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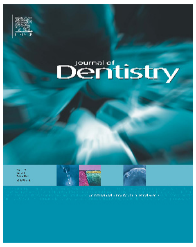

Wall shear stress effects of different endodontic irrigation techniques and systems

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ABSTRACT

Objectives: This study examined débridement efficacy as a result of wall shear stresses created by different irrigant delivery/agitation techniques in an inaccessible recess of a curved root canal model.

Methods: A reusable, curved canal cavity containing a simulated canal fin was milled into mirrored titanium blocks. Calcium hydroxide ($Ca(OH)_2$) paste was used as debris and loaded into the canal fin. The titanium blocks were bolted together to provide a fluid-tight seal. Sodium hypochlorite was delivered at a previously-determined flow rate of 1 mL/min that produced either negligible or no irrigant extrusion pressure into the periapex for all the techniques examined. Nine irrigation delivery/agitation techniques were examined: Navi-Tip passive irrigation control, Max-i-Probe® side-vented needle passive irrigation, manual dynamic agitation (MDA) using non-fitting and well-fitting gutta-percha points, EndoActivator™ sonic agitation with medium and large points, VPro™ EndoSafe™ irrigation system, VPro™ StreamClean™ continuous ultrasonic irrigation and EndoVac apical negative pressure irrigation. Débridement efficacies were analysed with Kruskal–Wallis ANOVA and Dunn's multiple comparisons tests ($\alpha = 0.05$).

Results: EndoVac was the only technique that removed more than 99% calcium hydroxide debris from the canal fin at the predefined flow rate. This group was significantly different ($p < 0.05$) from the other groups that exhibited incomplete $Ca(OH)_2$ removal.

Conclusions: The ability of the EndoVac system to significantly clean more debris from a mechanically inaccessible recess of the model curved root canal may be caused by robust bubble formation during irrigant delivery, creating higher wall shear stresses by a two-phase air–liquid flow phenomenon that is well known in other industrial débridement systems.

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1. Introduction

In root canal therapy, irrigants function as lubricants during canal instrumentation.[1] Some irrigants also help to eradicate canal wall biofilms via various antimicrobial strategies ranging from cell death[2] to complete hydrolysis.[3] As an irrigant moves through the root canal system, it produces a shear force parallel to the surface of the canal wall which is known as wall shear stress (WSS). The latter is responsible for mechanical débridement of the root canal space.[4] Wall shear stress is affected by a variety of conditions such as the canal taper.[5] The use of computer fluid dynamics has demonstrated a close relationship between calculated and observed results when side-vented irrigation needles are employed for root canal débridement.[6] For example, Boutsioukis et al. reported that WSS generated by a side-vented irrigation needle is the highest at the port's opening and drops rapidly towards the tip of the needle.[7] These results are in agreement with histological observations that side-vented needles are not very effective in cleaning instrumented root canals in the area 1 mm from the working length.[8]

Although various methods and techniques such as acoustic microstreaming,[9] manual dynamic agitation[10] and sonic agitation[11] have been used to enhance WSS, the ultimate magnitude of WSS is limited by patient safety issues arising from irrigant extrusion. Boutsioukis et al.[7] opined that from a clinical point of view, the prevention of irrigant extrusion should precede the requirement for adequate irrigant replacement and wall shear stress. Even though those authors[7] reported generation of an apically-directed pressure of about 75 mmHg when a 30-gauge side-vented needle was placed 3 mm from the working length (WL), a region of irrigant stagnation beyond the needle's termination was still apparent with an irrigant flow rate of 15.6 mL/min, confirming the earlier observation by Chow.[12]

Several new irrigation techniques have been developed in the past decade,[13] while classic strategies such as ultrasonic activation have been modified[14] and/or combined with new techniques[15] to enhance WSS. Jiang et al. evaluated a variety of these advancements in a straight canal model by placing the irrigation needle at 1 mm short of the WL and reducing the flow rate to 6 mL/min.[16] Khan et al. further tested several irrigant delivery needles, techniques and flow rates by placing the needles at 1 mm short of WL and insuring they were not bound in the canal.[17] In that study, a safety limit for root canal irrigant delivery was proposed to minimise extrusion of cytotoxic irrigants such as sodium hypochlorite into the periradicular regions. The proposed safety limit was defined as the point where the apically-directed pressure would not exceed the central venous pressure (CVP; 5.88 Hg). Adoption of such a safety limit avoids potentially fatal intravenous infusion, as reported during canal drying[18] and implant placement.[19] Although Khan et al. demonstrated the use of apical negative pressure as an irrigant delivery mechanism never exceeded CVP at any irrigant flow rate, all commercially available positive pressure root canal irrigant delivery systems produced apically-directed pressure in excess of the CVP at flow rates greater than 1 mL/min.

Since the efficacy of irrigant agitation is inversely proportional to the extent of wall contact of an irrigant delivery or agitation device,[20] canal curvature must also be considered when assessing WSS. Thus, the objective of the present study was to examine the effects of WSS in a curved canal, by comparing the efficacy of debris removal by nine irrigant delivery and/or agitation techniques in an inaccessible recess of a curved root canal model, using an irrigant flow rate of 1 mL/min that was previously determined to produce apically-directed pressure that is less than the CVP. Calcium hydroxide ($Ca(OH)_2$) paste was placed in the recess as an inert hydrophilic marker to simulate canal wall debris. The null hypothesis tested was that the method of irrigant delivery or agitation does not influence the efficacy of mechanical débridement when sodium hypochlorite is delivered at the universal flow rate of 1 mL/min.

2. Materials and methods

2.1. Root canal model

A reusable, curved root canal cavity was milled into mirrored medical-grade (Grade II) titanium blocks (Figs. 1 and 2) with the aid of a computer-aided 3-D design software (Dassault Systèmes SolidWorks Corp., Waltham, MA, USA). The canal had a primary curvature of 17°, a secondary curvature of 24° and a tertiary curvature of 68°. The blocks were precision-lapped to form a fluid-tight seal when bolted together. This fluid-tight seal was verified via under-water testing. The WL of the cavity was 17 mm. Canal geometry was equivalent to having taken a size-30, 0.06 taper rotary instrument to WL, and then clearing the apical seat with a size 40, 0.02 taper hand instrument. An inaccessible groove was milled in one titanium block (Fig. 2) to simulate a canal fin. It measured 0.2 mm wide, 0.5 mm deep and 4.0 mm long, commencing 2 mm coronal to the apical termination and was located between the secondary and tertiary curvatures of the canal.

2.2. Fin loading and predefined parameters

Due to its uniform particle size, predictable flow and definite opacity, $Ca(OH)_2$ paste (UltraCal XS, Ultradent Products Inc., South Jordan, UT, USA) was used as the test debris and marker. It was loaded into the fin by using a 30-gauge NaviTip (Ultradent) attached to the UltraCal XS syringe, starting from the apical aspect with the needle slowly advancing coronally. After the fin was filled, the opposing block was aligned with precision positioning pins; bolting of the blocks was performed exactly 60 s after $Ca(OH)_2$ loading to prevent drying of the paste. Sodium hypochlorite (2.6%) was used as the sole irrigant at the predefined flow rate of 1 mL/min. The rationales for using sodium hypochlorite include: it does not corrode titanium, does not chemically react with UltraCal and is a clinically-relevant intracanal irrigant. Irrigant delivery was controlled using an Aladdin precision syringe pump (World Precision Instruments, Sarasota, FL, USA) connected to all test groups via polyethylene tubings and Luer connectors. A master delivery tip derived from the EndoVac system (Sybron Dental Specialties, Orange, CA, USA) was permanently mounted over the access opening to aspirate overflowing irrigant during all testing.