SARS-CoV-2: characterisation and mitigation of risks associated with aerosol generating procedures in dental practices

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Key points

The particle size distribution of aerosols generated by dental procedures are predominantly <0.3 µm in diameter. This encompasses the reported size range of the SARS-CoV-2 virus (0.05–0.15 µm).

Even in the presence of aerosol-supressing interventions, particles <0.3 µm were substantially elevated during dental AGPs and thus demonstrate the importance of appropriate PPE such as FFP3 masks.

Intraoral high-volume suction was highly effective in rapidly reducing AGP-related particle concentrations to within background range, which raises the possibility of eliminating fallow time.

Abstract

Introduction The objectives were to characterise the particle size distribution of aerosols generated by standard dental aerosol generating procedures (AGPs) and to assess the impact of aerosol-management interventions on 'fallow time'. Interventions included combinations of high-volume intraoral suction (HVS[IO]), high-volume extraoral suction (HVS[EO]) and an air cleaning system (ACS).

Method A sequence of six AGPs were performed on a phantom head. Real-time aerosol measurements (particle size range 0.0062–9.6 µm) were acquired from six locations within a typical dental treatment room (35 m^3).

Results The majority (>99%) of AGP particles were <0.3 µm diameter and remained at elevated levels around the dental team during the AGPs. With no active aerosol-management interventions, AGP particles were estimated to remain above the baseline range for up to 30 minutes from the end of the sequence of procedures.

Conclusions The results emphasise the importance of personal protection equipment, particularly respiratory protection. Use of HVS(IO), either alone or in combination with the ACS, reduced particle concentrations to baseline levels on completion of AGPs. These data indicate potential to eliminate fallow time. The study was performed using a phantom head so confirmatory studies with patients are required.

Introduction

Potentially infectious agents (for example, bacteria, fungi and viruses) can be transmitted when droplets containing microorganisms generated from an infected person (for example, by breathing, talking or coughing) are propelled through the air and are directly inhaled, deposited on the skin or mucosal surfaces, or contaminate infrastructure.[1] High-speed dental instruments require effective cooling of the work area in order to avoid damage of the pulp-dentine system. These instruments generate a dental aerosol, as cooling water and air are sprayed around the instruments and the oral cavity.

Dental aerosols are distributions of particle sizes from 0.001 to >10 µm in diameter.[2,3] Traditionally, dental airborne aerosols were defined as being small particles <50 µm, with larger ballistic/projectile particles (>50–100 µm) being described as 'splatter'.[4] The World Health Organisation definition[5] of aerosols has been adopted in the dental field, which defines large projectile particles as being >5 µm, with smaller (<5 µm) 'droplet nuclei' particles forming through the evaporation of larger particles, generating an airborne solid residue.

Infectious droplets from saliva or blood may enter the aerosol and expose the dental team to an increased risk of infection though direct inhalation, contact with eyes and contact with contaminated work surfaces.[6,7] Dental aerosols therefore have the potential to provide a path for the transmission of COVID-19,[8,9] which may remain infectious for between two hours to nine days in a humid environment.[7] Research on the influenza virus has also demonstrated that the total viral copies are 8.8 times more numerous in particles <5 µm than in particles ≥5 µm.[10] Previous studies have demonstrated the dispersion of bioaerosols to all areas of the treatment room,[11] which remain airborne for 30 minutes following the procedure.[12] Therefore, there is a clear need

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for the effective removal of aerosols in dental practices.[13]

Protocols exist to minimise the risk of infection to clinical staff during dental procedures.[12,14,15,16,17] These include: low-volume suction (LVS) to remove saliva and excess coolant, coolant disinfectant, high-volume intraoral suction (HVS [IO]), personal protective equipment (PPE), and improved ergonomics and techniques (for example, dental dams). A range of additional aerosol-removal intervention have been proposed for use in dental procedures including high-volume extraoral suction (HVS [EO]), air cleaning systems (ACSs; designed to filter, purify and recirculate room air) and ventilation systems.[7,14,18,19] However, their effectiveness within a diverse range of dental practice environments is difficult to predict.[13]

A wide range of ACSs with different air flow rates and cleaning technology are commercially available or being marketed for dental use. However, dental practices have no clear standards or specifications to refer to before making an investment. HVS(EO) and ACSs[20,21] that contain high-efficiency particulate air (HEPA) filters are effective in removing airborne particles with sizes greater than 0.3 µm; viruses, such as coronaviruses, are in the size range of 0.05–0.15 µm[22] and thus may evade filtration. Hence, ACSs have evolved to include the addition of technology such as UV-C lamps (99.97% killing of H3N2 influenza virus), negative ion generators and high-pressure/voltage electrostatic plasma which eliminate particles greater than 0.0146 µm. The efficiency of these ACSs has not been evaluated for the removal of aerosol particles in the presence of HVS(IO)/HVS(EO).

While researchers have studied aerosol-removal intervention, few studies have examined their effectiveness across the full dental aerosol particle size distribution. For example, the use of HVS(IO) at air flow rates of 250–300 L min^{-1} is an established means of

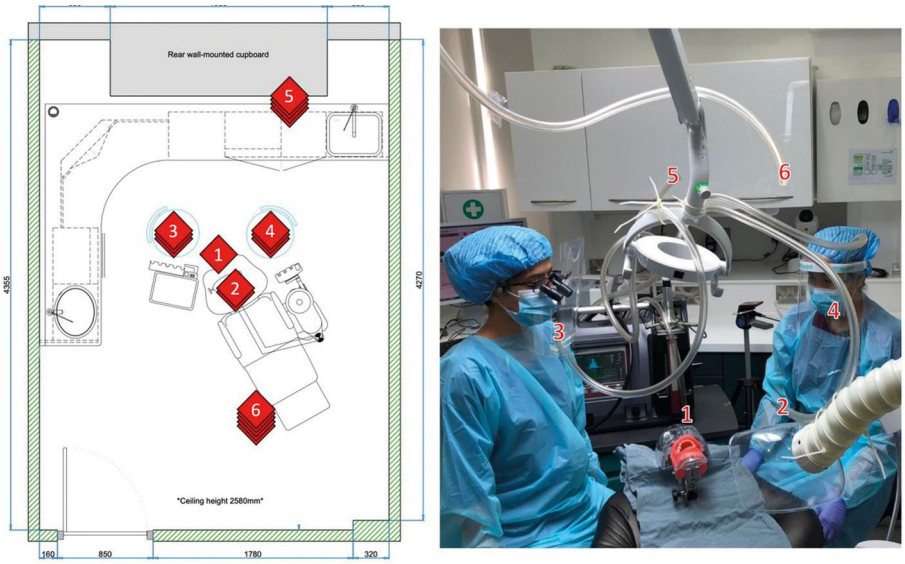

Fig. 1 Layout and sampling positions within the dental treatment room. Note that the tube at location 6 was moved from the ceiling light fitting to be visible in the photograph. X axis (room width) Y axis (room length) Z axis (room height)

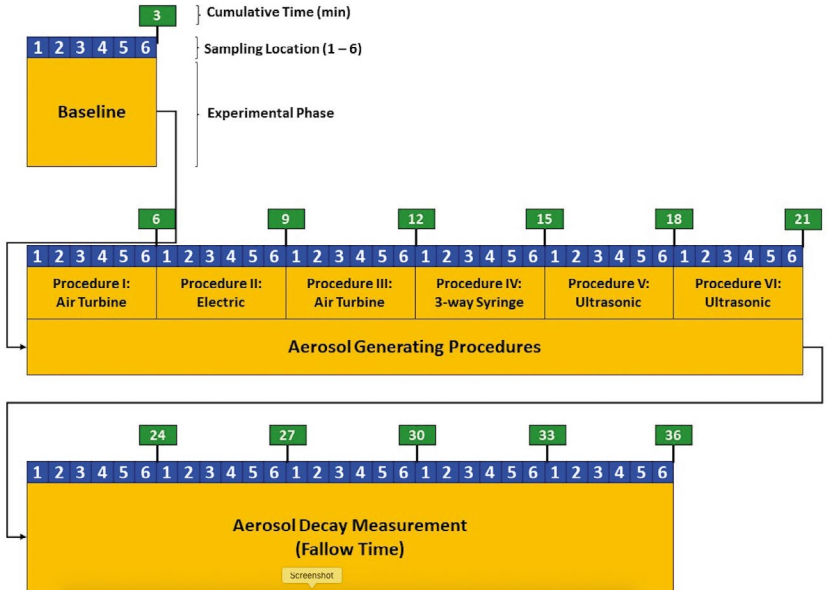

Fig. 2 Outline study design. After an initial baseline period (three minutes), six AGPs (I to VI) were performed in series (18 minutes) followed by a period to quantify aerosol decay kinetics (15 minutes). Air samples from each location (1–6) were acquired over a 30-second period. The total duration of each experiment was 36 minutes

Table 1 Summary of aerosol-removal interventions used in each experiment. Note that intraoral low-volume suction was used in all intervention groups (including control) to represent standard practice and to prevent excess fluid accumulation within the phantom head

Intervention group	Interventions			
	Low-volume suction	High-volume suction (intraoral) with air filtration system	High-volume suction (extraoral)	Air cleaning system
A	X			
B	X	X		
C	X	X		X
D	X	X	X	
E	X	X	X	X

Table 2 Aerosol-suppressing equipment and corresponding air/water flow rates. Low-volume suction was used in all intervention groups. In this study, the air cleaning system flow rate was equivalent to approximately 24 air changes per hour

Intervention	Equipment	Water flow (L min^{-1})	Air flow (L min^{-1})	Air changes per hour (in a 35 m^3 surgery)
Low-volume suction	Plastcare USA, 4 mm slow-speed salivary ejector	2.4	79	-
High-volume suction (intraoral)	Dürr Universal Cannula III 16 mm, connected to Dürr Dental VSA 300S Dürr Dental UK, Kettering, UK	–	297	-
High-volume suction (extraoral)	Eighteeth VacStation,* Sifary Medical Technology, Jiangsu, China	–	3,700	6
Air cleaning system	Woodpecker Q7 Plasma Air Purifier,** Guilin Woodpecker Medical Instrument Co, Guilin, China	–	14,167	24

Key:
* = the VacStation contains two H13-grade HEPA filters (lower particle size limit 0.3 µm) with a post-filter UVC light sterilisation stage
** = the Q7 air cleaning system is a filterless instrument which operates on a high-voltage plasma purification process with integral ion chamber sterilisation stage; the lower particle size limit is reportedly 14.6 nm

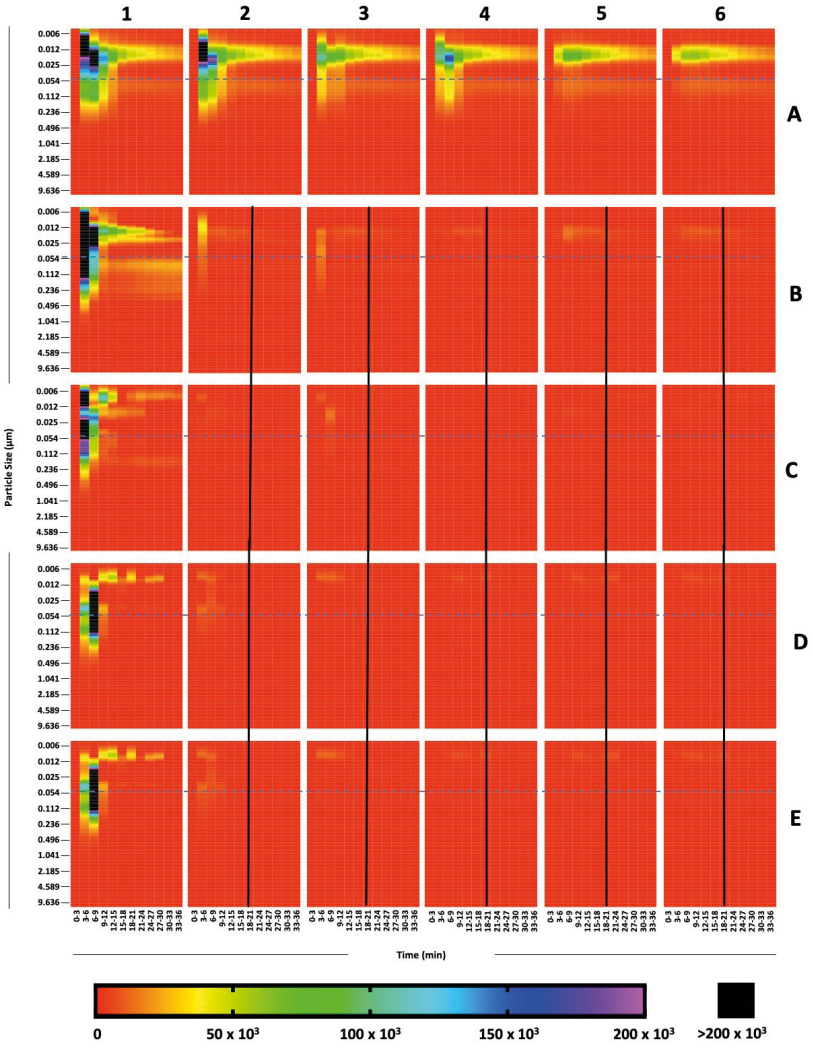

Fig. 3 Temporal, spatial and size characterisation of particles generated during AGPs (measured by HR-ELPI) for each location (1–6; Table 1) and intervention group (A–E; Table 2). Acquisition of air samples were performed during the baseline period (0–3 minutes), during the six procedures (3–21 minutes) and following cessation of procedures (21–36 minutes). Each data point represents the median particle concentration per size bin (# cm^{-3}) derived from n = 3 replicates. The dotted lines indicate the lower reported size for a SARS-CoV-2 virus particle (50 nm diameter)

controlling dental aerosols, but its effectiveness is based on a qualitative assessment of visible particles or particles greater than 0.65 µm.[19,23] Viruses are smaller than 0.65 µm and therefore the efficacy of HVS(IO) studies are not relevant to COVID-19.

The objectives of this current study were to characterise the aerosols generated by standard dental procedures and to investigate the effectiveness of different combinations of aerosol-management interventions across the particle distribution range 0.0062–10 µm diameter, to provide evidence for establishing a revised fallow time. A sequence of six standard dental procedures were performed in series to assess the effectiveness of four combinations of interventions based on LVS, HVS(IO), HVS(EO) and an ACS. The effectiveness of each intervention group was measured using a high-resolution particle size analyser, with air samples taken over a 36-minute period from six locations within a standard dental surgery.

Materials and methods

The study was performed within a dental surgery (dimensions 4.4 x 3.1 x 2.6 m: Figure 1). All non-experimental air-conditioning equipment was turned off during the experimental work, and the average room temperature and relative humidity over the study period were 27 °C and 67%, respectively.

A phantom head (Simple Manikin III, Phantom Head Dental, UK) was used as a patient surrogate containing a Kilgore Nissin 200-series typodont (containing melamine teeth) with SPMIII oral cavity cover.

Real-time aerosol analysis was performed with a high-resolution electrical low-pressure impactor particle sizer (HR-ELPI: 'ELPI+', Dekati, Kangasala, Finland). The instrument

recorded the concentration of particles detected within 100 pre-set 'bins' of particle size, ranging from 0.0062–9.6 µm, at a sampling frequency of 1 Hz. Air samples were acquired at six locations (Fig. 1, Supplementary Table 1). Each position was measured relative to the phantom head on which the dental aerosol generating procedures (AGPs) were performed. Air samples were directed to the ELPI+ via two-metre lengths of silicone tubing (Tygon; internal diameter 12.7 mm, external diameter 17.5 mm; Cole-Parmer Instrument Co, Illinois, USA: Supplementary Figure 1). Each tube was individually connected to the particle sizer for a period of 30 seconds before being replaced with a tube from the next sampling location to enable a serial analysis of all six air sample locations within a three-minute cycle. The initial five seconds of data acquisition were ignored to allow for purging of the sample air lines. A pilot study demonstrated that the tubing had no discernible effect on particle size measurements (see online supplementary information [Annex A; Supplementary Figures 1, 2 and 3]).

Each experiment comprised a three-minute baseline period, followed by a series of six three-minute AGPs, giving a total procedural duration of 18 minutes with a post-procedural duration of 15 minutes to monitor aerosol decay (Fig. 2). Each experiment was performed under one of five intervention group conditions: A–E (Table 1) performed in triplicate. Low-volume intraoral suction (LVS[IO]) was used in all intervention groups. The specifications of each aerosol-removal system are described in Table 2. The AGPs incorporated the serial use of six commonly used dental preparation instruments, each of which were operated for three minutes within the phantom head in the upper and lower arches in the following order: I) air turbine handpiece; II) electric contra-angle handpiece; III) air turbine handpiece; IV) three-in-one syringe; V) ultrasonic scaler; and VI) ultrasonic scaler (Supplementary Table 3). There was no delay between the use of each handpiece. Each procedure was performed on separate teeth using a consistent motion in a predefined sequence: I) upper left quadrant (from tooth 18–14); II) upper anterior quadrant (13–23); III) upper right quadrant (24–28); IV) lower left quadrant (38–34); V) lower anterior quadrant (33–43); and VI) lower right quadrant (44–48). The ultrasonic procedures (V and VI) were performed at the gingival margin (Supplementary Table 4).

Total particle concentration (calculated as the sum of particle concentrations over the

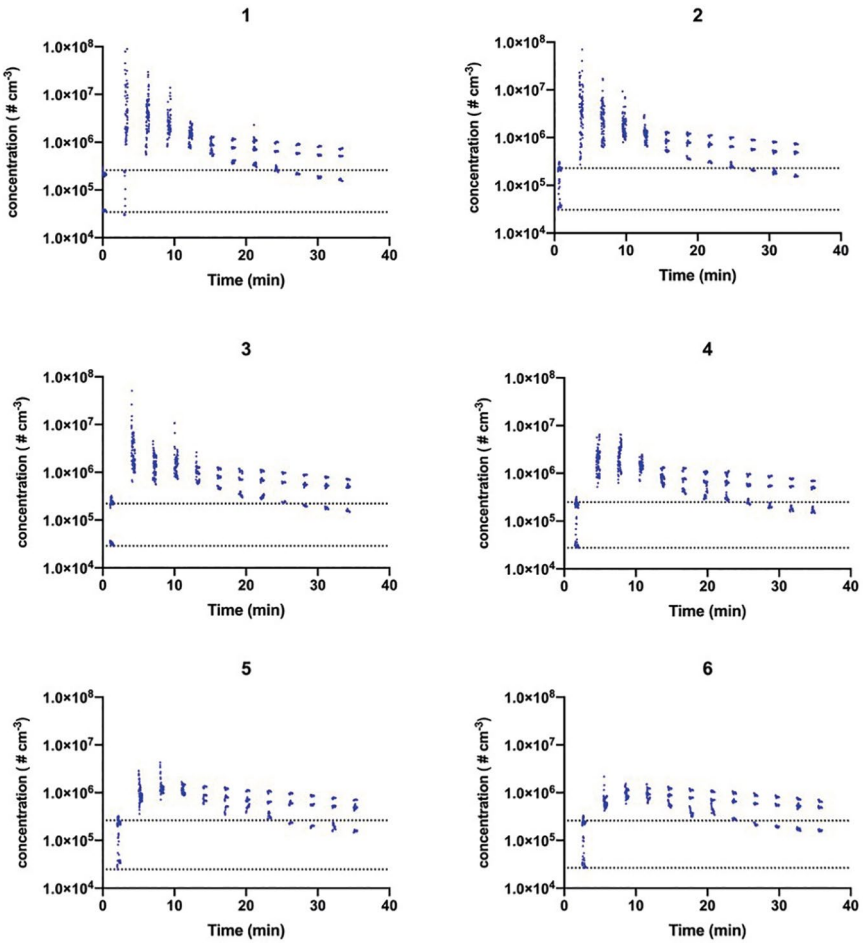

Fig. 4 Total particle concentration generated during AGPs in the absence of interventions (group A; Table 2) at each air sampling location (1–6; Table 1). Acquisition of air samples were performed during the baseline period (0–3 minutes), during the six procedures (3–21 minutes) and following cessation of procedures (21–36 minutes). Dotted lines indicate the upper and lower boundaries of the baseline data. Each data point represents the sum of particles measured by HR-ELPI over one second during each replicate (n = 3)

0.0062–9.6 µm bin range) did not consistently exhibit a Gaussian (normal) or log-normal distribution and so excluded the use of parametric statistical tests. The low sample number (n = 3) precluded non-parametric analyses. Therefore, descriptive statistics were used and all particle concentration data are expressed as median values. Area under curve (AUC) calculations were performed using GraphPad Prism (v7.0e for Mac OS, GraphPad Software, La Jolla California, USA). The AUC calculations reflect the total 'dose' of aerosol (units of mL cm^{-3} min). The AUC calculations were used to assess the overall efficiency of each intervention and were expressed as the median value ± minimum/maximum. Estimation of fallow time in the control intervention group was performed by linear regression of particle concentrations at each sample location following cessation of AGPs and was calculated as the time at which the extrapolated particle concentration decreased below the upper baseline particle concentration.

Results

The majority (>99.9%) of particles generated by the sequence of dental procedures were <0.3 µm in diameter when sampled at the proximal position (location 1: 8 cm). Instruments I, II and III (Supplementary Table 3) in the sequence generated the highest aerosol levels. Peak concentrations occurred between particle diameters 0.013–0.022 µm (Fig. 3; t = 3–6, 6–9 and 9–12 minutes).

Aerosol generated under the control conditions (Table 1, intervention group A [LVS only]) was observed at all locations within the surgery and remained detectable at 15 minutes

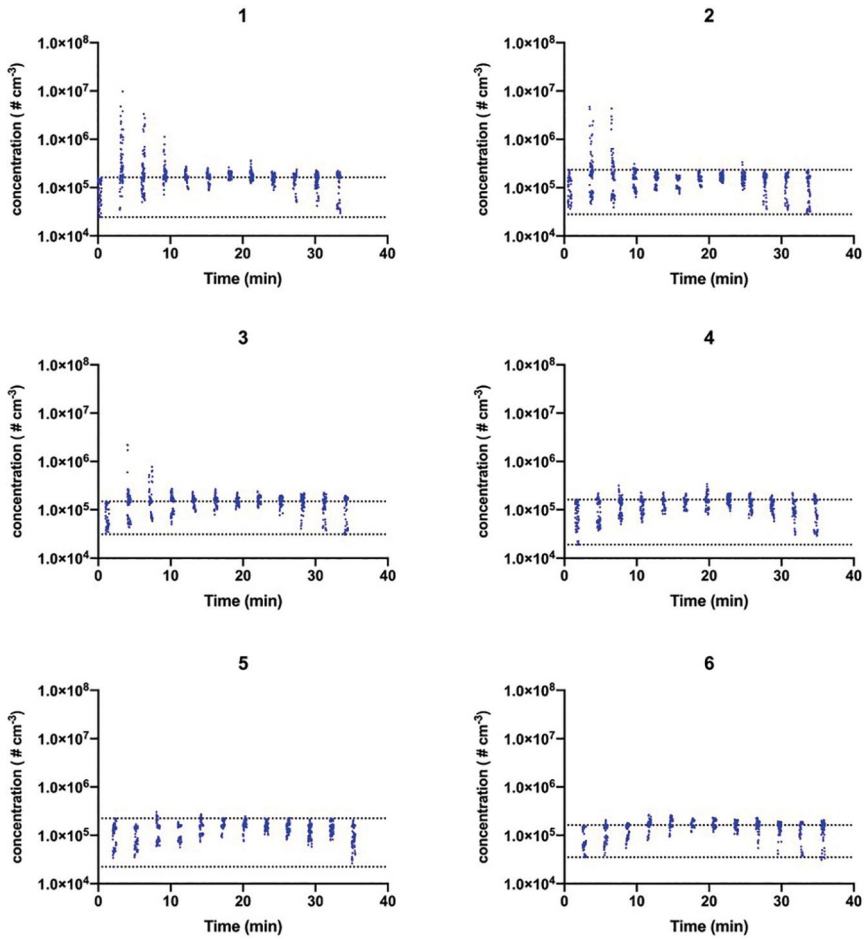

Fig. 5 Total particle concentration generated during AGPs in the presence of HVS(IO), HVS(EO) and ACS (group E; Table 2) at each air sampling location (1–6; Table 1). Acquisition of air samples were performed during the baseline period (0–3 minutes), during the six procedures (3–21 minutes) and following cessation of procedures (21–36 minutes). Dotted lines indicate the upper and lower boundaries of the baseline data. Each data point represents the sum of particles measured by HR-ELPI over one second during each replicate (n = 3)

(Fig. 3, t = 36 minutes) from the end of the last procedure (VI at t = 21 minutes). The most persistent particles were in the range 0.012–0.025 µm. Particle concentrations decreased with increasing distance from the phantom head, with a notable, time-related decrease of particles in the range of 0.054–0.236 µm diameter. Particles >0.05 µm persisted at low concentrations (approximately 25 x 10^3 cm^{-3}) for the duration of the study.

The particle size distributions generated during the use of all procedures and applying interventions B to E (Table 1) were similar to those in the control group A, but with markedly reduced concentrations (Fig. 3). Compared with control conditions, all interventions produced a remarkable decrease in the number and distribution of particles detected in the extraoral space (location 2: 20 cm) and more distal locations. Following the end of the sequence of procedures (t = 21 minutes), there was infrequent detection of low concentrations of aerosol particles from beyond the extraoral space and particles >0.05 µm were generally at the baseline level (Fig. 3).

In the control group, total particle counts remained above the baseline range for the duration of the experiment at all locations (Figure 4 and Supplementary Figure 4). Therefore, for the control group, linear regression was used to calculate the time needed for the total particle concentration at each location to return to baseline levels (Supplementary Figure 10). This produced an estimated median time of 26 minutes (range 25–31 minutes) from the end of the sequence of procedures (t = 21 minutes). In the case of experiments using either the HVS(IO) or the HVS(IO) combined with the ACS (Table 1; intervention groups B and C), the concentration of particles returned to within the baseline range at the end of the procedures (t = 21 minutes) (Supplementary Figures 7 and 8, respectively). However, the total number of aerosol particles remained marginally above the baseline for interventions which included the HVS(EO) (Figure 5 and Supplementary Figure 9).

When the aerosol concentrations are expressed as dose (mL cm^{-3} min), all interventions reduced total aerosol exposure (Fig. 6). Intervention group B (Table 1; HVS[IO] with LVS) reduced the median dose by 80%, while intervention group E (HVS[IO] + HVS[EO] + ACS with LVS) reduced the median dose by 90%. However, HVS(IO) was noticeably less effective than intervention groups C, D and E in controlling the range (maximum–minimum) of the dose. A pictorial summary of these data is provided in Supplementary Figure 6.

Discussion

The results of this study demonstrate that all aerosol-management interventions evaluated were relatively effective in controlling aerosols generated by the dental handpieces. Most particles produced by our sequence of AGPs were <0.3 µm. The use of either the HVS(IO), or the HVS(IO) combined with the ACS, was enough to reduce the fallow time to zero minutes. Please refer to Figure 2 for fallow time and Figure 3 for zero fallow time, right of the superimposed black vertical 18–21-minute lines.

During AGPs, the concentration of particles in the 0.05–0.15 µm diameter range is increased substantially. This size range corresponds to the reported size range of the SARS-CoV-2 virus (0.05–0.15 µm).[22] Within the working micro-environment (locations 3–4, <50 cm), the presence of active aerosol-management interventions substantially reduces the concentration of airborne particles in this range, but does not eliminate them. Thus, it is important for dental workers to utilise both appropriate and properly fitted respiratory protective equipment such as FFP3 masks in combination with aerosol-management interventions.[24]

In the absence of aerosol-management interventions, particles in the range of 0.05–0.236 µm remained at elevated concentrations within the macro-environment (locations 5–6, >50 cm) for longer than the experimental period. Our control study estimated that it may take at least 28 to 34 minutes after cessation

of AGPs for the total particle concentration to return to baseline levels. Intervention groups B and C, which included the addition of HVS(IO) or HVS(IO) with ACS, both had the effect of returning particle concentrations to within the baseline range by the end of the sequence of procedures; that is, no additional fallow time was required before particle concentrations returned to baseline levels. In the case of interventions D and E, which included HVS(EO), particle concentrations remained marginally above the baseline, which is in agreement with previous work which found HVS(EO) to be effective (>90%) at removing the particles down to 0.65 µm.[19]

Interventions B and C reduced particle concentrations in the macro-environment (locations 5–6, >50 cm) to within the baseline range during AGPs. Intervention C – HVS(IO) in combination with an ACS – was effective in controlling both the median and the range (maximum–minimum) of the aerosol dose at all locations. In a dental surgery of the size used in this study (35 m^3), and in the context of SARS-CoV-2, it provides further evidence to support a reduction in fallow time below the current recommend period of ten minutes,[24] in agreement with other recent studies.[25]

The use of a phantom head is a clear limitation of this study; the absence of saliva and other biological materials within the oral cavity may conceivably have influenced the particle size distribution of the aerosols. The standard procedures used in this study used aqueous coolant (Supplementary Table 3) which, under normal circumstances, would have led to a large (25–82-fold) dilution in patient-generated saliva. Thus, the impact of omitting salivary fluid on aerosol particle size range would likely be minimal. However, further confirmatory research should be performed using patients. Such work should incorporate surgeries of different sizes (including open-plan dental hospital clinics) to validate the scalability of aerosol-mitigation interventions. It should also be noted that a locally moist and warm atmosphere within a 'turbulent gas cloud' allows the contained continuum of droplet sizes to evade evaporation for much longer time periods than occurs with isolated droplets, from a fraction of a second to minutes.[26] This may explain why the most persistent particles measured in our study were within the smaller 0.012–0.025 µm range. Therefore, a patient-orientated study is needed to confirm the nature of the fine particle aerosols containing mixtures of saliva, coolant and pathogens. This may provide further evidence to support the use of antiviral disinfectants in coolant solutions.

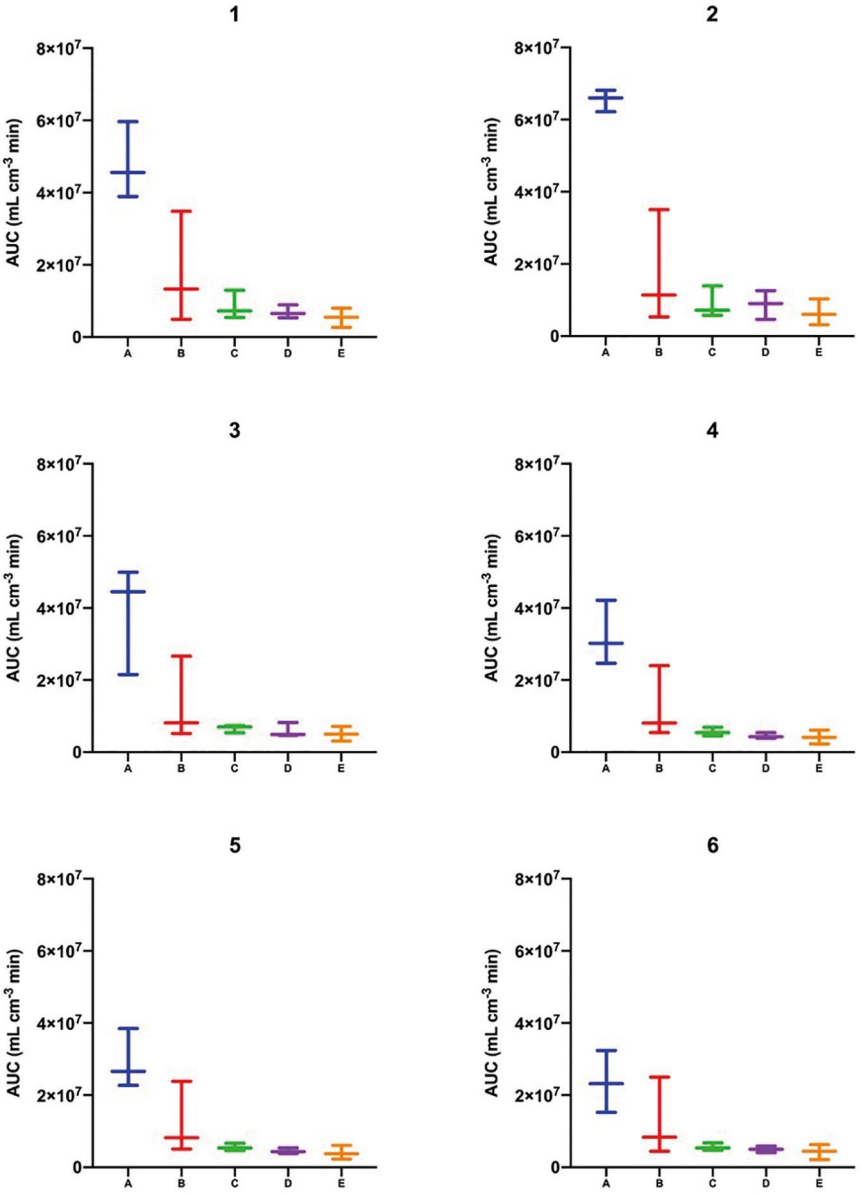

Fig. 6 Total dose of particles measured over the 36-minute experimental period (expressed as area under curve) for each location (1–6; Table 1) and intervention group (A–E; Table 2). Each data point represents the median ± minimum/maximum of n = 3 replicates

Conclusions

Dental AGPs produce aerosols characterised by particles <0.3 µm in diameter. Although aerosol-removal interventions such as HVS(IO) alone or in combination with an ACS may rapidly reduce particle concentrations to within background range, they do not eliminate exposure during AGPs and so the use of appropriate respiratory protective equipment by dental practitioners is essential.

HVS(IO) combined with the ACS was enough to reduce the fallow time to zero minutes, and to control the median and range of the aerosol particle dose at all areas in the surgery. The ACS used in these experiments was set to deliver 24 air changes per hour in a 35 m^3 surgery, which was close to maximum, and further experimental work is needed to optimise the location and setting of equipment of this type, and its effectiveness over time.

In the absence of ventilation within a modest-sized (35 m^3) surgery, particles associated with dental AGPs may persist for approximately half an hour. There appears to be scope for a reduction in fallow time from the

current guideline of ten minutes when effective aerosol-management system(s) are used.

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Conflict of interest

The authors have not declared any conflict of interest. Techceram Ltd is a commercial entity in the dental field, but has no interest in any of the equipment used in the present study, only in contributing its network of contacts towards the present study, in order to better understand dental AGPs, so that dental hospitals, practices, labs and associated dental supply chain smaller businesses can remain open and operate safely through any future viral pandemics.

References

1. Jayaweera M, Perera H, Gunawardana B, Manatunge J. Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. *Environ Res* 2020; DOI: 10.1016/j.envres.2020.109819.
2. Bogdan A, Buckett M I, Japuntich D A. Nano-sized aerosol classification, collection and analysis -method development using dental composite materials. *J Occup Environ Hyg* 2014; **11:** 415–426.
3. Day C J, Price R, Sandy J R, Ireland A J. Inhalation of aerosols produced during the removal of fixed orthodontic appliances: a comparison of 4 enamel cleanup methods. *Am J Orthod Dentofacial Orthop* 2008; **133:** 11–17.
4. Micik R E, Miller R L, Mazzarella M A, Ryge G. Studies on dental aerobiology. I. Bacterial aerosols generated during dental procedures. *J Dent Res* 1969; **48:** 49–56.
5. WHO. Infection prevention and control of epidemic- and pandemic-prone respiratory infections in health care. 2014. Available at https://apps.who.int/iris/bitstream/handle/10665/112656/9789241507134_eng.pdf (accessed November 2020).
6. Miller R, Micik R E. Air Pollution in the Dental Office. *Dent Clin North Am* 1978; **22:** 453–476.
7. Peng X, Xu X, Li Y, Cheng L, Zhou X, Ren B. Transmission routes of 2019-nCoV and controls in dental practice. *Int J Oral Sci* 2020; **12:** 9.
8. Epstein J B, Chow K, Mathias R. Dental procedure aerosols and COVID-19. *Lancet Infect Dis* 2020; DOI: 10.1016/S1473-3099(20)30636-8.
9. Ge Z Y, Yang L M, Xia J J, Fu X H, Zhang Y Z. Possible aerosol transmission of COVID-19 and special precautions in dentistry. *J Zhejiang Univ Sci B* 2020; **21:** 361–368.
10. Milton D K, Fabian M P, Cowling B J, Grantham M L, McDevitt J J. Influenza virus aerosols in human exhaled breath: particle size, culturability, and effect of surgical masks. *PLoS Pathog* 2013; DOI: 10.1371/journal.ppat.1003205.
11. Rautemaa R, Nordberg A, Wuolijoki-Saaristo K, Meurman J H. Bacterial aerosols in dental practice – a potential hospital infection problem? *J Hosp Infect* 2006; **64:** 76–81.
12. Veena H R, Mahantesha S, Joseph P A, Patil S R, Patil S H. Dissemination of aerosol and splatter during ultrasonic scaling: A pilot study. *J Infect Public Health* 2015; **8:** 260–265.
13. Sachdev R, Garg K, Singh G, Mehrotra V. Is safeguard compromised? Surgical mouth mask harbouring hazardous microorganisms in dental practice. *J Family Med Prim Care* 2020; **9:** 759–763.
14. Hallier C, Williams D W, Potts A J, Lewis M A. A pilot study of bioaerosol reduction using an air cleaning system during dental procedures. *Br Dent J* 2010; **209:** E14.
15. Mupparapu M, Kothari K R M. Review of surface disinfection protocols in dentistry: a 2019 update. *Quintessence Int* 2019; **50:** 58–65.
16. Sawhney A, Venugopal S, Babu G R J *et al.* Aerosols how dangerous they are in clinical practice. *J Clin Diagn Res* 2015; DOI: 10.7860/JCDR/2015/12038.5835.
17. Joshi A A, Padhye A M, Gupta H S. Efficacy of Two Pre-Procedural Rinses at Two Different Temperatures in Reducing Aerosol Contamination Produced During Ultrasonic Scaling in a Dental Set-up – A Microbiological Study. *J Int Acad Periodontol* 2017; **19:** 138–144.
18. Teanpaisan R, Taeporamaysamai M, Rattanachone P, Poldoung N, Srisintorn S. The usefulness of the modified extra-oral vacuum aspirator (EOVA) from household vacuum cleaner in reducing bacteria in dental aerosols. *Int Dent J* 2001; **51:** 413–416.
19. Noro A, Yanaka N, Takahashi K *et al.* A study on prevention of hospital infection control caused by tooth preparation dust in the dental clinic. Part 1. Preventive measures against environmental pollution in the dental clinic caused by microbial particles. *Bull Tokyo Dent Coll* 1995; **36:** 201–206.
20. Zhao B, An N, Chen C. Using air purifier as a supplementary protective measure in dental clinics during the COVID-19 pandemic. *Infect Control Hosp Epidemiol* 2020; DOI: 10.1017/ice.2020.292.
21. Hubar J S, Pelon W, Strother E A, Sicard F S. Reducing Staphylococcus aureus bacterial counts in a dental clinic using an Ionic Breeze air purifier: a preliminary study. *Gen Dent* 2009; **57:** 226–229.
22. Lin Y, Yan X, Cao W *et al.* Probing the structure of the SARS coronavirus using scanning electron microscopy. *Antivir Ther* 2004; **9:** 287–289.
23. Davies M H, Rosen M, Eccles J D, Marshal R J. Criteria of air flow and negative pressure for high volume dental suction. *Br Dent J* 1971; **130:** 483–487.
24. SDCEP. Mitigation of aerosol generating procedures in dentistry: a rapid review. 2020. Available at https://www.sdcep.org.uk/wp-content/uploads/2020/09/SDCEP-Mitigation-of-AGPS-in-Dentistry-Rapid-Review.pdf (accessed November 2020).
25. Holliday R, Allison J, Currie C *et al.* Evaluating dental aerosol and splatter in an open plan clinic environment: implications for the COVID-19 pandemic. 2020. Available online at https://osf.io/md49f/ (accessed November 2020).
26. Bourouiba L. Turbulent Gas Clouds and Respiratory Pathogen Emissions: Potential Implications for Reducing Transmission of COVID-19. *JAMA* 2020; **323:** 1837–1838.