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ORIGINAL ARTICLE

Assessment of Apical Pressures in Single and Joining Canals - An *Ex Vivo* Study Based on Computational Fluid Dynamic Analysis

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ABSTRACT

Objective: Computational fluid dynamic analysis (CFD) is claimed to be a reliable tool for analysing the fluid flow and the generated apical pressures in the simulated root canal. The current study aimed to analyse the apical pressures in extracted teeth with single and joining canals.

Methods: Forty-six freshly extracted teeth were collected for the present study. The power was set at 95%, with an effect size of 0.55 (1-β=95%, α=0.05). Once the root canal anatomy was confirmed with cone-beam computed tomography (CBCT), they were divided into two groups: group I: mandibular second premolars with Vertucci type-I (n=23), and group II: maxillary second premolars with Vertucci type-II (n=23). The instrumentation of the specimens was carried out to a 0.04-taper using rotary instruments. A post-instrumentation CBCT was obtained, and computer-aided design models were obtained. The CFD simulations were then conducted with simulated 30-gauge side vented needles at 25, 50, and 75% short of the working length (WL).

Results: Group I recorded significantly ($p<0.05$) higher apical pressures at needle positions 25% short of the WL. However, no significant differences were elicited in the groups at other needle positions.

Conclusion: Single canal specimens recorded higher apical pressures at needle positions 25% short of the WL. However, no differences were elicited between single and joining canals at higher needle positions.

Keywords: Endodontics, irrigant, premolars, root canal

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HIGHLIGHTS

- This study is the first to compare recorded apical pressure values in extracted teeth with single and joining canal anatomies.
- Apical pressure was significantly higher in single canals at needle position 25% short of the WL.
- No significant ($p>0.05$) difference was observed in the recorded pressure in single and joining canals at 50% and 75% from the WL.

INTRODUCTION

Root canal irrigation is a preliminary step for achieving effective root canal disinfection during endodontic treatment (1). However, the complicated canal anatomy hinders its potential (2). So, various studies focus on applying alternative irrigation modes to achieve irrigation efficacy in teeth with complex root canal anatomy (3). Although various techniques and devices have been developed for irrigation, syringe needle irrigation (SNI) is the most widely used by specialists and is reported to be the safest mode of irrigation delivery during root canal treatment (4). However, the real-time evaluation of the irrigant fluid dynamics can only be evaluated *in vitro* (5). Furthermore, a previous systematic review has clearly stated that multiple factors and parameters are involved in improving the effectiveness of SNI (5).

Sodium hypochlorite (NaOCl) is considered the gold standard for endodontic irrigants. Owing to its advantages, NaOCl is highly irritative when extruded into periapical tissues (6). The consequences of extrusion depend on the volume of the solution extruded, the duration of extrusion, and the site where the extrusion occurred (7). The manifestation of hypochlorite accidents varies from mild irritation to severe cases that require emergency treatment (7). Several other factors, such as the harmony between the physiological pressure of periapical tissues and the pressure of an irrigating solution in the root canal system, also affect the risk of extrusion. *In vitro* studies are the only way to evaluate the irrigant fluid dynamics in real time (5).

Although improved fluid dynamics can result in effective three-dimensional cleaning, induced apical pressures should not exceed the physiological limit (5). According to the previous literature, computational fluid dynamic analysis (CFD) is reliable for evaluating irrigation fluid dynamics (8). A 30-gauge side vent needle was claimed to produce the lowest apical pressures with higher lateral shear stress among the various needle designs evaluated in previous studies (9).

Root canal irrigation is a dynamic rather than a static process (10). Various physical factors and parameters, such as mass flow rate, flow velocity, turbulence, shear wall stress, and flow patterns, alter the clinical flow rate during root canal irrigation (5).

Several *in-vitro* studies have assessed the apical pressures in different tapers (11), apical preparation sizes (12), irrigant flow rates (13), needles (9) and needle placements (14). Previous research that compared the apical pressures of single and anastomosed polycarbonate models found that single canal models had higher apical pressures (15). So, the current study aimed to use CFD to measure the *ex-vivo* apical pressures in extracted premolars with single and joining canals at different needle positions.

MATERIALS AND METHODS

Prior ethical approval for the current study was obtained from the university-affiliated institutional ethical committee (SRB/SDC/ENDO-2102/21/031). Informed consent was also obtained from the patients before the tooth extraction. The study was conducted according to the recent PRILE guidelines (16). The study was conducted in accordance with the Declaration of Helsinki. The sample size estimation for the current study was based on a previous *ex-vivo* study, which assessed the apical pressures in different preparation sizes and tapers (10). The power was set at 95% with an effect size of 0.55 (1–β=95%, α=0.05). Based on the sample size calculation, a total sample size of 46 was obtained, resulting in a sample size of 23 per group.

The intact teeth from patients undergoing therapeutic orthodontic extraction were only collected for the study. The inclusion criteria were maxillary second premolar teeth and mandibular second premolar teeth with intact apices undergoing extraction. Teeth with extensive decay, calcifications, and resorptions were excluded. Immediately after the extraction, the surface tissue debris was curetted, and the specimens were stored in phosphate-buffered saline solution (P10400–1000.0, PBS 1X Solution, Sigma-Aldrich Chemicals Private Limited, Bangalore, India) for a day. Collected specimens were then subjected to intraoral periapical radiographs (IOPAR) in multiple angulations to confirm the canal anatomy.

Maxillary second premolars with Vertucci type II and mandibular second premolars with Vertucci type I canal anatomy were confirmed through IOPAR. After initial confirmation, the specimens were then decoronated to standardise the root length to 13 mm from the flat reference point. Following this, the initial patency was achieved using an ISO No. 10 K hand file (Dentsply Mallefer, Ballagues, Switzerland). The WL was then established at 1 mm short of the visible file tip. After this, the specimens were subjected to cone-beam computed tomography (CBCT) to confirm the canal anatomy. There were no restrictions based on the canal morphology. The specimens were scanned using a Kodak 9000 device (Carestream Dental Kodak Systems, Rochester, New York, USA) at a resolution of 0.076 mm, 70 kVp, 6.3 mA, and a FOV of 18.4 cm×20.6 cm with a 10.8 s scan time. The protocol mentioned above was carried out by an endodontist who was not involved in the study (S).

To ensure no difference in the apical sizes of the selected specimens in different groups, the initial apical sizes of the collected specimens were assessed using a previously published protocol (17). After the CBCT acquisition, the smallest diameter of the scanned images was measured at 1 mm short of the apex using OnDemand3D software (OnDemandApp 1.0.9.2225; Cybermed, Inc., Seoul, South Korea) directly on axial sections perpendicular to the canal. The evaluation was performed on an LCD monitor at 1366×768 pixels.

Once the specified criteria were satisfied, the specimens were then randomly allocated into two groups: group I: mandibular second premolars with Vertucci type I, and group II: maxillary second premolars with Vertucci type II. The specimens were then provided to a blind operator (S.C.), who had previously been instructed on the instrumentation and irrigation protocol to be followed by a supervisor (K.V.T.). The initially measured WL values were provided to the operator. The instrumentation was carried out three sizes larger than the initial apical binding file using 0.04-taper Hyflex CM rotary instruments (Coltene/Whaledent Inc., Cuyahoga Falls, Ohio, USA). In due course of instrumentation, the irrigation was carried out using 5.25% sodium hypochlorite (Parcan, Septodont, Saint-Maur-des-Fossés, France) and 17% ethylene diamine tetraacetic acid (EDTA) (MD Cleanser, MetaBiomed, Chungcheongbuk-do, Republic of Korea) using a 30-gauge side vented needle (NaviTip, Ultradent Products, South Jordan, UT, USA) kept 1 mm short of the WL. After the complete instrumentation, final irrigation was carried out using 4 mL of 5% NaOCl, 5 mL of 17% EDTA, and a final rinse of 5 mL of distilled water, and canals were dried using paper points.

Post-instrumentation, the specimens were subjected to CBCT and analysed in Galileos Viewer software, where 500 sections

TABLE 1. Comparing simulations carried out in different groups at 25% short of working length using Two-way ANOVA

Group	Simulations carried at 25% short of WL				
	Sample size	Mean (Pascals)	Standard deviation	Standard error mean	p
Single canal (group I)	23	9877.78	1282.59	267.43	
Joining canals (group II) - Buccal root	23	3303.78	330.25	68.86	<0.001*
Single canal (group I)	23	9877.78	1282.59	267.43	
Joining canal (group II) - Palatal root	23	3641.31	381.31	79.50	0.001*
Joining canal (group II) - Buccal root	23	3303.78	330.25	68.86	
Joining canal (group II) - Palatal root	23	3641.31	381.31	79.50	0.494

*: Statistical significance. ANOVA: Analysis of variance, WL: Working length

TABLE 2. Comparing simulations carried out in different groups at 50% short of working length using two-way ANOVA

Group	Simulations carried at 50% short of WL				
	Sample size	Mean (Pascals)	Standard deviation	Standard error mean	p
Single canal (group I)	23	3369.33	233.60	48.71	
Joining canals (group II) - Buccal root	23	3036.60	343.37	71.59	0.098
Single canal (group I)	23	3369.33	233.60	48.71	
Joining canal (group II) - Palatal root	23	3204.91	308.03	64.22	0.098
Joining canal (group II) - Buccal root	23	3036.60	343.37	71.59	
Joining canal (group II) - Palatal root	23	3204.91	308.03	64.22	0.779

TABLE 3. Comparing simulations carried out in different groups at 75% short of working length using two-way ANOVA

Group	Simulations carried at 75% short of WL				
	Sample size	Mean (Pascals)	Standard deviation	Standard error mean	p
Single canal (group I)	23	1846.23	105.59	22.01	
Joining canals (group II) - Buccal root	23	1374.79	143.35	29.89	0.487
Single canal (group I)	23	1846.23	105.59	22.01	
Joining canal (group II) - Palatal root	23	1515.29	172.92	36.05	0.12
Joining canal (group II) - Buccal root	23	1374.79	143.35	29.89	
Joining canal (group II) - Palatal root	23	1515.29	172.92	36.05	0.137

were analysed in different sections to recreate a three-dimensional computer-aided design (CAD) model of the prepared canal. Mimics Medical 21.0 was used to convert the DICOM file of the root canal cavity to an STL file. Then, using SpaceClaim 2021 R2, the STL file of the root canal was extracted and converted to a Parasolid file for analysis. The 30-gauge single-side vented needle (NaviTip, Ultradent Products, South Jordan, UT, USA) reconstruction was done similarly to a previous study (9). The actual geometry of the needles was standardised by recreating the length and external and internal diameters (Dext=320 µm, Dint=196 µm, l=31 mm). Finally, the simulations were carried out at 25, 50, and 75% short of the WL using CFD based on the previous literature (18). The values were considered separately for the buccal and palatal roots of group II, and the data was statistically analysed (Table 1-3).

Before the flow simulations, the three-dimensional geometry and the hexahedral mesh were constructed using a preprocessor, Gambit 2.4 (Fluent Inc., Lebanon, NH, USA), and grid refinement was done. To ensure the usage of the computational resources, a grid independence check was performed. Depending on the specimen shape, a final mesh was obtained with 477,000–783,000 cells (mean cell volume 0.7–2.1×10^{-5} mm^3). The simulations were carried out with Ansys Fluent 2012 R2 software. The entire simulation process was similar to a previous study (10), but in the current study, simulations were carried out at a constant flow rate of 0.26 mL/s. The volumetric flow rate of 0.26 mL/s corresponds to laminar flow with a Reynolds number of 1678 and a flow velocity of 8.99 m/s. The shear stress transport (SST) k-ω model was used to analyse the turbulent flow. The needle was positioned at 25, 50, and 75% from the apex, and the analysis was done (Fig. 1-3). The no-slip condition was enforced on the needle and root canal walls to take viscosity into account. Gravity was calculated in the flow direction (i.e., -z-axis). Four simulations were conducted for each scan model and the nozzle position (needle placement level). The mean value of all four readings was considered for the analysis. The apical pressure values were recorded in Pascal (Pa).

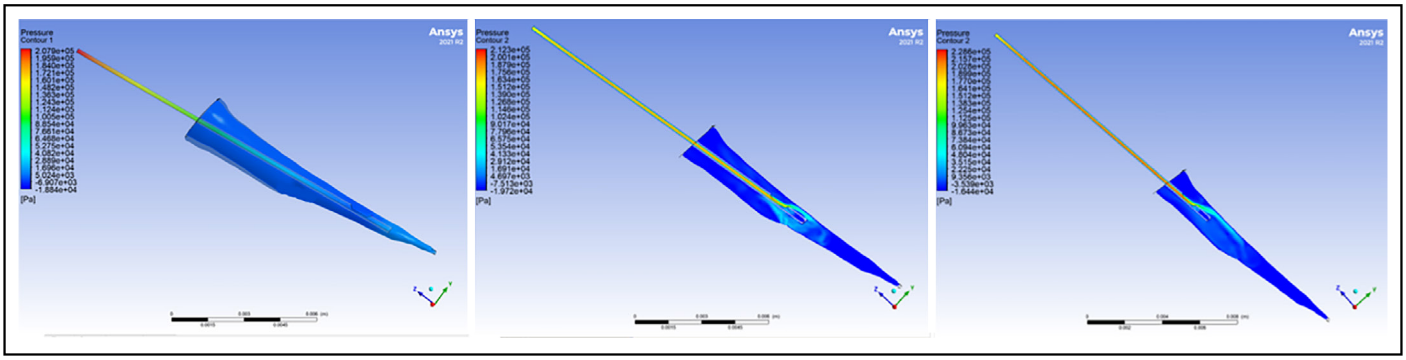

Figure 1. Simulations carried out at different needle positions in group I

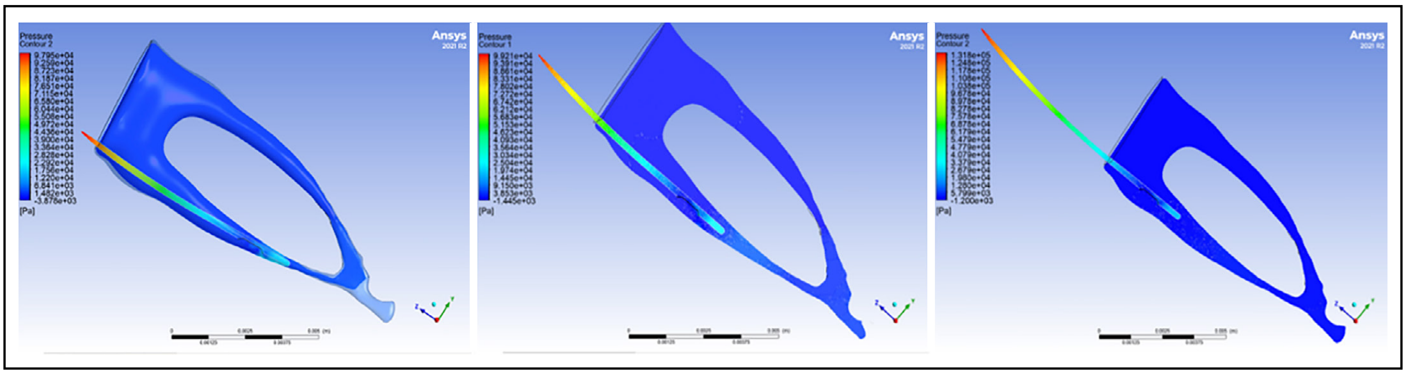

Figure 2. Simulations carried out at different needle positions in the buccal canal of group II

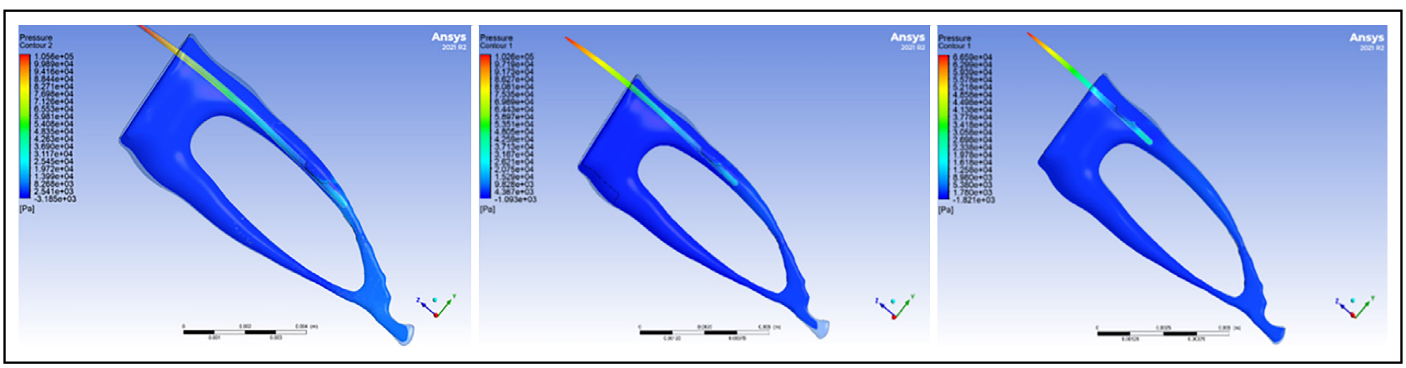

Figure 3. Simulations carried out at different needle positions in the palatal canal of group III

Statistical Analysis

IBM SPSS Statistics Software for Windows Version 23.0 (IBM Corp., Armonk, NY, USA) was used for data analysis. A two-way ANOVA test was used to compare the pressure at three different needle positions in different experimental groups (Table 1-3). The readings of the buccal and palatal roots of group II were separately analysed.

RESULTS

The current study results at 25% short of WL showed a statistically significant difference ($p<0.05$) in the apical pressure in groups I and II (Table 1). The mean highest recorded pressure in group I was around 9877.78 Pa. However, no statistical significance ($p>0.05$) was evident in the buccal and palatal roots of group II at a needle position 25% short of WL (Table 1). When other needle positions (50%, 75%) were assessed, there was no significant difference ($p>0.05$) in all the experimental groups (Table 2, 3).

DISCUSSION

The current study results showed significantly ($p<0.05$) higher recorded apical pressures in group I compared to group II, with needle placement 25% short of the WL. However, no significant ($p<0.05$) differences in pressure were observed in the buccal and palatal roots at that specific position. When the results were analysed at different needle positions (50%, 75%), there was no significant ($p>0.05$) difference in the recorded pressures in the different experimental groups. To our knowledge, the current study is the first to compare the recorded apical pressure values in extracted teeth with single and joining canal anatomies.

A previous study found that the single canal model had higher apical pressures than the anastomosed canal polycarbonate model at all needle levels studied (15). However, the current study results revealed higher significant recorded apical pressure values at the 25% position in single canals compared to the joining canal. The lack of significance elicited in other needle positions was mainly due to the simulated irrigant flow rate induced in our current study. A simulated flow rate of 0.26 mL/s was used, which is the most widely employed flow rate in most of the CFD-based *in vitro* simulations (19). As constant flow rates were employed, although there was a mean increase in recorded apical pressure values in single canals, there was no significant variation at 50% and 75% short of WL in different assessed groups.

The other reason for such results in the current study was the chosen apical preparation sizes. Although a previously reported study preferred a specific constant preparation size for each analysed specimen (10), it is not possible to shape all teeth to a constant size in the clinical scenario. The choice of preparation size also varies depending on the canal anatomy, curvatures, and operator choice (20). In the current study, the canals were enlarged by three sizes over the initial apical binding file, which has been frequently followed and reported in clinical trials (21–23). Since the enlargement was adequate in the current study, there were no variations in the recorded apical pressure values at other needle positions.

The other factor that needs to be considered is the needle choice. In the current study, the authors preferred using a simulated design of a 30-gauge single-side vented needle. Many clinicians reported using the needle in the clinician scenario (4), and previous literature claims significantly lower extrusion (24), as well as recorded apical pressure values with this needle type (5). Hence, a 30-gauge side vented needle was used in the current study to carry out the flow simulations. Because previous research has shown that these needle types have higher lateral shear stress than apical forces (12), the variation in the current study's recorded values was not statistically significant at the 50% and 75% levels.

Regarding preparation sizes, increased apical sizes greater than 25 have demonstrated better flow rates with lower recorded apical pressure values in previous studies (10, 12). As the preparation sizes in the current study were three sizes larger than the initial binding file, they were usually greater than 25. Hence, there would not have been many variations in the recorded pressure values at higher needle positions from the WL. As the recent interest among clinicians is in minimal shaping, in this study, the specimens were prepared to a 0.04-taper only. However, a study by Boutsioukis et al. (25) claimed the inefficiency of syringe needle irrigation with increased pressures at minimal sizes. Hence, the current study is more clinically realistic, as previous literature focuses on file separation in shaping, especially in the joining canals with increased tapered file systems (26). So, considering all these facts, the specimens were prepared to a 0.04-taper only.

In the previous literature on the different canal morphologies, some studies assessed the flow and recorded pressures in c-shaped canals (27), oval root canal morphologies (28, 29), and also at different needle positions in single-rooted teeth (10). However, no literature has been published on extracted teeth assessing the apical pressures in single versus joining canals. Hence, the current study is novel and clinically relevant.

Previous research has shown that increased apical pressures occur during irrigation and at higher irrigation flow rates, causes extrusion in periapical regions (18, 30–32). However, there is no clear clarification on the relationship between the fluid flow rates and the generated apical pressures, as they are non-linear (15). The critical threshold for irrigant extrusion is around 5.73 mm of Hg (14, 33), equivalent to 763.93 Pa. However, the results obtained in the current study are much higher than the threshold value. The reason was the employed irrigant flow rate of 0.26 mL/s, which is the maximum possible irrigant flow clinically. If the flow rates used were changed, the pressures obtained would have changed. So, future studies could focus on assessing the optimal recorded apical pressures in single and joining canals at altered irrigation flow simulations.

The apical pressures generated in single canals are significantly higher than in teeth with canal anastomosis or joining (15). Previously published literature showed a 90% decrease in periapical pressure buildup in the canal anastomosis model, irrespective of fluid flow rate and needle placement (15). In the case of joining canals, the channels provide the path of least resistance for the incoming fluid to be diverted from the canal being irrigated to the second canal, thereby reducing the induced apical pressures. Thus, the fluid forces travel mostly through these joining canals, thereby reducing the forces apically. Hence, the generated apical pressures are comparatively less in teeth with joined canals than those with single canals.

Regarding the study's standardization, preparation sizes, taper, irrigation protocol, and methods and protocols of assessment were uniform across all experimental groups, differing only in tooth selection criteria. So, the study-related bias was minimal in the current study. One of the current study's limitations was that micro-CT assessments were not used to confirm the canal's preoperative taper and size. The other limitation was simulating a constant flow rate of 0.26 mL/s. The pressure would have varied at other simulated flow rates. Future studies can assess different flow rates in minimally shaped canals and contracted access designs. Future studies can also consider conducting CFD assessments using simulated irrigation activation tips to assess the real-time flow and recorded pressures.

CONCLUSION

The recorded pressures were higher in the single canal specimens at a needle position 25% short of the WL. However, no variations were recorded in the experimental groups at 50 or 75% needle positions.

Disclosures

Conflict of interest: The authors deny any conflict of interest.

Ethics Committee Approval: This study was approved by the Institutional Human Ethics Committee of Saveetha Dental College and Hospitals (Date: 21/12/2021, Number: SRB/SDC/ENDO-2102/21/031).

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