Irrigation dynamics deals with the pattern of irrigant flow, penetration, exchange and the forces produced within the root canal space. Current modes of endodontic irrigation include the traditional syringe needle irrigation or physical methods, such as apical negative-pressure irrigation or sonic/ultrasonically assisted irrigation. Since the nature of irrigation influences the flow of irrigant up to the working length (WL) and interaction of irrigant with the canal wall, it is mandatory to understand the irrigation dynamics associated with various irrigation techniques.

Endodontic irrigants are liquid antimicrobials used to disinfect microbial biofilms within the root canal. The process of delivery of endodontic irrigants within the root canal is called irrigation. The overall objectives of root canal irrigation are to inactivate bacterial biofilms, inactivate endotoxins, and dissolve tissue remnants and the smear layer (chemical effects) in the root canals, as well as to allow the flow of irrigant entirely through the root canal system, in order to detach the biofilm structures and loosen and flush out the debris from the root canals (physical effects). While the chemical effectiveness will be influenced by the concentration of the antimicrobial and the duration of action, the physical effectiveness will depend upon the ability of irrigation to generate optimum streaming forces within the entire root canal system.

The final efficiency of endodontic disinfection will depend upon both chemical and physical effectiveness. It is important to realise that even the most powerful irrigant will be of no use if it cannot penetrate the apical portion of the root canal, interact with the root canal wall and exchange frequently within the root canal system.
Irrigation methods are categorised as positive-pressure or negative-pressure, according to the mode of delivery employed. In positive-pressure techniques, the pressure difference necessary for irrigant flow is created between a pressurised container (e.g. a syringe) and the root canal. In negative-pressure techniques, the irrigant is delivered passively near the canal orifice and a suction tip (negative-pressure) placed deep inside the root canal creates a pressure difference. The irrigant then flows from the orifice towards the apex, where it is evacuated. A detailed understanding of the irrigation dynamics associated with syringe-based irrigation would aid in improving its effectiveness in clinical practice.

Irrigant flow during syringe irrigation

The flow of irrigants is influenced by its physical characteristics, such as density and viscosity. These properties for the commonly used endodontic irrigants are very similar to those of distilled water. The surface tension of endodontic irrigants and its decrease by surfactants have also been studied extensively. The rationale of this combination is that it may significantly affect (a) the irrigant penetration into dentinal tubules and accessory root canals and (b) the dissolution of pulp tissue. However, it is important to note that surface tension would only influence the interface between two immiscible fluids, and not between the irrigant and dentinal fluid. Experiments have confirmed that surfactants do not enhance the ability of sodium hypochlorite to dissolve pulp tissue or the ability of chelating agents to remove the smear layer.

The type of needle used has a significant effect on the flow pattern formed within the root canal, while parameters such as depth of needle insertion and size or taper of the prepared root canal have only a limited influence. Generally, the available needles can be classified as closed-ended and open-ended needles. In the case of open-ended needles (flat, bevelled, notched), the irrigant stream is very intense and extends apically along the root canal. Depending upon the root canal geometry and the depth of needle insertion, reverse flow of irrigant occurs near the canal wall towards the canal orifice.

In the case of closed-ended needles (side-vented), the stream of irrigant is formed near the apical side of the outlet and is directed apically. The irrigant tends to follow a curved route around the needle tip, towards the coronal orifice. The flow of irrigant apical to the exit of the needle is generally observed to be a passive fluid flowing zone (dead zone), while the flow of irrigant in the remaining aspect of the root canal is observed to be an active fluid flowing zone (active zone; Figs. 1a–d & 2a–d). A series of vortices of flowing irrigant are generated apical to the tip. The velocity of irrigant inside each vortex decreases towards the apex.

Large needles when used within the root canal hardly penetrate beyond the coronal half of the root canal. Currently, smaller-diameter needles (28- or 30- gauge) have been recommended for root canal irrigation. This is mainly because of their ability to advance further up to the WL. This facilitates better irrigant exchange and debridement. In addition, the use of a larger needle would result in decreased space being available for the reverse flow of irrigant between the needle and the canal wall. This scenario has been associated with (a) an increased apical pressure for open-ended needles and (b) decreased irrigant refreshment apical to the tip for closed-ended needles. The influence of tooth location (mandibular, maxillary) on irrigant flow has been observed to be minor.

Irrigant refreshment

Irrigant exchange in the root canal system is a key prerequisite for achieving optimum chemical effect, because the chemical efficacy of the irrigants are known to be rapidly inactivated by dentine, tissue remnants or microbes. Investigations have explained the limitations in the irrigant refreshment apical to needles. Enlarging the root canal to place the needle to a few millimetres from the WL and ensuring adequate space around the needle for reverse flow of the irrigant towards the canal orifice allow effective irrigant refreshment coronal to the tip.
Furthermore, increasing the volume of irrigant delivered could help to improve refreshment in such cases.\textsuperscript{20,31,32} The effect of curvature on irrigant exchange has been studied indirectly by Nguy and Sedgley.\textsuperscript{33} They report that only severe curvatures in the order of 24–28° hampered the flow of irrigants. If the canal is enlarged to at least size 30 or 35 and a 30-gauge flexible needle placed near the WL is used, then irrigant refreshment can be expected even in severely curved canals.

Wall shear stress

The frictional stress that occurs between the flowing irrigant and the canal wall is termed “wall shear stress”. This force is of relevance in root canal irrigation because it tends to detach microbial biofilm from the root canal wall. Currently, there is no quantitative data on the minimum shear stress required for the removal of microbial biofilm from the canal wall. Yet, the nature of wall shear stresses produced within the root canals during irrigation provides an indication of the mechanical debridement efficacy.

In open-ended needles, an area of increased shear wall stresses develops apical to the needle tips, while in closed-ended needles, a higher maximum shear stress is generated near their tips, on the wall facing the needle outlet.\textsuperscript{34} Thus, in open- and closed-ended needles, optimum debridement is expected near the tip of the needle.\textsuperscript{16,33} Consequently, it is necessary to move the needle inside the root canal, so that the limited area of high wall shear stress involves as much of the root canal wall as possible. The maximum shear stress decreases with an increase in canal size or taper. Thus, overzealous root canal enlargement above a certain size or taper could diminish the debridement efficacy of irrigation (Figs. 1a–d & 2a–d).

Enhancing irrigation dynamics using physical irrigation methods

Fluid dynamics studies on apical negative-pressure irrigation have demonstrated maximum apical penetration of the irrigant, without any irrigant extrusion. This finding highlights the ability of apical negative-pressure irrigation to be safely used at the WL, circumventing the issues of vapour lock effect.\textsuperscript{35} Nonetheless, the apical negative-pressure irrigation produced the lowest wall shear stress. This decrease in the wall shear stress could be attributed in part to the reduction in the flow rate with this irrigation system.

Passive ultrasonically assisted irrigation, when compared with other irrigation methods, showed the highest wall shear stress along the root canal wall, with the highest turbulence intensity travelling coronal from the ultrasonic tip position. The lateral movement of the irrigant displayed by this method has important implications with respect to its ability to permit better interaction between the irrigant and the root canal wall, and to potentially enhance the interaction of irrigants with intra-canal biofilms\textsuperscript{2,3,35} (Figs. 1a–d & 2a–d).

Conclusion

The requirements of adequate irrigant penetration, irrigant exchange, mechanical effect and minimum risk of apical extrusion oppose each other and a subtle equilibrium is required during irrigation. Ideally, in a canal enlarged to size 30 or 35 and taper 0.04 or 0.06, an open-ended needle should be placed 2 or 3 mm short of the WL to ensure adequate irrigant exchange and high wall shear stress, while reducing the risk of extrusion.

In the case of a closed-ended needle, placement should be within 1 mm short of the WL, so that optimum irrigant exchange can be ensured. The apical negative-pressure irrigation did not generate marked wall shear stress values, but allowed the flow of irrigant consistently at the WL. It was the safest mode of irrigation when used close to the WL. The passive ultrasonically assisted irrigation generated the highest wall shear stress. The use of combined methods to obtain optimum disinfection and to circumvent the limitations of one method is recommended._

Editorial note: A list of references is available from the publisher.