Assessment of Irrigant Flow and Apical Pressure in Simulated Canals of Single Rooted Teeth with Different Root Canal Tapers and Apical Preparation Sizes-an Ex-Vivo Study

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Abstract

Background:

Irrigation dynamics vary in optimally shaped canals. Various factors combine to create a stress-induced environment leading to a dynamic irrigant flow.

Aim:

Evaluate the irrigant flow and apical pressure using 30 gauge open-ended needle in virtually created root canal model of single-rooted teeth.

Materials and Methods:

Sixty extracted single-rooted premolars were selected and prepared using a single rotary instrument HY-FLEX CM and grouped as : Group I: 30 size 0.6% taper (n=15), Group II: 30 size 0.4% taper (n=15), Group III: 25 size 0.6% taper (n=15), Group IV: 25 size 0.4% taper (n=15). Post instrumentation imaging was carried out using CBCT, and CAD models were obtained. Subgrouping was done based on the nozzle position, and computational fluid dynamic analysis was carried out for the respective parameters assessed.

Results:

Statistical significance was elicited in all the groups at different nozzle positions analysed. ($p < 0.05$) A post-Hoc test revealed a significance in the mean flow rate and flow velocity in Group I at low nozzle position ($p < 0.05$) as compared to others.

Conclusions:

30 size 0.6% tapered preparations proved efficient irrigant flow and least apical pressures at all nozzle positions.

Keywords: Cone beam computed tomography, Endodontics, Root canal irrigants

Introduction:

The endodontic treatment prognosis is dependent on a multitude of factors that contribute to clinical success.^{1,2} The most crucial and neglected aspect in the endodontic treatment is root canal irrigation. Root canal disinfection plays a vital role in endodontic treatment success.³ It's a known fact that, a three dimensionally obturated canal is a reciprocation of a three dimensionally cleaned and disinfected root canal system.^{4,5} It's preferable to define root canal as a complex or system as multiple portals exist in a single canal, especially the morphology is complicated at the apical one third.⁶

So, it's difficult to completely clean and shape the entire root canal system.⁷ So, considering all these facts importance has to be given more and studies have to concentrate numerously on various aspects of root canal irrigation dynamics. As discussed, cleaning and disinfecting all crooked spaces of root canal complex is never achievable.⁵ When root canal debridement is analysed, it can be divided majorly into two sections. Primarily, root canal debridement includes mechanical instrumentation using rotary and hand instruments with intermittent irrigation. The other is the actual irrigation done using various chemical irrigating solutions, which clean and disinfect the mechanically prepared root canals.⁸

So, the actual process of root canal irrigation and the dynamics involved in root canal irrigation can be observed and studied in a prepared root canal. When root canal irrigation has to be understood at a basic level, it's always a dynamic phenomenon, rather than a static process. Because studies in literature, majorly assessed the root canal irrigation by observing and evaluating the various parameters, including the mass flow rate, flow velocity, turbulence, shear wall stress, simulated flow time involved in irrigant flow in root canal space.^{9,10,11,12,13,14,15,16,17} When a dynamic phenomenon of root canal irrigation has to be studied, it is essential to observe the flow patterns during the process. Literature showed evidence and validated on computational fluid dynamic analysis as a reliable tool for assessing the root canal irrigation.¹⁸

The present concept is to optimise the root canal shape to clean more.⁷ The idea stated was to shape optimal so that the irrigating liquid has to flow, reach and disinfect till the apical terminus. So, the irrigation dynamics vary in optimally shaped canals. When understanding the root canal irrigation at the dynamic level, various parameters are combined to dictate the enhanced cleaning and disinfection of root canal space.^{8,19}

It's not the static fluid that is involved in clinical root canal irrigation process. The clinical root canal irrigation is always a dynamic phenomenon with various physical parameters involved such as flow velocity, flow patterns, wall shear stress and

turbulence.^{9,10,11,12,13,14,15,16,17} All these factors combine to create a stress-induced environment, which causes the flowing liquid to dislodge the tightly adherent bacterial biofilm along with the debris and smear layer.^{20,21}

In the present scenario, with the advanced irrigation agitation systems, which have the enhanced irrigant wall interactions, the dependency on the syringe needle system alone for clinical root canal irrigation procedure is eliminated. Although the dependence is reduced, syringe needle irrigation, is a primary mode of the delivery system, especially during the preparatory phases of root canal treatment. Clinically possible optimal irrigant flow rates using 30 gauge side vented needles were 1.5ml/min²² to 15ml/min.²³ But, the optimal flow rates decided were 3-4ml/min based on studies done using periapical pressure assessment models.²⁴

Considering all these parameters, studies assessing the root canal irrigant flow should also consider apical pressure. Although the entire root canal irrigation is a dynamic combination of factors that induce dislodging forces, in a clinical scenario, the dictating factor is ultimately the generated apical pressure in due course of root canal irrigation. So, the dynamic forces should not cross the physical and physiological limit.²⁴

The syringe needle of evaluation used for the present study was a 30 gauge open-ended needle. The study mainly aimed to evaluate the shear wall stress, mass flow rate, velocity, turbulence, and apical pressure using 30 gauge open-ended needle in a virtually created root canal model of single-rooted teeth.

Materials and Methods:

Sample size calculation:

The present study was conducted as a pilot study. Previous literature was only based on evaluating the single tooth specimens or geometrical three-dimensional reconstructions rather than analysing the samples.^{9,10,11,12,13,14,15,16,17} The estimated total sample size was 60 and 15 per each Group, with a sample of 5 per each subgroup, based on the nozzle positions analysed. The estimated power was 90%.

Teeth collection:

Before starting the research, approval was obtained from the Institutional Ethical Committee (SRB/SD/MDS12/179 ODS/19). Ethical consent was obtained from the patients before extraction. Freshly extracted human mandibular premolars with single-rooted teeth, indicated for therapeutic orthodontic extraction with normal pulpal response on sensibility testing were selected for the present study. Preoperative pulpal sensibility of the teeth indicated for extraction was determined before the anaesthetic administration, using a cold test (Green

Endo Ice; Hygienic Corp, Akron, OH, USA) and electric pulp testing (Kerr Analytic Technology Corp, Redmond, WA, USA). Patients under the age group of 20-25 years were only chosen for the present study because teeth were almost likely to be similar. Curvature was also standardised such that it was <5 degrees. Teeth with caries, restorations, fracture, immature root apices and curvatures >5 degrees were excluded.

Specimen Standardisation:

Once the teeth were extracted, the soft tissue attached to the tooth surface was curetted, and the specimens were stored in 5% formalin (Ricca Chemicals; fisher scientific; Mumbai; India). Specimens with Single root and single root apex were collected. Confirmation of the collected samples was done using angulated intraoral periapical radiographs. Confirmed specimens were decoronated using a straight handpiece using diamond disc (Confident Dental Equipments Ltd., India) under adequate water coolant. The samples' length was standardised to 17mm from the flat reference point to 1mm short of the working length.

Pre-instrumentation Imaging:

Teeth with patent canals were selected for the study. Canal patency was achieved using ISO 10-K hand file (M-Access File; Dentsply; Delhi; India). After achieving the patency, teeth were subjected to cone-beam computed tomography (Gallelios Viewer Software) to confirm the root canal specimen's shape, from the coronal reference point to the working terminus. Mandibular premolars were scanned using a Kodak 9000 device (Carestream Dental Kodak Systems, Rochester, NY). The resolution of acquired images was around 0.076mm, 70kVp, 6.3 mA and FOV of the image was adjusted to 18.4×20.6 cm, with 10.8 seconds scan time. About 500 sections of the entire tooth specimen were analysed to confirm the shape of the canal. The root canal volume was not analysed, nor the aspect ratio. Teeth with approximately round or irregular canals were included. Only teeth with completely oval canals were discarded.

The initial apical diameter of the selected specimens was assessed based on the previously published literature.²⁵ The parameters for CBCT acquisition were mentioned above. The smallest diameter of all the scanned specimens was measured using CBCT images at 1mm short of the root apex, using OnDemand3D software (OnDemandedApp 1.0.9.2225; Cybermed, Inc, Seoul, South Korea) directly on axial sections, perpendicular to the canal. The evaluation was carried out in an LCD monitor at (1366×768 pixels) resolution, to avoid selecting the premolars, whose apical diameter was more than specified preparation sizes used for the present study. The taper of the root canal was not assessed using CBCT. Instrumentation and Irrigation Protocol:

Once the teeth specimen were standardised, they were prepared using a single rotary instrument, with respective tapers, using HY-FLEX CM rotary files (Coltene/Whaledent, West Mumbai, India). The respective tapers prepared with different sizes were:

Group I: 30 size 0.6% taper (Scan Model 1) (n=15) Group

II: 30 size 0.4% taper (Scan Model 2) (n=15) Group III: 25

size 0.6% taper (Scan Model 3) (n=15) Group IV: 25 size

0.4% taper (Scan Model 4) (n=15)

In due course of instrumentation, irrigation was carried out using 10ml of 3% sodium hypochlorite (Parcan; Septodont; India), using 30 gauge side vented needle (NaviTip, Ultradent Products, South Jordan, UT, USA) placed 3mm short of the apex. Once the complete instrumentation was carried out, irrigation was done using 5ml of 3% sodium hypochlorite followed by 3ml of 17% EDTA liquid (MD Cleanser; MetaBiomed; India). Distilled water was used for final rinse, and canals were dried using absorbent paper points.

Post-instrumentation Imaging and Computer-Aided Design (CAD) Reconstruction:

Once the entire instrumentation and irrigation of the specimens were carried out, these specimens were again subjected to Cone-beam computed tomographic imaging (Gallelios Viewer Software). A total of 500 sections were analysed at different sections of the coronal, middle and apical third, to recreate a three dimensional CAD model (Figure 1) to simulate the prepared specimen's shape. CBCT scanned root, and the prepared root canal was reconstructed to a three-dimensional object in Stereolithography (STL) format using Scan Ip (Simplex, Essex, UK) software.¹⁵ The three-dimensional root canal CAD model was reconstructed using Design PTC creo Ver 5.0. CAD models were reconstructed for prepared tapers (Model 1: 30 size 0.6% taper, Model 2: 30 size 0.4% taper, Model 3: 25 0.6% taper, Model 4: 25 0.4% taper; respectively), as mentioned previously.

Geometrical Needle Reconstruction:

Needle type was modelled using commercially available 30 Gauge open-ended needle as a reference (NaviTip, Ultradent Products, South Jordan, UT, USA). The needle type used was open-ended. Three-dimensional geometrical needle reconstruction was similar to the previous study by Boutsioskis et al.,¹⁶ The needle length and the external and internal diameter were standardised (Dext= 320µm, Dint= 196 µm, l= 31mm). As determined by the previous study,¹⁶ the standardised needle length and diameter correspond to the needle's real geometry. The needle was centred and fixed in the simulated canal at 3mm short of the working length.

Needle insertion depth (Nozzle position) was standardised based on the previous computational fluid dynamic reports,¹⁴ which stated that open-ended needles placed 3mm short induced least apical pressures with optimal irrigant flow. In our study, needle insertion depth for a simulated open-ended type was standardised 3mm short of the working length for all the computational simulations carried out. Needle placement was standardised by placing the needle at 3mm at the apical level, 6mm at the middle level, 9mm at the coronal levels.

Once the instrumentation and the imaging were completed, five teeth under each Group were sub-grouped based on the nozzle positions. The computational fluid dynamic analysis was carried out for the set of the sub-grouped CAD models.

Subgroup I: Low nozzle position (N=5) Subgroup

II: Middle nozzle position (N=5) Subgroup III:

High nozzle position (N=5) Computational Fluid

Dynamic Analysis:

Computational fluid dynamic analysis was performed based on the previous literature by Boutsikouskis et al.,¹⁶ pre-processor Gambit 2.4 (Fluent Inc, Lebanon, NH) was used to reconstruct the three-dimensional geometry and the mesh. A hexahedral mesh was constructed, and in areas with anticipated high gradients of velocity, a grid refinement was performed near the walls. To ensure the reasonable use of computational resources, a grid independency check was performed. Depending on the root canal's shape, the final meshes consisted of 477 000-783 000 cells (mean cell volume $0.7\text{-}2.1 \times 10^{-5} \text{ mm}^3$).

No-slip boundary conditions were applied under the hypothesis of rigid, smooth and impermeable walls. The fluid flowed into the simulated domain through root canal orifice, where atmospheric pressure was imposed. The irrigant, 1% sodium hypochlorite, was modelled as an incompressible Newtonian fluid, with density = 1.04 g/m^3 and viscosity $\mu = 0.99 \cdot 10^{-3} \text{ Pa.s}$.¹³ Gravity was included in the flow field in the direction of the negative z-axis. To set up and solve the problem a Commercial Testing Ansys Workbench CFD Fluent Ver- 19 was used. A computer cluster (45 dual-core AMD Opteron 270 processors) running 64-bit SUSE Linux 10.1 (kernel version 2.6.16) was used for performing the computations. The flow fields for four different tapered preparations were compared and calculated in terms of mean flow rate and time, velocity, turbulence, wall shear stress and total pressure. Simulations were carried out in prepared scan models at different nozzle positions. (Figure 2 -

4) Low (which corresponds to the apical one-third level of needle placement), middle (which corresponds to the middle one-third level of needle placement), high (which corresponds to the coronal one-third of needle placement) respectively. A series of four simulations were

carried out for each Scan Model (taper), and the Nozzle Position (needle placement level) assessed the mean value of all the four readings was taken into consideration. A non-stationary and steady flow was observed at all the nozzle positions in the evaluated scan models.

Statistical Analysis:

IBM.SPSS Statistics Software for Windows Version 23.0 (Armonk, NY, IBM Corp), was used for data analysis. One way ANOVA with Post Hoc Tukey's test was used for multivariate analysis. The null hypothesis tested was, there was no significant difference in evaluated flow rate and apical pressure on computational fluid dynamic analysis in virtually created models with two different apical preparation sizes and root canal tapers.

Results:

Nozzle position depicts the needle insertion depth. It was divided into three positions:

- The low nozzle
- Middle and high nozzle position
- Corresponding to the depths of 3mm, 6mm and 9mm from the working lengths

Different scan models corresponded to each Group with a specific taper and apical preparation sizes.

Mass Flow Rate:

When the mass flow rate was evaluated, Group I at low nozzle position elicited higher mean value (0.6927ml/min) as compared to others. A statistically significant difference was elicited among the groups at different nozzle positions analysed. ($p < 0.05$) Post-Hoc Tukey's showed significantly lower values in Group IV ($p < 0.05$) than others. When different nozzle positions were analysed, significantly higher values were noted at low nozzle position ($p < 0.05$) as compared to the other positions analysed.

Mean Simulated Flow Time:

When mean simulated flow time was evaluated, the time taken for the complete simulated irrigant flow was more in Group IV, High nozzle position (8.12 seconds) than others. A statistically significant difference was elicited among the groups at different nozzle positions analysed. ($p < 0.05$) Post-Hoc Tukey's showed significantly higher values in Group IV ($p < 0.05$) than others. When different nozzle positions were analysed, significantly higher values were noted at low nozzle position ($p < 0.05$) as compared to the other positions analysed.

Mean Flow Velocity:

When mean flow velocity was evaluated, Group I, low nozzle position elicited higher mean velocity than others (0.6926 mm/sec). A statistically significant difference was elicited among the groups at different nozzle positions analysed. ($p<0.05$) Post-Hoc Tukey's showed significantly lower values in Group IV ($p<0.05$) than others. When different nozzle positions were analysed, significantly higher values were noted at low nozzle position ($p<0.05$) as compared to the other positions analysed.

Turbulence:

When turbulence was evaluated, Group IV and low nozzle position showed the highest possible mean values compared to others (306.51J/kg). A statistically significant difference was elicited among the groups at different nozzle positions analysed. ($p<0.05$) Post-Hoc Tukey's showed significantly higher values in Group IV ($p<0.05$) than others. When different nozzle positions were analysed, significantly higher values were noted at low nozzle position ($p<0.05$) as compared to the other positions analysed.

Shear Wall Stress:

When wall shear stress was evaluated, Group IV and low nozzle position showed the highest possible mean values than others (10.17 Pa). A statistically significant difference was elicited among the groups at different nozzle positions analysed. ($p<0.05$) Post-Hoc Tukey's showed significantly higher values in Group IV ($p<0.05$) than others. When different nozzle positions were analysed, significantly higher values were noted at low nozzle position ($p<0.05$) as compared to the other positions analysed.

Total Pressure:

Total pressure elicited in all the simulations was higher in Group IV at low nozzle position than others (306.55 Pa). A statistically significant difference was elicited among the groups at different nozzle positions analysed. ($p<0.05$) Post-Hoc Tukey's showed significantly higher values in Group IV ($p<0.05$) than others. When different nozzle positions were analysed, significantly higher values were noted at low nozzle position ($p<0.05$) as compared to the other positions analysed.

CAD model reconstruction of the different scan models is depicted in Figure 1. Simulations in 30 0.6% preparations at different nozzle position are depicted in Figure 2 -4.

Discussion:

The present study mainly targeted in evaluating the optimal root canal shapes preferred and prepared for day to day endodontic practice. When considered, there is still an ambiguity in preferable taper and apical preparation size advisable for a specific case. However, one cannot generalise a standard common taper and preparation size for all case scenarios.

Mostly, a clinical decision on specified taper and preparation sizes for a specific tooth undergoing endodontic therapy varies from a clinical condition, canal curvature, and intricate root canal anatomy and ultimately based on operators decision.

The parameters assessed in the present study were the mass flow rate, simulated delivery time, velocity, total pressure, turbulence and wall shear stress. The flow patterns in different nozzle positions were also evaluated in the scan models during the simulations. Current research assessed the possible optimal values in simulated scan models.

When parameters assessed in different scan models were evaluated, there was a decrease in the mean values obtained in compared scan models in all the nozzle positions. When wall shear stress, total pressure and mean irrigant flow time were assessed, there was an increase in the mean values obtained at different nozzle positions evaluated. So, it can be assessed that parameters varied based on other scan models compared to different nozzle positions.

When different nozzle positions were evaluated for the parameters assessed, there was a significant mean value in different nozzle positions in all the scan models compared. Higher mean flow rate, velocity, turbulence, total pressure, wall shear stress were obtained at low nozzle position followed by mid and high nozzle positions. The results were similar to Boutsioskis et al.,¹⁴ study, which stated that open-ended needles achieved maximum flow rates and adequate irrigant replacement when needles were placed close to working length.

But, the mean simulated flow time was more in high sections as compared to other nozzle positions. The reason for a deviated reading of increased mean simulated flow time would be due to the required wall contact time. In simulated models, when the needle was placed at a higher position, the time required for the continuous simulated wall contact in all root canals was more than the mid and low positions. Theoretically, the wall contact surface area was less at low and mid nozzle position than the high nozzle position.

The present study evaluated the maximum possible irrigant flow and the apical pressure generated in a virtually created single-rooted teeth models with different root canal tapers. The protocol of assessment of the current study was different from the previous literature. The present study concentrated on the maximum possible irrigant flow and apical pressure generated in single-rooted teeth at coronal, middle, and apical levels of the root canal's virtually created model.

Compared to the operator's choice and experience, the decision should be taken based on the available evidence. A systematic review has clearly stated in this aspect. Based on the literature evidence, increased apical preparation sizes showed improved healing outcomes on clinical and radiographic evaluation.²⁶ With the advent of the present concept of agitation

devices, the concept of optimal shapes for a specific root canal preparation is concentrated to a large extent. Although there is no clarification on the optimal large size,²⁷ a recent letter has enlightened an essential aspect of the depth of root canal irrigant penetration.⁷ As, stated by the author, the penetration of root canal irrigant and the availability of fresh liquid in the apical terminus, enhances the disinfection.⁷ So shape can be optimised if the irrigating solution reaches till the working length as it improves the cleanliness of the shaped root canal.

Considering all these, the current study mainly aimed to evaluate the two main factors taper and apical preparation size, which has a specific role in irrigant delivery at the most apical part of the root canal system. Needle selection was based on the study done by Boutsioskis et al.,¹⁶ which has evaluated various needle types and designs and concluded that the flow rates were better with open-ended flat needles compared to the other types. The reason for choosing the 30 gauge open-ended needle was based on the previous literature, which stated the maximal efficiency in terms of flow rate, resulting in more irrigant replacement than other needle types.¹⁶ But, the study also noted the importance of needle placement on apical pressure developed. Hence, to simulate the clinical scenario, the needle was placed 3mm short of working length.

As, the current study mainly aimed at evaluating the effect of needle position in different tapered and prepared canals, we were not particular in selecting perfectly round canals. It's quite unusual to find teeth having perfectly round or cylindrical and tapered root canals in an ideal clinical scenario. So, due to the practical difficulties, we choose only approximately round or irregular canals.

Although the present study's primary aim was not to simulate the ideal clinical situation, instead the study aimed to evaluate the various simulated patterns to assess the preferable optimal shape and size in approximately round or irregular canals with minimal or no curvature. The possible irrigant flow rate obtained in the present study was 0.67-0.69ml/min. The existing endodontic research reported a wide range of possible irrigant flow rates ranging from 0.03 ml/sec to 1.27 ml/sec.^{12,23,28,29} Park et al.,²² stated that the possible irrigant exchange and maximum effectiveness at a flow of 1 -4ml/min. Our study results were in correlation with the previous literature.

Present study results on other parameters such as mean flow velocity and turbulence were correlated with previous studies.^{9,10,13,16} The taper does influence on the irrigant flow. In the present study 30 0.6% tapered preparation showed better-simulated irrigant flow compared to others. But, an interesting point that was evaluated was the apical preparation size, which has

a significant role to play in apical irrigant delivery. The present study results proved an exciting trend considering factor on apical preparation sizes. Compared to the taper, apical preparation has a significant role in efficient irrigant delivery at the apical third. The Post Hoc Tukey results showed that 30 0.4% taper showed similar efficiency in irrigant flow compared to 30 0.6% tapered simulation.

When irrigant delivery time was evaluated, it was almost similar in all the models considered. The mean delivery time ranged from 7.2 to 8.1 seconds. So, the continuous flow may be achieved in this specified time frame. But, the clinical translation of this parameter is not possible. It varies on the operator and other factors such as needle gauge selection, canal curvature, and barrel selected for irrigation,¹² that have a role to play in different case scenarios. So considering the time of simulation as a factor of efficiency is not clinically applicable.

When wall shear stress was evaluated, 25 0.4% taper showed better values compared to others. With the advent of agitation systems, which have an enhanced irrigant wall contact, wall shear stress is not a deciding factor on irrigant contact efficiency, especially on manual syringe needles with different designs. The major safeguarding factor on clinical applicability is the generated apical pressure. Although wall shear stress was better in 25 0.4% preparations at the apical position, the apical pressure developed was very high, around 306.51pa. Such higher pressures developed apically in a clinical scenario cause massive irrigant extrusion.

A conclusive remark on the efficiency of the open-ended needle in terms of shear wall stress cannot be applied from the present study. But, results showed the efficiency of shear wall stress in 25 0.4% at the apical position. This may be due to the decreased lateral space between the needle and the simulated root canal wall, increasing shear wall stress. This increases massive apical pressure and cannot be considered a primary factor for efficient delivery of irrigant.

When the present study results on developed apical pressure were evaluated, the data obtained was in correlation with the previous literature, which stated the increased apical pressures as needle placement is 95% to the working length.^{14,15} When mean velocity and velocity streamline were evaluated, high nozzle position in all scan models proved constant increased values. So, by this factor, it can be stated that an adequate taper provides a space for irrigant to circulate and contact all the root canal walls efficiently.

When the assessments on apical preparation size regarding the irrigant extrusion have to be assessed, a systematic review by Boutsioskis et al., highlighted that over instrumentation

and destruction of apical foramen were the one among the considered factors, resulting in the irrigant extrusion.³⁰ The frequency of NaOCl extrusion depends on the apical preparation size, and the extrusions were less in teeth with preparation size of 35 0.6 (36%) as compared to 50 0.6 (60%).³¹ So, more significant the preparation sizes beyond the optimal limits tend to cause more extrusion of the root canal irrigant. There is only one study in the literature, which has analysed and proved the effect of needle gauge on the irrigant flow in clinical scenario.³² Finally, when limitations of the present study were considered, it's a preliminary simulated study, and the results might not translate an actual clinical scenario. The other factor that is lacking is the canal curvature. Future studies have to concentrate the irrigant flow in curved canals which lack irrigant flow at apical parts of the root canal. Future studies should be concentrated on the agitation devices on simulated flow patterns and apical pressures.

Conclusion:

30 sized 0.6% tapered preparations proved efficient irrigant flow and least apical pressures at all nozzle positions, compared to the other groups analysed.

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Conflicts of Interest:

Nil

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Table 1: Descriptive statistics of various parameters assessed in different groups

Groups		N	Mean	Std. Deviation
Mass flow rate	Group 1	15	.6927	.00286
	Group 2	15	.6896	.00165
	Group 3	15	.6885	.00236
	Group 4	15	.6159	.02983
	Total	60	.6716	.03567
Simulated flow time	Group 1	15	7.1887	.04809
	Group 2	15	7.2353	.02446
	Group 3	15	7.2613	.02748
	Group 4	15	8.1293	.37623
	Total	60	7.4537	.43578
Velocity	Group 1	15	.6926	.00305
	Group 2	15	.6900	.00130
	Group 3	15	.6874	.00129
	Group 4	15	.6154	.03047
	Total	60	.6713	.03590
Total pressure	Group 1	15	22.0187	15.31302
	Group 2	15	29.0200	17.96605
	Group 3	15	44.2367	28.41702
	Group 4	15	306.5527	294.44741
	Total	60	100.4570	188.04419
Turbulence	Group 1	15	9.3520	3.76524
	Group 2	15	15.2560	2.99649
	Group 3	15	44.0900	28.44865
	Group 4	15	306.5140	293.98194
	Total	60	93.8030	190.31172
Wall shear strength	Group 1	15	.3683	.12312
	Group 2	15	.5619	.18370
	Group 3	15	1.9071	.88203
	Group 4	15	10.1753	7.06410
	Total	60	3.2532	5.35138

Table 2: Depicting one-way ANOVA analysis for different parameters for the groups assessed

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Mass flow rate	Between Groups	.062	3	.021	91.749	.000
	Within Groups	.013	56	.000		
	Total	.075	59			
Simulated flow time	Between Groups	9.171	3	3.057	84.208	.000
	Within Groups	2.033	56	.036		
	Total	11.204	59			
Velocity	Between Groups	.063	3	.021	89.057	.000
	Within Groups	.013	56	.000		
	Total	.076	59			
Total pressure	Between Groups	853379.502	3	284459.834	12.921	.000
	Within Groups	1232896.999	56	22016.018		
	Total	2086276.501	59			
Turbulence	Between Groups	915284.318	3	305094.773	13.986	.000
	Within Groups	1221610.069	56	21814.466		
	Total	2136894.386	59			
Wall shear strength	Between Groups	979.400	3	326.467	25.742	.000
	Within Groups	710.198	56	12.682		
	Total	1689.598	59			

Table 3: Subgroup analysis depicting statistical significance among different nozzle positions analysed:

Different Nozzle Positions		N	Group I	Group II	Group III	Group IV
Mass flow rate	low	5	0.000	0.000	0.000	0.000
	medium	5				
	high	5				
	Total	15				
Simulated flow time	low	5	0.000	0.041	0.05	0.000
	medium	5				
	high	5				
	Total	15				
Velocity	low	5	0.000	0.000	0.000	0.000
	medium	5				
	high	5				
	Total	15				
Total pressure	low	5	0.000	0.000	0.000	0.000
	medium	5				
	high	5				
	Total	15				
Turbulence	low	5	0.000	0.000	0.000	0.000
	medium	5				
	high	5				
	Total	15				
Wall shear strength	low	5	0.000	0.000	0.000	0.000
	medium	5				
	high	5				
	Total	15

Figure 1: CAD Model Reconstruction

Figure 2: CFD Analysis on Parameters Assessed at Low Nozzle Position in 30 0.6% Preparation

Figure 3: CFD Analysis on Parameters Assessed at Middle Nozzle Position in 30 0.6% Preparation

Figure 4: CFD Analysis on Parameters Assessed at High Nozzle Position in 30 0.6% Preparation