SARS-CoV-2: Characterisation and Mitigation of Risks Associated with Aerosol Generating Procedures (AGPs) in Dental Practices

I D Jenkinson (i.d.jenkinson@ljmu.ac.uk)
Liverpool John Moores University

T Ehtezazi
Liverpool John Moores University

D Evans
Liverpool John Moores University

P Evans
Techceram Limited

VJ Vadgama
Woodbury Dental & Laser Clinic

J Vadgama
Woodbury Dental & Laser Clinic

F Jarad
University of Liverpool School of Dentistry

N Grey
University of Manchester School of Dentistry

R P Chilcott
University of Hertfordshire

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Abstract

The objectives of this study 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'. Aerosol management interventions included combinations of high-volume intra-oral suction (HVS(IO)), high volume extra-oral suction (HVS(EO)) and an air cleaning system (ACS). A sequence of six AGPs were performed in succession on a phantom head. Real-time aerosol measurements (size range 0.0062 – 9.6 μm) were taken using a high-resolution particle sizer acquiring air samples from six locations within a typical dental treatment room (35 m3). The majority (>99%) of AGP particles were < 0.3 μm diameter and remained at significant levels around the dental team during the AGPs. This emphasises the importance of personal protection equipment, particularly, the use of properly fitted respiratory protection to the appropriate (FFP3) standard. In the absence of active aerosol management interventions, AGP particles were estimated to remain above the baseline range for around 25-31 minutes from the end of the sequence of procedures. It was found that HVS(IO), either alone or in combination with the ACS, reduced particle concentrations to baseline levels on completion of AGPs. These data indicated that there is scope to reduce fallow time to 0 minutes.

Key Points

1. 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).

2. Even in the presence of interventions such as high volume inter-oral suction HVS(IO) combined with an air cleaning system (ACS), aerosol particles < 0.3 μm were substantially elevated above the baseline range during the dental aerosol generating procedures (AGP) used in this study (these included the use of air-turbine and electric handpieces operating at over 60,000 rpm). Levels of aerosol were especially elevated within the working micro-environment (50 cm radius from the mouth) of the dentist and assistant. This emphasises the importance of properly fitted personal protective equipment such as FFP3 masks.

3. Intra-oral high-volume suction, either alone or in combination with an air cleaning system (in this case operating at 24 room air changes per hour in a typical 35 m^3 surgery) was effective in rapidly reducing AGP-related particle concentrations to within background range in some cases, during or immediately, on cessation of AGPs negating the need for fallow time. These data indicate that a reduction in fallow time may be achieved below the current guidance of 10 minutes through judicious use of aerosol management interventions.

Introduction

Potentially infectious agents (e.g. bacteria, fungi and viruses) can be transmitted when droplets containing microorganisms generated from an infected person (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 WHO definition[5] of aerosols has been adopted in the dental field, which defines large projectile particles as being > 5μm, 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 2 hours to 9 days in a humid environment.[7] Research on the influenza virus has also demonstrated that the total viral copies were 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 for the effective removal of aerosols in dental practices.[13]

Protocols exist to minimise the risk of infection to clinical staff during dental procedures.[12,14-17] These include: low volume suction (LVS) to remove saliva and excess coolant, coolant disinfectant, high-volume intra-oral suction (HVS (IO)), personal protective equipment (PPE) and improved ergonomics and techniques (e.g. dental dams). A range of additional aerosol removal treatments have been proposed for use in dental procedures including extra-oral high volume suction (HVS (EO)), air cleaning systems (ACS), 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 ACS 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 ACS[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 – 0.15μm[22] and thus may evade filtration. Hence, ACS 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 air purifiers has not been evaluated for the removal aerosol particles in the presence of high volume intra-oral or extra-oral suction.

Whilst researchers have studied aerosol removal treatments, 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 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 aerosol management interventions across the particle distribution range from 0.0062 to 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 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.

Method

The study was performed within a dental surgery (dimensions 4.4 x 3.1 x 2.6 m: Figure 1). Real-time aerosol analysis was performed with a high-resolution Electric 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 to 9.6 μm, at a sampling frequency of 1 Hz. Air samples were acquired at six locations (Figure 1, Table 1). Each position was measured relative to the phantom head on which the dental AGPs were performed. Air samples were directed to the ELPI+ via 2 m lengths of silicone tubing (Tygon®"; internal diameter 12.7 mm, external diameter 17.5 mm; Cole-Parmer Instrument Co, Illinois, USA: Figure S1). 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 3 min cycle. A pilot study demonstrated that the tubing had no discernible effect on particle size measurements (see supplementary data: Annex A, Figures S1-S3). All non-experimental air-conditioning equipment was turned off during the experimental work, and the average room temperature and relative humidity were recorded at 27 C and 67% respectively.

Each experiment comprised a three-minute baseline period, followed by a series of six aerosol generating procedures (AGPs) carried out over 18 minutes with a post-procedural duration of 18 minutes to monitor aerosol decay (Figure 2). Each experiment was performed using one of four treatments (Table 2). The technical specifications of each aerosol removal system are described in Table 3. Each treatment was performed in triplicate. 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 anterior sextants, in the following order: (I) Air turbine hand-piece, (II) Electric contra-angle hand-

piece, (III) Air turbine hand-piece, (IV) Three in one syringe, (V) Ultrasonic scaler and (VI) Ultrasonic scaler (Table 4).

Total particle concentration (calculated as the sum of particle concentrations over the 0.0062 to 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 treatment and were expressed as the median value ± minimum/maximum. Estimation of fallow time in the control treatment 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 (Figure 2) were < 0.3 μm diameter when sampled at the proximal position (Location 1: 8 cm). Instruments I, II and III (Table 4) in the sequence generated the highest aerosol levels. Peak concentrations occurred between particle diameters 0.013 to 0.022 μm (Figure 3, t= 3-6, 6-9, and 9-12 min).

Aerosol generated under the control conditions (Table 2, intervention group A (LVS only)) was observed at all locations within the surgery and remained detectable at 15 min (Figure 3, t=36 min) from the end of the last procedure (instrument VI at t=21 min). The most persistent particles were in the range 0.012 to 0.025 μm. Particle concentrations decreased with increasing distance from the phantom head, with a notable, time-related decrease of particles in the range 0.054 to 0.236 μm diameter. Particles > 0.05 μm persisted at low concentrations (~25 x 10^3 cm^{-3}) for the duration of the study.

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

In the control group, total particle counts remained elevated above the baseline range for the duration of the experiment at all locations (Figure 4, and Figure S4). 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 (Figure 10). This produced an estimated median time of 26 min (range 25 – 31 min) from

the end of the sequence of procedures (t=21 min). In the case of experiments using either the HVS(IO), or the HVS(IO) combined with the ACS (Table 2, intervention groups B and C) the concentration of particles returned to within the baseline range at the end of the procedures (t=21 min) (Figures 5, and 6 respectively). However, the total number of aerosol particles remained marginally above the baseline for interventions which included the HVS(EO) (Figures 7 and 8).

When the aerosol concentrations are expressed as dose (mL cm^{-3} min) all interventions reduced total aerosol exposure (Figure 9). Intervention group B (Table 2, 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 of (maximum-minimum) of the dose.

Discussion

The results of this study demonstrate that all the aerosol management interventions evaluated were relatively effective in controlling aerosols generated by 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 0-min.

During AGPs the concentration of particles in the range 0.05 to 0.15 µm diameter range is increased substantially. This size range corresponds to the reported size range of the SARS-CoV2 virus (0.05 to 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 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 i.e. 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.[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 (max-min) 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 10 minutes[24] in agreement with other recent studies.[25]

The use of a phantom head is a clear limitation of this study: the presence of saliva and other biological materials within the oral cavity may conceivably affect the particle size distribution of AGPs and so further, confirmatory research should be performed using patients. Such work should incorporate different size surgeries 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.

Conclusions

Dental AGPs produce aerosols characterised by particles < 0.3 μm in diameter. Although, aerosol suppression treatments 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 0 minute, 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 an $35m^3$ surgery which was close to maximum and further experimental work is needed to optimise the location and setting of equipment of this type.

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 10 minutes when effective aerosol management system(s) are used.

Declarations

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Declaration of Interests

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.

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Tables

Table 1: Air sampling location coordinates, expressed relative to the phantom head (nominal coordinates x=0, y=0, z=0).

Sample Location No.	Name	Co-ordinates relative to phantom head (mm)			Linear Distance from source (mm)
		x	y	z	
1	Phantom head (source)	0	80	0	80
2	HVS (EO) in-take	135	-110	100	200
3	Dentist	-262	145	265	400
4	Assistant	354	160	300	500
5	Wall	0	900	1045	1480
6	Light	726	383	1495	1700

Table 2: Summary of aerosol removal treatments used in each experiment. Note that intra-oral low volume suction (LVS) was used in all treatment groups (including control) to represent standard practice and to prevent excess fluid accumulation within the phantom head.

	Interventions			
	LVS Low volume suction	HVS(IO) High Volume Suction (Intra-oral) with air filtration system.	HVS(EO) High Volume Suction (extra-oral).	ACS Air Cleaning System.
Intervention group				
A	X			
B	X	X		
C	X	X		X
D	X	X	X	
E	X	X	X	X

Table 3: Aerosol suppressing equipment and corresponding air/water flow rates. Low volume suction (LVS) was used in all treatment groups. In this study, the air cleaning system (ACS) flow rate was equivalent to ~ 20 air changes per hour.

Treatment	Equipment	Water Flow (L min^{-1})	Air Flow (L min^{-1})	Air changes per hour (in a 35 m^3 surgery)
LVS	Plastcare USA, 4 mm slow speed salivary ejector.	2.4	79	
HVS(IO)	Dürr Universal Cannula III 16 mm, connected to Dürr Dental VSA 300S Dürr Dental UK, Kettering, UK.	-	297	
HVS(EO)	Eighteeth VacStation, Sifary Medical Technology, Jiangsu, China.	-	3700	6
ACS	Woodpecker Q7 Plasma Air Purifier, Guilin Woodpecker Medical Instrument Co, Guilin, China.	-	14167	24

Table 4: Procedural equipment and corresponding coolant flow rates.

Procedure	Description	Coolant Flow Rate (mL min^{-1})
I	W&H Synea Vision TK94 hand-piece (Air Turbine) with long tapered bur	55
II	NSK Ti Max Z95L hand piece (Electric) with long tapered bur	67
III	Sirona T1 Control hand-piece (Air turbine) with long tapered bur	56
IV	3 in1 syringe from Belmont Cleo II chair	82
V	Cavitron Jet Plus Ultrasonic with 30K FSI-SLI tip	25
VI	NSK Vario Lux 2 (Piezo) with G8 tip	78

Figures

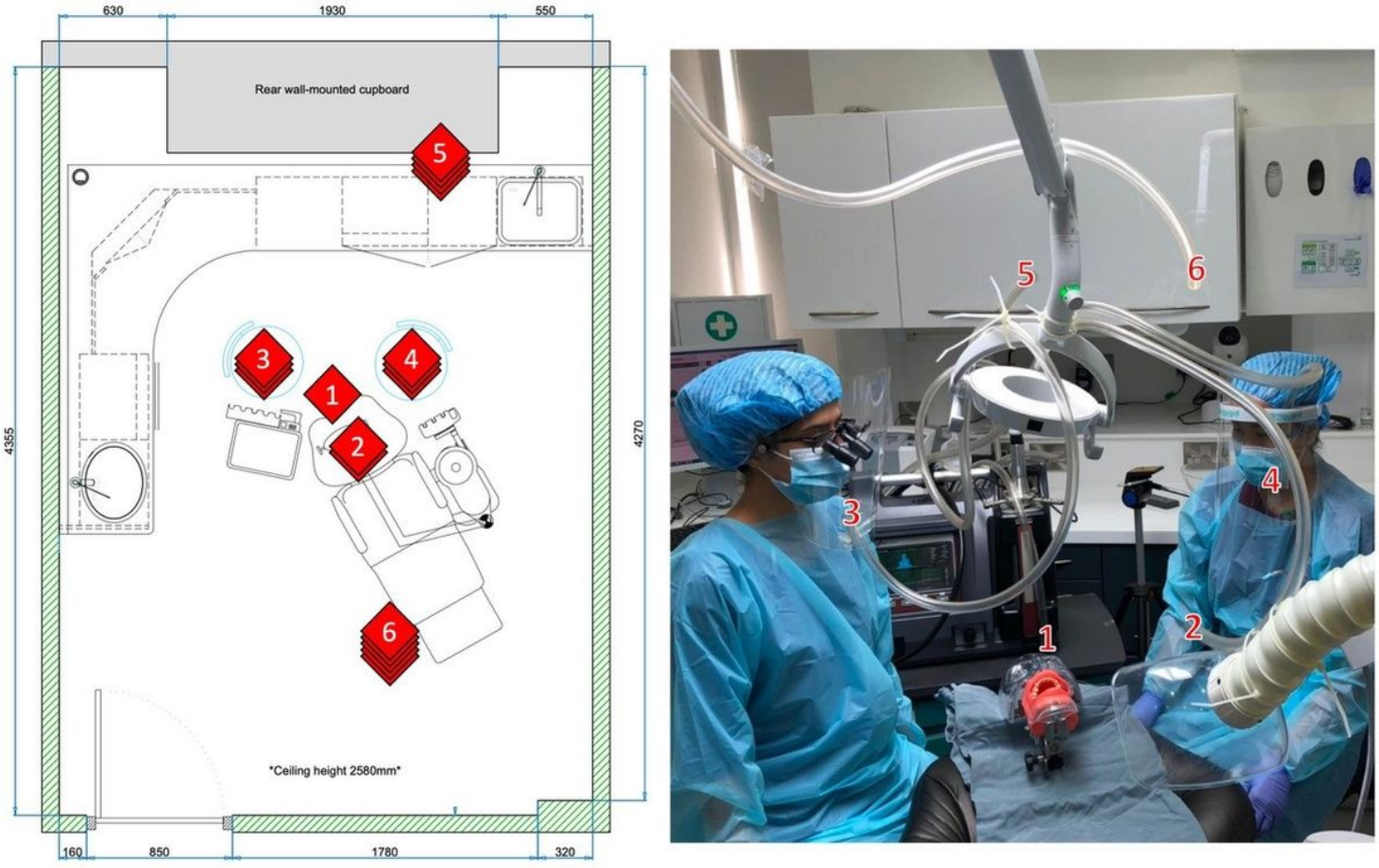


Figure 1

Layout and sampling positions of the dental treatment room. Note that tube location 6 was moved from the ceiling light fitting to be visible in the photograph.

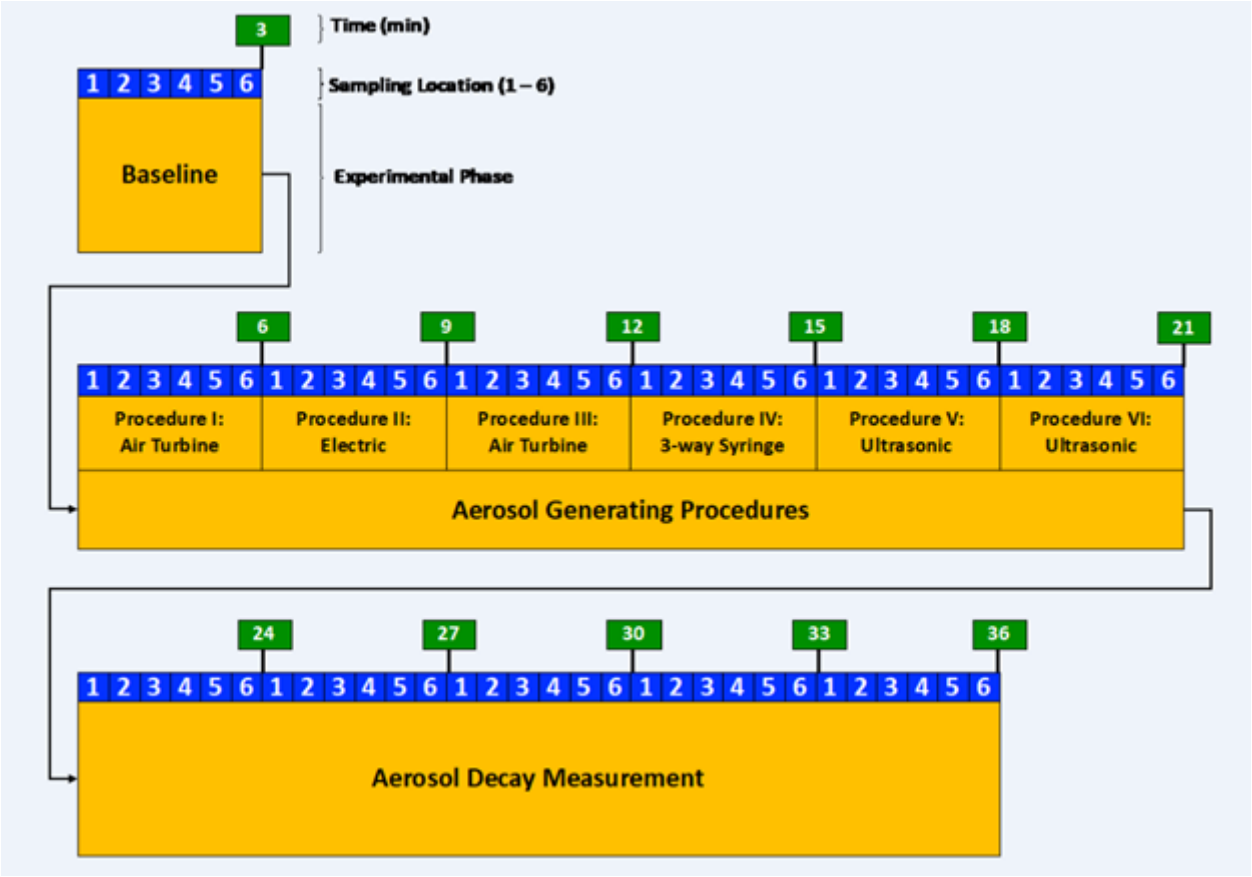


Figure 2

Outline study design. After an initial baseline period (3 min), six aerosol generating procedures (I to VI) were performed in series (18 min) followed by a period to quantify aerosol decay kinetics (15 min). Air samples from each location (1 – 6) were acquired over a 30 second period. The total duration of each experiment was 36 minutes.

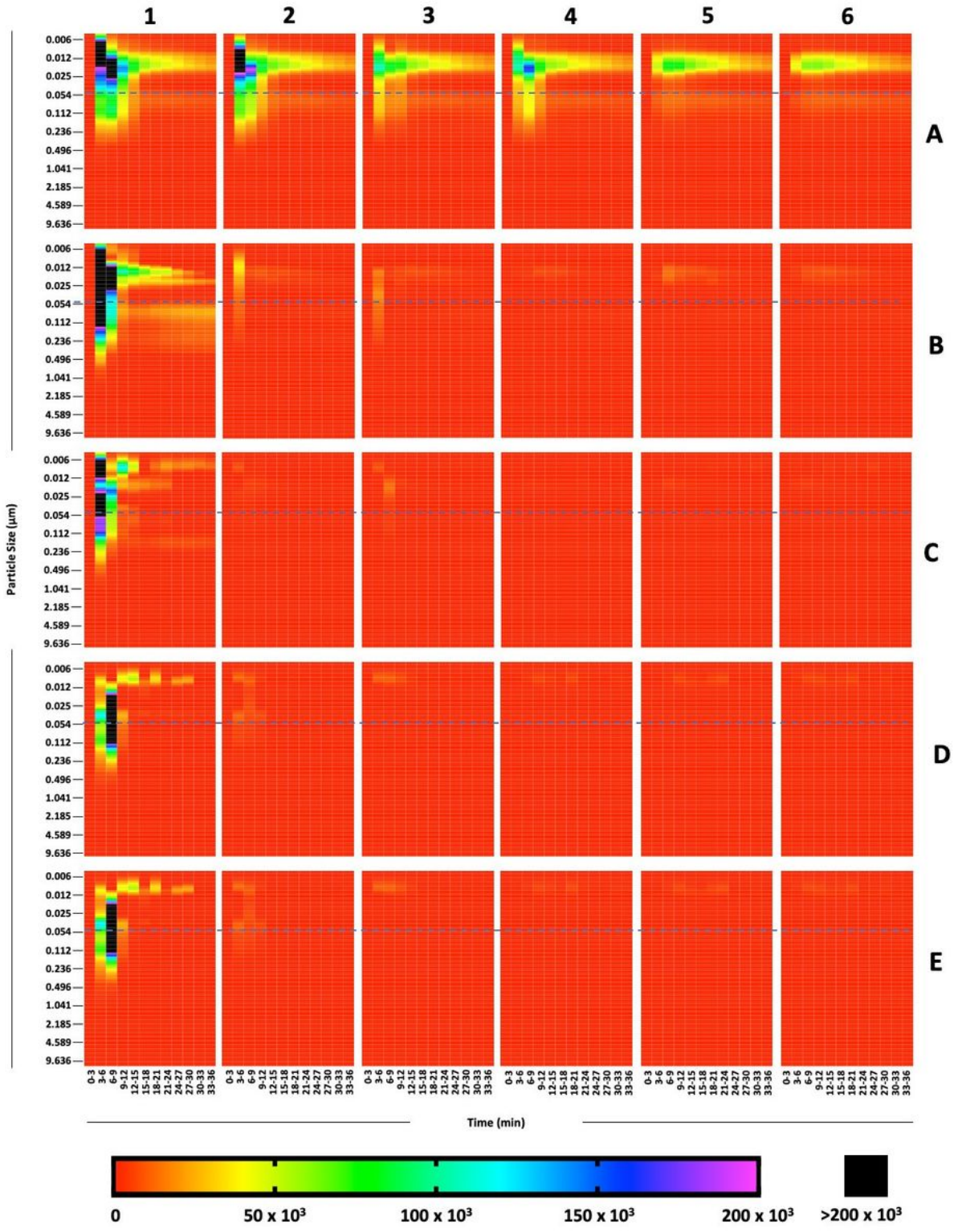


Figure 3

Temporal, spatial and size characterisation of particles generated during AGPs (measured by HR-ELPI) for each location (1 – 6; Table 1) and treatment group (A – E; Table 2). Acquisition of air samples were performed during the baseline period (0 – 3 min), during the six procedures (3 – 18 min) and following cessation of procedures (18 – 36 min). 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).

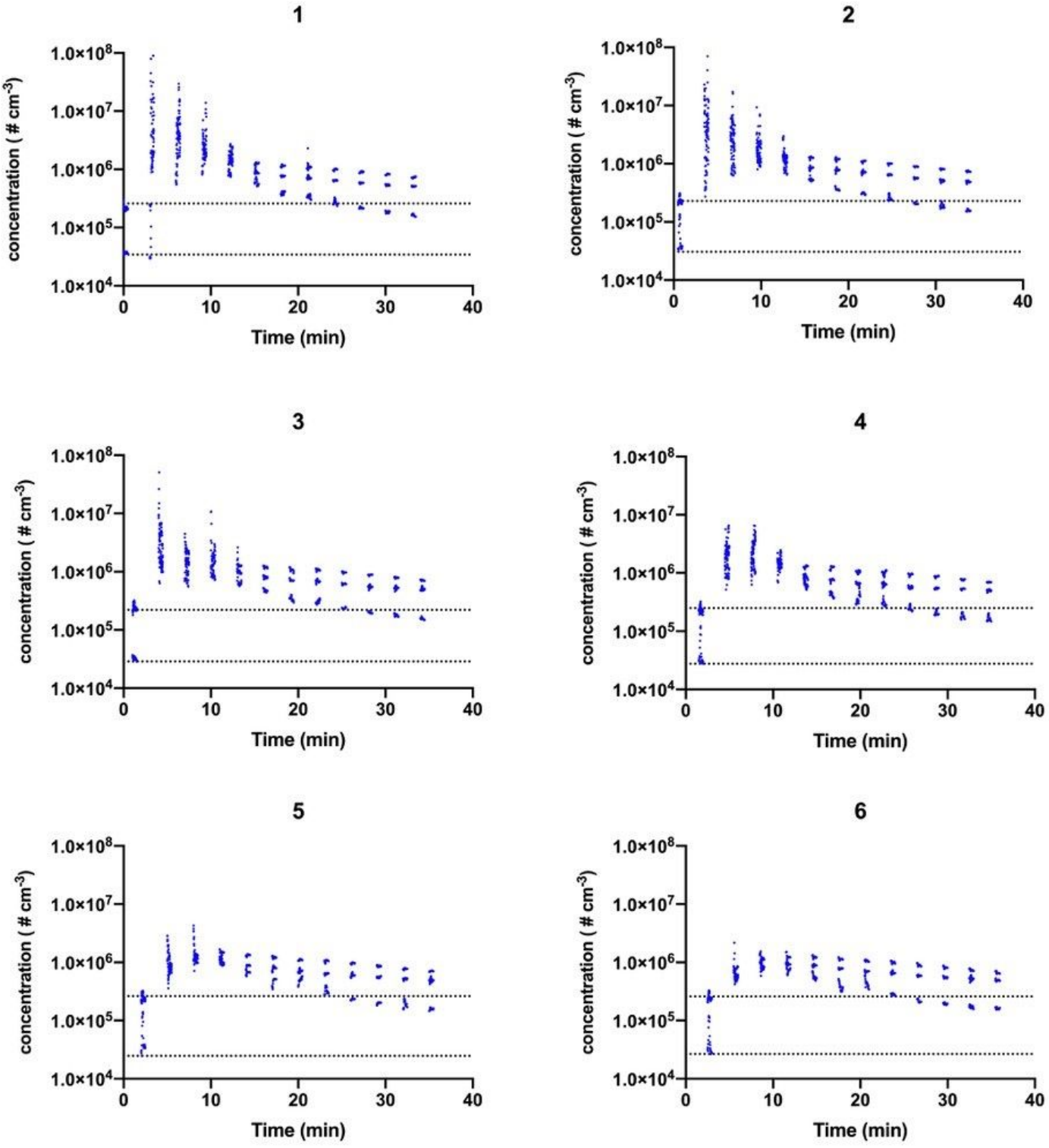


Figure 4

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 min), during the six procedures (3 – 18 min) and following cessation of procedures (18 – 36

min). 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 1 second during each replicate (n=3).

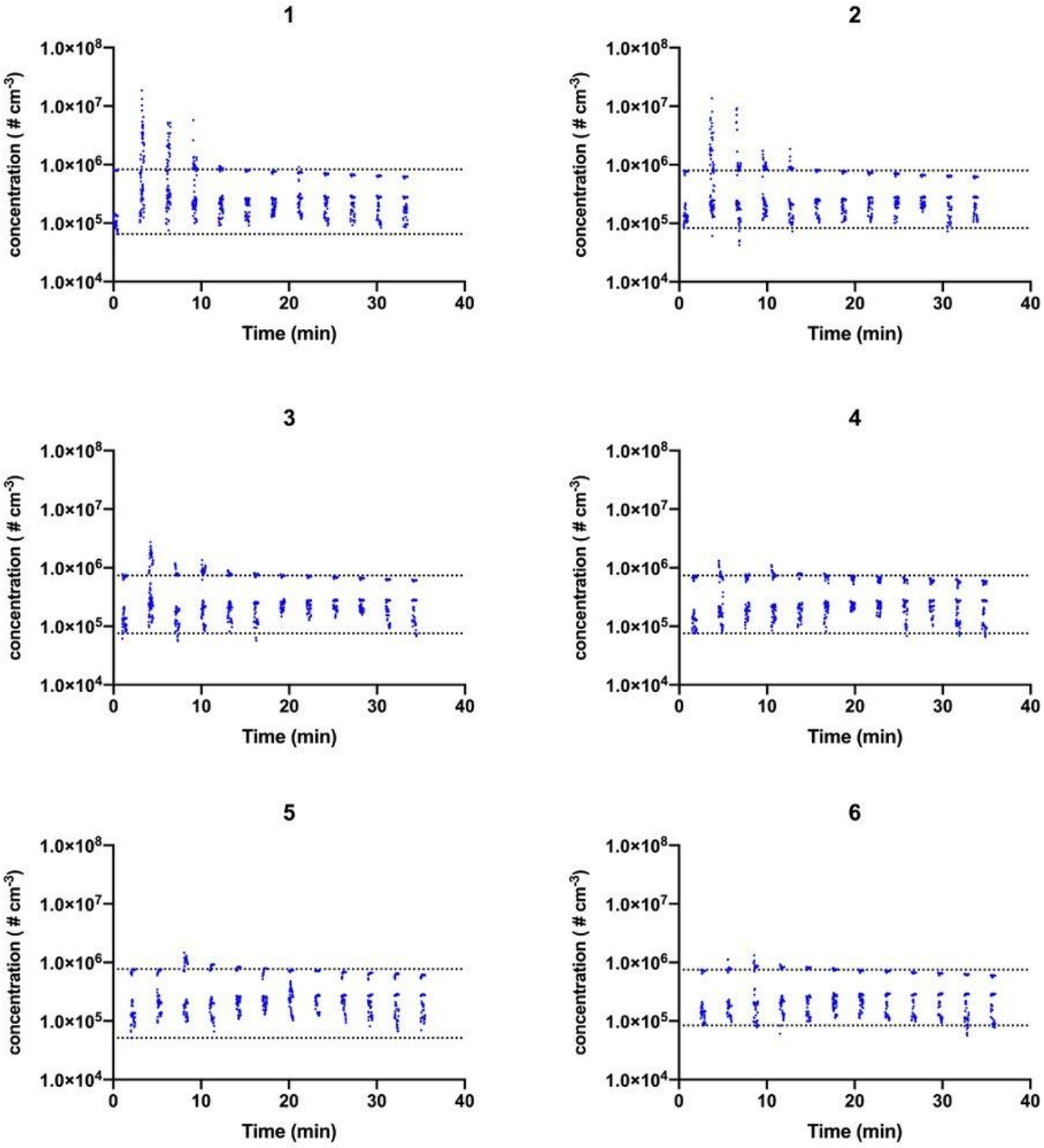


Figure 5

Total particle concentration generated during AGPs in the presence of HVS(IO) (group B; Table 2) at each air sampling location (1 – 6; Table 1). Acquisition of air samples were performed during the baseline period (0 – 3 min), during the six procedures (3 – 18 min) and following cessation of procedures (18 – 36

min). 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 1 second during each replicate (n=3).

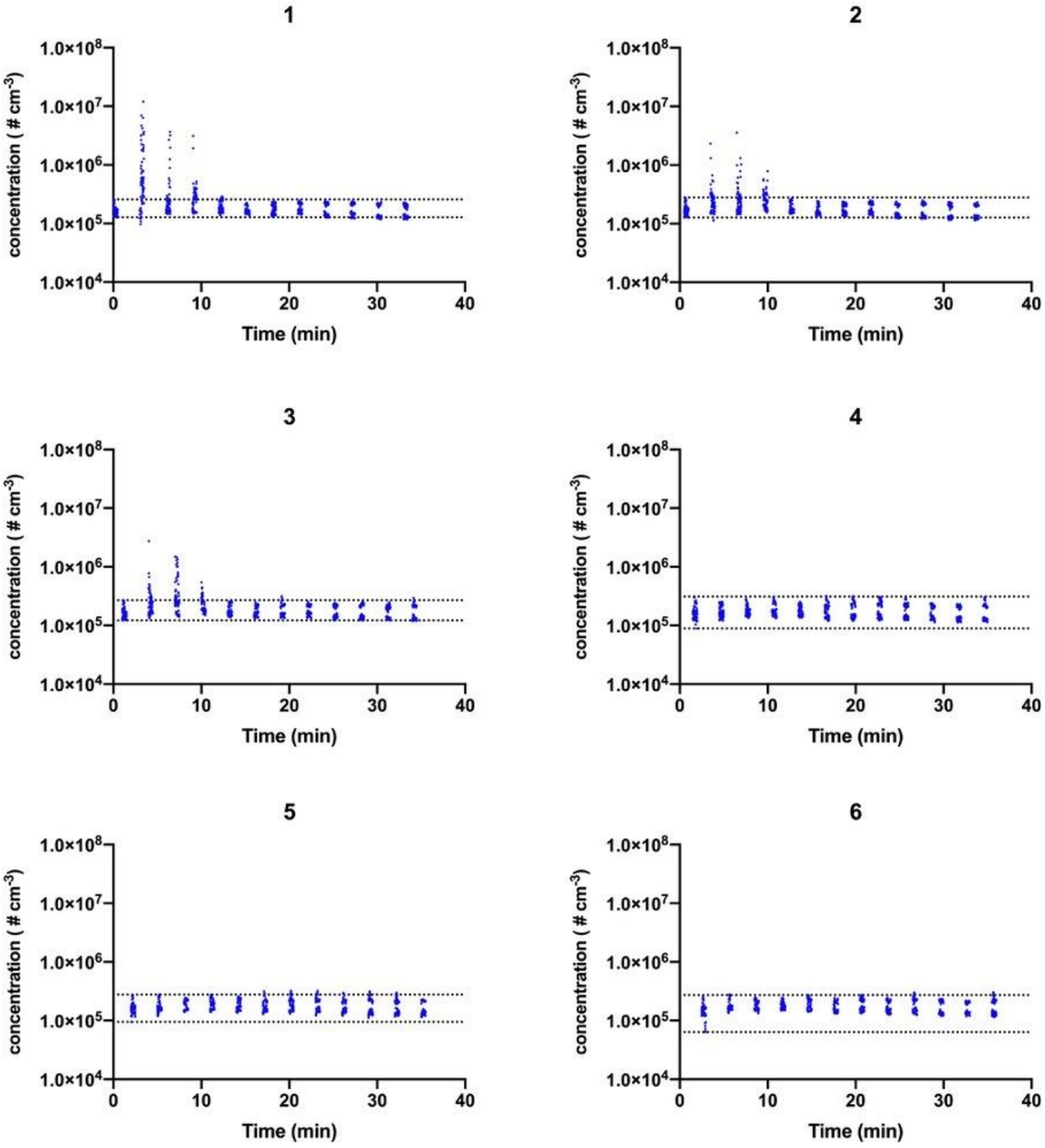


Figure 6

Total particle concentration generated during AGPs in the presence of HVS(IO) and ACS (group C; Table 2) at each air sampling location (1 – 6; Table 1). Acquisition of air samples were performed during the baseline period (0 – 3 min), during the six procedures (3 – 18 min) and following cessation of procedures

(18 – 36 min). 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 1 second during each replicate (n=3).

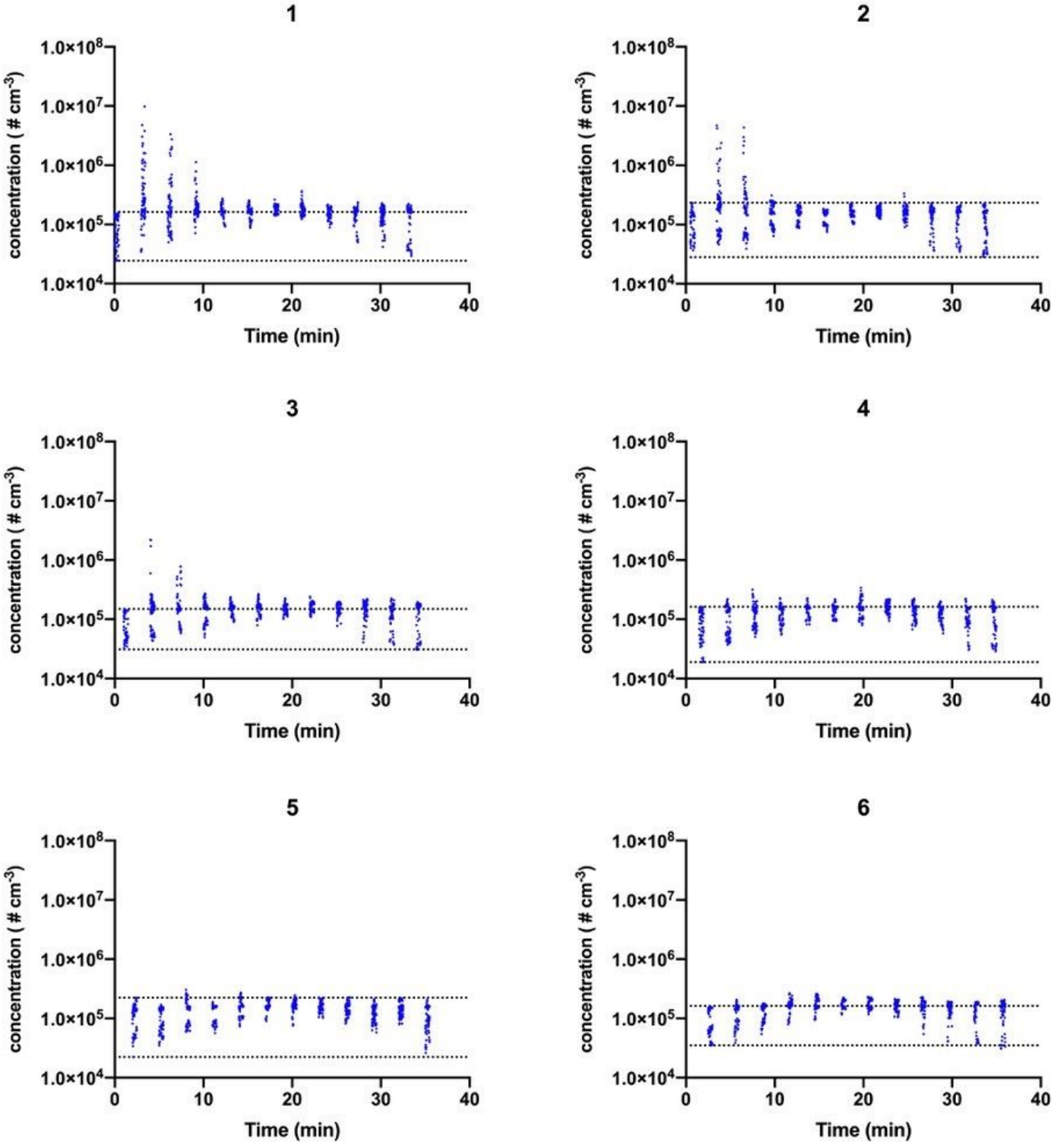


Figure 7

Total particle concentration generated during AGPs in the presence of HVS(IO) and HVS(EO) (group D; Table 2) at each air sampling location (1 – 6; Table 1). Acquisition of air samples were performed during the baseline period (0 – 3 min), during the six procedures (3 – 18 min) and following cessation of

procedures (18 – 36 min). 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 1 second during each replicate (n=3).

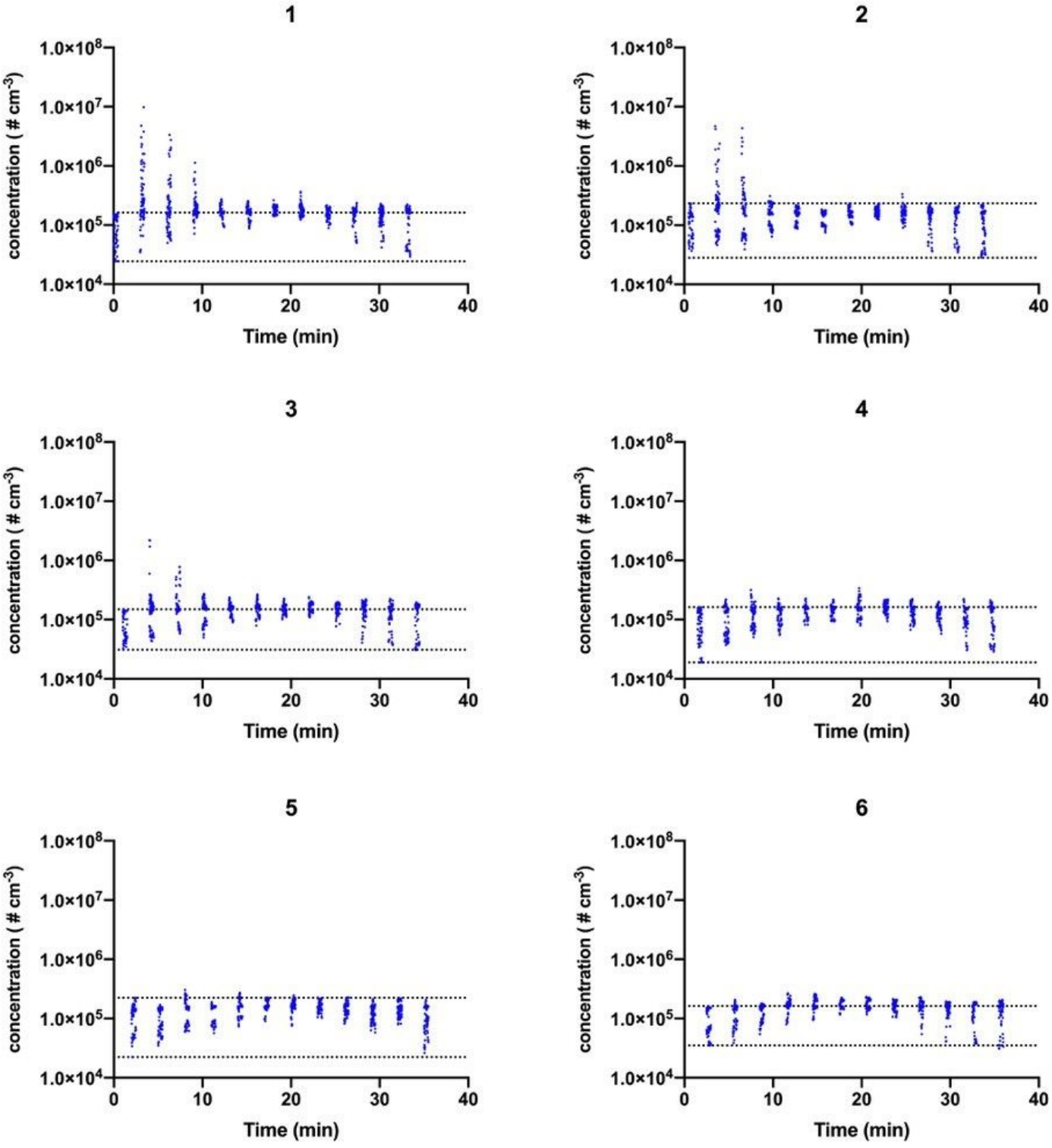


Figure 8

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 min), during the six procedures (3 – 18 min) and following cessation of procedures (18 – 36 min). 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 1 second during each replicate (n=3).

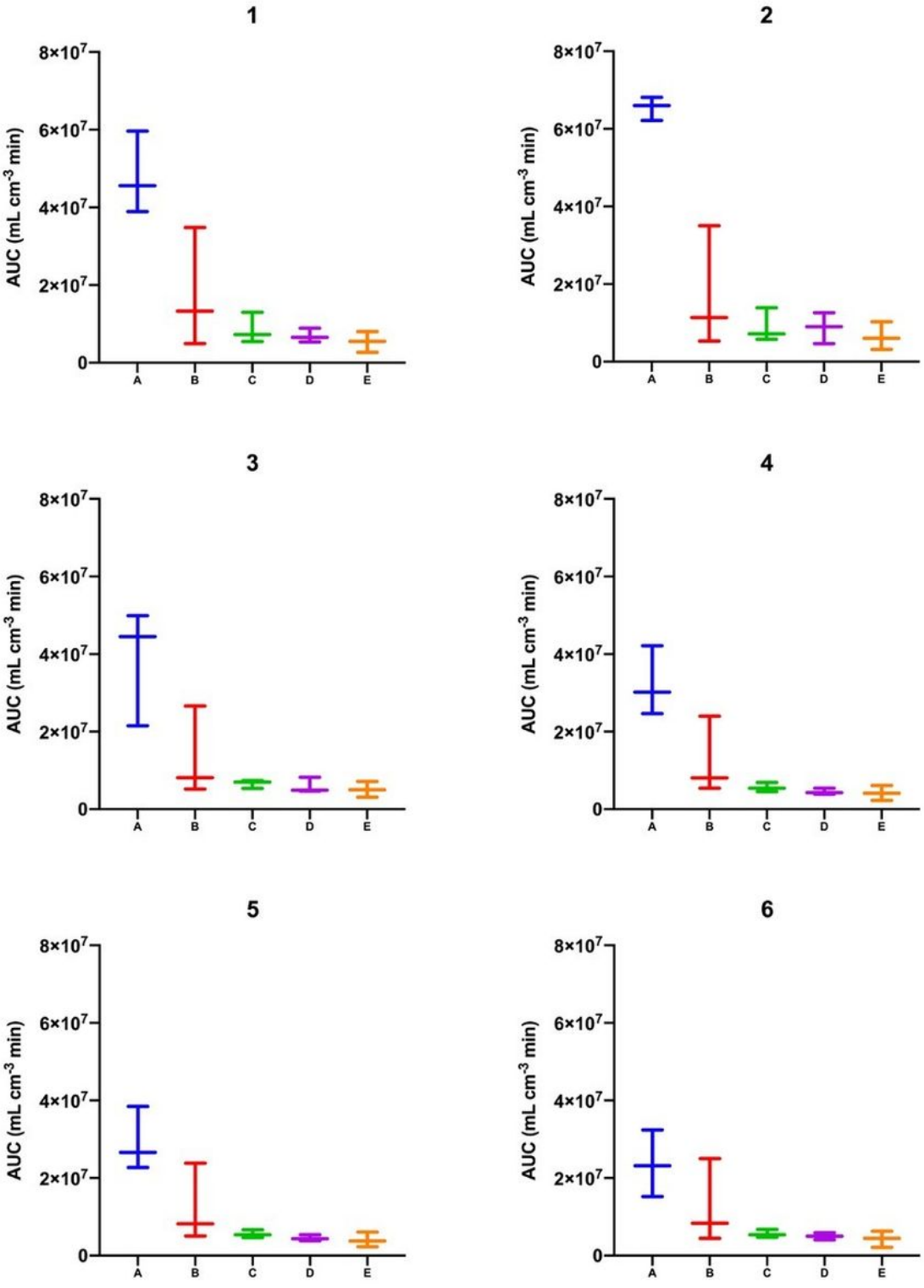
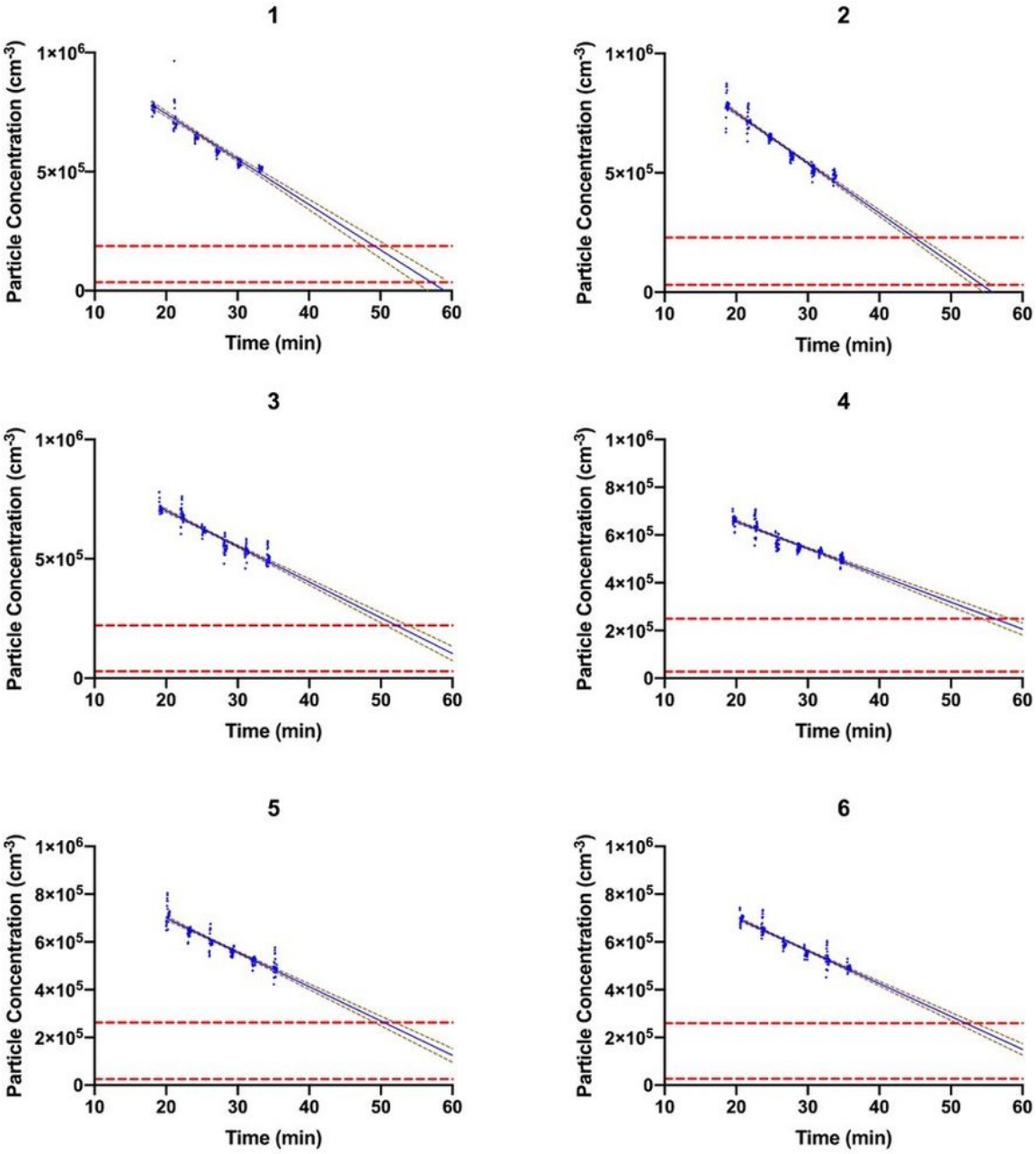


Figure 9

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



Regression parameter	Location					
	1	2	3	4	5	6
Y-Intercept	1.1E+06	1.2E+06	1.0E+06	8.8E+05	9.9E+05	9.8E+05
Slope	-1.9E+04	-2.1E+04	-1.5E+04	-1.1E+04	-1.4E+04	-1.4E+04
r^2	0.7967	0.9218	0.8609	0.8273	0.8533	0.8827

Figure 10

Linear regression (with 95% confidence intervals) of decay-phase particle concentration data. Each data point represents the median sum particle concentration measured by HR-ELPI per second during each

replicate (n=3). Horizontal dotted red lines indicate baseline particle range.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementarydataAnnexAFinalEdit2.pdf