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ORIGINAL ARTICLE

Computational fluid dynamic analysis on the induced apical pressures in simulated oval and irregular round canals: an ex-vivo study

ABSTRACT

Aim: *Fluid dynamics can be understood in-vitro by observing the fluid flow patterns in the simulated canal models. The current study aimed at assessing the apical pressures in simulated oval and irregular round canals using computational fluid dynamic analysis (CFD) as a tool.*
Methodology: *Following the ethical approval, a total of 58 freshly extracted mandibular second premolars were collected for the present study. Cone-beam computed tomography (CBCT) scanning was done to confirm the root canal morphology. Based on the specified inclusion and exclusion criteria, the specimens were divided into two groups: group I: irregular round canals (n=29), and group II: completely oval canals (n=29). Following this, the instrumentation of the specimens was carried out using the XP-Endo Shaper (XPS) file system. A post-instrumentation CBCT was then taken to obtain a computer-aided design (CAD) model. Once the CAD model was obtained the CFD simulations were then carried out at different needle placements.*
Results: *Group I showed significantly higher (P<0.05) apical pressures at all the needle positions analyzed.*
Conclusion: *Oval-shaped canals showed the least apical pressures at all needle positions as compared to irregular round canals.*

Sahil Choudhari[1]

Kavalipurapu Venkata Teja[1]

Sindhu Ramesh[1*]

Raja Kumar[1]

Marzia Maglitto[2]

Alessandra Valletta[2]

[1]Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India.

[2]Department of Neuroscience, Reproductive and Odontostomotological Sciences, University of Naples Federico II, Naples, Italy.

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Corresponding Author
Professor Sindhu Ramesh | Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, 162, Poonamalle High Road, Chennai-600 077, TamilNadu | India
Email: sindhuramesh@saveetha.com Phone +91 9840136543

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Introduction

Fluid dynamics is a complicated aspect which can only be understood by observing the fluid flow patterns through in-vitro analysis (1). The stresses generated on the root canal walls in due course of irrigation cause the effective smear and the biofilm removal (2, 3). Nevertheless, these stresses should never cross the physiological limit (1). The direction of the irrigant flow in the apical portion and the irrigant interaction with the canal walls depends on the nature of the delivery system used (4). As the fluid flow occurs in the root canal, there are wall shear stresses (2) and turbulent forces which are generated in the root canal system (5). So, clinically these increased forces generated tend to cause irrigant extrusions if the irrigant pressure exceeds apically (6). Especially the pressures generated tend to be higher with the usage of positive pressure irrigation systems (7, 8). However, a clinician should always maintain a subtle balance in maintaining both safety and efficacy during the irrigation with the positive pressure delivery systems (9).

Although it's effective to achieve enough fluid exchange by placing the irrigation needle close to the estimated working length, it's equally important to control the irrigant flow within the confines of the complicated root canal system (9). Studies claim the increased positive pressures in canals when the fluid flow rate increases (7, 10-13). Usually, these increased pressures cause irrigant extrusions clinically, when the flowing fluid pressure exceeds 30 mm Hg, which approximates the intraosseous blood pressure (9). Among the used positive pressure delivery systems, closed-ended side vented needles are claimed to be effective in inducing higher shear wall stress, with lower generated apical pressures (8, 14). and least extrusions (15). Current systematic review evidence based on computational fluid dynamic analysis (CFD) also showed the improvement in the irrigant flow parameters with reduced apical pressures, when a 30 gauge side vented was simulated during the laboratory irrigation (1). Among the different fluid flow rates investigated in-vitro using various non-binding needles, flow rates greater than 3-4m/min was claimed to cause excessive apical pressures (16). However, a practising clinician can never maintain a standard irrigant flow rate while using positive pressure syringe needle irrigation (17). There are various factors like the operator-based factors (10), the curvature of the tooth (18), choice of needle type and design (19), taper (20) and preparation sizes chosen (21), which play a vital role clinically in altering the irrigant flow rates. However, most often the extrusions tend to happen clinically when the needles are wedged into the root canal (22).

Among the various investigated needle types, closed-ended side vented needles are claimed to be the safest for clinical use (23). So in the current study, we have carried out all the evaluations with a simulated side vented closed-ended needle. As far as the previous literature is concerned such on root canal morphologies, to our knowledge, there are only two studies (8, 24), which assessed the apical pressures in simulated oval (8) and c-shaped canals (24). However, there are no focussed studies as such to date assessing the apical pressures in oval and irregular round canals, which are most frequently encountered clinically with mandibular premolars (25). Considering all these facts, the current study aimed at assessing the apical pressures in simulated oval and irregular round canals using CFD as a tool.

Materials and methods

Institutional human ethical committee approval was obtained from the university (SRB/SDC/ENDO-2102/21/030) before the research has begun. The recent PRILE guidelines were followed for conducting the current study (26). Sample size estimation was carried out based on previous research by our colleagues (27). A total sample of 58 was achieved at a power of 95% and an effect size of 0.97 (1-β=95%, α=0.05).

Before the extraction, informed consent

was obtained from the patients. A total of 58 freshly extracted mandibular second premolars were collected for the current study. The entire specimen collection process was carried out by a postgraduate (S), who was not involved in the study. Extracted teeth due to periodontal or orthodontic reasons, teeth with minimal curvatures <5 degrees, and teeth with intact apices were selected for the current study. Carious teeth and teeth with canal calcifications and resorption were excluded from the current study. Extracted specimens were immediately stored in phosphate-buffered saline solution (P10400-1000.0 - PBS 1X Solution) after curettage of the soft tissue debris from the extracted surface. After the storage of 24 hrs, the specimens were evaluated for a single canal morphology using an intra-oral periapical radiograph (IOPAR).

Following the initial conformation, the specimens were then subjected to cone-beam computed tomography (CBCT) to confirm the specified root canal morphologies. A Kodak 9000 device (Carestream Dental Kodak Systems, Rochester, NY) was used for the scanning of the collected specimens. The scanning was carried out at 70 kVp, 6.3 mA and a resolution of 0.76 mm. The scan time was around 10.8 seconds and at a FOV of 18.4cm x 20.6 cm. After subjecting to the CBCT, the specimens having either irregular round or completely oval canals were only considered for the study. The entire evaluation process was done by a radiologist (P) having more than 5 years of experience. Once the specimens were confirmed, they were decoronated using a diamond disc under adequate coolant to standardize the root length to 12 mm and the working length (WL) determination was carried out. The entire specimen collection, decoronation and WL determination were carried out by the same postgraduate (S) who was not involved in the study.

The specimens were then randomly divided into two groups based on the canal morphology as the group I: irregular round canals (n=29), and group II: completely oval canals (n=29). Following this, the specimens were provided to an operator (SC) who was blinded to the entire experimentation protocol. The instructions on the chemo-mechanical debridement were provided to the operator (SC) by a supervisor (KVT). The initial patency was achieved using an ISO No #10 K- hand file (Dentsply Maillefer, Ballaigues, Switzerland). Following this, the instrumentation was carried out using an XP-Endo Shaper (XPS) file system (XPS; FKG Dentaire SA, La Chaux-de-Fonds, Switzerland). Pecking motions were carried out for the instrumentation until the desired WL was reached. Debris accumulated on the instrument was cleaned after every three pecking motions using an alcohol swab. After each instrumentation, the files were immersed in the temperature-controlled water bath (35±1.0 °C) to maintain the XP phase of the system.(28) After the complete shaping, the final rinse was carried out using 4 ml of 5.25% sodium hypochlorite (NaOCL) (Parcan, Septodont, France) and 5ml of 17% ethylene diamine tetra-acetic acid solution (EDTA) (MD Cleanser, MetaBiomed, South Korea). The final flush was carried out using 5ml of distilled water. A total of 20 ml of 5.25% NaOCL was standardized for each specimen during the entire protocol. The entire irrigation was carried out using a 30 gauge single-side vented needle (NaviTip, Ultradent Products, South Jordan, UT, USA) attached to a 5ml syringe barrel. Following the instrumentation, the specimens were subjected to CBCT analysis. A total of five-hundred sections were analysed in Galileos Viewer Software to recreate a three-dimensional computer-aided design (CAD). The DICOM file of the isolated root canal was converted to an STL file format using Mimics Medical 2.0 software. The STL file was then converted to a Parasolid file for analysis using Space Claim 2021 R2 software. Following this, the real geometry of the 30 gauge side vented needle was recreated (Dext=320 µm, Dint=196 µm, l=31 mm). Gambit 2.4 (Fluent Inc., Lebanon, NH) was used for hexahedral mesh reconstruction. Grid refinement and the grid independency check were done to ensure computational resource usage. A final mesh was then obtained depending on the canal

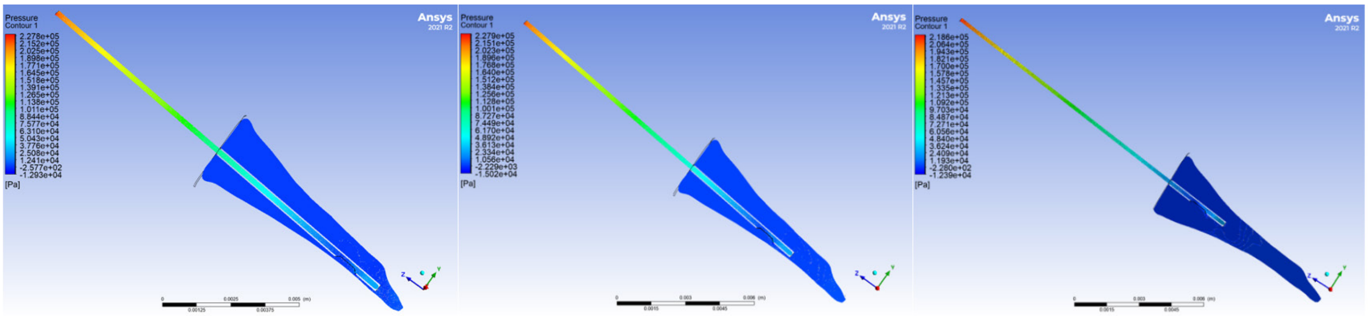

Figure 1
Depicting the simulation carried out at different needle positions in irregular round canals.

shape (mean cell volume 0.7–2.1×10−5 mm^3).
CFD simulations were then carried out using Ansys Fluent 2012 R2 software (Figure 1, Figure 2). The simulations were carried out at a constant volumetric flow rate of 0.26 mL/s by placing the needle at 25%, 50%, and 75% short of the working length (WL). A flow rate of 0.26 mL/s correlates to the laminar flow at a flow velocity of 8.99 m/s and with a Reynolds number of 1678. A shear stress transport (SST) k-ω model was then used for the turbulent flow analysis. Liquid viscosity was considered by reinforcing no slip conditions on the needle and the root canal walls. Gravity was considered in the direction of the flow (i.e., -z-axis). The mean value of four simulations was taken into account for the final analysis.

Statistical analysis
Data analysis was done using IBM SPSS Statistics Software for Windows Version 23.0 (Armonk, NY, USA, IBM Corp). The apical pressures in different groups were compared using an Independent T-test.

Results

The current study results showed significantly ($p<0.05$) higher apical pressures in group I (Table I) as compared to group II at all the needle positions analyzed (25%, 50%, 75% short of WL).

Discussion

The present study results showed a significant difference ($p<0.05$) in the recorded pressures at all needle positions in different groups analysed. Among the oval and irregular round canals compared, the mean pressure values were significantly higher ($P<0.05$) in irregular round canals as compared to the completely oval canals. To date, there is no specific literature as such comparing the apical pressures in single irregular round canals as compared to the completely oval ones. However, the previous studies state that, as the space between the positioning needle and the root canal walls increases, the pressures elicited tend to decrease (21). Hence, in the current study, the oval canals recorded lower pressures at all the needle positions. To our knowledge, there is only one study which assessed the pressures during root canal irrigation in single and anastomosed poly-carbonate models (9). The study results showed a similar outcome, where the recorded pressures were significantly higher with the single canal models (9). When the different needle positions were assessed, the recorded pressures were higher when the needle position was 25% short of WL. Previous studies were also in correlation with the current study which showed higher recorded pressures when the needle placement was more apical (27, 29). From this, it can be inferred that the pressures are more related to the needle placement than the type of canal morphology.
When the literature as such on root canal anatomy is concerned, one study has assessed the pressures in different facing of side vented needles in c-shaped canals (24), which is not in relevance to the present study rationale. The other study which assessed the positive pressure irrigation

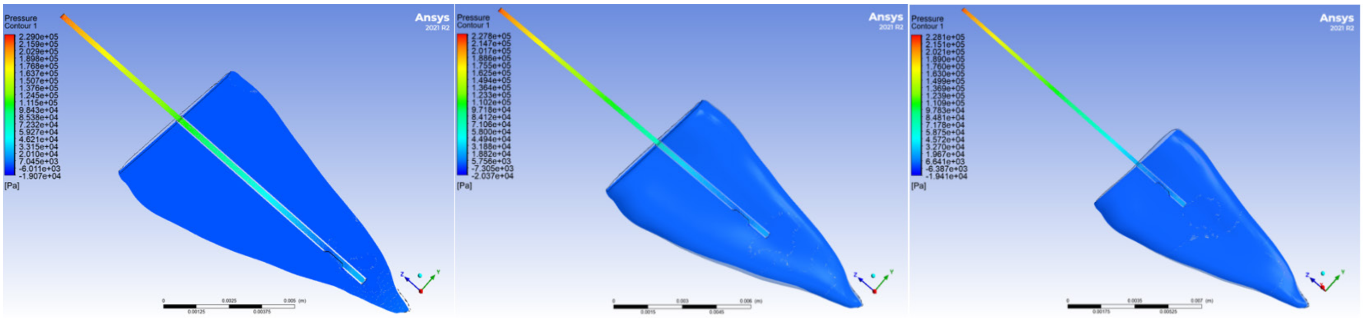

Figure 2
Depicting the simulation carried out at different needle positions in completely oval canals.

in oval-shaped canals confirmed lesser pressures with higher shear stress when a simulated side vented needle was used for the irrigation (8). To our knowledge to date, there is no focused research which evaluated the apical pressures in different canal morphologies. In the present study, we have simulated a similar flow rate of 0.26 ml/s which is claimed to be the highest possible flow rate clinically on using syringe needle irrigation (30). In vitro-based CFD studies also employed similar flow rates (31). Hence, we employed above mentioned flow in our current study. When the current study results were critically assessed, the entire protocol of instrumentation and irrigation was performed by a single operator who was blinded to the study design. The instrumentation was carried out using an XPS file system as it is effective in debriding the oval-shaped canals (32, 33). As far as the irrigation regimen is concerned, we have standardized the irrigant type, volume and concentration in both the groups. So the possibility of experimentation-related bias is avoided. The reason for choosing the irregular round canals was because it's quite unusual to find the complete round canals clinically (27). So, to simulate the most possible clinical condition, the extracted second premolars with completely oval and irregular round canals were only considered for the current study.
The current study's limitations were not considering the flow rate assessments with different possible flow simulations. In the current study, we employed a stationary needle placement during the entire simulation. But previous literature states the better flow and least pressure when the needle was oscillated continuously (34). So, future studies can better concentrate on assessments of different canal anato-

Table 1
Table presenting the pressures elicited in different groups at various needle positions assessed

Table depicting the pressures elicited in different groups at various needle positions						
Needle position	**Groups**	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**P-Value**
25% WL	Group I	29	11714.2418	1016.11732	188.68825	.001
	Group II	29	5100.2242	493.93498	91.72142	
50% WL	Group I	29	3244.2222	266.98782	49.57839	.004
	Group II	29	1012.5389	124.13089	23.05053	
75% WL	Group I	29	2107.3750	325.73380	60.48725	.000
	Group II	29	642.5249	79.97808	14.85156	

25% WL- 25% short of the working length; 50% WL- 50% short of the working length; 75% WL- 75% short of the working length.

mies at varied flow rates and needle placements. Future studies can also assess the simulated biofilm removal and shear stresses caused by different irrigation needles in varied canal anatomies.

Conclusion

Oval-shaped canals showed the least apical pressures at all needle positions as compared to irregular round canals. When different needle positions were compared, the recorded pressures were higher when the needle was placed 25% short of the WL.

Clinical relevance

Apical pressure generated in root canals during irrigation, clinically cause the extrusions. The literature is also scarce on the generated apical pressures in different canal morphologies. In the present study, we assessed the apical pressures produced in simulated irregular round and completely oval canals at different needle positions using CFD. The present study results showed significantly higher apical pressures at all needle positions.

Conflicts of Interest

No conflicts of interest.

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I affirm that I/we have no financial affiliation.

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