

CHARACTERIZATION OF IRRIGATION DYNAMICS IN PASSIVE ULTRASONIC AND PRESSURIZED IRRIGATION METHODS IN A ROOT CANAL USING A MICROFLUIDIC DEVICE

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ABSTRACT

This study reports an innovative method for the characterization of irrigant flows in a root canal model using microfluidic devices. Irrigation plays an important role in successful endodontic treatment. A more thorough understanding of different modes of irrigation will aid in disinfection during root canal treatment. An assessment method using root canal reconstruction, soft-lithography replication and micro particle image velocimetry has been established to compare the fluid dynamics associated with pressurized or syringe-based irrigation and passive ultrasonic irrigation. The velocity magnitude and the shear rate on the root canal wall using these modes of irrigation are evaluated and the results suggest ultrasonic irrigation creates stronger velocity (0.006 m/sec for PUI vs. 0.003 m/sec for pressurized injection) toward the apical part of the canal and also higher shear rate/stress on the canal wall along its file which will aid in endodontic disinfection.

KEYWORDS

root canal, passive ultrasonic irrigation, particle image velocimetry.

INTRODUCTION

Endodontic infections are mediated by microbial biofilms [1]. Complete elimination of microbial biofilms remains a challenge, in part due to their resistance, as well as due to the anatomical complexities seen in the root canal system [2]. Irrigation dynamics refers to how an irrigant flows, penetrates, and readily exchanges within the root canal system. A better understanding of the fluid dynamics of different modes of irrigation will contribute to achieving predictable disinfection of the root canal system. Through numerical based studies it has been shown that there is minimal interaction of the irrigant with the root canal wall when using pressurized or syringe-based irrigation, which is the most common mode of irrigation [3, 4]. Passive ultrasonic irrigation (PUI) attempts to enhance the interaction of the irrigant with the canal walls through the transmission of acoustic energy through microstreaming that produces high shear stress which can remove debris and bacteria from the root canal wall [5]. This study aims to characterize the irrigation dynamics of pressurized irrigation and PUI using a clinically realistic silicone model based on the scanned images of an instrumented canal. The optical transparency of the silicone will allow for “real-time imaging” of flow dynamics and will also be amenable for biofilm growth for future studies designed to correlate the irrigation dynamics with biofilm elimination.

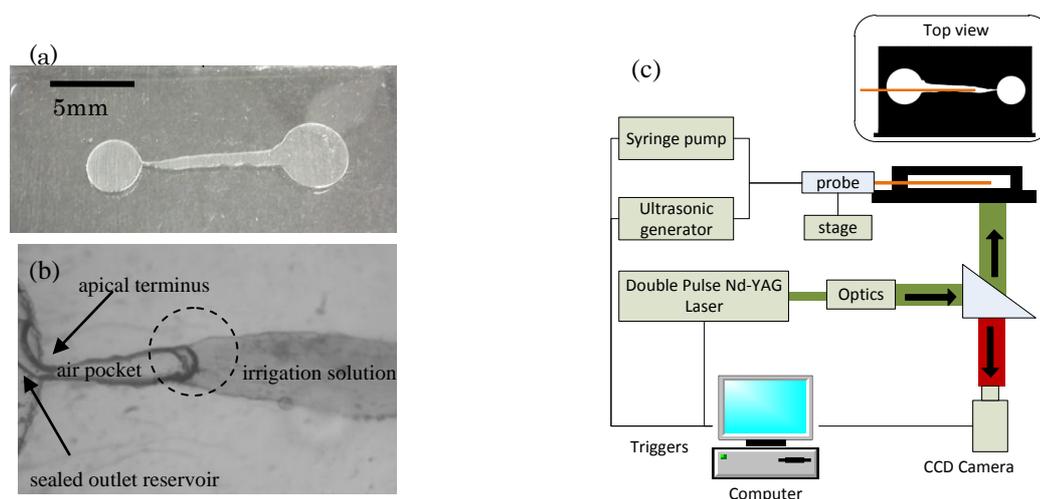


Figure 1: (a) Microfluidic devices of straight root canal; (b) microfluidic device with sealed outlet reservoir to mimic root canal with highlighted circle as the observation area in micro PIV and (c) schematic diagram of micro PIV setup

EXPERIMENT

One human extracted mandibular incisor was used for the fabrication of the soft lithography based model. The tooth was decoronated at the CEJ and the canal were negotiated with a size10 K-type file to the major apical foramen and flared coronally using Gates Glidden burs #1-2 (Dentsply Tulsa Dental Specialties). Working length was established at 1mm short of the major apical foramen and the canal was shaped with ProTaper Universal rotary system (Dentsply Maillefer, Balleigues, Switzerland) to size F3 at working length. Copious irrigation of 2.6%

NaOCl was used throughout. The root was then sectioned separating the buccal and lingual halves which were then scanned using a microscope and camera (Nikon P5100, NY, USA). The scanned images are then processed in ImageJ® software and Autodesk Inventor® to create molds which are printed out using high definition 3D printers (ProJet™ HD 3000, 3D SYSTEMS Corp., Rock Hill, USA). After casting PDMS (Sylgard 184, Dow Corning, Midland, USA), on the mold, the morphology of root canal is transferred to the replicas which are then bonded to glass slides by using oxygen plasma treatment for 1min at 30W (PDC-001, Harrick Plasma, NY, USA).

The straight canal considered in this study is depicted in Fig. 1(a). Microfluidic channels are 500 μm high and ~ 1 cm long with replicated root-canal shapes. The outlet reservoir in the device is reserved for the purpose of biofilm growth in the future and is then sealed by applying epoxy (LEPAGE, Mississauga, Canada) to mimic the dentine anatomy as shown in Fig. 1(b). The high viscosity and fast curing time of epoxy prevent its overflow into root canal. The devices are then filled with DI water and 1 μm fluorescent beads for visualization and air pockets are formed near the apical terminus mimicking realistic irrigation conditions. A 10 cc syringe with a side-port 30 gauge needle (Max-i-probe, Dentsply Tulsa Dental Specialties) was used for the pressurized group, and was inserted to 1mm short of the working length and a flow rate of 2 mL/min was used. For the PUI experiment, a non-cutting, ultrasonically-vibrated 200 μm stainless steel wire (Irrisafe, Satelec, Bordeaux, France) was inserted 1mm short of the working length and operated at 50% power on the ultrasonic device (Suprasson Pmax Newtron, Satelec) for a period of 1 minute, avoiding excessive heat generation. The schematic of the experimental setup is shown in Fig. 1(c). A double-pulse Nd-YAG laser with an interval of 500-1000 μs is used to illuminate the fluorescent seeding particles (F-13082, Invitrogen, Carlsbad, USA) and determine the velocity distribution inside the root canal. Observation areas near the interface of air pocket and irrigating solution in micro PIV to investigate the flow velocity and shear rate. Additionally, area near the middle section for PUI is also chosen to verify the advantage of PUI over regular pressurized injection.

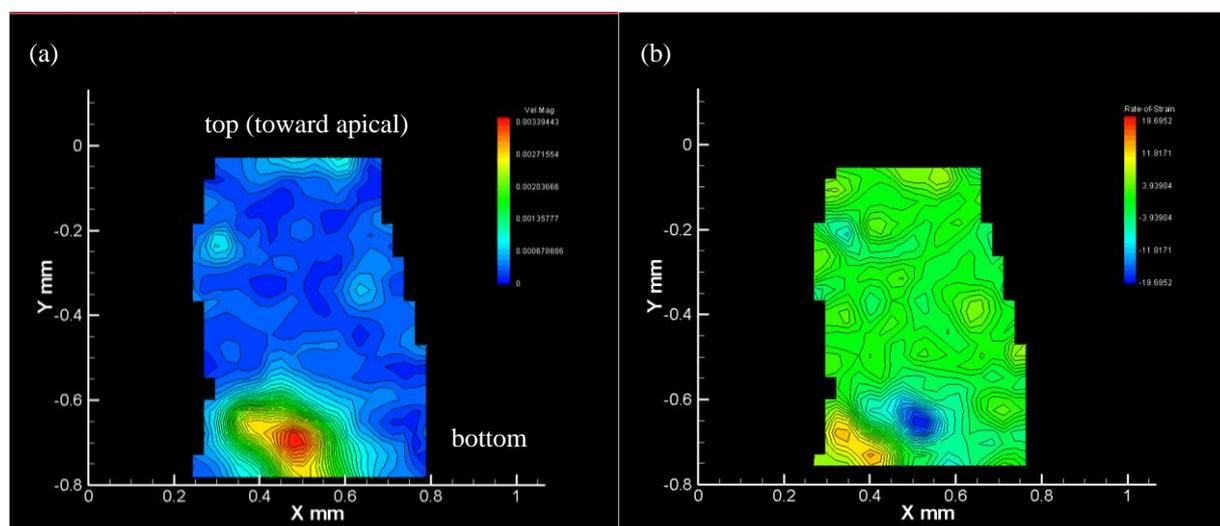


Figure 2. Contour of (a) velocity magnitude with a maximum of 0.003 m/s at the bottom and (b) shear rate magnitude with an average of $\pm 3 \text{ sec}^{-1}$ near the apical of root canal using flow injection at 2 mL/min.

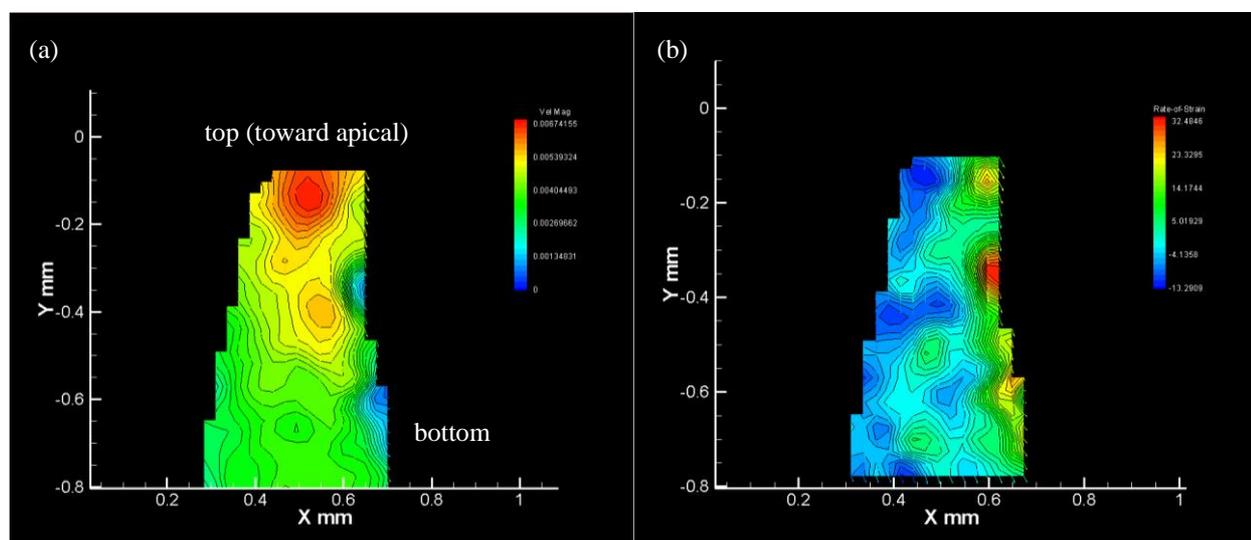


Figure 3. Contour of (a) velocity magnitude with a maximum of 0.006 m/s at the top and (b) shear rate magnitude with an average of $\pm 10 \text{ sec}^{-1}$ near the apical of root canal using ultrasonic irrigation.

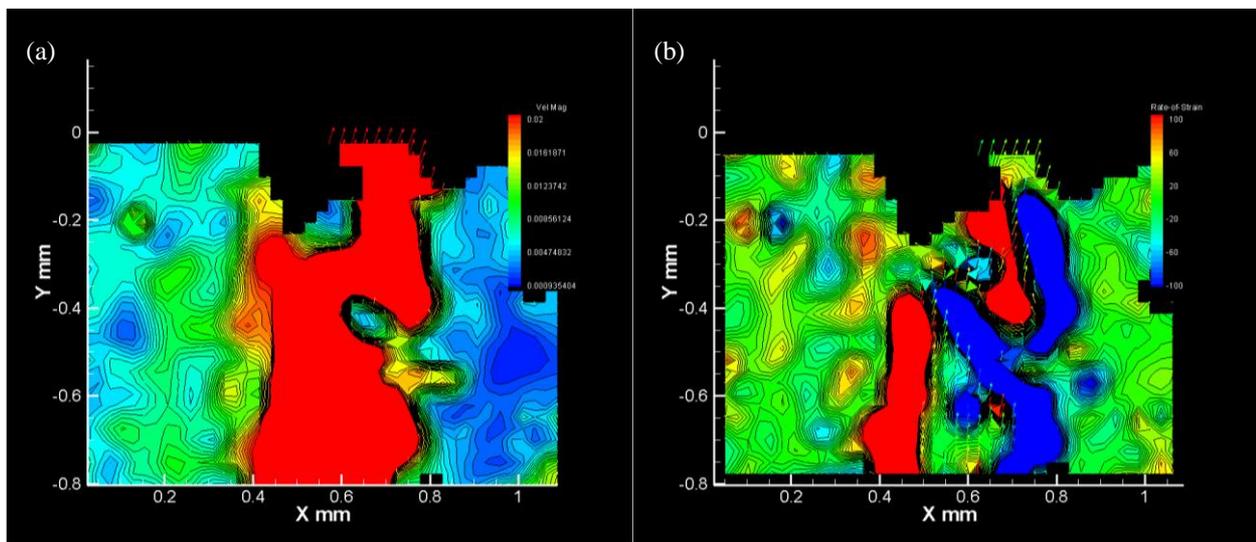


Figure 4. Contour of (a) velocity magnitude with an average of 0.004 m/s and (b) shear rate magnitude with an average of $\pm 20 \text{ sec}^{-1}$ near the middle section of root canal using ultrasonic irrigation.

RESULTS AND DISCUSSION

The velocity magnitude of flow field within the root canal is shown in Fig. 2(a) and Fig. 3(a) for pressurized injection and PUI respectively. While a maximum velocity of 0.003 m/sec is found at the bottom and an average velocity of 0.0006 m/sec is found near the top interface using syringe injection, PUI demonstrates its advantages over syringe injection by achieving a maximum velocity of 0.006 m/sec near the top which determines the effectiveness of removing tissues and debris from the apical. Moreover the shear rate distribution near the wall shown in Fig. 2(b) and Fig. 3(b) suggests an average magnitude of $\pm 10 \text{ sec}^{-1}$ on the surface of root canal which can disrupt microbial biofilms, while syringe injection only provides an average of $\pm 3 \text{ sec}^{-1}$ shear rate on the surface. Additionally, in case of the syringe injection the maximum velocity was localized to a small region on the canal wall near the outlet of the needle tip, whereas the PUI group showed high magnitude of velocity and high shear rate distribution over a larger area along the canal wall (Fig. 4). These results suggest that microfluidic replicas of root canal can serve as standardized models to characterize the fluids dynamics of different modes of irrigation and compare them for efficacy in endodontic disinfection.

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REFERENCES

1. Takahashi K. Microbiological, pathological, inflammatory, immunological and molecular biological aspects of periradicular disease. *Int Endod J.* 1998;31(5):311-25.
2. Nair P, Henry S, Cano V, Vera J. Microbial status of apical root canal system of human mandibular first molars with primary apical periodontitis after "one-visit" endodontic treatment. *Oral Surg Oral Med Oral Radiol Endod.* 2005 Feb;99(2):231-52.
3. Boutsoukis C, Verhaagen B, Versluis M, Kastrinakis E, Wesslink PR, van der Sluis LW. Evaluation of irrigant flow in the root canal using different needle types by an unsteady computational fluid dynamics model. *J Endod.* 2010 May;36(5):875-9.
4. Gao Y, Haapasalo M, Shen Y, Wu H, Li B, Ruse ND, et al. Development and validation of a three-dimensional computational fluid dynamics model of root canal irrigation. *J Endod.* 2009 Sep;35(9):1282-7.
5. van der Sluis LW, Versluis M, Wu MK, Wesslink PR. Passive ultrasonic irrigation of the root canal: a review of the literature. *Int Endod J.* 2007 Jun;40(6):415-26.

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