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Assessment of apical pressures at different automated irrigant flow rates: an *ex vivo* study based on computational fluid dynamic analysis

Avaliação de pressões apicais em diferentes taxas de fluxo irrigante automatizadas: um estudo *ex vivo* baseado em análise dinâmica de fluidos computacionais

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ABSTRACT

Objective: The current study aimed at assessing the induced apical pressure at various simulated irrigant flow rates. **Materials and Methods:** Forty eight freshly extracted single-rooted premolars were decoronated and prepared to size 30 0.04 taper using HY-Flex CM rotary file system and were scanned using cone-beam computed tomography (CBCT). The scanned images were reconstructed to three-dimensional Computer-aided design models (CAD) and the 3D needle was also reconstructed. Finally, simulations were done by placing the 30 gauge open-ended needle 3 mm short of the working length. **Results:** There was a statistically significant difference ($p<0.05$) among the different groups compared. 1 ml/min flow rate induced the least apical pressures ($p<0.05$) as compared to the other types. **Conclusion:** 1 ml/min flow rates induced the least apical pressures when open-ended needles are used for irrigation.

KEYWORDS

Apical pressure; Computational fluid dynamic analysis; Flow rate; Irrigation; Root canal.

RESUMO

Objetivo: O presente estudo teve como objetivo avaliar a indução de pressão apical em várias taxas de fluxo irrigante simuladas. **Material e Métodos:** Quarenta e oito raízes de pré-molares unirradiculares recém extraídos tiveram suas coroas removidas, foram preparados para uma conicidade de tamanho 30 0.04 através de um sistema rotatório de limas HYFlex CM e foram escaneados via tomografia computadorizada cone-beam (CBCT). As imagens escaneadas e as agulhas para irrigação foram reconstruídas em modelos tridimensionais de design assistido por computador (CAD). Ao final, foram feitas simulações através de agulhas de calibre 30 e 3 mm a menos que o comprimento de trabalho. **Resultados:** Houve diferença estatisticamente significativa ($p<0.05$) entre os diferentes grupos. A taxa de fluxo de 1 ml/min induziu as menores pressões apicais ($p<0.05$) quando comparada às demais taxas. **Conclusão:** Taxas de fluxo de 1 ml/min induziram as menores pressões apicais quando agulhas de ponta aberta foram utilizadas para irrigação.

PALAVRAS-CHAVE

Pressão apical; Análise fluidodinâmica computacional; Vazão; Irrigação; Canal radicular.

INTRODUCTION

Endodontic treatment success is multifactorial [1] and the endodontic treatment prognosis varies with the primary [2] and secondary root canal treatments carried out [3]. Nevertheless, current interest in endodontic literature shifted towards assessing the quality of life of patients after endodontic treatment [4] and also on periapical healing [5]. Although there is a drastic improvement in the technological advancements in endodontic literature in recent decades [6], the non-surgical endodontic treatment prognosis has not been improved comparatively [7].

Especially the root canal irrigation, which has been considered the most neglected and important aspect [8], that needs to be extensively studied. Although the crucial functions of primary irrigants seems to be organic tissue dissolution, inorganic smear layer removal and biofilm dislodgement [9]. The irrigant should also effectively cleanse the root canal system, and reach the corners where the instrument cannot reach [10]. So, to understand the real-time irrigation dynamics in root canals, the computational fluid dynamic analysis seems to be the most assessed and reliable tool [11]. Previous in-vitro and ex vivo studies analysed the irrigation dynamics using manual syringe needles and claimed that fluid velocity, the turbulence of the liquid, lateral shear wall stress, play a major role in inducing the dynamic forces in the root canal system [11]. Nevertheless, the physical and physiological dynamic flow of the irrigant should never cross the optimal limits [11]. Especially there is evidence from systematic review literature, stating the possible irrigant extrusion using syringe needle irrigation, causing the debilitating sodium hypochlorite accidents [12]. Hence, it is crucial to analyse the effect of various irrigant flow rates on the caused apical pressures at the laboratory level.

Although the literature is sparse on assessing the exact effect of various irrigant flow rates and their effect on created apical pressures [13,14]. At the ex vivo level, the results showed 4 ml/min as optimal irrigant flow rate, inducing the slightest apical pressures [13]. So, considering these factors, our ex vivo study aimed at assessing the induced apical pressures at different automated irrigant flow rates using computational fluid dynamic analysis.

MATERIALS AND METHODS

Sample size calculation

The sample size for the present study was analysed based on our previous pilot study [8]. The estimated total sample size was 48. The effect size was 0.63 with a power of 95% and a possible alpha error of 0.05.

The patient's consent was obtained prior to extraction. Single rooted premolars indicated for the therapeutic orthodontic extraction were considered. The vitality status of the teeth was confirmed prior to extraction using pulp sensibility testing aids (Cold test- Green Endo-Ice; Hygenic Corp, Akron, OH, USA & Electric Pulp Tester- Kerr Analytic Technology Corp, Redmond, WA, USA) before the extraction. The inclusion criteria for teeth selection were single rooted vital premolars with minimal (<5 degrees) or no curvatures, no signs of dental caries and cracks, resorptions or calcifications. Teeth with multiple roots or root canals, curvatures and incompletely formed apices were excluded.

Extracted teeth were stored in 5% formalin (Ricca Chemicals; Fisher Scientific; Mumbai; India), after curetting the attached soft tissue remnants. The morphology of the extracted specimens was confirmed using the angular intraoral periapical radiographs. The samples were standardised to 18mm by decoronating using a diamond disc attached to a straight handpiece(Confident Dental Equipments Ltd; India) under adequate water coolant.

An ISO 10-K hand file (M- Access File; Dentsply, Mallifer, Ballaigues, Switzerland) was used for achieving the canal patency. Once the patency was achieved, the canal shape of the selected specimens was confirmed. Specimens were assessed using a Cone Beam Computed Tomography (CBCT) Kodak 9000 device (Carestream Dental Kodak Systems, Rochester, NY) at 0.076 mm, 70 kVp, and 63 ma. The scan time was adjusted to 10.8sec with an adjusted FOV of 18.4 cm x 20.6 cm. The obtained images were viewed in Galileos Viewer Software. Additionally, the initial apical diameter of the obtained specimens was confirmed using CBCT using OnDemand3D software (OnDemandedApp 1.0.9.2225; Cybermed, Inc. Seoul, South Korea). The apical diameter evaluation of the obtained scans was carried out 1mm short from the initial working length in an LCD monitor at a resolution of 1366 x 768 pixels [15].

Once the canal anatomy, shape, size and patency were confirmed as mentioned above, the specimens were subjected to instrumentation to a specific size. Each specimen was prepared to size 30 and 0.04 taper, using a single rotary instrument (Hyflex CM, Coltene/Whaledent, West Mumbai, India). Intermittent irrigation during instrumentation was carried out with 3% sodium hypochlorite (Parcan; Septodont; India) using a 30 gauge closed-ended side vented needle (NaviTip, Ultradent Products, South Jordan, UT, USA). Final irrigation was done using 5ml of 3% sodium hypochlorite and 3 ml of 17% Ethylenediaminetetraacetic acid (EDTA), (MD Cleanser, MetaBiomed; India). Final rinse was carried out with distilled water and the canal was dried with paper point.

After the complete biomechanical preparation, the specimens were again subjected to CBCT to recreate a three-dimensional computer-aided design model (CAD) using DesignPTCCreoVer5.0CAD). The recreated model was reconstructed to a three-dimensional object in stereolithography format using ScanIP (Simplex, Essex, UK) software [16]. Geometrical needle reconstruction was similar to Boutskioskis et al [17]. A commercially available 30 gauge open-ended needle (NaviTip, Ultradent Products, South Jordan, UT, USA) was used as a reference. The needle length, internal and external diameter were standardised to Dext= 320 micrometer, Dint= 196 micrometer, length= 31 mm [17]. As previous studies have proved that the recorded higher pressure values at the apical most part of the root canal [11], so, our study primarily focused on assessing the recorded apical pressure values at different automated irrigant flow rates (1 ml/min, 4 ml/min, 6 ml/min and 12 ml/min) respectively. Hence the needle position was standardised by placing it 3 mm short of the estimated working length, which was based on the previous computational fluid dynamic analysis based study [16].

Once all the parameters were assessed, computational fluid dynamic analysis was performed by placing the needle 3 mm short of the working length. The three-dimensional geometrical mesh was reconstructed using pre-processor Gambit 2.4 (Fluent Inc., Lebanon, NH). Grid refinement and grid independence check was performed and the hexahedral mesh was constructed in areas anticipated with higher velocity gradients. Under the hypothesis of rigid, smooth and impermeable walls, No-slip boundary conditions were applied. 1% sodium hypochlorite irrigant at a density of 1.04 g/m3 and viscosity of 0.99.10-13 Pa.S. The fluid simulation was carried through the root canal orifice as an incompressible Newtonian liquid gravity was adjusted in the negative z-axis.

Computational fluid dynamic analysis was performed using Commercial Testing Ansys Workbench CFD Fluent Ver-19. Computations were performed using a computer cluster 45 dual-core AMD Opteron 270 processor running in 64bit SUSE Linux 10.1 (kernel version 2.6.16). All simulations were carried out by placing the needle 3 mm short of the working length. (Figure 1)

Statistical analysis

Data analysis was carried out using IBM SPSS Statistical Software for Windows Version 23.0 (Armonk, NY, USA, IBM, Corp). One way ANOVA (Table I) with post hoc Tukey test was used for multivariate analysis. (Table II)

RESULTS

There was a statically significant difference ($p<0.05$) elicited in the recorded apical pressures in different groups compared. (Figure 2)

DISCUSSION

As the current literature is primarily focused on evaluating the fluid dynamics in the minimally shaped root canal system [8,18], the current study also focused on assessing the recorded apical pressures in minimally shaped single-rooted premolars at different irrigant flow rates. The null hypothesis was rejected in the current study and the results showed a statistically significant difference in the recorded apical pressures at different irrigant flow rates. The protocol for the ex-vivo study assessment was similar to the study conducted by our colleagues [8].

As literature also states that the recorded apical pressures are higher, when the open-ended needle was placed at apical most portion [11], our study primarily focused on assessing the specific needle placed 3 mm short

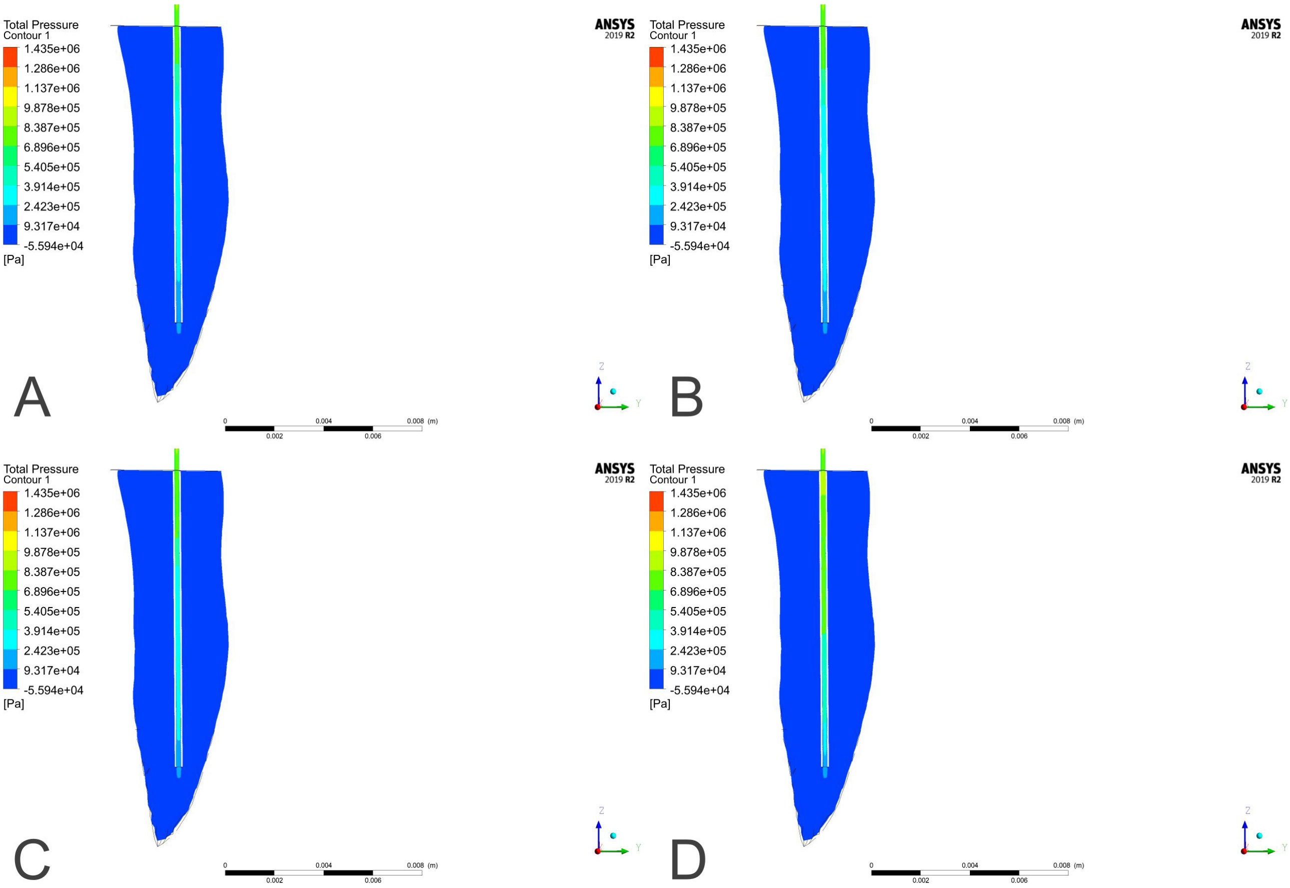

Figure 1 - CFD analysis of apical pressure assessed at different flow rate. A) 1 ml/min, B) 4 ml/min, C) 6 ml/min, D) 12 ml/min.

Table I - One-way ANOVA analysis comparing the apical pressure at different automated irrigant flow rates

	Sum of Squares	Df	Mean Square	F	P-Value
Between Groups	22940.086	3	7646.695	1531.668	.000
Within Groups	219.666	44	4.992		
Total	23159.751	47			

Table II - Tukey's post-hoc analysis showing multiple comparisons between the groups

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	P-Value	95% Confidence Interval	
					Lower Bound	Upper Bound
1 ml	4 ml	-8.5820667*	.9121768	.000	-11.017584	-6.146550
	6 ml	-14.3880750*	.9121768	.000	-16.823592	-11.952558
	12 ml	-56.7400583*	.9121768	.000	-59.175575	-54.304541
4 ml	1 ml	8.5820667*	.9121768	.000	6.146550	11.017584
	6 ml	-5.8060083*	.9121768	.000	-8.241525	-3.370491
	12 ml	-48.1579917*	.9121768	.000	-50.593509	-45.722475
6 ml	1 ml	14.3880750*	.9121768	.000	11.952558	16.823592
	4 ml	5.8060083*	.9121768	.000	3.370491	8.241525
	12 ml	-42.3519833*	.9121768	.000	-44.787500	-39.916466
12 ml	1 ml	56.7400583*	.9121768	.000	54.304541	59.175575
	4 ml	48.1579917*	.9121768	.000	45.722475	50.593509
	6 ml	42.3519833*	.9121768	.000	39.916466	44.787500

*: The mean difference is significant at the 0.05 level.

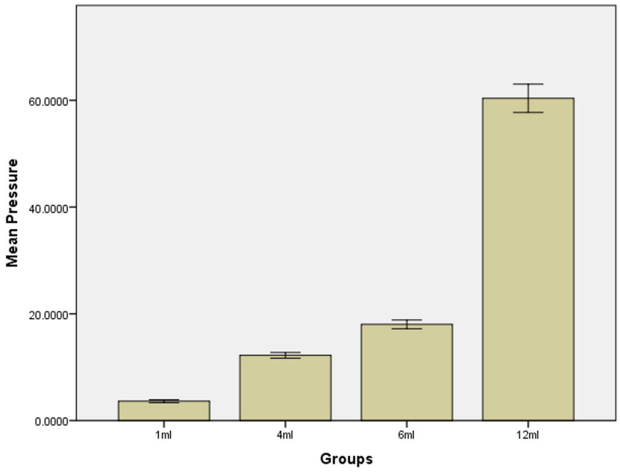

Figure 2 - Error bar showing mean ± SD of the apical pressure rates of different groups.

from the working length. As it's quite difficult to get perfectly round or oval canals in an ideal clinical scenario, we focused on assessments in irregular or approximately round canals of single-rooted premolars. The other valuable data from the previous literature also states that the induced pressures are greater with single canals than a joined type [19]. Hence, we only focused on assessing the single-rooted lower premolars.

We selected 30 size apical preparation for the current study as the previous literature specified that the irrigant extrusions were frequent in size 35 or higher preparations as compared to other assessed sizes [20]. When specifically the literature on the effect of various irrigant flow rates on induced apical pressures have to be assessed, the available evidence states that the higher the flow rates, the greater the evident pressures apically [13]. Our study results showed an evident rise in apical pressure values at higher irrigant flow rates.

The protocol chosen for the current study is clinically relevant as the previous states the optimal and clinically safe irrigant flow rates to be from 1-4 ml/min [13] with maximum clinically possible flow rates at 12-15 ml/min [19]. Another important clinical factor that needs to be considered is that it is impossible for a clinician to maintain a standard irrigant flow rate continuously. There are various other operator factors such as intra-barrel pressure, gender and experience of the operator. Clinical factors such as needle choice, needle placements, frequency of needle movement, the curvature of the canal, taper and apical preparation sizes [11]. Hence, it is impossible to standardise syringe needle irrigation clinically [11]. So, we standardised the clinical scenario in the present study by simulating optimal irrigant flow rates in single-rooted premolars with irregular canals and minimal curvatures.

When the limitations of the present study are considered, the current study would have focused on assessing the apical pressures in curved canals with various optimal shapes. Hence, future studies should more focus on the wider evaluation of flow and apical pressures in narrow and curved canals.

CONCLUSION

Study results showed that the apical pressures were least at 1 ml/min as compared to the other experimental flow rates.

Author's Contributions

SC: Software, Resources, Data Curation, Funding Acquisition. SC, KVT, RK: Conceptualization, Methodology. SC, KVT, SR: Validation, Formal Analysis, Investigation, Writing – Original Draft Preparation, Writing – Review & Editing. KVT, SR, JJ, KJ: Supervision. SR: Project Administration. SC, KVT, SR, JJ, KJ, RK: Visualization.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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Regulatory Statement

Before the commencement of research, the ethical approval for the current study was obtained from the institutional ethical committee. The approval code for this study is (SRB/SDC/ENDO-2102/22/040)

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