	Pulpal tissue, dentin debris	Yes
1986	Collinson and Zakariasen (109)	—	—	Yes/no	—	2, 4, 6 min	No	Bacteriologic evaluation (*S. sanguis*)	CFUs	—
1987	Ahmad et al (85)	—	#15–#45 endosonic files	No	—	—	Water, 2.5% NaOCl	SEM	Smear layer; dentin debris	No
1987	Ahmad et al (110)		I, #15–35 files; II, #15 file	I, No; II, yes		I, 4 min; II, 5 min	I, 2.5% NaOCl; II, 1.0% NaOCl	SEM	Smear layer; dentin debris	No
1987	Alacam (70)	#40	#15 file	Yes	Intermittent	3 min	5% NaOCl alone; 5% NaOCl + 3% H_2O; 17%EDTA; 2% glutaraldehyde; sterile saline	SEM	Smear layer	No
1987	Cameron (111)	#40–#50	Smooth broach	Yes	Intermittent	2 min	Distilled water; 0.5%, 1%, 2%, 4% NaOCl	SEM	Smear layer; dentin debris	No
1987	Lev et al (112)	#25–#30	#20 file	Yes	Continuous	1 min; 3 min	2.62% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1987	Reynolds et al (90)	—	#15, #20, #25 files	No	—	—	Water; 2.6% NaOCl	Histologic evaluation	Predentin and dentin debris	No

(*Continued*)

TABLE 2. *Continued*

			Irrigation					Evaluation		
Year	Author (reference no.)	MAF	Irrigation instrument	PUI	Flushing method	Time	Irrigant	Evaluation method	Evaluation criteria	Isthmus
1987	Stamos et al (89)	#25; #30	I, Zipperer K–files; II, endosonic files	No	—	—	Water; 2.6% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1987	Sjögren and Sundqvist (113)	—	#20 endosonic file	No	—	3 min	0.5% NaOCl	Bacteriologic evaluation	CFUs	No
1987	Teplitsky et al (114)	#10–40	#15 endosonic file	Yes	—	1 min	No	Radiopaque dye method	Dye penetration depth	No
1988	Ahmad et al (115)	#40	#15 file	Yes	—	5 min	2.5% NaOCl	SEM	Smear layer, dentin debris	No
1988	Baker et al (116)	—	#15, #20, #25 files	No	Intermittent	—	2.625% NaOCl	SEM	Canal wall cleanliness	No
1988	Goldman et al (117)	#25	#15, #20, #25 K-files; #25, #35, #45 endosonic diamond files	No	Continuous	—	5.25% NaOCl	Root canal silicone model; SEM	Canal morphology; dentin debris	No
1989	Ahmad et al (118)	—	#15 K-file	Yes	—	1 min; 5 min; 15 min	No (*E. intermedius* suspension)	Bacteriologic evaluation	CFUs	No
1989	Ciucchi et al (119)	#35	#20 ultrasonic file	Yes	Continuous	2 min	3% NaOCl; 15% EDTA	SEM	Smear layer	No
1989	DeNunzio et al (120)	#25	#15, #20, #25	No	Continuous	1 min/file	Sterile saline	Bacteriologic evaluation (*S. marcescens*)	CFUs	No
1989	Druttman and Stock (121)	#15, #20, #25	#15, #20, #25 endosonic files	—	—	—	Distilled water	1% toluene dye method	Degree of dye displacement	No
1989	Haidet et al (122)	#25 or #30	#20 endosonic file	No	—	3 min	2.5% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1989	Metzler et al. (123)	—	#15 endosonic file	Yes	—	2 min	2.6% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1989	Pugh et al (91)	—	#15, #30 file	No	Continuous	1 min	Tap water	Injection with impression material and clearing	Canal morphology	No
1989	Walker and del Rio (92)	#25	#25 endosonic file; #15 Zipperer K-file	No	Continuous	1 min	Tap water	Histologic evaluation	Debris	No
1990	Ahmad et al (124)	—	#15 K-file	Yes	—	5 min	2.5% NaOCl	Bacteriologic evaluation	CFUs	No
1991	Abbott et al (125)	#45	#20 ultrasonic file with Cavi-Endo	Yes	Intermittent	4 min	Savlon solution*; 15% EDTAC and 1% NaOCl	SEM	Smear layer; dentin debris	No

(*Continued*)

TABLE 2. *Continued*

Year	Author (reference no.)	MAF	Irrigation: Irrigation instrument	Irrigation: PUI	Irrigation: Flushing method	Irrigation: Time	Irrigation: Irrigant	Evaluation: Evaluation method	Evaluation: Evaluation criteria	Evaluation: Isthmus
1991	Walker and del Rio (126)	#25	#15 endosonic file, #25 diamond file	No	Continuous	4 min (3 + 1)	Tap water; 2.6% NaOCl	Histologic evaluation	Canal wall planning and soft tissue debridement scores	No
1992	Archer et al (127)	#25/#30	#15 endosonic file	No	—	3 min	5.25% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
1992	Lumley et al (128)	#25	#15, #20, #25 endosonic files	No	—	2 min	2.6% NaOCl	SEM	Smear layer; dentin debris	No
1993	Cheung and Stock (54)	#35	—	Yes	Continuous	2 min	Distilled water; 0.5% NaOCl; 1% NaOCl; biological washing liquid	SEM; stained-debris scoring	Smear layer; dentin debris	No
1993	Lumley et al (129)	#30	#15 endosonic file	No	—	2 min	Sterile water	SEM	Smear layer; dentin debris	No
1995	Cameron et al (71)	#35, #40, #45, #50	#15 endosonic file, #20 endosonic file, smooth broach	Yes	—	30 s; 1 min	Tap water; 4% NaOCL; EDTAC	SEM	Dentin debris	No
1997	Siqueira et al (130)	#50	#15 ultrasonic file	Yes	Intermittent	1 min	4.0% NaOCl; 4.0% NaOCl + 3% H_2O_2	Bacteriologic evaluation	Occurrence of broth turbidity	No
1998	Huque et al (131)	#40 or #60 K-file	# 15 file	Yes	Intermittent	20 s	0.5%, 2.5%, 5.5%, 12% NaOCl; 15% EDTA; sterile water	Bacteriologic evaluation	CFUs	No
1999	Jensen et al (93)	# 35/.10	# 15 ultrasonic file	Yes	Intermittent	3 min	5.25% NaOCl	Stereomicroscopic evaluation	Dentin debris	No
2002	Guerisoli et al (132)	—	#15 file	No	Continuous	1 min	1% NaOCl; 15% EDTAC	SEM	Smear layer	No
2002	Mayer et al (133)	#45/.04	#15 K-file; a noncutting nickel-titanium wire	—	—	—	5.25% NaOCl; 17% EDTA	SEM	Smear layer; dentin debris	No
2003	Sabins et al (94)	#35	#15 ultrasonic file	Yes	Intermittent	30 s; 60 s	5.25% NaOCl	Surgical operating microscope	Dentin debris	No
2003	Spoleti et al (134)	#35 or #50	#20 file	Yes	Intermittent	10 s	Sterile saline	Bacteriologic evaluation (*S. aureus*, *S. viridans*, *E. coli*)	CFUs	No

(*Continued*)

TABLE 2. *Continued*

			Irrigation					Evaluation		
Year	Author (reference no.)	MAF	Irrigation instrument	PUI	Flushing method	Time	Irrigant	Evaluation method	Evaluation criteria	Isthmus
2003	Weber et al (135)	—	#20 file	Yes	Intermittent	1 min	2% CHX, 5.25% NaOCl	Bacteriologic evaluation (*S. sanguis*)	Zone of inhibition around agar	No
2004	Lee et al (136)	#20/.04; #20/.06; #20/.08	#15 file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole'model	Dentin debris	No
2004	Lee et al (137)	#50	#15 file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole'model	Dentin debris	No
2004	Gulabivala et al (138)	#30/.06	#20 ultrasonic file	Yes	Intermittent	—	Neutral anolyte; acidic anolyte; catholyte; catholyte alternated with neutral anolyte; 3% NaOCl; PBS	Bacteriologic evaluation	CFUs	No
2005	Gutarts et al (7)	#35/.12	25-gauge irrigating needle	Yes	Continuous	1 min	6.0% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris	Yes
2005	van der Sluis et al (139)	# 20/.08	#15 smooth file; #15 K file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole' model	Dentin debris	No
2005	van der Sluis et al (140)	#20/.06, #20/.08, #20/.10	#15 file	Yes	Intermittent	3 min	2.0% NaOCl	'Groove and hole' model	Dentin debris	No
2006	Passarinho-Neto et al (141)	#30/.04	#20 ultrasonic file	Yes	Intermittent	1 min; 3 min; 5 min	1.0% NaOCl	Histologic evaluation	Dentin debris	No
2006	van der Sluis et al (46)	#20/.10	#15/.02 smooth wire	Yes	Intermittent / continuous	3 min	Water; 2.0% NaOCl	'Groove and hole' model	Dentin debris	No
2007	Carver et al (142)	#30/.04; #30/.06	25-gauge irrigating needle	Yes	Continuous	1 min	6.0% NaOCl	Histologic evaluation	CFUs	No
2007	Munley and Goodell (143)	#40/.04	#15 FlexoFile; a yellow finger spreader	Yes	Intermittent	1 min; 3 min	6.0% NaOCl	Dental operating microscope	Dentin debris	No
2007	Burleson et al (144)	#30	25-gauge irrigating needle	Yes	Continuous	1 min	6.0% NaOCl	Histologic evaluation	Bacterial biofilm and necrotic debris	Yes
2008	Ferreira et al (145)	#40/.02	#15 file	Yes	Intermittent	3 min	Water; 0.2% CHX; 2.5% NaOCl	Histologic evaluation	Dentin debris	No

CFU, colony-forming unit; CHX, chlorhexidine; EDTAC, ethylenediaminetetraacetic acid plus Cetavlon; MAF, master apical file; PUI, passive ultrasonic irrigation; SEM, scanning electron microscopy.

*Savlon solution (0.3% cetrimide and 0.03% chlorhexidine).

flush technique by using syringe delivery (148). In the intermittent flush technique, the irrigant is injected into the root canal by a syringe and replenished several times after each ultrasonic activation cycle. The amount of irrigant flowing through the apical region of the canal can be controlled because both the depth of syringe penetration and the volume of irrigant administered are known. This is not possible with the use of the continuous flush regime. Both flushing methods have been shown to be equally effective in removing dentin debris from the root canal in an *ex vivo* model when the irrigation time was set at 3 minutes (46).

Continuous Ultrasonic Irrigation

Chlorine, which is responsible for the dissolution of organic tissues and the antibacterial property of NaOCl (31), is unstable and is consumed rapidly during the first phase of tissue dissolution, probably within 2 minutes (149). Therefore, an improved delivery system that is capable of continuous replenishment of root canal irrigants is highly desirable. Recently, a needle-holding adapter to an ultrasonic handpiece has been developed by Nusstein (150). During ultrasonic activation, a 25-gauge irrigation needle is used instead of an endosonic file. This enables ultrasonic activation to be performed at the maximum power setting without causing needle breakage. The unique feature of this needle-holding adapter is that the needle is simultaneously activated by the ultrasonic handpiece, while an irrigant is delivered from an intravenous tubing connected via a Luer-lok to an irrigation-delivering syringe. The irrigant can thus be delivered apically through the needle under a continuous flow instead of being intermittently replenished from the coronal access opening, as reported in previous studies (108, 112, 122, 123, 127). The use of this continuous irrigation technology for final irrigation after hand/rotary instrumentation had been investigated *in vivo*. The data from these studies demonstrated that 1 minute of continuous ultrasonic irrigation produced significantly cleaner canals and isthmi in both vital and necrotic teeth (7, 144). It also resulted in a significantly greater reduction of colony-forming unit (CFU) counts in infected necrotic human molars (142). These positive results might be attributed to the delivery of fresh irrigating solution within the root canal. The technique also resulted in a reduction of the time required for ultrasonic irrigation (121, 141).

Intermittent Flush Ultrasonic Irrigation

In intermittent flushed ultrasonic irrigation, the irrigant is delivered to the root canal by a syringe needle. The irrigant is then activated with the use of an ultrasonically oscillating instrument. The root canal is then flushed with fresh irrigant to remove the dislodged or dissolved remnants from the canal walls. Because most of the previous studies evaluated the effectiveness of ultrasonic irrigation by using the intermittent flush technique, the efficacy of this technique in removing pulpal tissues, dentin debris, smear layers, and bacteria from the root canal system will be briefly described.

Removal of Pulpal Tissues and Dentin Debris

There is a general consensus that PUI is more effective than syringe needle irrigation in removing pulpal tissue remnants and dentin debris (94, 108, 111, 123, 136). This might be due to the much higher velocity and volume of irrigant flow that are created in the canal during ultrasonic irrigation (137). It has been shown that large amounts of dentin debris remain in canal irregularities and oval-shaped canals after syringe irrigation (21, 29, 103, 108). During ultrasonic irrigation, oscillation of the file adjacent to canal irregularities might also have removed more debris from these hard-to-reach locations (129, 137). Nevertheless, Mayer et al (133) reported no significant difference in the extent of dentin debris removal between PUI and syringe irrigation. In that study, EDTA was left in the root canal before ultrasonic activation of the subsequently introduced NaOCl. Removal of EDTA before the delivery of NaOCl was not mentioned, which could have been responsible for the authors' findings. When compared with sonic irrigation, the more powerful ultrasonic irrigation technique has been shown to be capable of removing more debris (94). However, it is possible that both techniques might produce similar degrees of canal cleanliness when sonic irrigation is applied for a longer time period (93, 136, 137).

Removal of Smear Layers

A large body of evidence has been accumulated indicating that PUI with water as an irrigant did not remove the smear layer (55, 106, 111, 131). When PUI was used with 3% NaOCl, complete removal of smear layer was reported by Cameron (106, 111). These results were confirmed in subsequent studies by Alacam (70) and Huque et al (131) with different concentrations of NaOCl. Guerisoli et al (132) reported that smear layers were effectively removed from the apical, middle, and cervical thirds of the canal walls by ethylenediaminetetraacetic acid plus Cetavlon (EDTAC) and NaOCl by using a size 15 file energized by ultrasonic agitation. Other studies reported conflicting results on the increased efficacy of ultrasonic irrigation on smear layer removal. Although PUI was shown to be significantly better than syringe needle irrigation, Cheung and Stock (54) could not completely remove the smear layer by using PUI with 1% NaOCl for 10 seconds. Other studies (71, 119, 125) also demonstrated that PUI with EDTA or a combination of EDTA and NaOCl did not completely remove smear layers from the apical third of the canal walls.

Removal of Bacteria

Numerous investigations have demonstrated that the use of PUI after hand or rotary instrumentation resulted in a significant reduction of the number of bacteria (16, 98, 103, 104, 109, 113, 118, 120, 130, 134, 135) or achieved significantly better results than syringe needle irrigation (131, 134, 135). These positive results with the use of PUI might be attributed to 2 main factors. (1) High-power ultrasound causes de-agglomeration of bacterial biofilms via the action of acoustic streaming. De-agglomeration of biofilms within a root canal might render the resultant planktonic bacteria more susceptible to the bactericidal activity of NaOCl (151). (2) Cavitation might have produced temporary weakening of the cell membrane, making the bacteria more permeable to NaOCl.

Pressure Alternation Devices

There are 2 apparently dilemmatic phenomena associated with conventional syringe needle delivery of irrigants. It is desirable for the irrigants to be in direct contact with canal walls for effective debris debridement and smear layer removal. Yet, it is difficult for these irrigants to reach the apical portions of the canals because of air entrapment (152), when the needle tips are placed too far away from the apical end of the canals. Conversely, if the needle tips are positioned too close to the apical foramen, there is an increased possibility of irrigant extrusion from the foramen that might result in severe iatrogenic damage to the periapical tissues (153). Concomitant irrigant delivery and aspiration via the use of pressure alternation devices provide a plausible solution to this problem.

Early Experimental Protocols

The first experimental use of a pressure alternation irrigation technique was the non-instrumentation technology (NIT) invented by Lussi et al (154). This technique did not enlarge root canals because there was no mechanical instrumentation of the canal walls. Instead, canal debridement and dissolution of organic debris, including the predentin collagen matrix, were achieved solely with the use of low concentration NaOCl that was introduced to and removed from the canal by using alternating, subambient pressure fields. The latter created bubble implosion and hydrodynamic turbulence that facilitated penetration of the NaOCl into the canal ramifications. Although NIT was unique and successful *in vitro* (155, 156) in creating cleaning canals when compared with conventional syringe needle irrigation with either balanced force hand instrumentation or GT Rotary (Tulsa Dental) instrumentation, the technique was not considered safe in *in vivo* animal studies and did not proceed to human clinical trials. Nevertheless, the reduced-pressure sealer obturation protocol originally designed to support the filling of noninstrumented canals was subsequently evaluated *in vivo* for filling instrumented canals with different gutta-percha–sealer combinations (157). Clinical root canal obturations performed by using the reduced-pressure sealer obturation protocol demonstrated radiographic qualities that were equivalent to those filled with conventional filling techniques (158).

Another experimental pressure alternation irrigation system was introduced by Fukumoto et al (159). This system comprised an injection needle (external diameter, 0.41 mm; internal diameter, 0.19 mm; Nipro Co, Osaka, Japan) and an aspiration needle (external diameter, 0.55 mm; internal diameter, 0.30 mm; Terumo Co, Tokyo, Japan) connected to an apex locator (Root ZX; J Morita USA, Inc, Irvine, CA). The aspiration pressure of the unit was maintained at −20 kPa. The device was evaluated by using different placement positions of the injection needle and the aspiration needle for the efficacy of smear layer removal from the apical third of the canal walls and the frequency of extrusion of NaOCl from the apical foramen. The most reliable results were achieved when NaOCl was introduced by using a coronally placed injection needle and aspirated via placement of the aspiration needle at 2 mm from the apex. Of particular importance was that when the aspiration needle was placed either 2 or 3 mm from the apical end of the root, the Root ZX readings registered a value of 0.5, indicating that the irrigant had reached the instrumented end of the apical delta. The authors surmised that the discrepancy between the physical location of the aspiration needle and the Root ZX reading could be explained by the NaOCl and EDTA irrigants displacing air trapped between the tip of the aspirating needle and the root end.

Vapor Lock Effect

Air entrapment by an advancing liquid front in closed-end microchannels is a well-recognized physical phenomenon (160–163). The ability of a liquid to penetrate these closed-end channels is dependent on the contact angle of the liquid and the depth and size of the channel (73). Under all circumstances, these closed-end microchannels will eventually be flooded after sufficient time (hours to days) (73). This phenomenon of air entrapment and the time frame in which complete flooding occurs has practical clinical implications when irrigants are delivered by using syringe needles from the coronal or middle third of a root canal. Because endodontic irrigation is performed within a time frame of minutes instead of hours or days, air entrapment in the apical portion of the canal might preclude this region from contact or disinfection by the irrigant.

The aforementioned physical phenomenon has been referred to as the vapor lock effect in the endodontic literature. In the classic study by Senia et al (152), they demonstrated that NaOCl did not extend any closer than 3 mm from working length, even after the root apex was enlarged to a size 30. This might be attributed to the fact that NaOCl 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 (74). Because the apical vapor lock cannot be displaced within a clinically relevant time frame through simple mechanical actions, it prevents further irrigants from flowing into the apical region. More importantly, acoustic microstreaming and cavitation can only occur in a liquid phase. Therefore, once a sonic or ultrasonically activated tip leaves the irrigant and enters the apical vapor lock, acoustic microstreaming and/or cavitation becomes physically impossible (74).

A simple method to disrupt the vapor lock might be achieved via the use of a hand-activated well-fitting root filling material (77, 78) (eg, a size 40, 0.06 taper gutta-percha point) that is introduced to working length after instrumentation with the corresponding nickel-titanium rotary instrument (ie, size 40, 0.06 taper). This method, although cumbersome, eliminates the vapor lock because the space previously occupied by air is replaced by the root filling material, carrying with it a film of irrigant to the working length.

The EndoVac System

In the EndoVac system (Discus Dental, Culver City, CA), a macrocannula or microcannula is connected via tubing to a syringe of irrigant and the high-speed suction of a dental unit (74). The plastic macrocannula has a size 55 open end with a .02 taper and is attached to a titanium handle for gross, initial flushing of the coronal part of the root canal. The size 32 stainless steel microcannula has 4 sets of 3 laser-cut, laterally positioned, offset holes adjacent to its closed end. This is attached to a titanium finger-piece for irrigation of the apical part of the canal by positioning it at the working length. The microcannula can be used in canals that are enlarged to size 35 or larger. During irrigation, the delivery/evacuation tip delivers irrigant to the pulp chamber and siphons off the excess irrigant to prevent overflow. The cannula in the canal simultaneously exerts negative pressure that pulls irrigant from its fresh supply in 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 being delivered by negative pressure to working length. A recent study showed that the volume of irrigant delivered by the EndoVac system was significantly higher than the volume delivered by conventional syringe needle irrigation during the same time period (164). This study also supported that the use of the EndoVac system resulted in significantly more debris removal at 1 mm from the working length than needle irrigation. Because the device is new, no clinical study is available yet on its clinical debridement efficacy. Although the device is promoted rather vigorously (74, 165, 166), it is not known whether the adjunctive use of such a device increases treatment outcomes that use stringent evaluation criteria for either initial treatment (167–169) or retreatment of persistent endodontic infections (170, 171).

Apart from being able to avoid air entrapment, the EndoVac system is also advantageous in its ability to safely deliver irrigants to working length without causing their undue extrusion into the periapex (164). During conventional root canal irrigation, clinicians must be careful in determining how far an irrigation needle is placed into the canal. Recommendations for avoiding NaOCl accidents include not binding the needle in the canal, not placing the needle close to working length, and using a gentle flow rate (153). With the EndoVac, irrigant is pulled into the canal at working length and removed by negative pressure.

The RinsEndo System

The RinsEndo system (Dürr Dental Co) is another root canal irrigation device that is based on pressure-suction technology (48, 77). With this system, 65 μL of a rinsing solution oscillating at a frequency of 1.6 Hz is drawn from an attached syringe and transported to the root canal via an adapted cannula. During the suction phase, the used solution and air are extracted from the root canal and automatically merged with fresh rinsing solution. The pressure-suction cycles change approximately 100 times per minute.

The manufacturer of RinsEndo claims that the apical third of the canal might be effectively rinsed, with the cannula restricted to the coronal third of the root canal because of the pulsating nature of the fluid flow. This system has been shown in an extracted tooth model to be superior to conventional static irrigation in dentin penetration of a dye marker; however, a higher risk of apical extrusion of the irrigant was also observed (48). The effectiveness of the RinsEndo system in cleaning canal walls was more recently challenged by McGill et al (77). In view of the difficulty in the generation of realistic and standardized multispecies biofilm in extracted teeth, they used a split-tooth model containing stained solubilized collagen to simulate a bacterial biofilm along the canal walls. Within any limitations imposed by the model, RinsEndo was found to be less effective in removing the stained collagen from root canal walls when compared with manual-dynamic irrigation by hand agitation of the instrumented canals with well-fitting gutta-percha points. Similar to the EndoVac system, there is no clinical study available to date supporting either the clinical debridement efficacy or improvements in treatment outcomes that are associated with the use of the RinsEndo system.

Concluding Remarks and Directions for Future Research

Effective irrigant delivery and agitation are prerequisites for successful endodontic treatment. This article presents an overview of the irrigant agitation methods currently available and their debridement efficacy. Technological advances during the last decade have brought to fruition new agitation devices that rely on various mechanisms of irrigant transfer, soft tissue debridement, and, depending on treatment philosophy, removal of smear layers. These devices might be divided into the manual and machine-assisted agitation systems. Overall, they appeared to have resulted in improved canal cleanliness when compared with conventional syringe needle irrigation.

To date, the existing literature on microbial mass reduction after root canal irrigation (104, 109, 113, 120, 134) encompassed the use of CFU counts of planktonic bacteria culture as the gold standard method for evaluating disinfection efficacy. However, numerous *in vitro* studies have demonstrated the ability of multiple bacteria to form a biofilm architecture on root canal walls (172–175). With the advent of the biofilm concept, the increased resistance of bacterial strains in biofilms, compared with their planktonic, “free-floating” counterparts (176–178), raises concerns on the validity of laboratory studies that reported their results on the basis of liquid-grown cultures. Such an issue has been further elaborated recently by Ehrlich et al (179). They introduced the concept of bacteria plurality in an attempt to account for the chronicity of biofilm-related infections and the difficulty in eradicating such chronic infections by antibiotic therapy (179). One of the most important conceptual parameters to understanding bacterial persistence is the realization of phenotypic diversity within an infecting population of bacteria. Bacterial plurality also embodies the concept of genotypic diversity that includes 2 separate phenomena, namely genetic heterogeneity and genomic plasticity (179). These heterogeneities can provide the “primitive” biofilm community with great capacity to withstand challenges from host defense systems or from pharmaceuticals (179). The bacteria plurality concept helps to explain the chronicity of biofilm infections in endodontics. During the past few years, more and more *ex vivo* biofilm models that were grown in wells (180–183) or on root dentin (43, 172, 174) by using single (138, 183, 184) or multiple (185) bacteria species have been developed and used in dentistry (180–184, 186–188). However, the potential of biofilm experimentation in endodontics has not been fully exploited. The Zürich biofilm model (180), for example, is a well-developed oral biofilm model. However, it is dubious whether this supragingival plaque model might be applicable to the anaerobic ecological niches within the root canal space (173). Although the importance of developing standardized intracanal microbial biofilm models for endodontic experiments has been well-recognized, no study has yet been published on the validity of single species versus dual or multiple endodontic biofilm models. Thus, future studies involving the efficacy of selected irrigation regimens on bacteria eradication should be oriented to include clinically relevant endodontic bacterial biofilm models.

Despite the plethora of studies on the effectiveness of various endodontic irrigation regimens, it is noteworthy that no well-controlled clinical study is available in the current endodontic literature. This raises imperative concerns on the need for studies in endodontic science that could more effectively measure the efficiency of specific agitation methods for root canal irrigation with the use of standardized dentin debris or microbial biofilm models. Development of such an approach will not only boost the importance of reviewing the current literature but will serve as an inspiring guide for future investigations on endodontic debridement. In addition, from a practical point of view, no evidence-based study is available to date that attempts to correlate the clinical efficacy of these devices with improved treatment outcomes. Thus, the question of whether these devices are really necessary remains unresolved. There is a need to determine from a practice management perspective how these devices are perceived in terms of their practicality and ease of use. Understanding these fundamental issues is crucial for clinical scientists to improve the design and user-friendliness of future generations of irrigant agitation systems.

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