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Aerosol Reduction of 2 Dental Extraoral Scavenger Devices In Vitro

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ABSTRACT

Objective: Since the outbreak of SARS-CoV-2, aerosol control in the operatory has become a key safety issue in dentistry. The utilisation of extraoral scavenger devices (EOSs) is one of the various approaches to in-treatment aerosol reduction in dentistry. The use and efficacy of EOSs in dental settings, however, are still a matter of debate in the literature and there are still open questions about their proper use. Thus, research into this area is essential to inform dental practice. The objective of this study was to examine the aerosol reduction efficacy of two different EOS in vitro.

Methods: Two commercially available EOSs were tested during modeled dental treatment in a setup that previously proved to generate high aerosol load. Measurements were done in two particle size ranges: 5.6–560 nm (the full range of the spectrometer) and 60.4–392.4 nm (a range that is especially relevant to the spread of SARS-CoV-2 with aerosol).

Results: Both devices managed to reduce the aerosol load to a statistically significant extent as compared to the scenario when only a high-volume evacuator and a saliva ejector (and no EOS) were used.

Conclusions: Within the limitations of the study, the results support the assumption that EOSs for aerosol reduction increase in-treatment safety in the dental operatory.

Introduction

Aerosol is generated during most dental procedures and patient interactions. As the COVID-19 pandemic, unfortunately, has reminded us, aerosol is a potent carrier of pathogenic microorganisms. Contamination from spatter and aerosol dissemination has been recognised as a significant hazard for dental personnel for about 30 years.[1-3] Similarly, extraoral suction units have been long recognised as an efficient means of reducing the aerosol burden of the dental operatory.[4,5] Teanpaisan et al demonstrated that a modified household vacuum cleaner can be effectively used for reducing aerosol dissemination into the airspace of the dental operatory.[4] King et al concluded that aerosol concentration was substantially reduced 6 inches away from a patient when using an aerosol reduction device.[6] However, until the onset of the COVID-19 pandemic, the topic had not generated much interest. Questions such as the particle size range in which such devices are effective or the comparative efficiency of the available models in specific dental interventions remained unanswered.

Transmission routes for SARS-CoV-2 include airborne transmission through the inhalation of droplets and aerosols, with an apparent predominance of aerosol

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transmission.[3,7-10] It has been documented that approximately 1 in 5 to 1 in 10 asymptomatic individuals harbor SARS-CoV-2 in either their saliva or respiratory secretions.[11] Thus, it has been recommended that dental personnel use protective equipment during treatment, such as FFP2 or 3 masks.[12] It has been concluded, though, that even FFP masks cannot offer complete protection.[13]

A recent study has described the contamination of the operatory during dental treatment of patients infected with SARS-CoV-2 and concluded that high-volume suction should be used during dental treatments in patients with COVID-19.[14] Such decontamination is especially important because SARS-CoV-2 can remain viable and infectious in aerosols for up to 3 hours,[15] which puts at risk not only the dental personnel but also the patients who enter the same operatory where patients with COVID-19 have previously been treated.

In this in vitro study, we sought to examine the aerosol reduction efficiency of 2 different extraoral scavenger devices (EOSs) in an experimental setting modelling dental treatment with a high-speed turbine. Our research group has already investigated aerosol production and aerosol control in a clinically relevant manner in different setups, including with a high-speed turbine and an ultrasonic scaler in an earlier study.[16] In this investigation, we sought to model only the most difficult-to-control scenario, where aerosol gets in the air directly from the high-speed turbine. An example of such a scenario is class III cavity preparation in the upper front teeth with palatal access, where the spray is directed outwards. In these scenarios, the effect of saliva ejector together with a high-volume evacuator (HVE) is not sufficient for satisfactory aerosol control. We hypothesised that both EOSs would significantly reduce the aerosol load, even in such extreme circumstances.

Methods

Experimental design

An experimental setup was prepared in a regular dental operatory (4.15 m x 2.6 m) with one door and one window, the same as used in our previous publication on this topic (Figure 1).[16] A mannequin head was mounted on the dental unit to simulate the patient in the supine position. A high-speed turbine (Gentle Silence, KaVo Dental) was attached to a holder, which allowed fastening of the instrument in a fixed and reproducible position.

Measurements were carried out with an Engine Exhaust Particle Sizer (EEPS-3090) spectrometer (TSI). According to the literature, working distance in dentistry can vary between 25 and 40 cm.[17,18] As protective equipment (particularly a face shield) can compromise vision, this is reduced when working in such equipment; thus maximum aerosol load was measured at 25 cm from the mannequin head. The endpiece of the spectrometer was positioned above the head of the mannequin at this distance. Following the manufacturer's instructions, the EOSs were positioned at 20 cm above the mannequin head, on the right side of the patient, below the level of the sampling tube of the spectrometer (Figure 2).

Test measurements

All measurements were carried out during the same day. Before the test measurements, the operatory had been intensively aired and air-purified (AC3256/20, Philips) for 12 hours. The following setups were tested.

For the baseline measurements, all units were arranged as during the test measurements (setups 2 to 4, below) but only the measuring unit was on. Neither the dental turbine nor

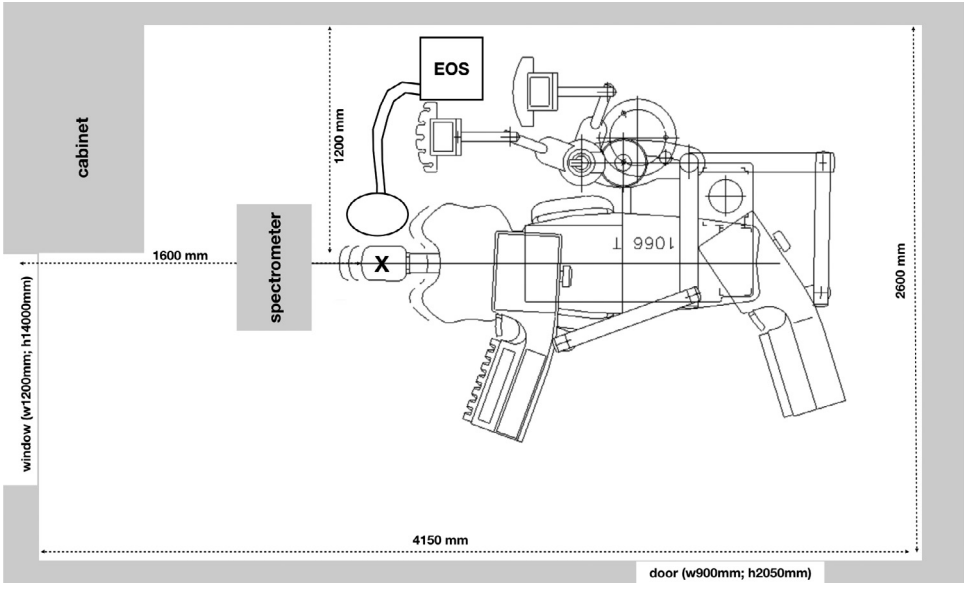

Fig. 1 – Arrangement of the site. X marks the position of the mannequin head. The spectrometer was placed on a 450-mm-high stool, so its sampling tube was 1000 mm above the floor of the room. At this height, the sampling tube was 25 cm over the mannequin head and 5 cm above the extraoral scavenger devices. The dimensions of the door and window are given as width x height.

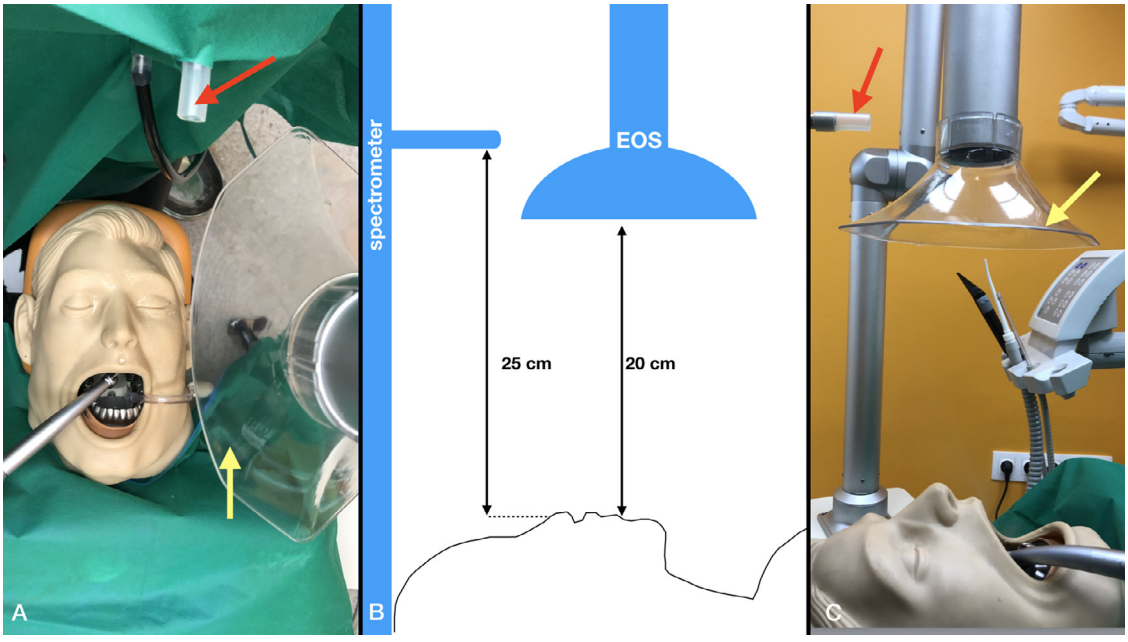

Fig. 2 – Arrangement of the instruments. The red arrows point to the sampling tube of the spectrometer. The yellow arrows point to the extraoral scavenger device (EOS). Left: top view. Right: lateral view. Red arrow: spectrometer sampling tube. Yellow arrow: EOS. Middle: a schematic representation of the setup.

any aerosol control unit was operated. This was the control setup.

For all the study setups, the dental turbine was set in a way to face the palatal surface of the maxillary front teeth, allowing the spray to spread directly towards the spectrometer (modelling the preparation of the palatal surface of the right central incisor). A high-volume evacuator (N1, Dürr Dental) and a saliva ejector were attached to the same dental unit (KaVo 1066 T, KaVo Dental) and positioned according to the manufacturer's instructions. In study setup 1 (NO EOS), no EOS was used in combination with the above. In study setup 2 (EOS A), we used Dental Aerosol System (Foshan COXO Medical Instrument Co., Ltd.), and in study setup 2 (EOS B), we used Eighteeth VacStation (Changzhou Sifary Medical Technology Co., Ltd).

For all 4 setups, 3 measurement cycles were carried out. Each cycle lasted 5 minutes and included 10 consecutive scans (sampling frequency: 30 s). Aerosol reduction by airing was repeated after each measurement by airing. Airing was done by opening both the door and the window of the operatory while operating a standard fan directed towards the window and air purifier turned on. An airing cycle lasted 5 minutes.

Parameters and statistical analysis

Measurements were done in the entire measurement range of the spectrometer (5.6–560 nm) and a critical range (60.4–392.4 nm).

Two parameters were recorded and analysed: total number concentration for the entire measurement range of the spectrometer, that is, 5.6–560 nm (*TNC*: the total number of particles/cm^3) and total number concentration within the range 60.4–392.4 nm (*TNC 60.4–392.4*: the number of particles in the 60.4–92.4 nm range/cm^3).

It has been reported earlier that FFP masks offer somewhat reduced protection against aerosol contamination below 384 nm.[13] It is also known that the SARS-CoV-2 virus may attach to aerosol particles of various sizes, resulting in combined particle sizes from 60 nm to approximately 300 nm.[19] Thus, to get relevant results both in terms of SARS-CoV-2 and the relative deficits of FFP mask protection, we concentrated on the 60- to 384-nm critical range in our previous study.[16] In the present study, we had to slightly modify this range, as the spectrometer we used performs a stepwise range analysis, and the closest available range to the earlier described critical range was 60.4–392.4 nm.

To characterise the size distribution of particles in the generated aerosol, number concentrations by particle diameter were also calculated and plotted for both size ranges.

Aerosol control was defined as the degree to which a given aerosol control system managed to keep water aerosol concentrations close to the baseline in any given setup. Aerosol control for any given setup was expressed as the magnitude of the difference between the mean baseline concentration and the mean concentration generated during the measurement cycles for the given setup.

Please note that the aim of this study was to compare the efficacy of 2 EOSs. The question of aerosol down times was addressed in our previous study[16] in the same operatory and under the same conditions. The interested reader may find information regarding this aspect of aerosol control in the cited study.

Statistical analyses were performed in SPSS 26.0 (IBM). Both parameters of all setups were characterised by the 30 data points from the 3 measurement cycles.

Shapiro–Wilk normality tests were performed for both variables in each setup. As the test indicated non-normal distribution in most cases ($P < .05$), the Kruskal–Wallis test was used for the hypothesis tests. The level of significance was lowered to $P = .008$ (according to Bonferroni) because of the multiple comparisons. Post hoc pairwise comparisons were also performed. For the descriptive characterisation of the data, medians, minima, and maxima were used. Aerosol control was also characterised by a multiplier calculated as $\text{median}_{\text{test setup}}/\text{median}_{\text{baseline}}$.

Results

Aerosol control: deviations from the baseline and the relative effectiveness of the tested devices

After 12 hours of airing, the following median baseline values were measured: *TNC*: 2472.51 (2239.61–2625.60) particles/cm^3; *TNC 60.4–392.4*: 1329.57 (1206.29–1383.91) particles/cm^3. These were considered as the baseline or background values, against which all other measurements were compared. The detailed descriptive statistics for the baseline and study setups are given in the Table.

Regarding *TNC*, the Kruskal–Wallis test indicated a significant overall variance ($H = 80.8$, $df = 3$, $P < .001$). The post hoc test indicated that the elevation compared to baseline was significant in all 3 test setups at $P < .001$. Furthermore, the elevation measured for EOS A was not significantly different from NO EOS ($P = .761$), but it differed significantly from EOS B ($P < .05$). EOS B also differed significantly from NO EOS ($P < .05$). Thus, in this size range, EOS B allowed the most efficient aerosol reduction also with the smallest dispersion of the 3 study setups.

Regarding *TNC 60.4–392.4*, the Kruskal–Wallis test indicated a significant overall variance ($H = 100.43$, $df = 3$, $P < .001$). Tukey's honestly significant difference test indicated that the elevation compared to baseline was significant in all 3 test setups at $P < .001$. Furthermore, the elevation measured for EOS A was not significantly different from EOS B ($P = .900$), but both setups allowed a significantly greater reduction of particle counts than NO EOS at $P < .001$. In this size range, the efficiency of EOS A and EOS B was comparable, and both were superior to NO EOS. Figure 3 summarises the above results.

Number concentrations and particle sizes

Figure 4 shows number concentrations by particle size for the entire measurement range of the spectrometer and for the narrower critical range. As for the full range, the number concentrations for NO EOS and EOS A were quite similar over a wide range of particle sizes. In fact, the number concentrations were somewhat higher for EOS A between 9.31 and 34 nm for EOS A; however, the TNC count was still slightly lower than for NO EOS. As for the critical range, both EOSs were superior to NO EOS in aerosol reduction, over the entire range. For EOS A, there was also a slight shift towards smaller particle sizes, which shows as peaks at 10.8 and 16.5 nm in the figure. When the whole spectrum is analysed, these peaks add much to the amount of produced aerosol, which explains why the results for EOS A were so similar to those of NO EOS.

Discussion

This study compared 2 commercially available EOSs in terms of their efficacy in aerosol control. Such devices are becoming more widespread, and while some studies suggested that their use is not absolutely necessary for good aerosol control,[20] there is an agreement in the literature that they are efficient and increase the safety of the dental operatory.[21-24] The results of a previous study of our own group corroborate this.[16]

In this study, we found somewhat higher aerosol concentrations compared to our earlier study, which was carried out in the same operatory.[16] One reason for this could be that in this study, we used a more advanced spectrometer, which resulted in a larger amount of more precise data. Another reason could be the different baseline aerosol concentrations. In this study, the baseline values were more than 3 times higher on average in both the full and the critical range than in our previous study, even though we prepared the operatory in the same way as before. This shows that there are several, probably uncontrollable factors that determine baseline aerosol concentrations. We suggest, thus, that the efficacy of the

Table – Descriptive statistics of the results by parameter and setup.

TNC (particles/cm^3)					
	N	Median	Minimum	Maximum	Aerosol control*
BASELINE	30	2472.51	2239.61	2625.60	N/A
NO EOS	30	44,043.85	18,225.03	142,091.45	17.81
EOS A	30	34,025.21	21,402.18	149,811.30	13.76
EOS B	30	14,801.07	11,363.21	45,547.91	5.99
TNC 60.4–392.4 (particles/cm^3)					
	N	**Median**	**Minimum**	**Maximum**	**Aerosol control***
BASELINE	30	1329.57	1206.29	1383.91	N/A
NO EOS	30	7866.24	5069.73	13,947.97	5.92
EOS A	30	2714.33	1597.20	4672.17	2.04
EOS B	30	3174.18	1552.06	4407.94	2.39

* Aerosol control: This is a multiplier calculated as $\text{median}_{\text{test setup}}/\text{median}_{\text{baseline}}$ and is used to characterise the efficiency of aerosol control in the given setup. The lower the value, the lower the elevation compared to baseline and the more efficient the control.EOS, extraoral scavenger device; TNC, total number concentration.

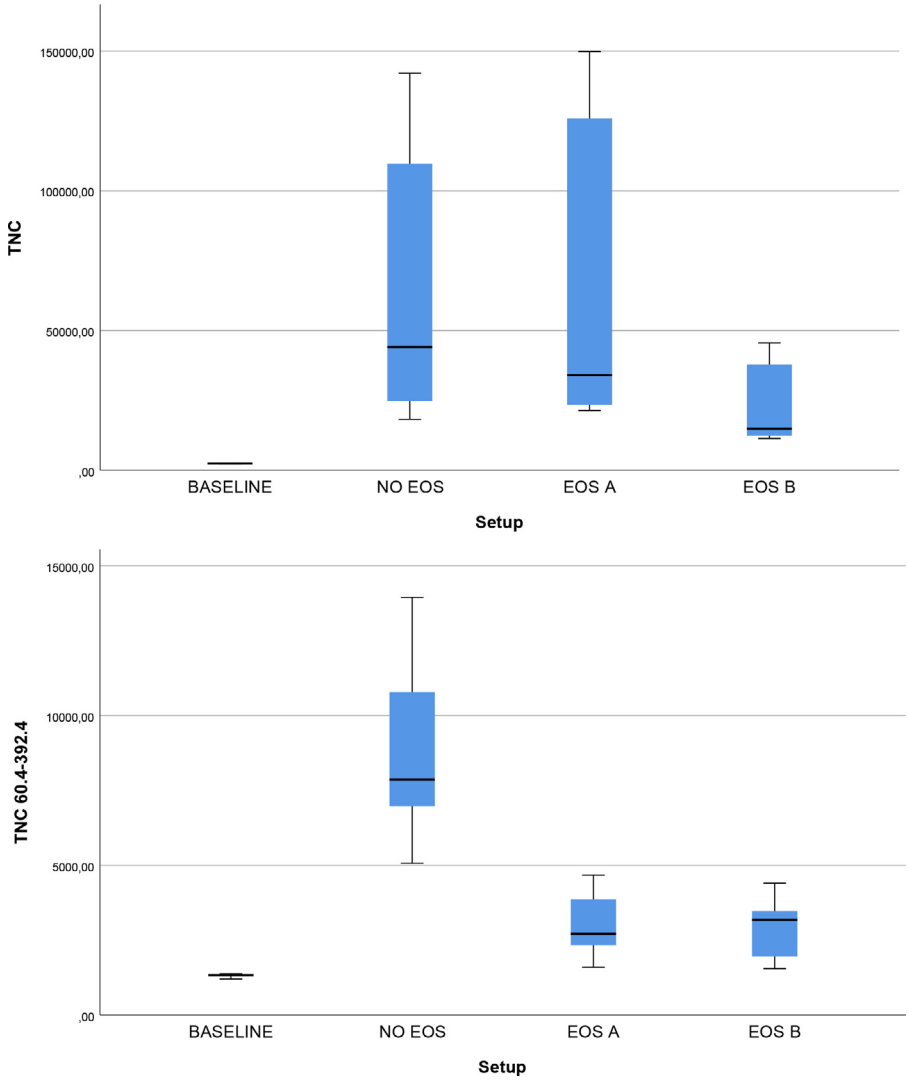

Fig. 3 – Top: TNC (particles/cm^3). Bottom: TNC 60.4–392.4 (particles/cm^3) - box plot comparison of the setups. The lower margin of the boxes represents the 25th percentile. The line within the boxes marks the median, and the upper margin of the boxes indicates the 75th percentile. The error bars (whiskers) above and below the boxes denote the 90th and 10th percentiles, respectively.

tested systems (or any aerosol control system for that matter) should not be judged based on absolute values, rather the degree to which each system can reduce aerosol concentration.

Our results show that EOSs can differ in their aerosol-reduction efficacy and the particle size range in which they are most efficient. In the full particle size range of the spectrometer, only EOS B could achieve significant aerosol reduction, but in the critical 60.4–392.4 nm range, both devices achieved significant reduction. At the same time, neither of the devices could reduce aerosol counts to an extent to make the difference from the NO EOS setup nonsignificant. It must be seen, however, that the variance of the baseline values was extremely narrow, so statistically nonsignificant should by no means be interpreted as practically nonsignificant. As the aerosol control multipliers show, total number concentrations in the 60.4–392.4 nm range were approximately 2 times the baseline with both EOS A and EOS B, while without any EOS, approximately 6 times higher values were measured.

Our results corroborate the findings of Nulty et al, who concluded that extraoral suction can be a useful means of mitigating the risk of SARS-CoV-2 infection in a clinical context.[25] The authors used an industrial particle counter, and their findings indicated a significant decrease in the number of aerosol counts when using an EOS in different clinical setups and with different operators. However, it was an obvious weakness of their study that the aerosol source was not standardised, which introduced uncontrolled and potentially confounding variables, such as the intensity and direction of the aerosol spray. Furthermore, their measurement distance was 42 cm, which is larger than the usual working distance under PPE. Finally, they used a particle counter with a lower detection limit of 300 nm, so the results allow limited conclusions regarding an actual SARS-CoV-2 scenario. Despite all these limitations, the authors seem to have concluded correctly that an external high-volume suction device may potentially mitigate the risk of transmission of viral particulate.

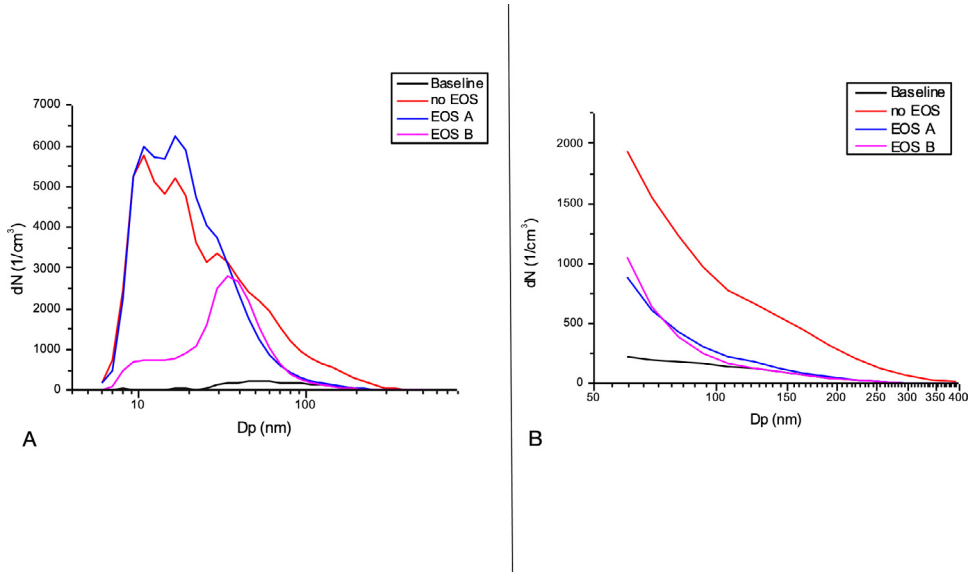

Fig. 4 – Size distribution of the generated water aerosol for the baseline measurements and the study setups. A, Size distribution of generated aerosol for the entire measurement range of the spectrometer (5.6–560 nm). B, Size distribution of generated aerosol in the critical spectrum (60.4–392.4 nm). dN, total number concentration; Dp, particle diameter.

Graetz et al also concluded that the use of an EOS significantly reduced the number of generated particles during different aerosol-generating procedures.[26] The lower detection limit of the sampling device used in their study was 100 nm, which is much more optimal for SARS-CoV-2–relevant conclusions than the 300-nm limit of the Nulty group, even if it misses a fraction of the spectrum of interest (from 60 nm up).[19] A further limitation was the relatively short (2-minute) sampling time, which might have contributed to the low measured values. Finally, sampling took place at 35 cm above the mannequin head, the same level as the EOS ending. Assuming that sampling should take place at approximately the level of the operator's head, this fails to correspond to most manufacturers' instructions, which usually suggest that the ending of the device should be closer to the patient than to the operator.

It must be noted, though, that there is a lack of consensus about the optimal use of EOSs in many respects. For instance, even the manufacturers are not consistent about the distance that provides maximum protection and allows minimal interference with the treatment. The distance we used (20 cm) is quite close to the patient within the suggested range of 15–40 cm. In most real-life treatment scenarios, such a short distance would lead to a situation where the operator would see the treatment area through the transparent ending of the device most of the time. On one hand, the ending functions as an extra layer of physical protection in this situation, but on the other hand, it is also an extra layer of visual hindrance, especially if the operator is wearing protective equipment (such as a face shield). Skilled and experienced operators might still be able to work properly under such circumstances, but even then, looking at the treatment area through multiple layers of plastic is hardly the optimal approach to patient treatment. The question of optimal distance is indeed one that needs to be addressed in further studies or a review of studies once enough data have been gathered. We would like to call the reader's attention to the fact that these measurements are especially distance-sensitive: The farther the device, the less efficient the suction. Therefore, our results are to be interpreted as valid for scenarios where the ending of the device is positioned at a short distance from the aerosol source.

The results of this study allow quantitative characterisation of the generated water aerosol and its depression with 2 different commercially available EOSs. Our results do not allow conclusions either regarding the circumstances in which the individual particles were formed or the changes they underwent during their spread, nor do they inform about the real viral load of a possible scenario. The analysis of such fine changes is beyond the scope of this study, and it is highly unlikely that in the given setting, they could considerably have influenced the results. However, these are limitations to this study, as are its in vitro nature and that the data may be influenced by the all-time aerosol content of the environment to a considerable extent. All these limitations make the study exploratory in nature.

It might appear to be a limitation that we did not consider the effect of air movement. It has been demonstrated that air conditioning may contribute to the transmission of SARS-CoV-2 [27] and the movement of persons might also have an effect on the spread of aerosol. However, the study setup of this study was designed especially for the comparison of 2 EOSs under controlled conditions, and air movement was a controlled variable (ie, the measurements were done with closed doors, closed windows, and no air conditioning and preventing any significant air movement). We had no reason to believe that minor disturbances, such as the hand movements of the person operating the spectrometer, should be

potential confounders. Therefore, we did not take this factor into consideration. The use and efficacy of EOSs in dental settings are still a matter of debate in the literature. In this study, we tested the aerosol-reducing efficacy of 2 commercially available EOSs during modeled dental treatment in a setup that proved to generate high aerosol load in a previous study of our research group. In the SARS-CoV-2–relevant particle size range, both devices managed to reduce the aerosol load to a statistically significant extent as compared to the scenario when only a high-volume evacuator and a saliva ejector (and no EOS) were used. Within the limitations of the study, the results support the assumption that EOSs for aerosol reduction increase safety in the dental operatory, but important questions have yet to be answered regarding their proper use in everyday practice.

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Conflict of interest

None disclosed.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi: 10.1016/j.identj.2022.05.007.

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