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The effect of location and method of tooth preparation on aerosol and splatter mitigation

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Abstract

Objectives: This study investigated the influence of tooth position within the quadrant and method of tooth preparation on aerosol and splatter reduction by suction techniques.
Materials and methods: Using four suction techniques, tooth preparation was done using fast handpiece and combined air and water spray on tooth #28, #29 and #30. Splatter, aerosol and total sound generated were recorded. Two-way analysis of variance and posthoc pairwise comparisons compared amount of aerosol, spatter and total sound among suction techniques, tooth location and method of preparation.
Results: There were statistically significant more splatter ($P < 0.000$) for tooth preparation with air and water spray compared with high-speed handpiece for all suction techniques, but no significant difference in aerosol and total sound ($P > 0.05$) was recorded. A significant reduction in environmental splatter during tooth preparation of the distal tooth #30 by all suction methods was observed compared with tooth #28. However, there was no significant difference in the amount of face shield, chest, right arm and left arm splatter, aerosol and total sound based on tooth location. Overall, the prototype suction device had statistically significant less environmental splatter ($P < 0.001$) and aerosol ($P = 0.004$) than the conventional HVE device.
Conclusions: The method of tooth preparation affected splatter mitigation by suction techniques but had no influence on aerosol mitigation. Mitigation of environmental splatter by suction techniques was affected by tooth position within the arch. The prototype suction device reduced environmental spatter and aerosol more than the conventional HVE device.
Clinical Significance: The variations observed in aerosol and splatter mitigation based on tooth preparation methods and tooth location provides evidence for adjunctive means of reducing risk of direct transmission of infection in the dental practice such as combining strategies of protective equipment, improved room ventilation and use of air filtration system.

KEYWORDS: Aerosol; Spatter: Noise: Infection Control; High-Volume Evacuator; Isolation

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1.0 Introduction

The possibility of inhalation of aerosols deep into the lung poses a likelihood of alveolar tissue infection in the lower respiratory tract (Singh and Mabe, 2009). Aerosols smaller than 10 µm may persist airborne (Kumar and Subramanian, 2020), while splatter are larger elements which settle rapidly on surrounding surfaces (Singh and Mabe, 2009). This increases the possibility of disease transmission such as tuberculosis, influenza, and severe acute respiratory syndrome (SARS-CoV-2) (Yang et al., 2021).

Dental practitioners may be subjected to work-related noise from numerous sources such as ultrasonic scalers, handpieces, and suction devices. Dental equipment previously emitted noise that surpassed the recommended level of exposure (Da Cunha et al., 2017), thus putting dentists at risk of developing hearing loss (Hopp, 1962). Although contemporary dental equipments are less harmful due to technological advancement in noise reduction, (Burk and Neitzel, 2016; Ramsey et al., 2020) occupational hearing loss is still a concern. Furthermore, procedures in dentistry that make use of handpieces, ultrasonic scalers, or air-water spray syringe usually generate a lot of aerosols with possible saliva and/or blood contamination (Bizzoca et al, 2020).

Data available concerning aerosol and splatter contamination from dental procedures had methodological limitations, including the use of microbiology culture media which limits their detection to only those with culturable bacteria (Watanabe et al., 2018). In addition, dye tracers and image analysis primarily assess splatter rather than aerosol (Chiramana et al., 1970; Veena et al., 2015) and particle counters primarily detect aerosol rather than splatter (Nulty et al., 2020).

In order to reduce the transmission of COVID-19 disease, several recommendations were made regarding aerosol generating procedures although the lack of evidence for some of the proposed recommendations were acknowledged (ADA, 2020). The function of high-volume evacuators (HVE) in controlling aerosol and splatter from rotary instruments during dental procedures has been highlighted (Cochran et al., 1989; Jacks, 2002; Ravenel et al., 2020; Remington et al., 2022). Rubber dam (RD) isolation was reported to reduce contamination by reducing the spread of aerosol and splatter, although some authors reported contrary results (Al-Amad et al., 2017; Desarda et al., 2014). It was suggested that more studies are needed to assess the effectiveness of these isolation devices for aerosol and splatter reduction (Bizzoca et al, 2020).

Only a few studies have investigated the influence of some restorative procedures on the mitigation of aerosol and splatter by these isolation methods (Tan et al., 2021). There is however paucity of information concerning how the location of a tooth in a dental arch impacts aerosol and splatter mitigation by these isolation techniques during tooth preparation procedures as well as the total sound generated during these procedures.

This study therefore used two dental procedures (high-speed handpiece and air-water spray) on three teeth at the mandibular right quadrant and examined their effect on four isolation methods (HVE, RD with HVE, prototype 3D-printed funnel HVE (PROTO), and PROTO with RD). The aim was to determine the effect of tooth location and the type of dental procedure on total sound generated and distribution of aerosol and splatter. The null hypothesis was that tooth location and type of dental procedure would not affect total sound generated as well as distribution of aerosol and splatter.

2.0 Experimental

2.1. Study design

A laboratory study conducted within a closed door operatory as benchtop simulated procedures.

2.2. Location

An enclosed dental operatory at the Faculty of Dentistry, Lagos State University College of Medicine, Nigeria. The air inlet vent was sealed to prevent airflow currents that could affect the spatter pattern.

2.3. Ethics

Study approval was obtained from the Lagos State University Teaching Hospital HREC (LREC/06/10/1642).

2.4. Method

The research methods were modified from a previous study (Dahlke et al., 2012). The procedures were repeated six times for each dry-field technique device. All 72 trials were conducted using the same setting.

2.5. Test Device

The test dry-field system (PROTO) was a 3D-printed funnel shaped suction device created with the Ender-3 3D printer (Creality, Shenzhen, China) using PLA (Fillamentum, Hulin, Czech Republic) using a layer height of 100 mm, 220°C extruder temperature, 68°C bed temperature and 100% infill (Figure 1). This system has a disposable funnel mouthpiece (65mm by 11mm aperture) designed to retrofit onto the high-volume suction hose, with an integrated cheek retractor that fits in the vestibule area.

2.6. Control Device

The control dry-field method was a disposable conventional HVE with vented tip (Henry Schein, Melville, New York, U.S.A).

2.7. Rubber Dam Isolation

Isolation by a standard latex 6-inches dam (HYGENIC Dental Dam, Coltène/Whaledent, Inc., Cuyahoga Falls, Ohio, U.S.A) with six punched holes.

2.8. Manikin

A wooden platform (4 × 3-feet) was constructed and positioned around a manikin head (KaVo Dental, Charlotte, North Carolina, U.S.A) fastened to a dental chair and reclined with the occlusal plane of the maxillary arch perpendicular to the floor. Maxillary and mandibular typodonts (D95SDP-200 32 Teeth Soft Gingivae Type, Kilgore International, Coldwater, Michigan, U.S.A) were fixed onto the manikin head. A trimmed cardboard paper was taped to the platform.

To replicate the volumetric size of the oral cavity vinyl polysiloxane putty (VP Mix regular set mint, Henry Schein, Melville, New York, U.S.A) was placed within the typodont where water may leak from. A laboratory stand with a three-pronged clamp was placed at the 5 o'clock position to hold the dry-field systems in position using vinyl polysiloxane to modify the clamps to the evacuators (Figure 2). A 0.1% fluorescein dye solution (Sigma Aldrich, St. Louis, Missouri, U.S.A) was added to the water supply to the dental unit.

2.9. Handpiece

The handpiece used was a high-speed handpiece (NSK Ti-Max X95L, Hoffman Estates, Illinois, U.S.A) ran at its highest torque, speed of rotation set at 200,000 revolutions per minute, water flow set at 25 ml/min, and the air pressure set to attain an aerosol mist. The air/water syringe was set at 25ml/min. The dental chair (Ritter, Germany) was equipped with HVE and saliva ejector lines. The suction setups used included:

1. The disposable standard HVE with vented tip (Henry Schein, Melville, New York, U.S.A) inserted into the HVE line with its orifice parallel to and placed 1 cm from the tooth being prepared (Figure 2).
2. The PROTO system fitted into the HVE line and fixed 4cm in front of the manikin mouth (Figure 2).
3. Rubber Dam with HVE and PROTO suction methods with standard latex 6-inch dental dam with holes punched to isolate teeth #26–31 (Figure 2).

2.10. Simulated procedure

Before each procedure, the mannequin and wooden platform were both wiped with 70% ethanol and air dried. The platform was covered with cardboard paper that was trimmed to fit. Filter papers were attached to a right-handed operator's mid-forearms and upper chest with a full-face visor (width: 29cm, height: 21cm) who sat 40cm from the patient at 8.o. clock position.

A diamond bur, 878K016 (Brasseler USA, Savannah, Georgia, U.S.A) was used to prepare all-ceramic crown on tooth #28 and #30 with a high-speed handpiece for 60 seconds. Mesial-occlusal cavity in tooth #29 was rinsed using air/water syringe for 60 seconds.

Following each trial, the filter papers, face shield visors and cardboard papers were maintained for 10 minutes for the spatter to settle and dry. Thereafter, they were picked with clean tweezers and air-dried, before being stored each in a sealed polyethylene bag.

2.11. Measurements

Both HVE and PROTO devices were each used to clear water out of a 2-liter cylinder filled with 2,000 mL of water. Both tests were repeated three times for each device. The HVE cleared all water at a rate of 46.5mL/second while the PROTO device cleared the water from the cylinder at a rate of 48.8mL/second.

Environmental Spatter

A custom four by three-foot grid was made with strings fixed at 5cm intervals to form squares of 5cm2 and placed on each board paper. A light-emitting diode curing blue light (JAS-2001B, China) with a spectrum of 400nm and 490nm was held at a distance of 8cm to the cardboard to fluoresce spatter droplets and visualized with amber-colored glasses (Figure 3). Identification of fluorescence spot within a 5 cm^2 square was counted positive for contamination. The number of contaminated squares were recorded for each trial. Spatter generated during tooth preparation procedures without suction device was taken as the positive control trials.

Body spatter

The 5cm^2 grid was placed on each filter paper (110mm Whatman, Buckinghamshire, UK) from the operator's chest and upper arm sleeves and visualized using dental curing light. Identification of a fluorescence spot within a 5cm^2 square was counted positive for contamination. The number of contaminated squares were recorded for each trial. Spatter generated during tooth preparation procedures without suction device was taken as the positive control trials.

Face Shield spatter

The 5cm^2 grid was placed on a Face Shield visor (ZSR-M01, Dongguan ZSR Biomedical Technology Company Limited, Guangdong, China) worn by the operator and visualized using dental curing light. Identification of a fluorescence spot within a 5cm^2 square was counted positive for contamination. The number of contaminated squares were recorded for each trial. Spatter generated during tooth preparation procedures without suction device was taken as the positive control trials.

Aerosol

During the teeth preparation procedure, a calibrated laser particle counter (DT-9850M Particle counter, CEM, Shenzhen, China) was held 4 cm from the oral cavity to record particulate matter of less than 2.5μm in diameter (PM2.5) for 20seconds and displayed in mg/m3 units. Aerosol recorded during tooth preparation without suction device was taken as positive control values. The negative control value was the ambient PM2.5 in the experimental room before commencement of the experiment.

Sound

Noise generated was measured in decibels by Soundmeter X application developed by Faber Acoustical downloaded into an iPhone

X placed at 6inches from soft tissue glabella of head of the mannequin. A 30-second noise measurement was recorded with a wide range of sound frequencies. The application computed and recorded the total sound level (TSL). Noise recorded during tooth preparation without suction device was taken as positive control values. The negative control value was the noise in the operatory before performing any experiment.

2.12. Reliability of measurements

Duplicate measurements were taken on 30 randomly selected board and filter papers three weeks after the initial measurements to evaluate intra-examiner reproducibility. The κ values for Intra-examiner reproducibility ranged from 0.94 to 0.96.

2.13. Statistical Analysis

It was determined from a previous publication (Dahlke et al., 2012) that six trials were required for each experimental setup to attain a power of 0.80 (effect size = 0.20; $p < 0.05$) with a total of 72 trials. Data for environmental, face shield, chest, right and left arm spatter, aerosol, and total sound were recorded. The data was analysed by conducting a two-way analysis of variance (ANOVA) with statistical software SPSS, version 24 (IBM Corp.; New York, USA). Main effects, Bonferroni correction and pairwise comparisons of interaction effects were evaluated using Tukey tests. A statistical significance level of $p < 0.05$ was selected.

3.0 Results

The Shapiro-Wilk test found that for the grouping of tooth number and isolation method, the amount of spatter, total sound and aerosol was not normally distributed ($P < 0.05$). Levene's test for equality of error variances observed that variances across groups were not equal ($P < 0.05$). The descriptive statistics for splatter, aerosol and total sound level is shown in Table 1.

3.1. Flow rates

There was no statistically significant variation in suction flow rate ($p = 0.362$) of the HVE (46.5ml/sec) and that of PROTO (48.8ml/sec) devices.

3.2. Effect of method of suction

Two way ANOVA showed statistically significant differences between PROTO system, HVE device and rubber dam groups in the amount of environmental spatter ($F_{4,62} = 22.629$, $P < .001$ with 59.3% of variance), face shield spatter ($F_{4,62} = 8.249$, $P < .001$ with 34.7% of variance), chest spatter ($F_{4,60} = 9.682$, $P < .001$ with 39.2% of variance), right arm spatter ($F_{4,60} = 9.209$, $P < .001$ with 38.0% of variance), left arm spatter ($F_{4,60} = 10.573$, $P < .001$ with 41.3% of variance), aerosol ($F_{4,61} = 21.024$, $P < .001$ with 58.0% of variance) and total sound generated ($F_{4,62} = 14.298$, $P < .001$ with 48.0% of variance).

Comparison of PROTO versus HVE

The PROTO method had statistically significant reduced environmental spatter ($P = 0.000$) and aerosol ($P = 0.004$) than the conventional HVE device (Table 2). Both devices showed no significant difference in face shield, chest, right and left arm spatter and total sound ($P > 0.05$).

Comparison of PROTO versus PROTO with rubber dam

There were no statistically significant differences between environmental spatter, chest spatter, right arm and left spatter, aerosol and total sound generated by PROTO alone and PROTO with rubber dam ($P > 0.05$). However, PROTO with rubber dam isolation produced statistically significant reduced face shield spatter ($P = 0.002$) compared with prototype device alone (Table 2).

Comparison of HVE versus HVE with rubber dam

HVE with rubber dam technique produced statistically significant reduced environmental spatter ($P = 0.000$) and aerosol ($P = 0.000$), with statistically significant increased total sound compared with the HVE alone ($P = 0.002$). There was no statistically significant differences observed between face shield, right arm and left arm spatter from HVE and HVE with rubber dam (Table 2). However, HVE with rubber dam technique produced statistically significant more chest spatter compared with HVE alone ($P = 0.038$).

3.3. Effect of type of procedure

The 3-in-1 air and water spray produced statistically significant more spatter compared with preparation by high speed handpiece ($P = 0.000$) for all isolation methods (Table 2). However, the levels of aerosol and total sound showed no significant difference ($P > 0.05$) for all isolation methods.

3.4. Effect of tooth location

There were statistically significant differences among teeth #28, #29 and #30 in the amount of environmental spatter ($F_{2,62} = 184.262$, $P < 0.001$ with 85.6% of variance), face shield spatter ($F_{2,62} = 59.110$, $P < 0.001$ with 65.6% of variance), chest spatter ($F_{2,60} = 22.568$, $P < 0.001$ with 42.9% of variance), right arm spatter ($F_{2,60} = 17.390$, $P < 0.001$ with 36.7% of variance) and left arm spatter ($F_{2,60} = 107.195$, $P < 0.001$ with 78.1% of variance). However, there were no significant differences observed among the teeth for aerosol ($F_{2,61} = 2.974$, $P = 0.059$ with 8.9% of variance) and total sound ($F_{2,62} = 2.303$, $P = 0.108$ with 6.9% of variance).

Comparison by tooth location

The more distal tooth #30 in the mandibular right quadrant for all isolation methods had statistically significant reduced environmental splatter compared with the more anterior tooth #28. However, no significant difference was observed in the amount of face shield, chest, right arm and left arm spatter, aerosol and total sound.

3.5. Effect of interaction between tooth location and suction method

There were statistically significant differences in the interaction between the isolation method and the tooth number for

Table 1. Descriptive statistics

TOOTH NUMBER	Outcome	Ambient room N = 6		Control N = 6		HVE N = 6		PROTO N = 6		HVE + RD N = 6		PROTO + RD N = 6	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
#28	Spatter	N/A		96.00	1.10	110.67	32.17	61.67	14.67	57.17	9.77	91.50	15.67
	Face shield spatter	N/A		0.00	0.00	1.67	2.07	1.33	1.51	4.83	2.32	0.17	0.41
	Chest spatter	N/A		7.50	0.55	0.83	0.75	0.00	0.00	4.33	2.88	2.17	2.32
	Right arm spatter	N/A		5.50	0.55	1.00	0.89	0.00	0.00	0.83	0.75	0.67	1.03
	Left arm spatter	N/A		0.00	0.00	0.33	0.52	0.17	0.41	0.50	0.84	0.17	0.41
	Aerosol	0.80	0.04	1.42	1.64	0.38	0.13	0.49	0.08	0.29	0.07	0.37	0.06
	Total sound	62.05	1.04	71.00	1.10	77.53	4.10	78.67	2.17	81.40	4.78	81.08	0.63
#29	Spatter	N/A		274.00	4.38	275.17	36.72	201.50	64.74	150.67	31.05	112.20	6.02
	Face shield spatter	N/A		23.00	1.10	19.00	6.54	16.17	8.82	13.67	9.83	1.00	2.24
	Chest spatter	N/A		5.50	0.55	5.33	2.94	6.33	2.25	6.60	1.67	3.33	2.25
	Right arm spatter	N/A		7.00	0.00	5.50	2.59	4.50	3.27	3.20	3.56	2.00	2.00
	Left arm spatter	N/A		5.50	0.55	6.50	1.05	4.33	2.81	7.20	1.10	1.17	1.60
	Aerosol	0.80	0.04	1.03	1.10	0.87	0.22	0.57	0.19	0.57	0.35	0.47	0.03
	Total sound	62.05	1.04	66.35	1.48	75.02	7.76	79.93	0.49	81.56	2.38	82.05	2.63
#30	Spatter	N/A		69.50	1.64	58.67	19.38	31.83	4.45	28.17	16.43	22.33	7.03
	Face shield spatter	N/A		7.00	1.10	0.83	1.33	1.33	0.82	1.17	1.17	0.17	0.41
	Chest spatter	N/A		6.00	0.00	0.40	0.89	0.17	0.41	1.40	1.14	0.67	1.21
	Right arm spatter	N/A		5.50	0.55	0.20	0.45	0.83	0.98	1.60	1.14	0.50	0.84
	Left arm spatter	N/A		1.00	0.00	0.60	0.89	0.33	0.82	1.00	0.71	0.50	0.84
	Aerosol	0.80	0.04	1.02	1.10	1.07	0.39	0.52	0.21	0.45	0.14	0.59	0.12
	Total sound	62.05	1.04	77.15	1.15	77.55	0.98	80.32	2.34	80.12	1.92	80.40	0.74

Measurement units: 1. Spatter — number of contaminated squares in the experimental grid. 2. Aerosols - mg/m^3. 3. Sound – dB. HVE with RD (HVE + RD), PROTO with RD (PROTO + RD)

HVE, high-volume evacuation; RD, rubber dam; PROTO, Prototype 3D printed lip retractor with funnel; SD, Standard Deviation

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Table 2. Pairwise comparisons using post hoc tests

Model effect	P value						
	Environmental spatter	Face shield spatter	Chest spatter	Right arm spatter	Left arm spatter	Aerosol	Sound
Isolation method							
PROTO versus HVE	0.000*	0.973	1.000	0.869	0.101	0.004*	0.060
PROTO versus PROTO + rubber dam	0.076	0.002*	1.000	0.732	0.058	0.950	0.610
HVE versus HVE + rubber dam	0.000*	0.993	0.038*	0.902	0.994	0.000*	0.002*
Tooth No.							
28 versus 29	0.000*	0.000*	0.000*	0.000*	0.000*	0.004*	0.843
29 versus 30	0.000*	0.000*	0.000*	0.000*	0.000*	0.760	0.577
28 versus 30	0.000*	0.911	0.059	0.940	0.602	0.000*	0.894
Interaction according to tooth number and isolation method							
Tooth #28							
PROTO versus HVE	0.002*	0.997	0.933	0.207	0.984	0.282	0.989
PROTO versus PROTO + rubber dam	0.096	0.756	0.285	0.582	1.000	0.198	0.781
HVE versus HVE + rubber dam	0.001*	0.029*	0.026*	0.996	0.984	0.404	0.332
Tooth no. 29							
PROTO versus HVE	0.056	0.963	0.941	0.971	0.252	0.206	0.353
PROTO versus PROTO + rubber dam	0.021*	0.023*	0.199	0.549	0.041*	0.965	0.947
HVE versus HVE + rubber dam	0.001*	0.728	0.890	0.663	0.964	0.192	0.143
Tooth no. 30							
PROTO versus HVE	0.014*	0.912	0.993	0.760	0.980	0.007*	0.067
PROTO versus PROTO + rubber dam	0.717	0.308	0.883	0.964	0.996	0.995	1.000
HVE versus HVE + rubber dam	0.005*	0.979	0.461	0.131	0.929	0.001*	0.103

* Significant at ⩽ 0 .05.

HVE, high-volume evacuation; RD, rubber dam; PROTO, Prototype 3D printed lip retractor with funnel

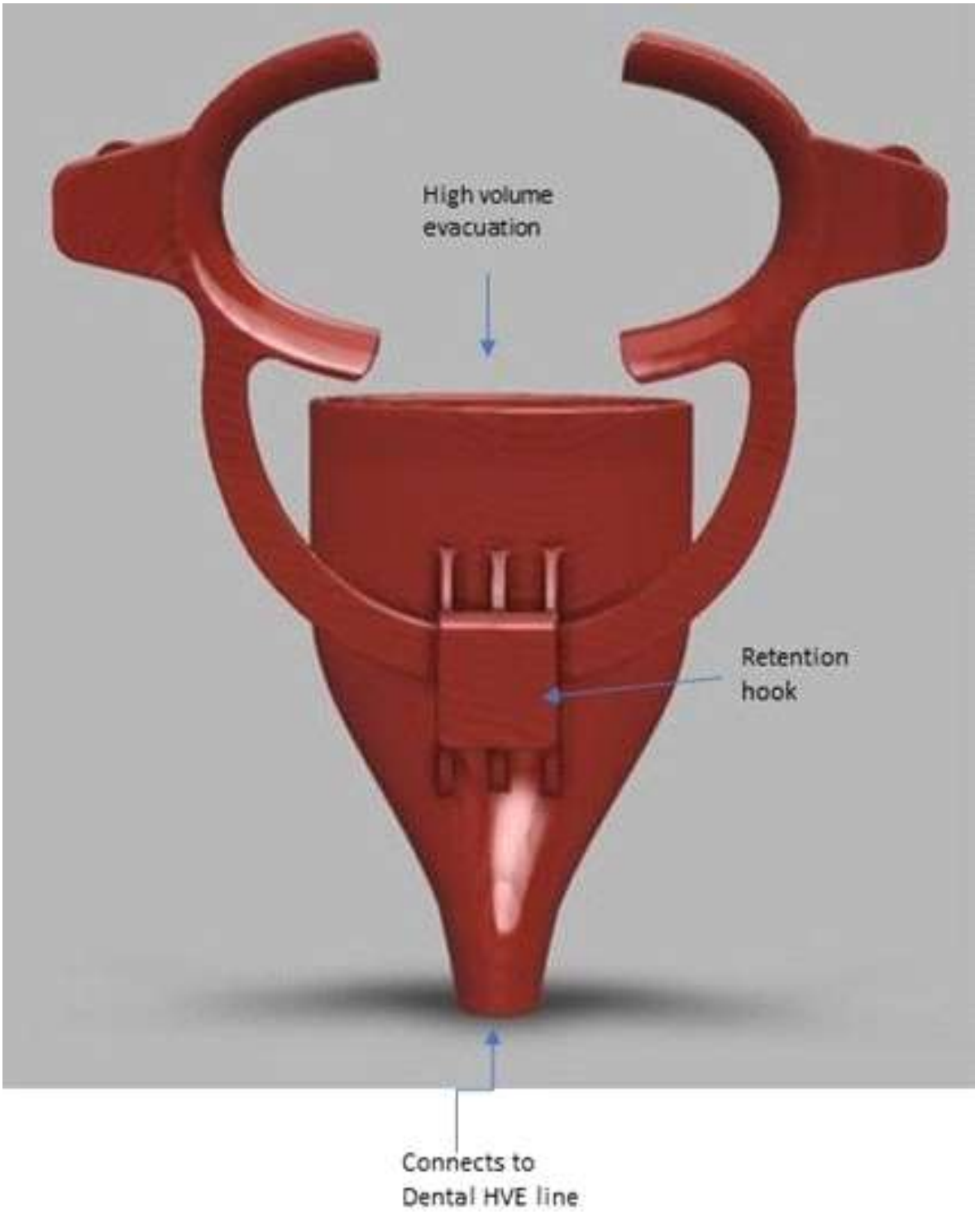

Figure 1: Diagram showing the 3D printed retraction and funnel suction device (PROTO)

Figure 2: Experimental setup for the dental dam with a high-volume evacuator (HVE), on the left and 3D-printed funnel suction device (PROTO) on the right

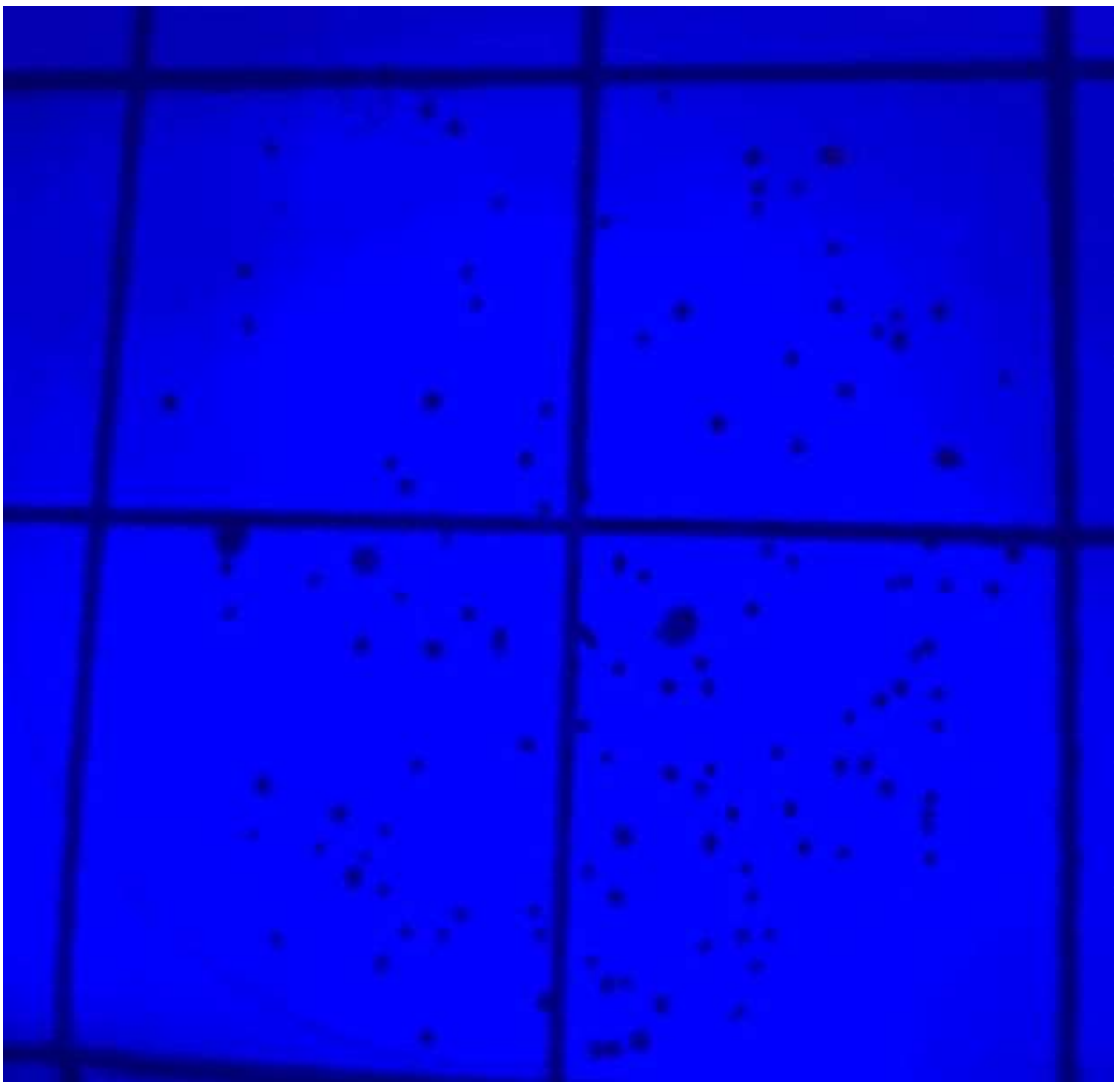

Figure 3: Fluorescent spatter with overlay grid

right arm spatter ($F_{8,60}$ = 1.606, P=0.142 with 17.6% of variance) aerosol ($F_{2,61}$ = 2.974, P = 0.059 with 8.9% of variance) and total sound ($F_{8,62}$ = 1.906, P = 0.075 with 19.7% of variance).

4.0 Discussion

Dental procedures that can generate aerosols and splatter include use of dental turbines, handpieces, micromotor, ultrasonic scalers, and air-water spray (OSHA, 2021). Techniques aimed at reducing dental aerosol and splatter contamination include rubber dam and HVEs (Aurangjeb et al., 2013).

This study assessed the quantity of aerosol and splatter generated during restorative procedures from high-speed handpiece and air water syringe, from various tooth positions using various suction techniques. Specifically, it demonstrated differences in spread of aerosol and splatter based on dental procedures, suction techniques, and tooth position.

This present study used visual examination of dye tracers to assess splatter while aerosol was recorded with particle counter. Splatter and aerosol have been assessed by various methods including visual evaluation of dyes or through image analysis techniques which evaluates mainly splatter instead of aerosol because only large sized droplets are visible (Allison et al., 2021). Other studies used high-speed imaging to capture aerosol clouds as well as particle sampling for aerosol concentration measurements and aerosol size distribution at various location (Zhu et al., 2022), industrial particle counter, measurement of aerosol concentration with optical spectrometer and

wearable sensors (Matys and Grzech-Leśniak, 2020; Choudhary et al., 2022).

High-volume evacuator is recommended in most guidelines and standard operating procedures related to COVID-19, as a vital infection control procedure during aerosol generating procedures. In the present study, the water flow rates for the two HVE devices tested did not show a statistically significant difference. However, PROTO significantly reduced environmental splatter and aerosol compared to HVE. This may be due to the comparatively larger surface area of the PROTO device. This is similar to studies that found some devices (Choudhary et al., 2022) to be more effective than standard HVE evacuators during dental procedures that generate aerosol. It was suggested that size and shape were important considerations in the design of suction devices to ensure aerosol reduction (Matys and Grzech-Leśniak, 2020). The wide catchment section of PROTO may have enhanced the HVE capacity of the dental unit. It can also be positioned close to oral orifice using the integrated cheek retractor that fits in the vestibule, thus continuously removing aerosols compared to the HVE tip which only functions intermittently when it is close to the tooth, thus reducing the mitigation of potentially harmful aerosols.

During conservative procedures, RD barriers has been reported to lessen potential contamination considerably up to 98.5% (Al-Amad et al., 2017). This present study showed that HVE with rubber dam technique produced statistically significant reduced environmental splatter and aerosol compared with HVE alone (Table 2). However, use of rubber dams has been associated with contamination of headcaps, which may be due to increase in the average particle size (Cochran et al., 1989) which is in agreement with findings in the present study which found that HVE with rubber dam technique mitigated statistically significant less chest splatter compared with HVE alone (Table 2).

This study investigated whether the type of procedure affected the amount of contaminants generated. The results showed that the 3-in-1 air and water spray produced statistically significant more spatter than the high speed handpiece ($P < 0.000$) for all isolation techniques (Table 2). However, the levels of aerosol showed no significant difference ($P > 0.05$). This result however differs from a previous study which found that the triplex air water spray syringe generated more aerosol particles than the high- and low- speed handpieces and ultrasonic scaler (Han et al., 2021).

This present study investigated whether tooth position influenced the quantity of splatter and aerosol formed. Results (Table 2) showed that the quantity of environmental splatter reduced moving distally from tooth #28 to #30. However, all other operator's body spatter and aerosol were not significantly different. This difference may be because the position of the water source is nearer to the mouth orifice for tooth #28, therefore and it was easier for water to escape from the mouth.

The variations in the mitigation of aerosol and splatter by these suction techniques shows the importance of suitable personal protective equipment (PPE) during aerosol generating procedures, including masks, gloves, face shields, goggles and headcaps (Sebastiani et al., 2017; Ahmed and Jouhar, 2021), use of antiseptic pre-procedural rinse with Peroxyl/povidone-iodine or chlorhexidine (Logothetis and Martinez-Welles, 1995), use of HVE device (Ravenel et al., 2020), use of an air filtration tool (Klyn et al., 2001), and use of negative-pressure airflow (Kampf et al., 2020).

Prolonged exposure to elevated noise levels may cause non-hearing effects, such as irritation, apprehension, discussion interference, difficulty in attentiveness (Ai et al., 2017), as well as exhaustion and tension headaches (Cabrera and Lee, 2000). According to NIOSH (National Institute for Occupational Safety and Health) guidelines, noise levels below 85 dBA (decibels) are considered safe, while levels above 85 dBA may cause hearing loss (Jadid et al., 2011). Furthermore, the permissible exposure limit (PEL) recommendation by OSHA (Occupational Safety and Health Administration) is 90 dBA for 8-hour per day workers (OSHA, 2008). In this present study, the addition of RD to PROTO and HVE generated a significantly louder noise (Table 2); however, none of the level of noise generated exceeded the NIOSH guidelines or the OSHA recommended thresholds (Table 1).

Noise induced hearing loss was found to be prevalent among dentists (Shetty et al., 2020), the hearing loss significantly more prevalent among those with longer working period and older age groups (Al-Rawi et al., 2019).

Although, contemporary dental equipment are within the parameters set by NIOSH as a result of improvements in technology (Choosong et al., 2011), there are however concerns that their noise levels can cause hearing loss, especially in dental practice where dentists perform different procedures simultaneously, sounds may be close to average limits of risk (Baseer et al., 2021).

This study has several limitations. Firstly, the concentration of spatter was not assessed as each square was scored as positive for contamination irrespective of the number of drops. Therefore, squares with many drops were graded the same as a square with one drop of splatter. Secondly, the use of fluorescein dye could possibly alter the tension of the water as well as the flow and sizes of the aerosol and splatter. Thirdly, aerosol measurement was only considered for PM2.5 although there were PM5 and PM10 particle components of aerosol. Evidence (Sotiriou et al., 2008) suggests that dental procedures produce a higher concentration of relatively small particles that can penetrate deep into lungs compared to relatively larger particles. This guided the decision to focus on measuring the PM2.5 particles. Furthermore, measurements of noise levels were limited to 30

seconds, therefore, the time-weighted average, which assesses a worker's daily exposure, which requires a longer time to record the noise level was not calculated. Therefore, comparisons of these results with the NIOSH and OSHA guidelines that prescribe time-weighted average thresholds should be done with caution.

5.0 Conclusion

Despite the limitations of this study, the results suggested the following:

1. The method of tooth preparation affected splatter mitigation by suction techniques but had no influence on aerosol mitigation.
2. Mitigation of environmental splatter by suction techniques was affected by tooth position within the arch.
3. The prototype suction device reduced environmental splatter and aerosol more than the conventional HVE device.
4. None of the levels of noise generated exceeded the NIOSH guidelines or the OSHA recommended thresholds.

Therefore, we recommend further studies to compare more aerosol and spatter mitigation techniques in varying arch quadrants and to explore the bacterial content of the spatter in an in vivo setting.

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7.0 Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contributions

Conception: TAY and SAK
Design: TAY, AML and OAA
Execution: TAY, AML, OAA, AOA and SAK
Interpretation: TAY, OAA, AOA and AML
Writing the manuscript: TAY, OAA, AML and AOA

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