Visualization of Removal of Trapped Air from the Apical Region of the Straight Root Canal Models Generating 2-phase Intermittent Counter Flow during Ultrasonically Activated Irrigation

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Abstract

Introduction: The purpose of this *in vitro* study was to obtain a better understanding of the mechanism of irrigant traveling apically and generating 2-phase intermittent counter flow in straight root canal models during activation of the irrigant by ultrasonic means in an endodontic procedure. **Methods:** A high-speed imaging system, with high temporal and spatial resolution (FastCam SA5; Photron, Tokyo, Japan) at a frame rate of 100,000 frames per second using a macro lens (60 mm, f/2.8; Nikon, Tokyo, Japan), was used to visualize, in glass models of root canals, an ultrasonically induced acoustic pressure wave in an EDTA solution environment. A 25-mm stainless steel noncutting file #20 driven by an ultrasonic device (P5 Newtron; Satelec Acteon, Mérignac, France) at power settings of 5 and 7 produced disturbances at the solution-air interface. **Results:** We found that apically directed travel of the irrigant was caused by disruption of the surface tension at the solution-air interface. This disruption caused by ultrasonic activation energy displaced air in the form of bubbles from the apical region toward the solution. **Conclusions:** The apical movement of the solution may be attributed to ultrasonically induced wave generation at the solution-air interface, resulting in the removal of trapped air from the root canal and allowing the solution to travel apically in the opposite directions (via a 2-phase intermittent counter flow). *(J Endod 2014;40:857–861)*

Key Words

2-Phase intermittent counter flow, acoustic pressure wave, endodontics, solution-air interface, surface tension, ultrasonic

Shaping of the root canal has improved with advances in metal technology. However, because of the anatomic complexity and irregularity of teeth, cleaning of the canal still relies heavily on the adjunctive use of chemical rinsing and soaking solutions (1). The delivery of irrigants is important for debridement and disinfection of the root canal space. Syringe irrigation is the standard cleaning procedure, but unfortunately is insufficiently effective in the apical third of the canal (2–4). As a consequence, acoustic and hydrodynamic activation of the irrigant have been developed; these techniques have been shown to increase cleaning efficiency (5).

Although irrigation with open-ended or side-vented syringe needles is widely used, other cleansing techniques such as continuous ultrasonic irrigation, an apical negative-pressure irrigant delivery device (6, 7), and a laser-driven irrigation technique (8) have become clinically accepted. For the optimal effectiveness of irrigation, the preparation of the root canal should facilitate the insertion of the irrigation needle and agitation devices to 1–2 mm short of the working length (WL). To enhance the dispersal and activation of the irrigant, various agitation techniques have been developed (eg, the use of hand files, gutta-percha cones, plastic instruments, and sonic and ultrasonic techniques) (6).

A study by Ahmad (9) showed that the degree of cleanliness of canals seems to be a function of the type of irrigant rather than the technique used; consequently, the efficacy of cleaning relies on the irrigant. The irrigation solution should contact the canal wall directly and entirely (9); furthermore, a flushing action is necessary for optimal cleaning of the root canal (10).

Inasmuch as the root is surrounded by periodontal ligament and bone, the canal serves as a closed-end system (11–13). Consequently, if for some reason an insertion of a needle is shorter than the WL in a dry root canal, air may become trapped in the apical region, creating a solution column and an air column in the root canal (solution-air system). Air entrapment prevents the exchange of solution in the apical region (an airlock effect), thus reducing the effectiveness of the cleaning process (2–4). However, the physical mechanisms that underlie these cleaning procedures are not well understood (14).

It is assumed that when the irrigation solution travels apically in a dry root canal during ultrasonic activation, trapped air is removed from the apical region, overcoming the airlock effect. What occurs inside the canal when an irrigant is activated

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ultrasonically is only briefly and hypothetically discussed in the literature and does not explain how irrigation solution can travel to the WL in a dry root canal. In other words, the process involves air (compressible fluid) and solution (incompressible fluid), which differ in density (2 phase). The authors term this phenomenon 2-phase intermittent counter flow because 2 different phases of fluid flow in opposite directions intermittently. To date, no study has been undertaken of the mechanism of ultrasound in removing trapped air from the apical region of a root canal in which the irrigant travels apically during agitation. This study aims to obtain evidence of the means by which an irrigant solution traveling apically in a root canal during ultrasonic activation removes trapped air from the apical region in a transparent straight root canal model.

Materials and Methods

High-speed Digital Imaging Setup

Root Canal Model. To simulate and visualize the conditions within a straight root canal, we used glass models with artificial canals and pulp cavities. These included a glass cylindrical root canal model (inner diameter = 1 mm, crown height = 10 mm, and overall length = 40 mm) and a glass block model. The dimensions of the glass block model were as follows: inner diameter at the apex = 0.08 mm, taper = 4%, crown height = 10 mm, and overall length = 40 mm. The length of the root canal (from the orifice to the apex) was 15 mm. The solution (EDTA mixed with red dye) was inserted 10 mm below the cervical line (orifice), and the pulp cavity was filled with the solution. To simulate the conditions within a root canal, the apex of the model was sealed with composite.

Ultrasonic Parameters and Procedure. A 25-mm stainless steel noncutting tip # 20 (Irrisafe; Satelec Acteon, Mérignac, France) was driven by an ultrasonic device (P5 Newtron, Satelec Acteon) at power settings of 5 and 7 (frequency = 28–36 kHz) in accordance with the manufacturer's instructions. The models underwent active ultrasonic irrigation without water spray. The tip of the ultrasonic was inserted to 5 mm above the interface and activated passively without any filling motion. To ensure this distance was maintained, the handpiece was fixed in a holder. The pulp chamber served as a reservoir for the irrigation solution.

Basic Experiments. The process was recorded using a high-speed digital imaging system (FastCam SA5; Photron, Tokyo, Japan) at a frame rate of 100,000 frames per second using a macro lens (60 mm, f/2.8; Nikon, Tokyo, Japan). The root canal model (Fig. 1) was illuminated in a bright field by a continuous light source (Fibre-Lite, LMI-6000 LED; Dolan-Jenner Industries, Boxborough, MA). The canal was irrigated by inserting a 30-G needle (Navitip; Ultradent, South Jordan, UT) as deep as 20 mm from the crown. At this point, the root was fully filled to the pulp cavity. The lens was focused at the level of the solution-air interface (around the end of the tip) for a time of 3 milliseconds (power setting of 7) and 5.5 milliseconds (power setting of 5).

Results

Activation in the Glass Cylindrical Model (Power Setting of 5)

In the first 0.9 milliseconds, the vibrating file caused microbubbles to form around the ultrasonic tip, and after around 1.2 milliseconds, the ultrasonic energy caused the solution surface (the solution-air interface) to move (Fig. 2*A,* C) and then to form waves (Fig. 2*A,* D–K). After 1.5–4 milliseconds, a bubble formed from the air column and migrated toward the solution column. Consequently, the solution surrounding the bubble was forced downward to fill the space remaining in the air column (Fig. 2*A,* D–K). A thin liquid film on the canal wall was moving downward. The net effect was that the solution had traveled closer to the apex. The solution moved downward to fill the air column, reducing the distance between the solution-air interface and the apex. Figure 2*A,* A–K shows that the solution-air interface disturbance took place at an exposure time of around 4 milliseconds. It was obvious that at a power setting of 5, the ultrasonic apparatus was able to energize the intermittent counter flow.

Activation in the Glass Box Model (Power Setting of 7)

A similar phenomenon of 2-phase intermittent counter flow occurred in this experiment (see Supplemental Video S1, available online at www.jendodon.com). The ultrasonic energy initially caused the solution surface (the solution-air interface) to move after about 2.01 milliseconds (Fig. 2*B,* A) and then to form waves (Fig. 2*B,* B–K). After 2.27–7 milliseconds, a bubble formed from the air column and migrated toward the solution column. Consequently, the solution surrounding the bubble was forced downward to fill the space remaining in the air column (Fig. 2*B,* B–K). A thin liquid film on the canal wall was observed in this experiment as well. The solution moved downward to replace the air column, reducing the distance between the solution-air interface and the apex. Figure 2*B,* A–K shows that the onset of wave generation took place at an exposure time of around 7 milliseconds.

Discussion

It is interesting to try to understand how an irrigating solution eventually fills the entire root canal despite the fact that an empty space is always formed in the apical region when the solution enters a dry canal during either laser or hand irrigation (15). By assuming that when a dry root canal is inserted by a needle shorter than the WL during irrigation, the solution is unable to flow to the WL (eg, because of a curved canal) and therefore cannot move apically. Surface tension is defined as the attractive force between molecules acting to decrease the surface area of a liquid (16). This produces a layer of surface molecules on the liquid that acts like a stretched membrane (17). In particular, this force limits the flow of the liquid into narrow canals. When the solution cannot move apically and stops, the weight of the solution column in the narrow canal is supported by the surface tension together with an airlock effect. It suggests that the surface tension of the solution, acting at the solution-air interface, has an important role in preventing the solution from reaching the end of the narrow canal.

In a preliminary test, vibrating the file in the solution ultrasonically at a power setting of 2 produced acoustic streaming (pressure); however, at this setting, the solution could not be forced to travel apically. The surface tension of the solution (at the solution-air interface) was just adequate to generate waves. We assume that the ultrasonic energy at a power setting of 2 was not sufficient to break the surface tension at the solution-air interface (data not shown). At the maximum power setting, the ultrasonic apparatus consumed 30 W of electric power. Considering the energy conversion in the apparatus, the vibrating file was estimated (at 30 kHz) to produce less than 1 mJ of energy per cycle. The setting of the power scale can then be determined if the energy is sufficient to disturb the surface tension and create counter flow. To observe the underlying behavior of the surface tension of the solution at the solution-air interface, we used a 25-mm stainless steel noncutting tip #20 (Irrisafe) driven by an ultrasonic device (P5 Newtron) at power settings of 5 and 7. The proposed power settings were expected to produce sufficient acoustic streaming to create a disturbance near the solution-air interface.

The process could be closely observed at the solution-air interface in the glass canal model. The high-speed imaging method used enables the capture of images within intervals of milli- to microseconds. The red