Evaluation of Irrigant Flow in the Root Canal Using Different Needle Types by an Unsteady Computational Fluid Dynamics Model

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Abstract

Introduction: The aim of this study was to evaluate the effect of needle tip design on the irrigant flow inside a prepared root canal during final irrigation with a syringe using a validated Computational Fluid Dynamics (CFD) model. **Methods:** A CFD model was created to simulate the irrigant flow inside a prepared root canal. Six different types of 30-G needles, three open-ended needles and three close-ended needles, were tested. Using this CFD model, the irrigant flow in the apical root canal was calculated and visualized. As a result, the streaming velocity, the apical pressure, and the shear stress on the root canal wall were evaluated. **Results:** The open-ended needles created a jet toward the apex and maximum irrigant replacement. Within this group, the notched needle appeared less efficient in terms of irrigant replacement than the other two types. Within the close-ended group, the side-vented and double side-vented needle created a series of vortices and a less efficient irrigant replacement; the side-vented needle was slightly more efficient. The multi-vented needle created almost no flow apically to its tip, and wall shear stress was concentrated on a limited area, but the apical pressure was significantly lower than the other types. **Conclusions:** The flow pattern of the open-ended needles was different from the close-ended needles, resulting in more irrigant replacement in front of the open-ended needles but also higher apical pressure. *(J Endod 2010;36:875–879)*

Key Words

Computational Fluid Dynamics, irrigation, needle, tip

The irrigation of root canals with antibacterial solutions is considered an essential part of chemomechanical preparation (1). Irrigation with a syringe and a needle remains the most commonly used procedure (2, 3). However, there is an uncertainty about the efficiency of this procedure in the apical part of the root canal (4–6).

To increase the efficiency of syringe irrigation, different needle types have been proposed (7–13). Previous studies of the resulting flow (7, 8, 10, 12) were limited because an indirect or a macroscopic approach can only provide a coarse and incomplete estimation of the irrigant flow. Consequently, there is still no consensus on the superiority of any of these types.

Computational Fluid Dynamics (CFD) represents a powerful tool to investigate flow patterns by mathematical modeling and computer simulation (14, 15). CFD simulations can provide details of the velocity field, shear stress, and pressure in areas in which experimental measurements are difficult to perform. Recently, a CFD model was proposed for the evaluation of irrigant flow in the root canal (16) and was subsequently validated by comparison with experimental high-speed imaging data (17). The aim of this study was to evaluate the effect of needle tip design on the apical irrigant flow inside a prepared root canal during final irrigation with a syringe using this validated CFD model.

Materials and Methods

The root canal and apical anatomy were simulated similarly to a previous study (16), assuming a length of 19 mm, an apical diameter of 0.45 mm (ISO size 45), and 6% taper. The apical foramen was simulated as a rigid and impermeable wall.

Six different needle types were modeled using commercially available 30-G needles as a reference (Fig. 1). The needle types can be divided in two main groups: open-ended (Fig. 1*A-C*) and close-ended (Fig. 1*D-F*). The external and internal diameter and the length of all needles were standardized ($D_{ext} = 320\ \mu m, D_{int} = 196\ \mu m, l = 31$ mm, respectively) in order to isolate the effect of needle tip design. These values correspond closely to the real geometry of the needles, which was determined according to a previous study (18). The two outlets of the double side-vented needle were modeled identical to the outlet of the side-vented needle to exclude the possible effect of the outlet design. The needles were fixed and centered within the canal, 3 mm short of the working length (WL).

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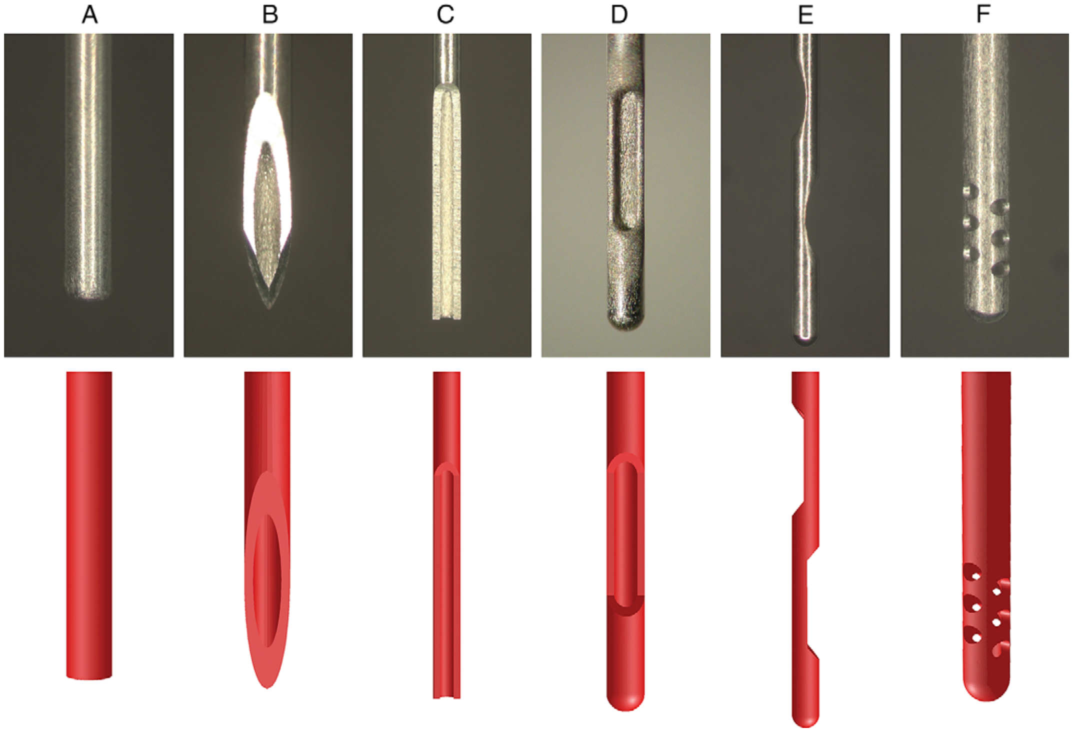

Figure 1. Commercially available 30-G needles used as references (top) and corresponding three-dimensional models created (bottom). (*A-C*) Open-ended needles: (*A*) flat (NaviTip; Ultradent, South Jordan, UT), (*B*) beveled (PrecisionGlide Needle; Becton Dickinson & Co, Franklin Lakes, NJ), and (*C*) notched (Appli-Vac Irrigating Needle Tip; Vista Dental, Racine, WI). (*D-F*) Close-ended needles: (*D*) side-vented (KerrHawe Irrigation Probe; KerrHawe SA, Bioggio, Switzerland), (*E*) double side-vented (Endo-Irrigation Needle; Transcodent, Neumünster, Germany), and (*F*) multi-vented (EndoVac Microcannula; Discus Dental, Culver City, CA). Variable views and magnification were used to highlight differences in tip design.

The preprocessor Gambit 2.4 (Fluent Inc, Lebanon, NH) was used to build the 3-dimensional geometry and the mesh. A hexahedral mesh was constructed, and a grid refinement was performed near the walls and in areas in which high gradients of velocity were anticipated. A grid-independency check was performed to ensure the reasonable use of computational resources. The final meshes consisted of 597,400 to 810,600 cells depending on needle type (mean cell volume $= 2.07\text{-}2.82 \cdot 10^{-5}$ mm^3).

No-slip boundary conditions were applied under the hypothesis of rigid, smooth, and impermeable walls. The fluid flowed into the simulated domain through the needle inlet and out of the domain through the root canal orifice where atmospheric pressure was imposed. The root canal and needle were assumed to be completely filled with the irrigant. A flat velocity profile with a constant axial velocity of 8.6 m/s was imposed at the needle inlet, which is consistent with a clinically realistic irrigant flow rate of 0.26 mL/s through a 30-G needle (19). The irrigant, sodium hypochlorite 1%, was modeled as an incompressible Newtonian fluid, with density $\rho = 1.04$ g/cm^3 and viscosity $\mu = 0.99 \cdot 10^{-3}$ Pa$\cdot$s (16). Gravity was included in the flow field in the direction of the negative z axis.

The commercial CFD code FLUENT 6.3 (Fluent Inc) was used to set up and solve the problem. Detailed settings of the solver can be found in another study (17). Computations were performed in a computer cluster (45 dual-core AMD Opteron 270 processors) running 64-bit SUSE Linux 10.1 (kernel version 2.6.16). The flow fields for the six needle types were calculated and compared in terms of velocity, shear stress, and apical pressure.

Results

Of the open-ended needles, the flat and beveled needle presented similar high-velocity jets of irrigant in the root canal (Fig. 2.1*A* and *B*). For the notched needle, the velocities in the jet were slightly lower (Fig. 2.1*C*). The flow pattern of the close-ended needles was different compared with the open-ended needles. The flow was more directed to the root canal wall in place of the apex. The side-vented and double side-vented needle presented a flow pattern with a jet of irrigant formed at the outlet (the one proximal to the tip for the double side-vented) and directed toward the apex with a divergence of approximately 30° (Fig. 2.1*D-E*). The irrigant followed a curved path around the tip. A series of three counter-rotating vortices were identified apically to the tip. The irrigant flowing out of the proximal outlet of the double side-vented needle amounted to 93.5% of the total flow. As a result, the flow from the distal outlet presented only a minor influence on the flow pattern.

Several small jets were formed by the irrigant exiting the multi-vented needle from the six outlets proximal to the tip (Fig. 2.1*F*). The most intense jets were formed through the most proximal pair of outlets, which was responsible for 73% of the total flow, whereas the second and third pair of outlets were responsible for 25% and 2%, respectively. The other three pairs of outlets did not contribute to the outflow. Very low velocities were noted apically to the tip.

Streamlines indicating the route of massless particles released downstream from the needle inlet depicted the main flow of the delivered irrigant in three dimensions (Fig. 2.2). Analysis of the axial z component of irrigant velocity in the apical part of the canal as a function of the distance from the WL (Fig. 3.1) provided a more detailed overview of irrigant replacement, which was considered clinically significant for velocities >0.1 m/s. The replacement of irrigant extended further than 2 mm apically to the tip of the open-ended needles, whereas it was limited within 1 to 1.5 mm apically to the tip of the close-ended needles.

The shear stress pattern on the canal wall was similar between the flat, beveled, and notched needle, but the beveled and notched types

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