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**TESTING OF A FUME AND DUST EXTRACTION SYSTEM AS
MITIGATION FOR AEROSOL GENERATING PROCEDURES IN A
DENTAL SURGERY**

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DENTAL SURGERY

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EXECUTIVE SUMMARY

Evidence shows that viruses can be carried on airborne particulate matter, and that viral infections can spread by aerosol transmission. To reduce the transmission risk, especially in enclosed spaces where ventilation methods to reduce or remove PM might be limited or non-existent, various mitigating strategies can be employed.

This project investigated the performance of the BOFA DentalPRO UVc extraoral aerosol filtration system when Aerosol Generating Procedures (AGPs) were performed on a training manikin at the mydentist dental practice, Sydenham, London in June 2021. Using an optical particle counter (OPC), condensation particle counter (CPC), scanning mobility particle sizer (SMPS) and an AQMesh air quality monitor, measurements were taken across a particle size range of approximately 4 nm to 10 μm : this allowed an assessment of the effects of AGPs and (air) extraction activities to be conducted in the closed surgery setting.

Following some initial tests at the dental practice on 18 June 2021, a campaign of measurements took place on 22 June 2021 (with background measurements starting on 21 June). A series of eleven 15-minute AGPs were conducted on a dental manikin followed by 5-minute fallow periods. For the duration of the tests, particle number concentration and particle size distributions were measured in the immediate vicinity of the manikin (near-field measurements); particle mass concentration measurements were made in a far corner of the surgery (far-field measurements).

The results showed that near-field particle number concentrations could be measurably and repeatably reduced when the BOFA unit under test was operated during AGPs at its maximum flow rate of nominally 220 $\text{m}^3\cdot\text{h}^{-1}$. When the BOFA unit was positioned 14 cm from the manikin, the CPC-measured particle number concentrations were seen to reduce by approximately 50 % during an AGP performed with the BOFA unit on, compared to when an AGP was performed with the BOFA unit off. Similarly, OPC-measured particle number concentrations were seen to reduce by up to 98 %. A similar (95 %) decrease in OPC-measured particle number concentrations was observed with the BOFA unit positioned 30 cm from the manikin. Care must however be taken when interpreting these last two results – although they show good repeatability, the 3% difference may be smaller than the overall uncertainty of the measurement.

Near-field particle size distribution measurements showed a significant reduction in particles above 35 nm, which was supported by the large reduction in particle number concentrations measured by the OPC (particle size range: 0.5 μm to 10 μm). Particle mass concentration measurements with the AQMesh air quality monitor showed that the BOFA units had the capability to lower the whole surgery particle mass concentrations (PM_{10} to PM_{100}) and once the mass concentration had been lowered it remained low for the rest of the day, even though the BOFA unit was not on continuously.

The project was funded by the UK Government's Department for Business, Energy and Industrial Strategy (BEIS) through the UK's National Measurement System Measurement for Recovery (M4R) Programme.

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1. AIM

The aim of this project was to investigate the performance of the BOFA DentalPRO UVc extraoral aerosol filtration system when Aerosol Generating Procedures (AGPs) were performed on a training manikin. Evidence shows that viruses can be carried on airborne particulate matter¹ (PM), and that viral infections can spread by aerosol transmission. To reduce the transmission risk, especially in enclosed spaces where ventilation methods to reduce or remove PM might be limited or non-existent, various mitigating strategies can be employed.

This investigation was conducted at the mydentist Sydenham dental practice between 18 and 22 June 2021, with the results from initial tests on 18 June used to refine the final test plan. Overnight background tests were performed from 18 - 22 June and the main tests carried out on 22 June.

A series of nominally identical AGPs were performed on a manikin and the near-field particle number concentrations and particle size distributions were measured throughout the day. The far-field particle mass concentrations were also measured using an air quality monitor. Tests were first performed with the BOFA unit off, then with the BOFA unit on with the head of the unit positioned in a number of different locations.

The work is related to two earlier studies by NPL: M4R project 'Measurement of Airborne Particles in The MyDentist Tonbridge Dental Practice using Multiple Optical Particle Counter Instruments'² which itself was a follow-on from the project 'Feasibility Study on the Detection of Airborne Particulates in a Dental Surgery using an Optical Particle Counter'³.

The project was funded by the UK Government's Department for Business, Energy and Industrial Strategy (BEIS) through the UK's National Measurement System Measurement for Recovery (M4R) Programme⁴.

2. EXPERIMENTAL

2.1 Instrumentation and device under test

2.1.1 *Optical particle counter (OPC)*

The PROMO 2000P is an optical particle counter used with a WELAS 2200P head. In these tests, the instrument measured a particle size range of 0.5 μm to 10 μm . The instrument measures particle number concentrations. The instrument was calibrated on site using the PALAS reference material and procedure, and, in these tests, also operated as an Optical Particle Size Spectrometer (OPSS).

2.1.2 *Scanning Mobility Particle Sizer (SMPS)*

The SMPS comprised a TSI 3080 Electrostatic Classifier with X-ray neutralizer, TSI 3081 long-DMA, coupled to a TSI 3775 Condensation Particle Counter (CPC). The system is designed to sample airborne particulate matter and provides particle size distribution measurements over a ~ 14 nm to ~ 737 nm range. The SMPS had been calibrated at NPL – both with a Kr-85 source and x-ray neutralizer – prior to conducting measurements at the mydentist practice.

2.1.3 *Condensation Particle Counter (CPC)*

A standalone, NPL-calibrated TSI 3775 CPC was used to measure particle number concentrations. The manufacturer states that this device can detect airborne particles in the size range of approximately 4 nm to approximately 3 μm .

2.1.4 *Air quality monitor*

The AQMesh is a small-sensor air quality monitoring system. It can be configured to measure a range of parameters including temperature, pressure, concentrations of particular gas species, and various aerosol parameters such as particle mass concentrations. In these tests, the instrument was used to measure particle mass concentrations in the PM_{10} , $\text{PM}_{2.5}$, PM_4 and PM_{10} fractions. The instrument was set up with the factory calibration.

2.1.5 *BOFA fume and dust extraction system*

The fume and dust extraction unit under test was the DentalPRO UVc extraoral aerosol filtration system manufactured by BOFA (Figure 1) – Figure 2 shows the device as set up at site. The key features are the configurable extraction arm, internal UVc lamp, carbon and H14 HEPA filters, and a user-selected air extraction flow rate. The system was operated in high-speed mode during all the tests in this report – the nominal maximum flow rate stated by the manufacturer is $220 \text{ m}^3 \cdot \text{h}^{-1}$. All tests were performed using this flow rate ('high-speed mode').

Figure 1 BOFA DentalPRO UVc extraoral aerosol filtration system. Photograph credit: BOFA

2.2 Experimental set-up

Measurements were performed in the ground floor surgery at the mydentist dental practice in Sydenham, London (Figure 2); the building is located on a busy urban high street with high volumes of road traffic. The surgery floor space was approximately 2.92 m x 3.00 m, with a sloped ceiling 2.60 m high nearest the front of the practice and descending to 2.00 m at the back – the estimated volume of the surgery was therefore 20.2 m³. The surgery door and skylight window were kept closed for the duration of the measurements taken on 22 June 2021.

Figure 2 Ground floor dental surgery, mydentist dental practice (Sydenham, London)

Figure 3 shows a simplified, schematic overhead view of the surgery, to illustrate the relative positions of the instrumentation and devices used. For all AGPs performed on the manikin (pink rectangle and white ellipse), the dental practitioner was seated at location 'D'. The specific AGP performed for the tests was a descaling process – usually by a hygienist – with a water-fed descaler (the white-coloured tool on the metal tray in Figure 2). The descaler was supplied from a refillable water container located below the metal tray in Figure 2. The water feed rate was controlled by a manually adjustable valve; it was set to provide a 'typical' flow rate as used by hygienists (not measured), the same nominal setting was used for the duration of the tests on 22 June.

Figure 3 Schematic diagram of ground floor dental surgery (features on floorplan not to scale)

The SMPS, standalone CPC, and OPC (Promo) instruments were placed on the trolley shown in Figure 3, but the sampling tube inlets to each were co-located at position 'S', i.e. supported just below the manikin, itself fixed to the dental chair. Given the proximity of the sampling inlets to where the AGPs were performed, these measurements were regarded as near-field measurements. For background measurements, i.e. far-field measurements, the AQMesh air quality monitor was located at position 'A' in the far corner of the surgery. The main body of the BOFA unit was first located at position 'B1' for one set of measurements and was later moved to position 'B2'. This meant that measurements when extraction was performed from the LHS (left-hand side) or RHS (right-hand side) of the manikin could be compared. Note the x-y-z co-ordinate system shown - this specifies the positioning of the BOFA inlet duct as shown in Figure 4.

The second image in Figure 4 shows schematically how the BOFA inlet duct was positioned relative to the manikin, when the BOFA unit was located at B1 in Figure 3 (as viewed from the manikin's RHS). For aerosol measurements taken while AGPs were performed, the elliptical face of the extraction duct was initially centred on an imaginary line passing through the top of the manikin's set of lower jaw teeth as shown. Note, however, that the extraction arm would sometimes move under its own weight from the initial set-up position during measurements – these incidences are recorded in Table 1. Aerosol measurements were performed with the face of the extraction duct located in the co-ordinate system as shown in the side and overhead views in Figure 4 (e.g. $x = 14$ cm indicates a distance of 14 cm from the centre of the manikin's lower jaw teeth, as shown, to the plane of the BOFA inlet duct face positioned perpendicularly to that line).

Figure 4 Schematic side and overhead views of the dental manikin, BOFA inlet duct, and co-ordinate system used

As shown in Figure 3, measurements were taken with BOFA aerosol extraction performed from both sides of the manikin – Figure 5 shows how the BOFA unit and extraction arm had been positioned in the surgery to achieve this in practice.

Figure 5 BOFA unit and extraction arm positions on the LHS and RHS of the manikin during tests

2.3 Summary of tests on 21-22 June 2021

2.3.1 Evening of 21 June 2021

On 21 June, the SMPS, CPC and OPC instruments were switched on at approximately 18:00 local time (note that the AQMesh air quality monitor had already been set up to continuously record 'far-field' data in the surgery since Friday 18 June). Before taking background readings

in the closed surgery overnight, 'zero signal' readings were taken by fitting a HEPA filter to the air inlets to the SMPS and CPC in turn, and recording datafiles (this is also a way to leak-check the devices before taking data). The OPC was also re-calibrated prior to setting it up to record background data overnight.

Having performed pre-measurement run checks, the SMPS, CPC, and OPC were set up to record data from 19:00 local time onwards. The measurement files were configured as follows:

- CPC: repeat every hour, each file taking data for 59 min 50 s
- SMPS: repeat every 5 min (scan for 240 s, 15 s retrace)
- OPC: repeat every 1 min
- AQMesh air quality monitor: repeat every 1 min

2.3.2 Background monitoring: overnight from 22 June 2021

An evaluation of the background aerosol levels (with no surgery activity) was performed by recording measurements from 20:20 on 21 June to 06:20 on 22 June.

2.3.3 Main measurements on 22 June 2021: List of dental procedures and configurations of the BOFA unit

Table 1 provides details of the AGPs conducted on 22 June, along with configuration details of the BOFA unit. The SMPS, CPC, OPC, and AQMesh air quality monitor were all recording continuously over the whole time period covered by the tests

Table 1 List of test runs and activities performed on 22 June 2021

Run number	AGP Duration	BOFA unit status	Extraction head positioning (x, y, z)
1	10:00 – 10:15	Off	(14, 0, 0)
2	10:20 – 10:35	Off	(14, 0, 0)
3	10:40 – 10:55	Off	(14, 0, 0)
4	11:10 - 11:25	On	(14, 0, 0) *
5	11:35 - 11:50	On	(14, 0, 0) *
6	11:55 – 12:10	On	(14, 0, 0) *
7	13:40 – 13:55	On	(30, 0, 0)
8	14:00 – 14:15	On	(30, 7, 0) *
9	14:20 – 14:35	On	(14, 7, 0) *
10	14:40 – 14:55	On	(-14, 0, 0) *
11	15:00 – 15:15	On	(-30, 0, 0) *

Note: * indicates that the extraction head of the BOFA instrument fell up to 14 cm (z = -14 cm) during the course of the AGP. This also resulted in a movement away from the manikin of up to 4 cm (x = -4 cm or x = 4 cm when the BOFA unit was positioned on the LHS or RHS of the manikin respectively).

3. RESULTS AND DISCUSSION

3.1 Near-field CPC particle number concentration measurements

Table 2 gives a summary of the overnight background particle number concentration as measured with the standalone CPC (surgery door closed, no occupants or activity):

Table 2 Mean overnight particle number concentration

Time	Mean particle number concentration / cm^{-3}	Standard deviation / cm^3
21 June 20:20 to 22 June 06:20	1139	93

Figure 6 shows a time series of various measurements taken on 22 June, with AGP performed and the BOFA unit used as described in Table 1. Near-field measurements were recorded with the SMPS, CPC, and OPC. Figure 6 also includes two datasets recorded by the AQMesh air quality monitor in the far-field: namely, particulate mass concentrations in the $\text{PM}_{2.5}$ and PM_{10} fractions.

Figure 6 Whole-day data (22 June 2021) from CPC, SMPS and OPC instruments. Note that the SMPS total particle number concentration measurements were uncalibrated and are to be used as a relative indicator only.

Figure 7 shows a time series of the near-field CPC measurements only. The key points to note are:

- 10:00 – 11:00: 3 x 15 min AGPs indicated by the green ‘top-hat’ profiles, BOFA off (LHS of manikin)
- 11:10 – 12:15: 3 x 15 min AGPs indicated by the blue ‘top-hat’ profiles, BOFA on during the 15 min procedures only (LHS of manikin)
- 12:15 – 13:30: break - no AGP activity, BOFA off
- 13:40 – 14:40: 3 x 15 min AGPs indicated by the blue ‘top-hat’ profiles, BOFA on during the 15 min procedures only, with inlet placed in 3 different locations relative to manikin (BOFA system on LHS of manikin)
- 14:40 – 15:20: 2 x 15 min AGPs indicated by the final two blue ‘top-hat’ profiles with BOFA on during the 15 min procedures only, inlet face in two different positions relative to manikin, *but placed on RHS of manikin* (i.e. see Figure 3 and RHS of Figure 5)

Figure 7 Near-field CPC measurements during AGP/BOFA activity

The following figures break down Figure 7 into shorter time periods. The figures are in time order, but to summarise their contents before describing each in turn:

- Figure 8: AGP tests with no BOFA operation (10:00 – 11:10)
- Figure 9: AGP tests with the BOFA in position B1 (11:10 – 14:40; see Figures 3 and 5)
- Figure 10: AGP tests with the BOFA unit in position B1 (see Figures 3 and 5), various inlet duct positions (13:40 – 14:40)
- Figure 11: AGP tests with the BOFA in position B2, various inlet duct positions (14:40 – 15:20; see Figures 3 and 5)

To assess the effect of AGP activity on aerosol levels with no BOFA extraction, three nominally identical 15-minute AGPs were performed – the particle number concentration results from the

standalone CPC in Figure 8 clearly shows the effect of operating the water-fed descender on the manikin. Each AGP activity led to large increases in near-field particle number concentration but falling back to baseline almost immediately when AGP activity was stopped.

Figure 8 Near-field CPC measurements, three AGP tests with no BOFA operation (10:00 – 11:10), i.e. runs 1-3 in Table 1

Figure 9 shows the first CPC measurements of the day with the BOFA unit in operation: three nominally identical 15-minute AGPs were performed with simultaneous BOFA extraction (high-speed mode setting). The three AGP and BOFA runs (yellow and red lines) show a reduction in near-field particle number concentration during the course of the AGPs. Note too that during the 5-minute fallow period immediately after each 15-minute AGP and BOFA run, the CPC-measured concentrations rose immediately (green and purple lines).

Figure 9 Near-field CPC, three AGP tests with the BOFA operation, aerosol extraction from LHS of manikin (11:10 – 12:15) i.e. runs 4-6 in Table 1

No AGPs were performed from 12:15 to 13:40 – the CPC measurements in Figure 10 show how this correlated with a significant increase then levelling off in near-field particle number concentration as measured (the step-change at ~13:30 coincides with the time the surgery was re-entered by the three occupants working in the enclosed space). For comparison, see the selection of AQMesh air quality monitor far-field mass concentration measurements for the same time period in Figure 19.

The latter half of Figure 10 shows the near-field CPC measurements for three 15-minute AGP and BOFA runs for which the BOFA inlet had been positioned further away or offset from the manikin (runs 7 – 9 in Table 1). As observed in Figure 9, the measured particle number concentration reduced during AGP and BOFA activity, with levels rising during the fallow period when AGP activity was stopped and the BOFA switched off. As in Figure 9, the use of the BOFA unit during the first AGP resulted in a large decrease in the measured particle number concentration.

Figure 10 Near-field CPC, break with no AGP/BOFA activity (12:15 – 13:40) and three AGP/BOFA runs, BOFA inlet in various positions on LHS of manikin (13:40 – 14:40) i.e. runs 7-9 in Table 1

Figure 11 shows near-field CPC measurements taken for the final AGP activity conducted on 22 June, i.e. two 15-minute runs of AGP and BOFA operation with 5-minute fallow periods after each but with aerosol extraction performed from the RHS of the manikin (runs 10 and 11 in Table 1).

Figure 11 AGP tests with the BOFA aerosol extraction on RHS of manikin, two different inlet positions (14:40 – 15:20) i.e. runs 10 and 11 in Table 1

Table 3 summarizes the near-field CPC results for selected runs on 22 June. The data show acceptable repeatability for runs repeated under the same conditions and allow comparison of results between groups of runs performed under different conditions, e.g. comparisons between the 'BOFA off' and 'BOFA on' runs. In particular, the results show that mean particle number concentrations with the BOFA unit on are less than half the mean values for when it was not in operation.

Table 3 Results from near-field CPC measurement runs described in Table 1

Run number (4 and 7 excluded)	AGP time	BOFA unit on-off (when on, matched 15-minute AGP activity)	BOFA unit and inlet position (LHS or RHS of manikin), and coordinates (x, y, z in cm)	CPC mean particle number conc. [cm^{-3}]	Std. dev. of CPC measurements [cm^{-3}]
1	10:00 – 10:15	OFF	n/a	2323	289
2	10:20 – 10:35	OFF	n/a	2218	320
3	10:40 – 10:55	OFF	n/a	2726	358
5	11:35 – 11:50	ON	L (14, 0, 0) *	920	212
6	11:55 – 12:10	ON	L (14, 0, 0) *	814	190
8	14:00 – 14:15	ON	L (30, 7, 0) *	908	214
9	14:20 – 14:35	ON	L (14, 7, 0) *	933	97
10	14:40 – 14:55	ON	R (-14, 0, 0) *	1031	197
11	15:00 – 15:15	ON	R (-30, 0, 0) *	1057	187

Notes:

- All calculations discard the first minute of measurements after the AGP starts and run to the end of the AGP.
- Results from runs 4 and 7 in Table 1 have been excluded from data presented in Table 3 as the near-field particle concentrations were reduced significantly below the pre-AGP baseline.
- A * indicates where the nozzle of the BOFA unit moved during the AGP.

3.2 Near-field SMPS particle size distribution measurements

The contour plot in Figures 12 shows how the particle size distributions measured by SMPS changed throughout the day. The plot shows that the periods when the BOFA unit was on (11:10 – 12:10 and 13:40 – 15:15) correlate with the particle size distributions showing reduced concentrations at the larger sizes (above 35 nm). The noticeably dark region of densely spaced contour lines from ~ 12:30 to 13:40 is due to the rise in particle number concentrations at smaller sizes during the lunchtime break with no AGP or BOFA operation.

Figure 12 Near-field SMPS measurements showing the effects of AGP and no BOFA extraction, AGP and BOFA extraction, and no activity, on size distributions (whole day, 22 June)

3.3 Near-field OPC particle size distribution measurements

The following figures and commentary are based on the measurements obtained with the near-field OPC, which was co-located with the CPC and SMPS instruments. Due to a possible error ± 1 minute in establishing the time difference between the OPC clock and the other (synchronised) clocks used to timestamp AGP activities, the positions of the schematic ‘top-

hat' profiles in Figures 13 – 17 will have a similar uncertainty, but this is sufficiently small to make the correlations observed between AGP and BOFA activities and the OPC data still valid.

Figure 13 shows a time series of the near-field OPC measurements on 22 June 2021 (see Table 1). The key points to note are:

- 10:00 – 11:00: 3 x 15 min AGPs indicated by the orange 'top-hat' profiles, BOFA off (lhs of manikin).
- 11:10 – 12:15: 3 x 15 min AGPs indicated by the grey 'top-hat' profiles, BOFA on during the 15 min procedures only (LHS of manikin).
- 12:15 – 13:30: break - no AGP activity, BOFA off.
- 13:40 – 14:40: 3 x 15 min AGPs indicated by the grey 'top-hat' profiles, BOFA on during the 15 min procedures only, with inlet placed in 3 different locations relative to manikin (BOFA unit on LHS of manikin).
- 14:40 – 15:20: 2 x 15 min AGPs indicated by the final two grey 'top-hat' profiles with BOFA on during the 15 min procedures only, inlet face in two different positions relative to manikin, *but placed on the RHS of the BOFA unit* (i.e. see Figure 3 and RHS of Figure 5).

Figure 13 Near-field OPC measurements during AGP and BOFA activity

The following figures break down Figure 13 into shorter time periods. The figures are in time order, but to summarise their contents before describing each in turn:

- Figure 14: AGP tests with no BOFA operation (10:00 – 11:10)
- Figure 15: AGP tests with the BOFA in position B1 (11:10 – 14:40; see Figures 3 and 5)
- Figure 16: AGP tests with the BOFA unit in position B1 (see Figures 3 and 5), various inlet duct positions (13:40 – 14:40)
- Figure 17: AGP tests with the BOFA in position B2, various inlet duct positions (14:40 – 15:20; see Figures 3 and 5)

To assess the effect of AGP activity on aerosol levels with no BOFA extraction, three identical 15-minute AGPs were performed – the particle number concentration data obtained from the OPC in Figure 14 clearly shows the effect of operating the water-fed descender on the manikin, with each AGP activity leading to large increases in near-field particle number concentration but falling back to baseline sharply with cessation of AGP activity.

Figure 14 Near-field OPC measurements, three repeated AGP tests with no BOFA operation (10:00 – 11:10), i.e. runs 1-3 in Table 1

Figure 15 shows the first OPC measurements of the day with the BOFA unit in operation: three AGPs were performed with simultaneous BOFA extraction (high-speed mode setting). In comparison with Figure 14, the three AGP and BOFA runs show a significant reduction in near-field particle number concentration both during the 15-minute runs and the background during the fallow periods (see the near-field CPC measurements in Figure 9 for comparison).

Figure 15 Near-field OPC, three AGP tests with the BOFA operation, BOFA on LHS of manikin (11:10 – 12:15) i.e. runs 4-6 in Table 1

Note: See Table 1 note concerning spike in particle number concentration before first run in the Figure.

No AGPs were performed from 12:15 to 13:40 and the OPC measurements in Figure 16 show a relatively stable baseline during this period (the step-change at ~13:30 coincides with the time the surgery was re-entered by the three occupants working in the enclosed space). For comparison, see the selection of AQMesh air quality monitor far-field mass concentration measurements (for the same time period) in Figure 19.

The latter half of Figure 16 shows the near-field OPC measurements for three AGP and BOFA runs for which the BOFA inlet had been positioned further away or offset from the manikin (runs 7 – 9). Despite the noisy signal, there is evidence of temporary increases during AGPs with the BOFA unit in operation but the general trend is a reduction in particle number concentration (including the baseline) between approximately 13:30 and 14:40. Note that the BOFA inlet face was first placed 30 cm away horizontally from the centre of the manikin and finally at a distance of 14 cm (see Figures 3 and 4) – the results suggest that the BOFA unit was more effective at removing larger AGP-generated particles when positioned closer to the source.

Figure 16 Near-field OPC, break with no AGP/BOFA activity (12:15 – 13:40) and three AGP/BOFA runs, BOFA inlet in various positions on LHS of manikin (13:40 – 14:40) i.e. runs 7-9 in Table 1

Figure 17 shows near-field OPC measurements taken for the final AGP activity conducted on 22 June 2021, i.e. two 15-minute runs of AGP and BOFA operation with 5-minute fallow periods after each but with aerosol extraction performed from the RHS of the manikin (runs 10 – 11 in Table 1). Note that the BOFA inlet face was first placed 14 cm away horizontally from the centre of the manikin and finally at a distance of 30 cm (see Figures 3 and 4) – the results suggest that the BOFA unit was more effective at removing larger AGP-generated particles when positioned closer to the source.

Figure 17 AGP tests with the BOFA aerosol extraction on RHS of manikin, two different inlet positions (14:40 – 15:20) i.e. runs 10 and 11 in Table 1

Figure 18 shows particle size distributions vs. time obtained from the near-field OPC (measuring PM up to ~ 10 µm in size). The changes in particle size distribution over time correlate with the periods of AGP activity (no BOFA) during 10:00 to 11:00, and the subsequent periods of AGP and BOFA activity during 11:10 – 12:10, 13:40 – 15:15, and the break in between. Note in particular that after BOFA operations commenced at 11:10, particle number concentrations fell across all sizes measurable by the OPC and remained at low levels for the rest of the day.

Figure 18 OPC near-field size distribution measurements (whole day, 22 June 2021)

Table 4 summarizes near-field OPC particle number concentration data for selected runs on 22 June. The particle number concentration decrease from 'BOFA off' to 'BOFA on' runs was nominally 98 % for runs at a separation of 14 cm (runs 5, 6, 9 and 10) and nominally 95 % for runs at a separation of 30 cm (runs 8 and 11). The large relative standard deviations in the table are more representative of the aerosol source generation process rather than the changes in the response of the instrument.

Table 4 Results from near-field OPC measurement runs described in Table 1

Run number (4 and 7 excluded)	AGP time	BOFA unit (when on, matched 15-minute AGP activity)	BOFA unit+ inlet position (LHS or RHS of manikin), and coordinates (x, y, z in cm)	OPC mean particle number conc. [cm ⁻³]	Std. dev. of OPC measurements [cm ⁻³]
1	10:00 – 10:15	OFF	n/a	78.9	23.6
2	10:20 – 10:35	OFF	n/a	72.1	19.7
3	10:40 – 10:55	OFF	n/a	88.1	25.1
5	11:35 – 11:50	ON	L (14, 0, 0) *	1.3	0.7
6	11:55 – 12:10	ON	L (14, 0, 0) *	1.2	0.6
8	14:00 – 14:15	ON	L (30, 7, 0) *	3.9	1.7
9	14:20 – 14:35	ON	L (14, 7, 0)	1.1	0.6
10	14:40 – 14:55	ON	R (-14, 0, 0) *	1.3	0.5
11	15:00 – 15:15	ON	R (-30, 0, 0) *	4.0	1.4

Notes:

- As runs 4 and 7 have been excluded from the Table 3, the same runs are excluded here as cross-comparisons cannot be usefully made with the excluded corresponding CPC data.
- A * indicates where the nozzle of the BOFA unit moved during the AGP.

3.4 Far-field AQMesh air quality monitor particle mass concentration measurements

Figure 19 AQMesh air quality monitor far-field particle mass concentration measurements for four different PM fractions

While the near-field CPC, SMPS, and OPC measurements were made close to the manikin, the far-field AQMesh air quality monitor measurements were made from the far corner of the room and hence assessed 'whole room' concentrations (assuming sampling of well-mixed air) instead of the local emission source. Figure 19 shows a time series of PM₁, PM_{2.5}, PM₄ and PM₁₀ particle mass concentrations measured by the AQMesh air quality monitor.

During the first 'BOFA off' period, where three AGPs were performed, the mass concentrations for the larger size fractions increase, but given the trends prior to 10:00, it is not clear that this can be firmly ascribed to AGP activity alone. The presence and activity of the three occupants in the closed surgery, for example, could have been a contributory factor to the increase in PM₁₀ mass concentration). The operation of the BOFA unit (11:10 onwards) does however correlate with significant falls across all size fractions displayed in Figure 19.

All measured particle mass concentrations appear to rise when the lunchtime break commenced and AGP and BOFA activity had stopped. However, the subsequent fall in PM₁₀ particle mass concentrations compared to the other size fractions during this time period should be noted. This is most likely due to the opening of the door to leave and re-enter the surgery; the influx of a small number of large particles, which would have a large effect on the particle mass concentration but a much smaller effect on the particle number concentration. This is supported by the lack of a significant increase in the particle number concentration in the OPC measurements in Figure 18 for the 12:15 – 13:40 period.

The rise in particle mass concentrations after the lunch break that occurred *before* AGP and BOFA activities recommenced corresponds to the three occupants re-entering the closed surgery at ~13:30. This suggests that the occupants' activity and/or the temporary opening of the surgery door led to an increase in aerosols in the vicinity of the AQMesh air quality monitor.

The afternoon period of AGP and BOFA activity again corresponds with a general falling trend for all the far-field particle mass fractions measured. Note that the baseline is similar to that achieved during the morning's AGP and BOFA activities – this is consistent with the near-field OPC results in Figure 18.

4. CONCLUSIONS

Near-field CPC & OPC particle number concentration measurements

- There was good repeatability in measured near-field particle number concentrations during the three AGPs performed with the BOFA unit off. This good repeatability provided confidence that conclusions drawn from data obtained from subsequent tests were valid.
- A significant decrease in near-field particle number concentrations measured by both CPC and OPC instruments was observed when AGPs were performed with the BOFA unit on.
- With the BOFA extraction head positioned 14 cm from the manikin ($x = 14$ cm, $y = 0$ cm, $z = 0$ cm), a decrease in CPC-measured particle number concentrations (particle size range: 4 nm to ~ 3 μm) of approximately 50 % was observed when AGPs were performed with the BOFA unit on, compared to when AGPs were performed with the BOFA unit off. The measured particle number concentrations were less than the overnight background concentrations.
- Also, with the BOFA extraction head positioned 14 cm from the manikin, a decrease in OPC-measured particle number concentrations (particle size range: 0.5 μm to 10 μm) of approximately 98 % was observed when AGPs were performed with the BOFA unit on, compared to when AGPs were performed with the BOFA unit off.

Extraction head positioning

- With the BOFA unit positioned on the LHS of the manikin, there appeared to be no significant difference in near-field CPC-measured particle number concentrations related to the positioning of the extract head. This was the case even though a slow fall of the head position (negative z direction) was observed during some of the measurements.
- With the BOFA unit positioned on the RHS of the manikin, increased CPC-measured particle number concentrations were observed when compared to the same position on the LHS of the manikin. These increases, however, were relatively small and it is therefore difficult to be certain of their significance. As with the tests on the LHS of the manikin, the exact positioning of the extraction head did not seem to affect the measured particle number concentrations, despite a slow fall of the head position being observed during some of the measurements.
- The positioning of the BOFA unit on the LHS or RHS of the manikin did not affect the OPC-measured particle number concentration. The distance from the manikin ($x = 14$ cm vs $x = 30$ cm) did however affect the reduction in the OPC-measured particle number concentration with the BOFA unit on compared to when the unit was off: a ~ 98 % decrease was observed at 14 cm compared with a ~ 95 % decrease at 30 cm. Care must however be taken when interpreting these results – although they show good repeatability, the 3% difference may be smaller than the overall uncertainty of the measurement.

Near-field SMPS particle size distribution measurements

- The near-field SMPS measurements showed that when the BOFA unit was on there was a significant reduction in the number of particles above 35 nm in diameter.
- The near-field OPC (OPSS) size measurements showed that when the BOFA device was running there was a large reduction in all particle sizes across its range (approximately 0.5 μm – 10 μm).

Far-field measurements (and comparison with near-field measurements)

- The AQMesh air quality monitor showed that the use of the BOFA unit lowered the measured far-field particle mass concentrations for all particle size fractions measured (PM_{10} , $\text{PM}_{2.5}$, PM_4 and PM_{10}).
- Comparing the far-field measurements to near-field measurements, the near-field OPC saw a similar trend in particulate number concentrations to the far-field AQMesh for particle size fractions up to 10 μm . The near-field background was reduced throughout the day of measurements and remained significantly lower than at the start of the day. This suggests that for the larger size fractions (above 150 nm), the BOFA unit was removing particles in both the near-field and the surgery as a whole.
- The CPC observed a different pattern to the instruments measuring larger particle sizes. Although use of the BOFA unit reduced the near-field CPC-measured particle number concentration, the particle number concentration increased again when the unit was switched off. This suggests that for the smaller particle size fractions (below 150 nm) the BOFA unit was only removing particles in the near-field and not in the surgery as a whole.

5. REFERENCES

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