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Evaluation and comparison of spatter-reduction effectiveness and aerosol containment of five dry-field isolation techniques – In vitro study

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Abstract

Objective: It is known that SARS-CoV-2 can bind to human angiotensin-converting enzyme-2 receptors, which are highly concentrated in salivary glands; this may be an explanation for the presence of SARS-CoV-2 in saliva. Therefore, there is a potential for transmission of COVID-19 via droplets, which may contribute to nosocomial spread in the dental settings. This study is aimed at performing qualitative analysis of splatter distribution and quantitative analysis of aerosol production during aerosol procedures to evaluate the effectiveness of different suction systems.

Materials and methods: 5 different evacuation devices were tested for their aerosol containment and spatter reduction effectiveness. Three 3-D printed devices were compared against in-built HVE and Confident Extra Oral evacuation device in a simulated clinical set-up on a manikin. Aerosol particles with diameter smaller than 5μ were measured using an aerosol volume detector (Prana Air pocket monitor+) and spatter reduction was measured by observing the generated spatter on a customized grid of 3cm^2 squares.

Results: Confident aerosol suction device was amongst the best in mitigating spatter (p<o.oo1) being statistically highly significant. Amongst the 3D printed devices, aerosol evacuation coupe mitigated spatter more effectively. Aerosol evacuation of all suction setups was significant when compared to the control group where no aerosol mitigation was applied. However, amongst the suction setups, the findings were non- significant (p>0.05).

Conclusion: Results indicate that spatter reduction was significantly better amongst the setups with Confident aerosol suction. Most effective aerosol evacuation was

seen in the Confident aerosol suction and 3D printed aerosol evacuation coupe.

Keywords: Aerosol, covid-19, infection control, suction

Introduction

At the end of 2019, the first cases of a pulmonary disease of unknown aetiology were detected in Wuhan City, China. This new virus, highly infective especially through airborne transmission, is responsible for an acute respiratory syndrome, distinguished by an often asymptomatic, but potentially lethal, interstitial bilateral pneumonia.[1] This virus, initially named 2019-nCoV and subsequently renamed Sars-CoV-2, belongs to the Coronoviridae family, along with the Middle East respiratory syndrome (MERS-CoV) and the severe acute respiratory syndrome (SARS-CoV) viruses.[2]

Of interest to the dental community is the presence of SARS-CoV-2 in the saliva of the affected patients. It is known that SARS-CoV-2 can bind to human angiotensin-converting enzyme-2 receptors, which are highly concentrated in salivary glands; this may be a possible explanation for the presence of SARS-CoV-2 in secretory saliva. Therefore, there is a potential for transmission of COVID-19 via droplets, which may contribute to nosocomial spread in the dental office setting.[3,4]

Even before the discovery of specific infectious agents such as bacteria and viruses, the potential of infection by the airborne route was recognized. The airborne spread of measles, tuberculosis, pneumonic plague, influenza, Legionnaire's disease and SARS is well-documented in the medical literature. The dental literature shows that many dental procedures produce aerosols and droplets that are contaminated with bacteria and blood. These aerosols represent a potential route for disease transmission.[5]

Studies have clearly demonstrated that dental procedures create splatter and aerosols.[5,6] Aerosol and spatter production during dental procedures commonly are derived from the utilization of a high-speed dental handpiece and an ultrasonic scaler. These drops might contain infectious agents originating from the patient or the dental unit waterlines that pose a health threat to the dental practitioner, patient, and staff members who are within the spray's pattern.[7]

Hence, the aim of this study is to perform qualitative analysis of splatter distribution and quantitative analysis of aerosol production during aerosol procedures to evaluate the effectiveness of different suction systems.

Materials and methods

The method and materials were adapted from Dalke et al [8]. The trials were performed in dental operatory with closed windows to prevent air circulation.

Manikin

A manikin head from Pre-clinical laboratory was selected to simulate the patient, with a metal skull, flexible silicone face and mouth lining over a typhodont teeth set of 28 permanent teeth. The simulator was attached to the headset of a dental chair in the usual working position where the maxillary occlusal plane was perpendicular to the floor. A custom 4 X 3 foot wooden board was cut to fit around the manikin head. A custom iron grid was fabricated with 3-cm^2 to be placed over the wooden board to create 3-cm^2 areas to score spatter. Two three- pronged clamps held the dental handpiece and suction devices in a fixed position. The dental handpiece and HVE were oriented in such a way to simulate the position of a right-handed dentist during the preparation of the occlusal surface of the mandibular left second premolar (tooth 35 according to FDI notation. (Fig. 1)

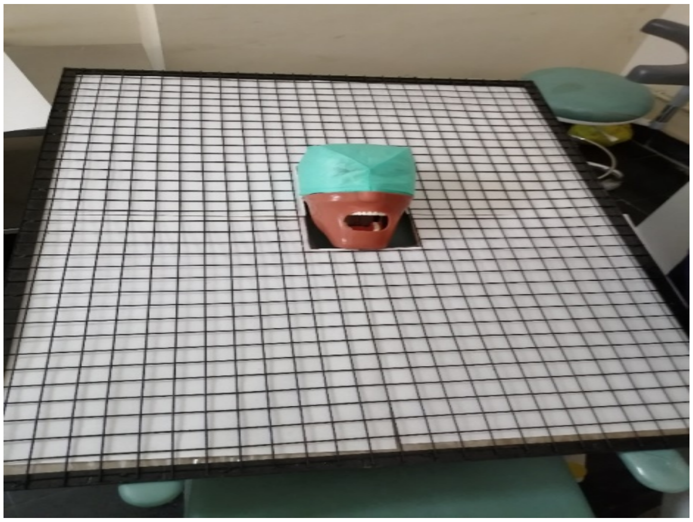


Fig.1: Manikin head

Handpiece

A single high-speed handpiece (NSK) was used and operated at the maximum torque and rotation speed of 200,000 revolutions per minute for 60 seconds. The water flow through the handpiece was set at 30ml/minute, and the air pressure was selected to achieve a typical aerosol plume.

A diamond round bur 801L was placed in the dental handpiece and oriented into a small occlusal preparation in the tooth to act as an index for position reproducibility.

Suction devices

The dental chair (by Confident) used in this investigation was equipped with one HVE line and one saliva ejector line.

The 3-D printed suction devices were created with PLA material (FLASHFORGE USA) using the FLASHFORGE CREATOR PRO 3-D Printer.

3-D printed devices include the following-

1. Aerosol evacuation coupe (61 x 61mm) (Fig. 2)
2. Aerosol evacuation funnel (155mm diameter) (Fig. 3)
3. Aerosol aspiration tip (Largest diameter 45mm, Elliptical orifice) (Fig. 4)
4. Extra – oral high volume suction device (CONFIDENT DENTAL EQUIPMENTS LTD.) (fig.
5. was used alongside the above mentioned 3-D printed equipments.

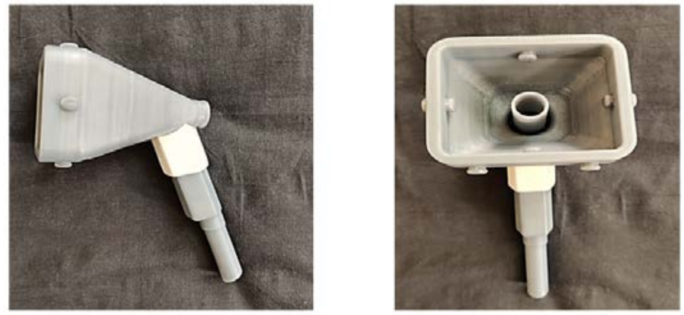


Fig.2: Aerosol evacuation coupe

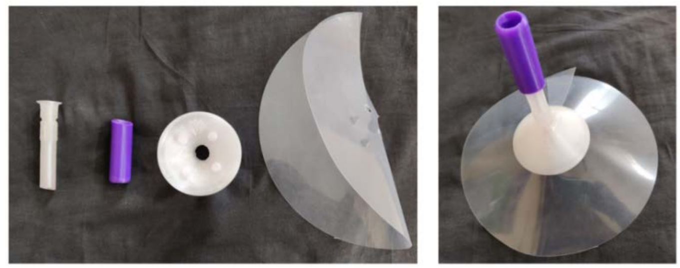


Fig.3: Aerosol evacuation funnel

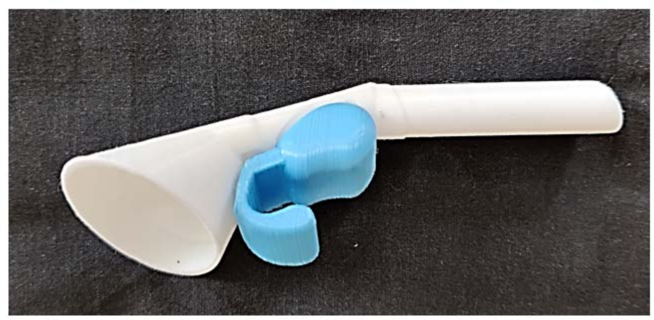


Fig.4: Aerosol aspiration tip

Fig.5: Confident Aerosol suction

Spatter

Erythroscein red dye solution was added to the dental unit water supply for use during the simulated tooth preparation procedure(Fig 6).

The resulting spatter generated during the high-speed handpiece operation and that escaped the suction was visualised by a single observer to eliminate bias (Fig. 6). If even one spot of dye was detected within the square (3-cm^2), the cell was scored as being contaminated. The number of squares with contamination was counted to determine the amount of spatter produced in each trial. Spatter generated using the high-speed handpiece with no suction served as the control value.

Aerosol

Aerosol particles with a diameter smaller than 5µ were measured using an aerosol volume detector (Prana Air pocket monitor+, Fig. 7) which uses laser sensor monitor using light scattering method to detect particulate matter of 2.5 µ size and above. The device was held 6cm away from the orifice of the mouth. Results were displayed in ug/m3 units. This unit was calibrated by running a 10-minute calibration cycle in open fresh air. Average particle counts were recorded for 60 seconds during handpiece operation in separate trials to avoid spatter block by the aerosol measurement device.

Fig.6: Spatter spread evaluation

Fig.7: Aerosol volume detector (Prana air pocket monitor+)

Statistical analysis

The data captured by the particle counter were tabulated in Excel spreadsheet for Mac 2016 and analysed in SPSS 26 by IBM. Comparisons were made using a one-way analysis of variance (ANOVA) for independent groups followed by Tukey post hoc test. Significance level was set at $P < 0.05$ for all analyses.

Results

Spatter

The (Table 01 and graph 1) show the mean values and standard deviation of spatter production obtained using ANOVA. p value obtained is 0.00. Hence the results obtained for spatter production are very highly significant. Maximum spatter production was seen in Group 1 (Without evacuation tip) and minimum was seen in Group 6(Confident aerosol suction). Table 3 shows the mean differences of values of spatter production in between groups. The result is very highly significant ($p<0.001$) except for HVE tip & aerosol evacuation tip and aerosol evacuation coup & funnel ($p>0.05$) is non-significant.

Table 1: statistics showing overall comparison between groups based on spatter production using one way analysis of variance (ANOVA).

	Groups	Mean	Standard Deviation	N
1.	Without Evacuation device	41.2500	7.70035	12
2.	HVE Tip	30.5000	4.03395	12
3.	Aerosol Evacuation Tip	32.0833	4.18783	12
4.	Aerosol Evacuation Coupe	21.6667	3.42008	12
5.	Aerosol Evacuation Funnel	19.9167	4.18783	12
6.	Confident Aerosol Suction	5.6667	2.22928	12
f value	85.40			Total : 72
p value	0.00			

Aerosol

The (Table 2 and graph 2) shows the mean values and standard deviation of Aerosol production obtained using ANOVA. p value obtained is 0.00. Hence the results obtained for Aerosol production are very highly significant. Maximum aerosol production was seen in Group 1 (Without evacuation device) and minimum was seen in Group 6(Confident aerosol suction). Table 3 shows the mean differences of values of aerosol production in between groups. The result is very highly significant ($p<0.001$) when without evacuation device compared to all other devices. The comparison between all the other groups in non-significant ($p>0.05$).

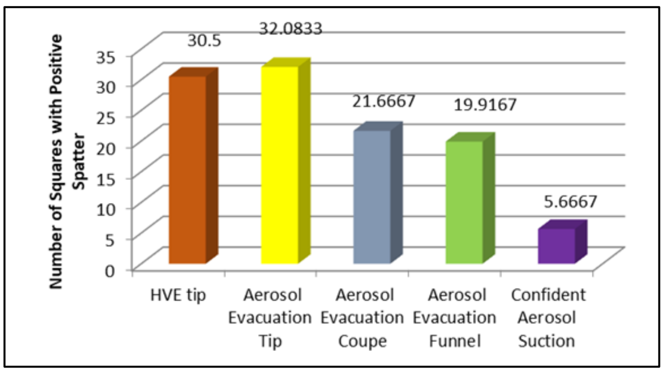
Table 2: statistics showing overall comparison between groups based on aerosol production using one way analysis of variance (ANOVA).

	Groups	Mean	Standard Deviation	N
1.	Without Evacuation device	1049.0833	336.37113	12
2.	HVE Tip	13.6667	3.67630	12
3.	Aerosol Evacuation Tip	17.3333	2.18812	12
4.	Aerosol Evacuation Coupe	10.1667	2.97973	12
5.	Aerosol Evacuation Funnel	13.5833	2.90637	12
6.	Confident Aerosol Suction	9.3333	1.82574	12
f value	113.856			Total : 72
p value	0.00			

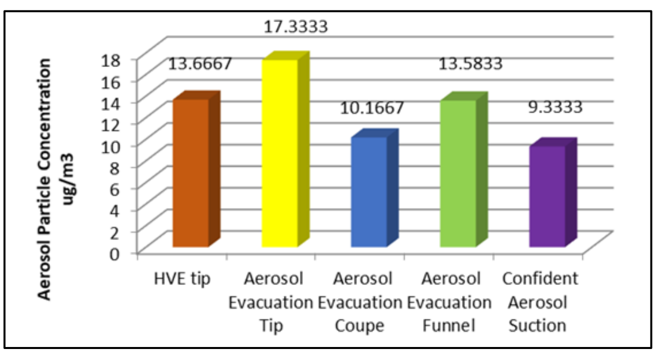
Table 3 : Post hoc comparison between groups based on spatter and aerosol production

(I) Group Vs(J) Group			Mean Difference (I-J)	Std. Error	95% Confidence Interval		P Value
					Lower bound	Upper bound	
Without Evacuation device	HVE Tip	Spatter Aerosol	10.75 1035.4166	1.88053 56.0751	5.2305 870.841	16.2695 1199.99	0.00 0.00
Without Evacuation device	Aerosol Evacuation Tip	Spatter Aerosol	9.1666 1031.7500	1.88053 56.0751	3.6471 867.174	14.68 1196.32	0.00 0.00
Without Evacuation device	Aerosol Evacuation Coupe	Spatter Aerosol	19.58333 1038.9166	1.88053 56.0751	14.0638 874.341	25.1029 1203.49	0.00 0.00
Without Evacuation device	Aerosol Evacuation Funnel	Spatter Aerosol	21.3333 1035.500	1.88053 56.0751	15.8138 870.924	26.8529 1200.07	0.00 0.00
Without Evacuation device	Confident Aerosol Suction	Spatter Aerosol	35.58333 1039.75	1.88053 56.0751	30.0638 875.174	41.1029 1204.32	0.00 0.00
HVE Tip	Aerosol Evacuation Tip	Spatter Aerosol	- 1.5833 -3.6667	1.88053 56.0751	-7.1029 -168.24	3.9362 160.908	0.958 1.00
HVE Tip	Aerosol Evacuation Coupe	Spatter Aerosol	8.83333 3.500	1.88053 56.0751	3.3138 -161.07	14.3529 168.075	0.00 1.00
HVE Tip	Aerosol Evacuation Funnel	Spatter Aerosol	10.58333 0.08333	1.88053 56.0751	5.0638 -164.49	16.1029 164.658	0.00 1.00
HVE Tip	Confident Aerosol Suction	Spatter Aerosol	24.8333 4.3333	1.88053 56.0751	19.3138 -160.24	30.3529 168.908	0.00 1.00
Aerosol Evacuation Tip	Aerosol Evacuation Coupe	Spatter Aerosol	10.41667 7.1666	1.88053 56.0751	4.8971 -157.40	15.9362 171.741	0.00 1.00
Aerosol	Aerosol	Spatter	12.1666	1.88053	6.6471	17.6862	0.00

Evacuation Tip	Evacuation Funnel	Aerosol	3.7500	56.0751	-160.82	168.325	1.00
Aerosol Evacuation Tip	Confident Aerosol Suction	Spatter Aerosol	26.41667 4.3333	1.88053 56.0751	20.8971 -156.57	31.9362 172.575	0.00 1.00
Aerosol Evacuation Coupe	Aerosol Evacuation Funnel	Spatter Aerosol	1.7500 -3.4167	1.88053 56.0751	-3.7695 -167.99	7.2695 161.158	0.937 1.00
Aerosol Evacuation Coupe	Confident Aerosol Suction	Spatter Aerosol	16.000 0.8333	1.88053 56.0751	10.4805 -163.74	21.5195 165.408	0,00 1.00
Aerosol Evacuation Funnel	Confident Aerosol Suction	Spatter Aerosol	14.2 4.25	1.88053 56.0751	8.7305 -160.32	19.7695 168.825	0.00 1.00



Graph 1: Comparison between groups based on spatter production



Graph 2: Comparison between groups based on aerosol production

Discussion

This study evaluated the aerosol and spatter, concerns that directly affect dental practitioners and their teams.[8-12]

The terms "aerosol" and "splatter" in the dental environment were used by Micik and colleagues in their pioneering work on aerobiology.[13]

In these articles, aerosols were defined as particles less than 50 micrometers in diameter. Particles of this size are small enough to stay airborne for an extended period before they settle on environmental surfaces or enter the respiratory tract. The smaller particles of an aerosol (0.5 to10 µm in diameter) have the potential to penetrate and lodge in the smaller passages of the lungs and are thought to carry the greatest potential for transmitting infections.

Splatter was defined by Micik and colleagues as airborne particles larger than 50 µm in diameter. Micik and colleagues stated that these particles behaved in a ballistic manner. This means that these particles or droplets are ejected forcibly from the operating site and arc in a trajectory similar to that of a bullet until they contact a surface or fall to the floor.[13]

In this present study, experimental setups were based on existing techniques, and also novel 3-D printed extra- oral suction devices connected to the high speed evacuation lines. Question remains whether it also has clinical relevance.

It was previously reported that particles in the range of 1 to 3 μm are present in higher amounts when dental procedures are performed.[14] Other studies reported that these particles increase 1.9- to 3.7-fold compared to the background control values, depending on the type of procedure done in the dental office (grinding, drilling, scaling, etc).[15,16]

In the present setup, spatter reduction was observed most efficient with the use of extra oral high volume evacuation by Confident compared to the novel 3-D printed extra oral suction devices, while the aerosol volume reduction was relatively similar with the use of HVE line connected to the 3-D printed devices.

Extra oral suction device by Confident was amongst the best in mitigating spatter (p<o.oo1) being statistically highly significant. Amongst the 3D printed devices, aerosol evacuation coupe mitigated spatter more effectively. This could be contributed to the size of the coupe which acted as barrier for preventing spatter. In the absence of a high volume extra oral suction, it seems that larger coverage of surface area is the key to reduce the spread of spatter. Least amount of spatter mitigation was seen with aerosol evacuation tip and HVE tip, which could be due to the seize and design of the device which covered lesser surface area as compared to other devices.

Aerosol evacuation of all suction setups were significant when compared to the control group where no aerosol mitigation was applied. However, amongst the suction setups, the findings were non- significant ($p>0.05$). 3D printed aerosol evacuation coupe showed mean values relative to the Confident high volume extra oral evacuator. This can be contributed to the design of the evacuation coupe, which allowed greater amount of vacuum generation at the centre of the device, leading to effective aerosol mitigation.

The devices in this study have substantial differences. The Confident aerosol suction device comes with a higher compressor volume, higher cost and cumbersome maintenance. On the other hand, the 3D printed device can be directly connected the in-build HVE port of the dental chair, are much more cost effective, and can be easily chemically disinfected.

This study has several limitations. Spatter concentration was not assessed. Each square that contained even one drop of spatter was considered positive for contamination. Therefore, squares containing many drops would score the same as a square that contained just one drop. Spatter also was not measured outside the experimental custom 4 × 3-foot grid mounted around the manikin head.

Aerosol measurements only considered PM>2.5 μm. There are also PM5 and PM10, which measure larger particle components of aerosols. PM with aerodynamic diameter 2.5 to 10 μm are mainly deposited on the trachea. PM less than 2.5 μm in diameter can get deep into the terminal bronchioles and alveoli, and some < 0.1 μm in diameter may enter the bloodstream, affecting other organs.[17] Particles of this small size can pass through the filtration of nose hair, reaching the end of the respiratory tract with airflow and accumulating there by diffusion.[18]

Another limitation consists in the fact that the manikin does not have saliva. It also should be noted that no drilling into tooth material was performed and the drilling bur was oriented into a previously prepared occlusal cavity to ensure position standardization. the experimental setting may not reproduce real-life work scenarios in which suction device positioning is expected to lack consistency.

Conclusion

The present study evaluated aerosols and spatter reduction with dry-field techniques in a simulated dental setting. Results indicate that spatter reduction was significantly better amongst the setups with Confident aerosol suction device. All experimental setups were similar in mitigating aerosol compared with control group of no evacuation setup. Most effective aeorosol evacuation was seen in the mean values of Confident aerosol suction device and 3D printed aerosol evacuation coupe.

Declaration

The authors mention no conflict of interest associated with this manuscript. The 3D printed devices were provided by Vatsalya Inventures, Bangalore, and are under "patent pending" status.

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