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Rinse, Refresh, Revitalize: The Evolution of Irrigation in Endodontics

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ABSTRACT: Irrigation in endodontics is vital for achieving successful root canal therapy, as it aids in the cleaning, disinfection, and shaping of the root canal system. The primary goals of endodontic irrigation are to remove debris, eliminate bacterial infections, and properly prepare the canal for sealing. Commonly used irrigation solutions have strong antimicrobial properties that provide broad-spectrum antibacterial activity, helping to remove the smear layer. Innovative techniques, such as ultrasonic irrigation, laser-assisted irrigation, and positive/negative pressure irrigation systems, have been developed to improve cleaning efficiency and enhance the penetration of irrigants into complex canal anatomies. These advances aim to disrupt biofilms, disinfect the canal system, and ensure the complete removal of contaminants, ultimately improving treatment outcomes. The application of specific irrigation protocols and tailored solutions for different canal conditions is critical to achieving the best irrigation results. Effective irrigation techniques are foundational to endodontic disinfection, ensuring both the mechanical and chemical preparation of the root canal system, preventing reinfection, and promoting successful healing.

Keywords: Root canal irrigation, irrigation solutions, endodontic disinfection, smear layer removal

I. INTRODUCTION:

Irrigation in endodontics is a vital step in root canal therapy, aimed at cleaning and disinfecting the root canal system.[1] The primary goals are to remove debris, bacteria, and infected tissue, ensuring the canal is adequately prepared for filling and sealing.[2] During irrigation, two key processes occur: the physical removal of macro debris through techniques like macro debris removal, and chemical disinfection, which eliminates microorganisms in the canal.[3] This step is crucial for creating an environment conducive to successful obturation.[4] Endodontic irrigation plays a pivotal role in treatment success by removing necrotic pulp, bacteria, biofilms, and debris.[5] Chemical solutions effectively target microorganisms in hard-to-reach areas, such as dentinal tubules, where mechanical instruments cannot reach, while mechanical instrumentation shapes the canal to optimize irrigation and ensure complete obturation. This dual approach enhances the disinfection process, combining mechanical and chemical actions to significantly improve treatment outcomes and ensure long-term success.[6]

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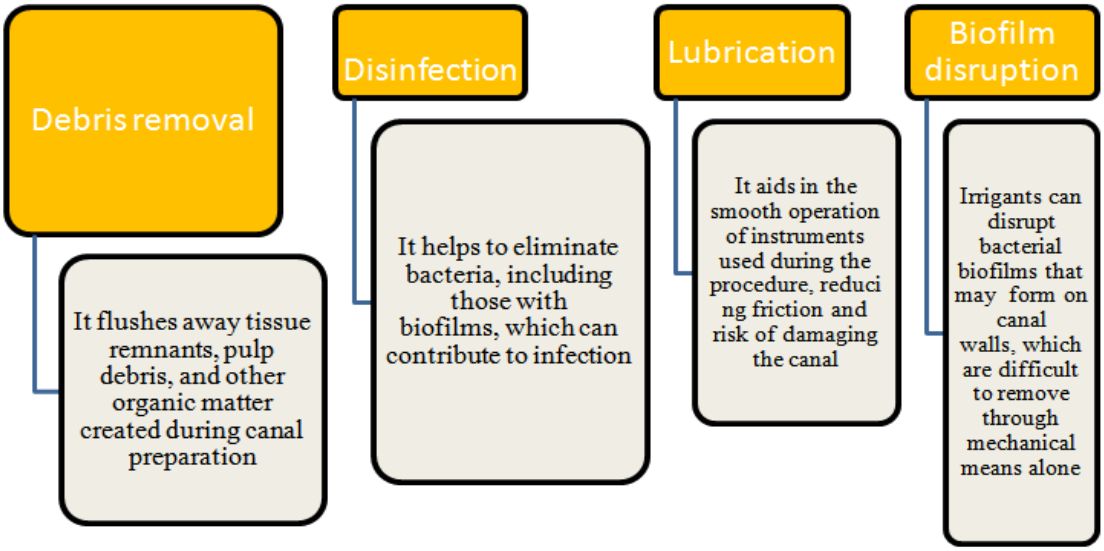

Figure 1: Functions of irrigants

Various irrigation techniques are used, including manual and machine-assisted methods (**Figure 2**). [7]

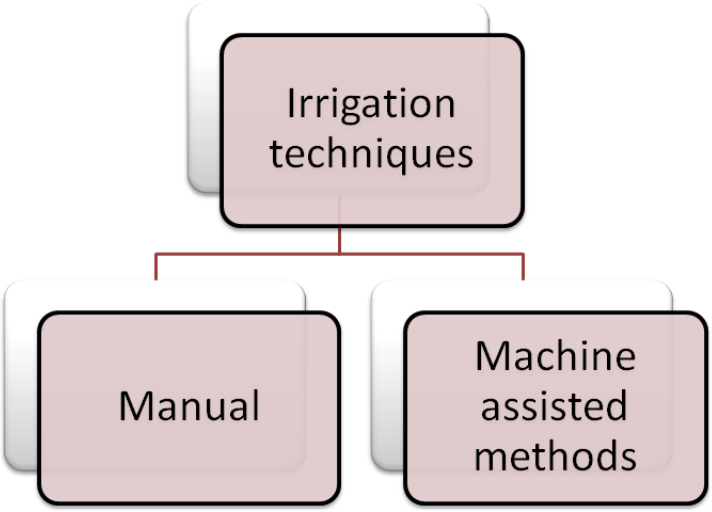

Figure 2: Irrigation techniques

Manual techniques utilize syringe needles, brushes, or files to agitate irrigants but often face challenges when cleaning complex canal anatomies.[8] Over time, needle designs have evolved to minimize the risk of irrigant extrusion beyond the root apex.[9] The use of potent irrigants like sodium hypochlorite (**Figure 3**), chlorhexidine (**Figure 4**), and Ethylene di amine tetracetic acid EDTA (**Figure 5**), combined with advanced debris removal techniques, ensures a sterile environment, significantly enhancing treatment outcomes. Sodium hypochlorite is valued for its strong antimicrobial and tissue-dissolving properties, while chlorhexidine offers broad-spectrum antimicrobial activity without tissue dissolution. EDTA effectively removes inorganic materials and the smear layer. Additional irrigants, such as saline (**Figure 6**), hydrogen peroxide (**Figure 7**), citric acid (**Figure 8**), iodine-potassium-iodide (**Figure 9**) and advanced solutions like bioglass (**Figure 10)**, MTAD (**Figure 11**), Q-Mix (**Figure 12**) and tetraclean (**Figure 13**), further improve disinfection and cleaning, ensuring a more effective and thorough treatment process.[14] This review highlights the significant advancements in irrigation techniques and their impact on root canal treatment success. Traditionally, irrigation involved manually delivering fluids to clear debris and disinfects the canal. However, innovations such as specialized needles, sonic and ultrasonic systems,

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and peristaltic pumps (**Figure 14**) have dramatically enhanced irrigant penetration, particularly in complex canal anatomies. The integration of mechanical shaping with chemical disinfection has been crucial in ensuring effective cleaning and microbial eradication, creating a cleaner, more sterile environment and ultimately increasing the likelihood of successful treatment outcomes.[15]

Figure 3: Sodium hypochlorite
Courtesy:https://www.dentganga.com/product/sodium-hypochorite-500ml-pack-

Figure 4: Chlorhexidene

Courtesy:https://www.arkhealth.com.au/Endodontics/Irrigation/pl.php

Figure 5: EDTA

Courtesy:https://dentalexpress.in/products/prevest-edta-solution

Figure 6: Normal saline
Courtesy:https://medimart.com/product/normal-saline-sodium-chloride-0-9-for-wound-irrigation-with-dual-flow-cap-100ml-squeeze-bottle-sterile/

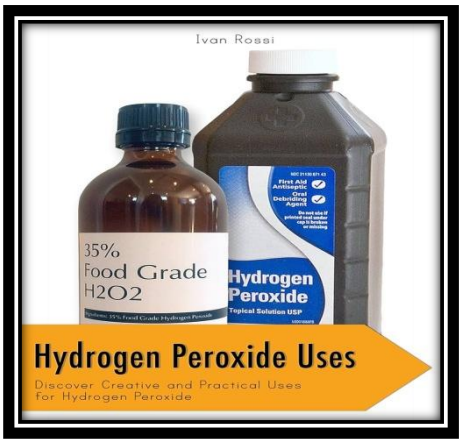

Figure 7: Hydrogen peroxide
Courtesy:https://www.amazon.in/Hydrogen-Peroxide-Uses-Discover-Practical-ebook/dp/B00SF8ITFC

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Figure 8: Citric acid
Courtesy:https://www.thedentistshop.com/Ammdent-Citocid-10-PERCENT-Citric-Acid?gtm_country=INDIA

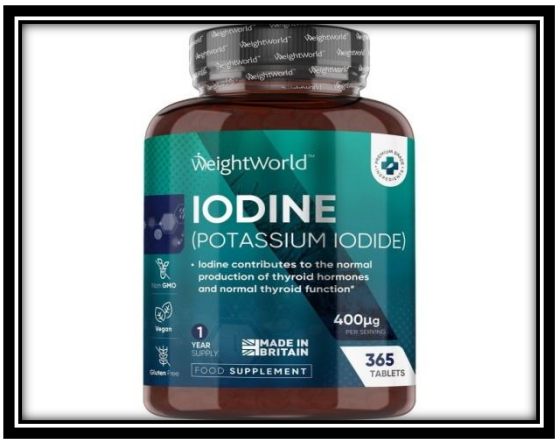

Figure 9: Iodine-potassium-iodide
Courtesy:
https://www.ebay.co.uk/p/13056460718

Figure 10: Bioglass
Courtesy:https://www.amazon.in/BIOGLASS-Gold-GIC-Restorative-Pack/dp/B08ZCD9G9Q

Figure 11: MTAD
Courtesy:https://www.dentsplysirona.com/en-ca/shop/product-page.html/BP-303326/biopure-mtad-antibacterial-root-canal-cleanser.html

Figure 12: Q-Mix
Courtesy:https://7157e75ac0509b6a8f5c5b19c577d01b9ccfe75d2f9e4b17ab55.ssl.cf1.rackcdn.com/DDGXQIVD-PDF-2-447492-4427858698.pdf

Figure 13: Tetraclean
Courtesy:https://www.dentaltix.com/en/blog/learn-all-about-irrigant-solutions-endodontics-complete-guide-dental-professionals

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Figure 14: Peristaltic pump
Courtesy:https://www.ottomed.com/peristaltic-water-irrigation-pump-gastroenterology

II. DISCUSSION:

The technique of manual irrigation with needles is often used in dental procedures, especially by general practitioners and endodontists, to clean and disinfect root canals. This process involves introducing an irrigant into the canal through needles or cannulas and utilizing mechanical agitation by moving the needle up and down within the canal.[16]

Equipment and Techniques:

Syringes: Plastic syringes of various sizes are commonly used for irrigation, with the general recommendation being syringes ranging from 1 to 5 mL for better control and safety (**Figure 15**). Larger syringes may be harder to manage and pose a higher risk of accidents. For safe usage, syringes must have a Luer-Lok design to ensure a secure connection. To prevent unwanted chemical reactions, different syringes should be used for different irrigation solutions.[17]

Figure 15: Syringes
Courtesy: https://www.kmedhealth.com/types-of-syringes/

Needles: Historically, 25-gauge needles were the standard for endodontic irrigation, but they have largely been replaced by smaller gauge needles, such as 27-gauge, 30-gauge, and 31-gauge, for improved precision and reduced risks. The smaller gauge needles, like the 27-gauge (ISO 0.42) and 30-gauge (ISO 0.31), are now preferred for routine use due to their ability to access narrower spaces more easily and minimize the risk of tissue trauma (**Figure 16**).[18]

Figure 16: Irrigation needles
Courtesy:https://www.physicsforceps.com/endo-irrigation?product_id=521

Vibringe system: It is a cutting-edge tool for endodontic irrigation, combining manual delivery with sonic energy activation of the irrigant. Featuring a cordless handpiece that connects to a disposable Luer-Lok syringe, it offers a single-button operation, automatic two-minute shut-off, battery indicator, and Light Emitting Diode feedback lights.[19] Research indicates that the Vibringe system outperforms conventional syringe-based irrigation, particularly in the apical third of the root canal, though it doesn't match the efficacy of passive ultrasonic irrigation. Innovations like smaller needle designs and systems like the Vibringe are advancing both the effectiveness and safety of endodontic irrigation (**Figure 17**).[20]

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Figure 17: Vibringe

Courtesy:https://www.dentalpractice.com.au/news/new-study-on-the-effectiveness-of-the-vibringe-system-for-canal-irrigation/88581751-9a65-c541-d98a-4f4212cdcf29

Irrivac needle pressure system: The Quantec irrigation system features both positive and negative pressure models for different stages of root canal treatment. The positive pressure model delivers sodium hypochlorite and removes debris, while the negative pressure model uses suction for final irrigation and cleaning. Both include titanium handpieces and caustic-resistant tubing. [21]The Quantec-E model provides continuous irrigation during rotary instrumentation, improving irrigant penetration in the coronal third of the canal. However, studies show it may not surpass syringe needle irrigation in overall cleaning, particularly in the apical areas. In comparison, the Stropko Irrigator combines solution delivery and recovery in one probe, simplifying the process while enhancing debris removal.[22] These innovations significantly improve irrigant penetration and canal cleanliness. (**Figure 18**) depicts the TotalVac Irrigation System, consisting of three main components: 1) The High-Speed Evacuation Tip, 2) The Surgical Suction Adaptor, and 3) The Negative Pressure Tubing. The High-Volume Evacuation Tip is utilized during access and high-volume cleaning and shaping procedures. merge into impactful heading.[23]

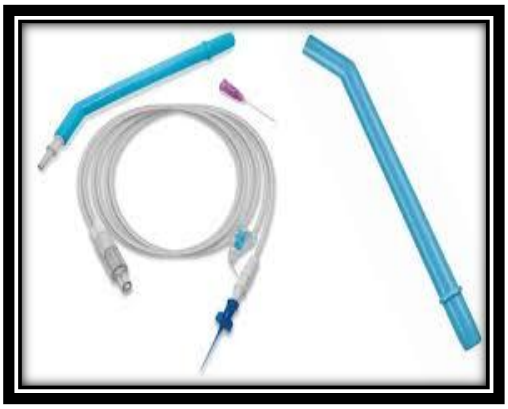

Figure 18: Irrivac needle pressure system: key components and high-volume evacuation for efficient cleaning and shaping

Courtesy: https://endopracticeus.com/negative-and-positive-pressure-irrigation-all-in-one/

The Max-i Probe, with a flexible design, offers comfort, safety, and effectiveness in irrigation, featuring a rounded end and side port, and is available in both 28 and 30 gauges (**Figure 19**). [24]

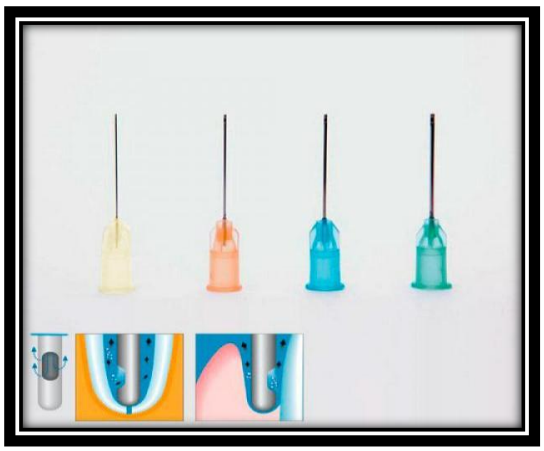

Figure 19: Max-I Probe

Courtesy: https://www.dentaltix.com/en/hawe-neos/max-i-probe-irrigation-needles-40u

The Pro Rinse Endodontic Irrigating Probe, one of the smallest-bore needles, offers flexibility, side venting, and a closed blunt end for safety (**Figure 20**). [25]

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Figure 20: Pro rinse ultraprobe
Courtesy:https://www.dentsplysirona.com/en-us/shop/BP-303347/prorinse-endo-irrigation-needles.html

Proultra Piezo: Ultrasonic needles are utilized in nonsurgical root canal irrigation by applying ultrasonic vibrations, powered by a piezoelectric ultrasonic device (**Figure 21)**. These needles are connected to a syringe or other irrigation source through a luer-lock connection. The removal of the irrigant is achieved through standard suction.[26]

Figure 21: Pro ultrapiezo
Courtesy: https://www.dentsplysirona.com/en-us/shop/BP-304290/proultra-piezo-ultrasonic-unit-and-handpiece.html

The **Vista Probe** is a versatile subgingival irrigation tool designed for precise application in surgical and subgingival areas, including gingival margin and periodontal sulcus sites. [27] It features a flexible one-inch needle tip that can be bent for accurate placement, making it ideal for irrigation in difficult-to-reach regions. The probe's universal luer-lock design ensures secure attachment, while its closed-end tip with side port delivery allows for effective lateral fluid release.[28] Available in 23, 27, and 30 gauges, the Vista Probe offers flexibility for various procedures (**Figure 22**). Recent advances in needle design, including smaller gauges like 27-G, 30-G, and 31-G, have improved the safety, precision, and effectiveness of irrigation techniques in endodontic treatments.[29]

Figure 22: Vista probe
Courtesy:https://vistaapex.com/product/vista-probe-irrigating-tips/

The **Ni-Ti Superflex:** These needles offer 2.5 times the flexibility of standard needles, enhancing maneuverability and precision in root canal procedures.[30] Designed for durability, they feature an adjustable angle and clog-resistant construction for consistent, efficient performance. The 30-gauge version, with a secure luer-lock connection, is ideal for various applications.[31] When paired with Apple-Vac needles, Flex, Navitip, NaviTip FX, and canal brushes, this collection ensures optimal root canal irrigation, delivering exceptional results even in complex cases. Available in 23, 27, and 30 gauges, the Ni-Ti Superflex needles are engineered for reliability and precision (**Figure 23**).[32]

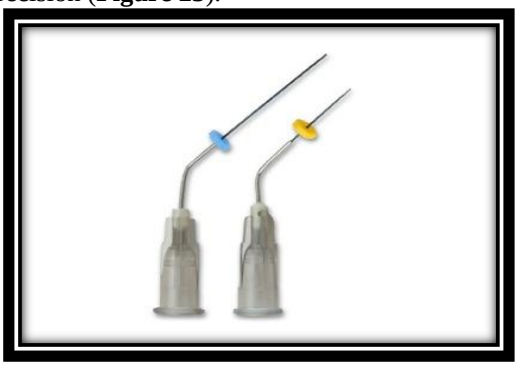

Figure 23: Ni-Ti superflex needles
Courtesy: https://www.dentalcompare.com/4707-Endodontic-Irrigation-Instruments/34925-Ni-Ti-SuperFlex/

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Gutta-percha points: The challenge of apical canal irrigation has led to the development of innovative techniques to enhance solution penetration. One such method involves using apically fitting gutta-percha cones (**Figure 24**) in an up-and-down motion at the working length. While this promotes the exchange of the apical solution, the overall volume of fresh solution in the apical canal remains limited, highlighting the need for more effective irrigation strategies.[33]

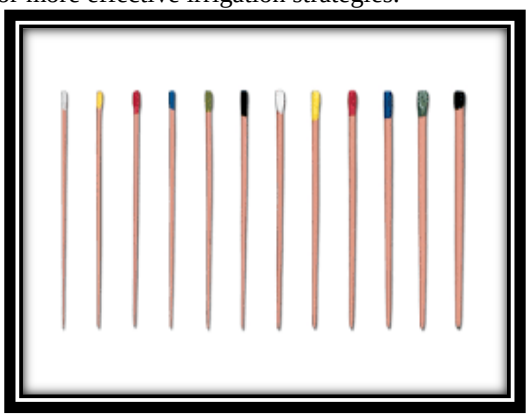

Figure 24: Gutta Percha points
Courtesy:https://www.premierdentalco.com/product/endo/obturation-materials/gutta-percha-points/

Endo Activator: It is an advanced device designed to improve irrigation during root canal treatments using sonic vibrations up to 10,000 cpm to enhance irrigant flow (**Figure 25**). Featuring three flexible, interchangeable tips that attach to a handpiece, it optimizes irrigant penetration and renewal without the risk of extrusion through the apex. [34]Studies by Townsend C. and Maki J. show that the Endo Activator significantly improves irrigant penetration and mechanical cleaning compared to traditional needle irrigation, without increasing the risk of extrusion.[35] Its powerful hydrodynamic action is especially effective in cleaning complex canal systems and lateral canals, aiding in biofilm removal and enhancing overall debridement efficiency.[36]

Figure 25: Endoactivator
Courtesy:https://www.dentsplysirona.com/en-ae/discover/discover-by-brand/endoactivator.html

The EndoVac system revolutionizes endodontic irrigation with its unique design and negative-pressure approach. Comprising three key components—the master delivery tip, macro cannula, and microcannula—it efficiently delivers and evacuates irrigant.[37] The master delivery tip facilitates both delivery and suction, while the macrocannula removes irrigant from the chamber to the coronal and middle segments of the canal. The microcannula targets precise irrigation of the apical portion.[38] This system ensures continuous fresh irrigant flow, preventing air entrapment and overcoming apical vapor lock.[39] Studies demonstrate that EndoVac outperforms other systems, achieving complete cleaning of the isthmus area and reducing the risk of dangerous irrigant extrusion, such as sodium hypochlorite incidents.[40] By employing a reversed flow for irrigant delivery, the system provides superior apical cleaning and a potent antibacterial effect when using hypochlorite. The EndoVac's negative-pressure technique significantly reduces irrigation risks near the apical foramen, ensuring safer and more effective root canal treatments (**Figure 26**).[41]

Figure 26: Endovac
Courtesy:https://www.kerrdental.com/sites/default/files/styles/product__main_image/public/endovac-973-3020_MacroCannulas.jpg?itok=laS0cbEG

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The RinsEndo System, powered by dental air compressors, uses a pressure-suction cycle to oscillate a rinsing solution in the root canal (**Figure 27**). While the system effectively delivers fresh rinsing solution, it has shown limitations in removing debris compared to manual dynamic irrigation.[42]

Figure 27: RinsEndo
Courtesy:https://stomdevice.ru/bazovoe-oborudovanie/sterilizacionnoe-oborudovanie/durr-dental-germaniya-rinsendo-nakonechnik-dlya-dezinfekcii-kornevogo-kanala

Photo-Activated Disinfection: It is also referred to as photochemically induced disinfection or light-activated sterilization, a state-of-the-art technique that utilizes light-sensitive dyes and low-intensity visible light to neutralize microbes.[43] Photodynamic sterilization integrates photosensitive agents with visible light to effectively eradicate bacteria and other harmful pathogens. This innovative approach uses light-activated compounds to target and destroy dangerous microorganisms.[44] Similarly, the light-driven antimicrobial method employs photosensitive materials and light exposure to combat a wide range of pathogens, including bacteria, viruses, and fungi. Moreover, photo-catalytic disinfection makes use of light-activated catalysts to eliminate microbial threats, providing a flexible and groundbreaking solution for microbial control (**Figure 28**).[45]

Figure 28: Photo- activated disinfection
Courtesy:https://www.dentaldenshine.com/products/oral-laser-disinfection-light-32568044

The Ozone-based delivery system uses ozonated water, which is highly effective in killing both gram-positive and gram-negative microorganisms, especially when applied at the end of the cleaning and shaping process. Ozone generates strong oxidizing agents, making it highly effective in disinfecting the root canal (**Figure 29**).[46]

Figure 29: Ozone based delivery system
Courtesy: Baysan A, Lynch E. The use of ozone in dentistry and medicine. Prim Dent J. 2005; 12(2):47-52.

The VATEA System, integrated with the Self Adjusting File (SAF) (**Figure 30**) rotary system, delivers irrigation through a fluid delivery unit, adjusting flow rates from 1-10 ml/min. It has been proven superior to traditional needle irrigation in oval canals, offering efficient debridement.[47]

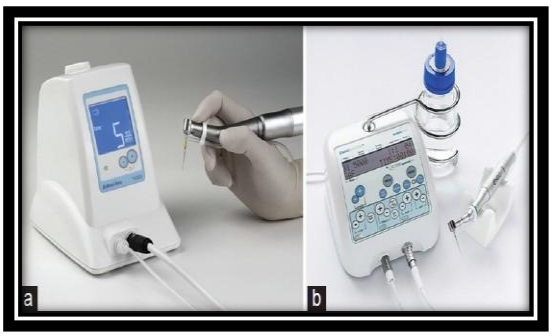

Figure 30: Self-adjusting file system
Courtesy: Metzger Z. The self-adjusting file (SAF) system: An evidence-based update. J Conserv Dent. 2014; 17(5):401-419.

Ultrasound: Ultrasonic energy plays a critical role in enhancing root canal cleaning and disinfection, especially when combined with irrigants.[48] Studies show that ultrasonic activation significantly improves cleaning efficacy over hand instrumentation alone by leveraging cavitation and acoustic streaming to enhance the biological and chemical effects of the irrigant.[49] These hydrodynamic effects, including stable and transient cavitation, are crucial in effectively cleaning complex root canal systems.[50] Research has shown that ultrasonic files must move freely

within the canal to avoid wall contact, with studies highlighting the importance of ultrasonic preparation for debriding complex structures like isthmuses and anastomoses.[51] Systems like the Vibringe and EndoActivator, which combine sonic or ultrasonic activation with irrigation, have been shown to provide superior debris removal, particularly in the apical third of the canal.[52] Key phenomena, such as acoustic microstreaming and cavitation, are fundamental to ultrasonic irrigation.[53] Acoustic microstreaming helps dislodge debris by creating fluid movement along canal walls, while cavitation, the formation and collapse of bubbles, further aids in cleaning. However, apical vapor lock—gas entrapment in the apical third—can impede irrigant flow, and the only effective solution to this is apical negative pressure, which ensures better irrigant penetration and thorough debridement.[54] Innovative systems, like continuous ultrasonic irrigation, use a 25-gauge needle for activation at maximum power, improving safety and cleaning efficacy while avoiding the risk of needle breakage. These advancements in ultrasonic irrigation are reshaping endodontic practices, offering improved cleaning, safety, and efficiency in root canal treatments.[55]

Clinical and technical aspects of irrigation: Effective root canal irrigation is strongly influenced by the relationship between the irrigating needle's diameter and the apical preparation size. The irrigant's impact is typically limited to about 3-4 mm from the needle tip, so positioning the needle as close to the working length as possible is crucial.[56] Studies show that a needle placed 1 mm short of the working length is more efficient at reducing residual bacteria than one placed 6 mm short.[57] For optimal irrigation, a 30-gauge needle is recommended for apical preparations sized 35-40, which can be achieved using modern rotary nickel-titanium instruments, even in curved canals, without the need for straightening.[58] Flexible, safety-tipped irrigation needles are ideal for curved canals, as they can be pre-bent to fit the canal shape, ensuring effective cleaning of the apical area.[59] However, if resistance is met during needle insertion, it should be withdrawn by 2 mm to allow space for the irrigant to flow out safely and prevent extrusion into periapical tissues.[60] The recommended irrigation protocol involves flushing the canal with sodium hypochlorite after access cavity preparation and during instrumentation. After shaping, irrigate with EDTA or citric acid to remove the smear layer, followed by a final rinse with sodium hypochlorite.[61] In retreatment cases, 2% Chlorhexidine can be used after removing sodium hypochlorite.[62] Finally, rinse with alcohol before filling the canal to assist with drying. Proper needle placement and adherence to this protocol are essential for effective cleaning and disinfection during root canal therapy.[63]

III. FUTURE PROSPECTS:

The future prospects of irrigation systems in endodontics are incredibly promising, as ongoing advancements in technology, materials, and techniques continue to reshape the field. Several key trends and innovations are expected to enhance the effectiveness, efficiency, and safety of root canal treatments in the coming years.[64]

1. Integration of Artificial Intelligence (AI) and Machine Learning:

AI and machine learning algorithms have the potential to revolutionize irrigation systems by personalizing treatment protocols. These technologies could analyze patient-specific factors, including canal anatomy, pulp tissue condition, and infection level, to determine the optimal irrigation strategies. AI could also help clinicians make real-time adjustments during procedures, ensuring the most effective cleaning and disinfection based on dynamic feedback.[65]

2. Smart irrigation systems with real-time feedback:

Future irrigation systems may incorporate smart technologies that provide real-time feedback on the irrigation process. By utilizing sensors and imaging techniques, these systems could continuously monitor the efficiency of irrigant delivery and ensure that all areas of the root canal are thoroughly cleaned. Real-time data could help adjust flow rates, pressure, and irrigation cycles, offering better control over treatment and improving the precision of cleaning in complex anatomies.[66]

3. Advanced irrigant formulations:

As research progresses, more advanced and biocompatible irrigant solutions are likely to emerge. New formulations could offer enhanced antibacterial and biofilm-dissolving properties, with fewer side effects or toxicity concerns for surrounding tissues. The development of more effective irrigants would improve disinfection, especially in hard-to-reach areas like lateral canals and apical regions, thus enhancing overall treatment success.[67]

4. Miniaturized and flexible irrigation tools:

There is potential for continued development of smaller, more flexible irrigation needles and probes. These advancements could enable better access to intricate and challenging canal anatomies, allowing for more effective delivery of irrigants even in narrow or curved canals. Smaller gauge needles could also reduce trauma and improve patient comfort during procedures.[68]

5. Enhanced ultrasonic and sonic activation:

Ultrasonic and sonic activation technologies will likely become even more advanced, offering deeper penetration and more efficient cleaning of the root canal system. These systems could be further refined to improve the activation of irrigants, especially in complex anatomical regions, reducing the need for excessive manual intervention while enhancing disinfection.[69]

6. Automated irrigation systems:

Future systems may see the integration of automated irrigation, working in synergy with rotary instruments and other endodontic tools. These fully automated systems could perform irrigation steps with minimal input from the clinician, allowing for more efficient and precise cleaning while reducing treatment times. Automation could also improve consistency in delivering optimal irrigation protocols.[70]

7. Integration with digital workflow:

The incorporation of digital technology into irrigation systems could streamline the endodontic treatment process. For example, real-time digital imaging or 3D mapping could guide irrigant delivery, ensuring complete disinfection of the root canal system. These digital tools could integrate with rotary systems and other advanced devices, creating a more seamless and efficient treatment workflow.[71]

8. Focus on biocompatible and eco-friendly solutions:

There is a growing emphasis on biocompatibility and environmental sustainability in dentistry. Future irrigant solutions may be designed with minimal toxicity to surrounding tissues while maintaining maximum effectiveness. Additionally, there may be a push toward eco-friendly packaging and disposal methods for irrigant solutions, contributing to the overall sustainability of endodontic practices.

The future of irrigation systems in endodontics is marked by rapid innovation and an emphasis on precision, efficiency, and patient safety. With the integration of AI, smart systems, advanced irrigants, and improved tools, root canal treatments are likely to become faster, more predictable, and more comfortable for patients. The ongoing advancements in technology and materials will continue to push the boundaries of what is possible in root canal therapy, ensuring better outcomes and higher success rates in endodontic care.[72]

IV. CONCLUSION:

Recent advances in irrigation technology have greatly improved the efficiency and safety of root canal treatments. The integration of advanced technologies, including sonic and ultrasonic activation, positive and negative pressure systems, and peristaltic pumps, allows for deeper cleaning and more thorough disinfection of the root canal system. These innovations, combined with stronger irrigant solutions, enhance the removal of debris, bacteria, and biofilms from intricate canal structures. Furthermore, the development of specialized needles and delivery systems has made the irrigation process more precise, safer, and efficient. As technology continues to progress, it holds the potential to further improve clinical outcomes, shorten treatment times, and increase success rates in endodontics. The continuous evolution of irrigation systems highlights the importance of embracing modern techniques and tools to meet the growing demands of contemporary dentistry.

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Conflicts of interest There are no conflicts of interest

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