

Effectiveness of Selected Air Cleaning Devices During Dental Procedures

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ABSTRACT

Introduction:

The recent COVID-19 pandemic has underscored the necessity of protecting health care providers (HCPs) against the transmission of infectious agents during dental procedures. To this end, the effectiveness of several air cleaning devices (ACDs) in reducing HCPs exposure to aerosols generated during dental procedures was estimated, separately or in combination with each other. These ACDs were a chairside unit capturing aerosols at the source of generation, and four ambient ACDs: a portable ambient ACD; a negative pressure module; a custom made, fan-operated and wall-mounted air filter (WMAF); and a smaller and passive version of the latter. The last three ACDs were intended for mobile dental clinics (MDCs) only.

Materials and Methods:

This assessment was performed in two different environments: in a dental clinic operator and in a MDC. Two dental personnel, acting in the roles of dentist and dental assistant, performed on simulated patient aerosol-generating and non-aerosol-generating procedures. For each 5-minute scenario, the cumulative exposure to airborne particulate matter 10 µm in size or smaller (PM₁₀) was determined by calculating the sum of all 1 second readings obtained with personal and ambient air monitors. The effectiveness of the ACDs in capturing PM₁₀ was estimated based on the capability of the ACDs to keep PM₁₀ level at or below the initial background level.

Results:

In all conditions assessed in the dental clinic operator, when both the chairside and portable ambient ACDs were functioning, an estimated effectiveness of 100% in capturing PM₁₀ was achieved. In the MDC, in all conditions where the chairside ACD was used without the negative pressure module, an estimated effectiveness of 100% was also achieved. The simultaneous operation of the negative pressure module in the MDC, which led to a room negative pressure of -0.25 inch wc, reduced the chairside ACD's effectiveness in capturing aerosols. Conversely, the use of the WMAF in the MDC in combination with the chairside ACD further reduced exposure to PM₁₀ below the initial background level. Nonetheless, in all conditions assessed in both settings (dental clinic operator and MDC), larger visible aerosols were produced, often landing on the surrounding environment. A fair portion of these aerosols landed on the inside of the chairside ACD flange.

Conclusions:

This assessment suggests that the use of the tested chairside ACD, by capturing aerosols at the source of generation, had the greatest impact on reducing exposure of dental personnel to PM₁₀ produced during dental procedures. This study also indicates that such exposure is further reduced with the addition of an ambient ACD. However, creating a negative pressure room as high as -0.25 inch wc can lead to air turbulence reducing the effectiveness of ACDs in capturing aerosols at the source. Furthermore, the presence of uncaptured droplets and spatter on the surrounding environment supports the need to complement the use of engineering controls with proper administrative controls and personal protective equipment, as recommended by governmental agencies and the scientific community for preventing the transmission of infection in health care settings.

INTRODUCTION

The recent COVID-19 pandemic has underscored the necessity of protecting HCPs against the transmission of infectious agents during dental procedures. Common infection control measures to reduce the potential risks associated with aerosols generated during dental procedures include the use of personal protective equipment, an antiseptic preprocedural rinse with a mouthwash, and a high-volume evacuator (HVE).¹ An additional engineering control to further reduce the concentration of aerosols consists of using an air purifying system.² Such a system can be expected to decrease the risk of exposure of dental personnel to severe acute respiratory

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syndrome coronavirus 2 (SARS-CoV-2) during the provision of dental care to patients known or suspected of being infected by the virus.³ Although ambient air monitoring and various modeling approaches have been used to investigate the effectiveness of air cleaning devices (ACDs) in removing dental aerosols,^{2,4} personal monitoring during dental procedures to confirm a reduced exposure to aerosols has not been thoroughly assessed. Consequently, through personal and ambient air monitoring, an assessment of the effectiveness of selected ACDs in capturing dental aerosols at the source and from the ambient air was conducted in two different environments: in a dental clinic operatory (1 Dental Unit Detachment Ottawa, ON) and in a mobile dental clinic (MDC; Canadian Forces Base Uplands, Ottawa, ON).

All the ACDs assessed used solely filtration to remove aerosols through high-efficiency particulate air filters. The selected ACDs assessed consisted of a chairside unit capturing aerosols at the source and of four ambient air filtering units intended to support the chairside ACD.

METHODOLOGY

Assessed ACDs

The following were the assessed ACDs:

- (1) A chairside ACD capturing aerosols at the source: MedEVAC-A Chair-side AirFlow (Quatro Air Technologies Inc., Pointe-Claire, QC, Canada) providing a filtering airflow of 150 cubic feet per minute (CFM);
- (2) A portable ambient ACD: AF400M ACD (Quatro Air Technologies Inc.) providing a filtering airflow of 300 CFM;
- (3) A negative pressure module intended to be used to exhaust air directly outside the MDC: XPOWER X-2580 Professional 4-Stage HEPA Mini Air Scrubber (AS; XPOWER, City of Industry, CA, USA) providing a filtering airflow of 300 CFM;
- (4) A custom-made fan-operated wall-mounted air filter (WMAF) connected to the MDC's heating, ventilation, and air conditioning (HVAC) system and providing a combined filtering airflow of 1,080 CFM; and
- (5) A passive (i.e., no integrated fan) and smaller version of the latter (SWMAF) tested at the MDC and leading to a filtering airflow of 480 CFM provided by the HVAC system.

Dental Procedures

Dental procedures were performed on a full-scale simulated patient (head only) with extracted human teeth (none contained restorative materials) by personnel performing the tasks of a dentist and of a dental assistant. The same two dental providers took part in both assessments (dental clinic operatory and MDC), keeping their respective role. The dentist was right handed and operated from the 11 o'clock position with the dental chair reclined as normal (patient supine).

Testing conditions included aerosol-generating procedures (AGPs) and non-aerosol-generating procedures (NAGPs; at the dental clinic operatory only). The AGPs consisted of the dentist preparing the teeth using a high-speed air-driven hand piece with #557 carbide burs, with the air-water spray coolant turned on as normal. The NAGPs consisted of the dentist preparing the teeth using a low-speed electric-driven hand piece with #6 and #8 round carbide burs, with the air-water spray coolant turned off. Burs were changed when dull. In all cases, an HVE suction was used full-time by the dental assistant to replicate effective four-handed dentistry. The air-water syringe was used as normal procedure (to clean and dry the teeth) during AGPs, but not during NAGPs.

The dental procedures were standardized in order to limit differences in aerosol generation from one condition to another. Each 5 minute dental procedure was conducted by dental personnel as follows: consecutive 1 minute posterior occlusal preparations in quadrant 1 (maxillary right), quadrant 2 (maxillary left), quadrant 3 (mandibular left), and quadrant 4 (mandibular right), and ending with a 1 minute maxillary incisor endodontic access preparation.

Determination of the Optimal Position of the Chairside ACD Flange

The optimal position of the chairside ACD flange was determined by measuring the capture velocity at the mouth of the simulated patient. The optimal position had to simultaneously allow for adequate visibility and freedom of movement for four-handed dentistry, while maximizing the air flow velocity at the operating field. A smoke tube test was performed to visualize the air flow pattern and to ensure the best positioning of the ACD flange.

Personal and Ambient Air Monitoring of PM₁₀

The majority (90%) of aerosols produced in dental settings are smaller than 5 μm .⁵ Consequently, particulate matter 10 μm in size or smaller (PM₁₀) were the selected aerosols to monitor for this assessment.

Personal monitoring of PM₁₀ was measured in the breathing zone of the dentist and of the dental assistant using laser photometers (SidePak AM510). PM₁₀ levels were also measured in the ambient air via two laser photometers (DustTrak DRX). A one-second logging interval was used by all photometers to record PM₁₀ levels during each test. Testing time was 5 minutes per condition assessed. The recorded value for each condition assessed was the cumulative exposure of all 1 second readings. At both locations, the background levels of PM₁₀ were measured first. This measurement was taken by having the ACDs functioning until PM₁₀ concentrations stabilized (chairside and portable ambient ACDs in the dental clinic operatory; chairside ACD and WMAF in the MDC). Measurements (1 second readings) that were more than 50 times higher than the calculated averages were considered outliers and excluded from data analysis.

Assessment in the Dental Clinic Operatory

Aside from background PM₁₀ levels, three conditions were assessed during NAGPs and AGPs, for a total of six conditions during which personal and ambient air monitoring of PM₁₀ was performed:

- (1) Chairside ACD off and portable ambient ACD off (both ACDs off);
- (2) Chairside ACD on; and
- (3) Chairside ACD on and portable ambient ACD on (both ACDs on).

Assessment in the MDC

In the MDC, operations were limited to 5 minute AGP scenarios. In addition to the measurement of PM₁₀ background levels, personal and ambient air monitoring of PM₁₀ was performed for a total of eight conditions representing various combinations of all five ACDs previously mentioned.

Room Characterization

The dental clinic operatory measured 17'3" by 13'4", with a height of 8'1" for a room volume of 1,860 ft.³ The MDC measured 14'3" by 14'3" with a ceiling at 7'1" for one half of the room and gradually descending to a minimum height of 6'3" from the centerline to the other side of the room, for a total volume of 1,400 ft.³ At both locations, the total supply and/or exhaust airflow was measured using a thermoanemometer (TSI VelociCalc) or an air capture hood (TSI AccuBalance) in order to calculate the air changes per hour

(ACH). Room differential pressure was measured using the TSI VelociCalc.

Calculation of the Effectiveness of the Chairside ACD in Capturing PM₁₀

From the cumulative exposures obtained from personal monitoring, the effectiveness of the ACDs could be estimated as follows: $(PM_{10\text{OFF}} - PM_{10\text{ON}}) / (PM_{10\text{OFF}} - PM_{10\text{Background}}) \times 100\%$, using the values obtained with (ON) and without (OFF) the ACD(s) functioning.

RESULTS

Adjustment of the Chairside ACD Flange

The chairside ACD flange, when placed at a distance of 7.25 inches from the mannequin's nose and 0.5 inch from the mannequin's chin, provided the highest capture velocity achievable at the patient's teeth: 47 feet per minute.

Dental Clinic Operatory

The dental clinic operatory had an ACH of 6 and room pressure was neutral. Personal monitoring on the dentist and dental assistant performing AGPs and NAGPs showed that having both the portable ambient air and chairside ACDs functioning, and to a lesser extent the chairside ACD alone, decreased on average the level of PM₁₀ that dental providers are exposed to (Fig. 1).

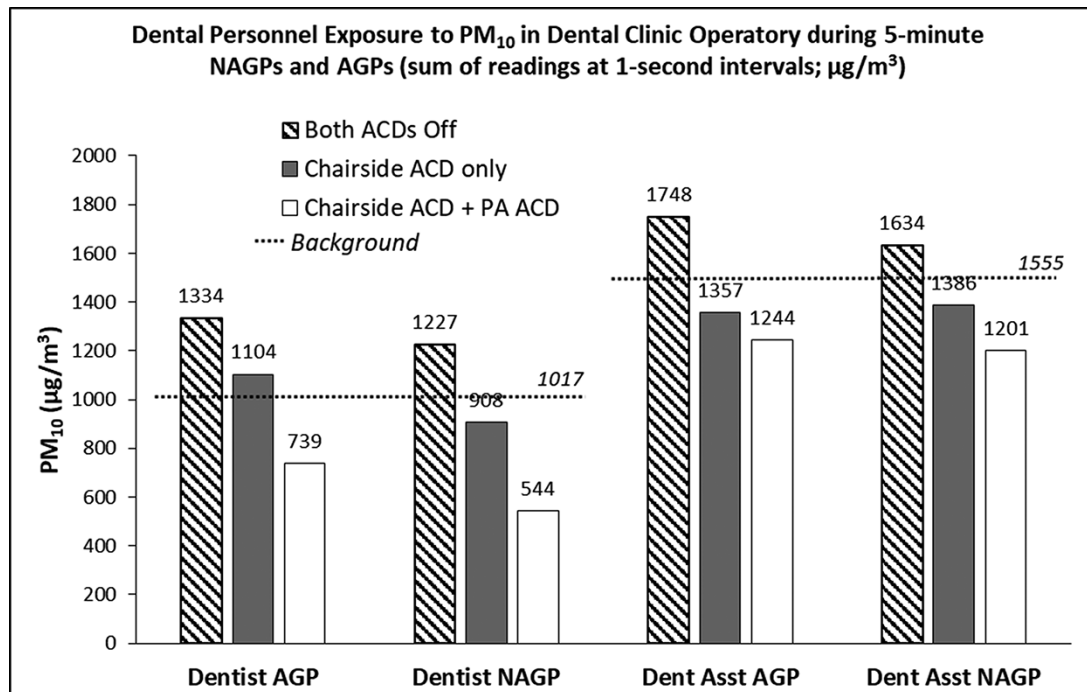


FIGURE 1. Dentist and dental assistant (Dent Asst) cumulative exposure to PM₁₀ in the dental clinic operatory during aerosol-generating procedures and non-aerosol-generating procedure with different combinations of air cleaning devices (ACDs). PA, portable ambient (ACD).

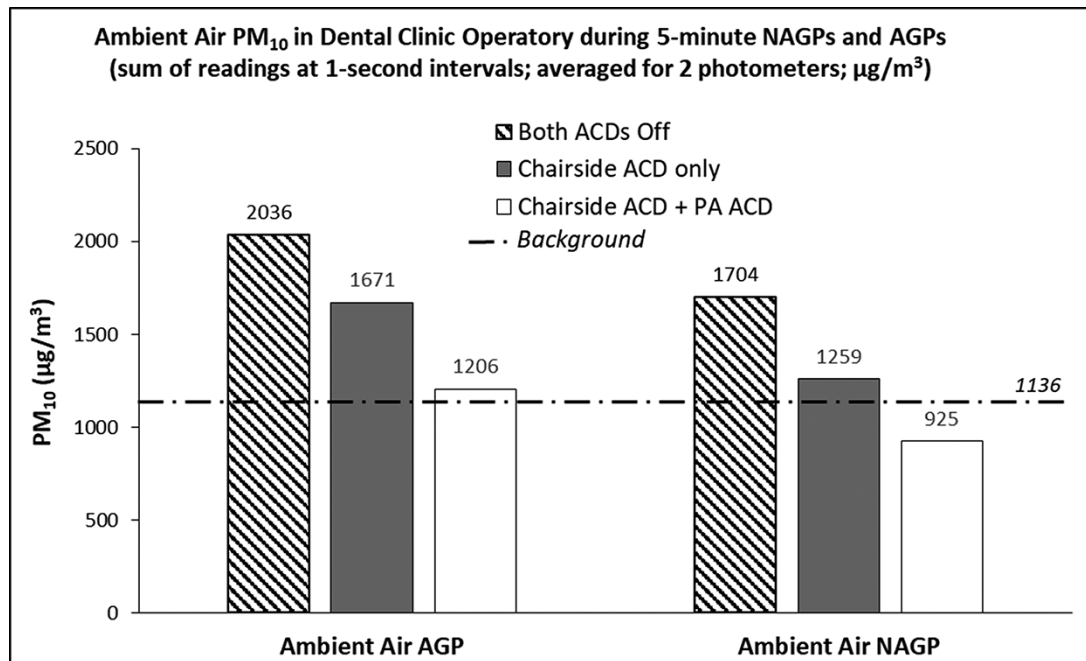


FIGURE 2. PM₁₀ ambient air concentrations in the dental clinic operatory during aerosol-generating procedure and non-aerosol-generating procedure with different combinations of air cleaning devices (ACDs). Both ACDs, chairside and portable ambient ACDs. PA, portable ambient (ACD).

For all assessed conditions, the lowest PM₁₀ levels in ambient air were recorded when both ACDs were in operation (Fig. 2). After an AGP without any ACD functioning, returning ambient air PM₁₀ levels to background levels by reactivating the portable ambient air and chairside ACDs took 7.5 minutes as opposed to an undetermined time above 30 minutes without any ACDs.

Mobile Dental Clinic

The MDC was under a negative pressure of -0.250 inch wc and had an ACH of 13 when the negative pressure module was functioning. Results from personal monitoring conducted on the dentist showed that the highest cumulative exposure was obtained with the WMAF and negative pressure module in operation, which was even higher than when there was no air filtration unit functioning (Fig. 3). The lowest cumulative exposure was achieved with the WMAF functioning with the chairside ACD. The four conditions with the negative pressure module functioning are among the highest concentrations recorded. Dentist exposure to PM₁₀ when the SWMAF and the negative pressure module were functioning was above background but lower than the “all off” condition, with the addition of the chairside ACD, exposure was reduced by a factor of three. When only the chairside ACD was functioning, with or without the portable ambient ACD, dentist exposure to aerosols was reduced below background levels.

As observed from personal monitoring conducted on the dentist, the dental assistant’s cumulative exposure to PM₁₀ in all assessed configurations that included the chairside ACD were at or below that of the “all on” condition (WMAF,

chairside ACD, and negative pressure module on) and were similar to background levels (Fig. 3). Configurations without the chairside ACD were similar to or exceeded the “all off” condition. Logged per-second data could not be extracted for the dental assistant due to technical issues and the cumulative exposure was calculated by multiplying the recorded concentrations by 300 (seconds).

Cumulative exposures to PM₁₀ calculated from ambient air concentrations were equivalent to background levels under the “all on” condition; they were also at background levels under the “all off” condition but with an increased fluctuation of PM₁₀ concentrations. Both configurations with the negative pressure module functioning without the chairside ACD led to an ambient air concentration of PM₁₀ above the background level.

Estimated Effectiveness of the Chairside ACD under Various Conditions

In all conditions assessed in the dental clinic operatory, when both the chairside and ambient air ACDs were functioning, an effectiveness of 100% was achieved (Supplementary Table S1). In the MDC, in all conditions where the chairside ACD was used without the negative pressure module, an effectiveness of 100% was achieved (Supplementary Table S2).

Though an effectiveness of 100% at capturing PM₁₀ was calculated for specific conditions, in all cases, larger visible droplets and aerosols were produced, often landing on the surrounding environment, uncaptured by the chairside ACD. A fair portion of these debris also landed on the inside of the chairside ACD flange.

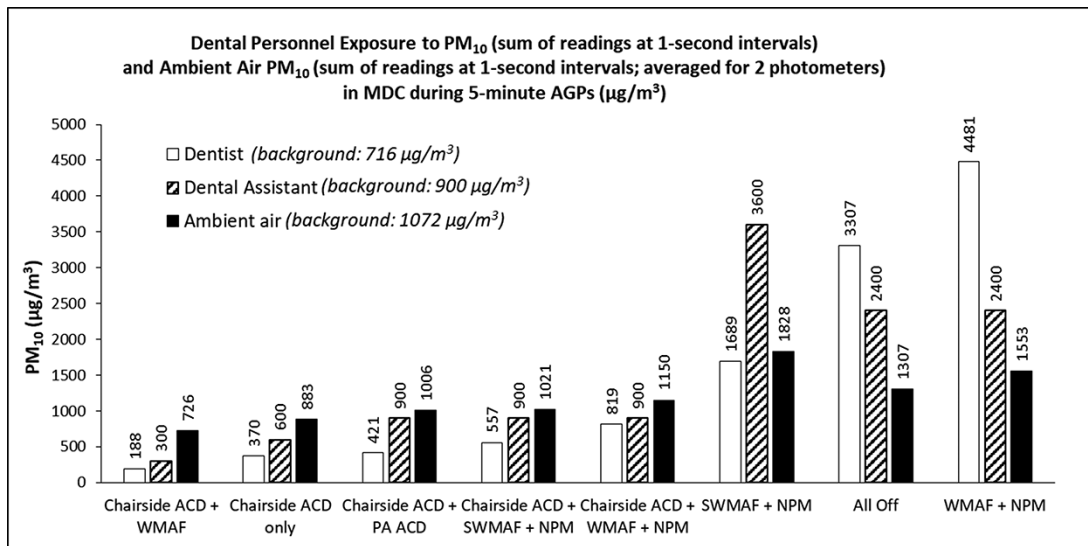


FIGURE 3. Participants' cumulative exposure to PM₁₀ in the MDC during aerosol-generating procedures with different combinations of air cleaning devices (ACDs). CS, chairside; PA, portable ambient (ACD); WMAF, wall-mounted air filter; SWMAF, Small WMAF; NPM, negative pressure module.

DISCUSSION

Effectiveness of the Assessed ACDs

During AGPs and NAGPs in the dental clinic operatory, the chairside ACD decreased cumulative exposure to PM₁₀ to background levels in many scenarios tested, and a further decrease was observed when used in combination with the portable ambient ACD. This observation was made from both personal and ambient air monitoring. This shows that capturing a contaminant at the source not only limits exposure of dental providers to aerosols but also limits these aerosols from diffusing in ambient air and from dispersing in the general ventilation system. This is consistent with studies that showed the effectiveness of ACDs in controlling aerosol dispersion emitted from a patient's mouth in dental clinics.^{2,6-8}

The use of the portable ambient ACD in the dental clinic operatory not only decreased PM₁₀ concentrations in the ambient air but also decreased the exposure of dental providers to the generated aerosols during the procedures as shown by the results from personal monitoring. This observation is supported by the known ability of aerosols produced in dentistry to remain airborne, contributing to an increased exposure in the absence of effective controls.⁹

Studies and governmental agencies recommend using a negative pressure isolation room as the preferred model for protecting health care providers when performing care to a patient suspected or known to carry an infectious agent, to include patients with COVID-19.^{2,10-12} Both the U.S. CDC and the Academy of Architecture for Health recommend a minimum pressure differential of 0.01 inch water gauge to sustain a negative pressure room.^{13,14}

Although a negative pressure was easily achieved in the MDC, results from PM₁₀ monitoring indicate a decrease in the efficiency of the chairside ACD. The creation of a relatively

high negative pressure (−0.250 inch WC) in such a small room through the use of the negative pressure module may create air turbulence and cross drafts that decrease the efficiency of the chairside ACD to capture aerosols generated by dental procedures. Miller-Leiden et al. (1996) explain that both the air flow configuration of the ACDs and their placement within the room are important, influencing room air flow patterns and the spatial distribution of airborne particulates. Also, it can be noted that the dental chair was angled compared to the air flow generated by the pressure gradient in the MDC (from the front of the MDC to the back). Air drafts crossing the front section of the chairside ACD flange could prevent particles from being effectively captured by the ACD.

The estimated effectiveness of the chairside ACD in various conditions demonstrates that combining the filtration capacity of an ACD capturing aerosols at the source and of another filtering ambient air leads to the lowest PM₁₀ concentrations possible with the various ACDs assessed. This is consistent with a former study demonstrating that the key to aerosol control is to capture droplet nuclei in high concentrations near the source before they disperse throughout the room.⁸ The same study also explains that an additional ambient air filtration unit offers supplementary protection by capturing dispersed droplet nuclei.

Though the majority (90%) of aerosols produced in dental settings are smaller than 5 μm, and the larger generated aerosols (droplets (≤50 μm) and spatter (>50 μm)), nonetheless, represent a significant volume.^{1,5} As such, though an effectiveness of 100% in capturing PM₁₀ was calculated for the chairside ACD for many assessed conditions, larger uncaptured aerosols were visibly contaminating the surrounding surfaces. This reinforces the need, even when ACDs are used during dental procedures, for the proper donning of personal protective equipment and the

implementation of efficient administrative controls as recommended by governmental agencies and the scientific literature.^{11,12,15–19} Also, though the initial background PM₁₀ level was used as a surrogate indicating the complete clearance of aerosols generated during dental procedures, it is understood that such PM₁₀ level would most likely contain a proportion of aerosols generated during the dental procedures. Leaving the ACDs functioning after the dental procedures would facilitate the clearance of the remaining dental aerosols.

Limitations

Statistical significance was not expected in this assessment given that only two dental providers were available and the high number of conditions to assess for the resources and time available. Furthermore, the measured concentrations were relatively low, close to the detection limit of the photometers (1 µg/m³). This can be explained by the use of the HVE as part of scenarios reflecting standard dental practice. The latter is expected to contribute significantly to dental aerosol removal.

CONCLUSIONS

Results from this assessment indicate that the use of the chairside ACD, by capturing aerosols at the source of generation, had the greatest impact on reducing exposure of dental personnel to aerosols generated during AGPs and NAGPs, regardless of the type of dental operatory and room pressure, often bringing PM₁₀ concentrations to background levels. In both environments assessed, when the chairside ACD was used in combination with specific ambient ACD (portable ambient ACD in the dental clinic operatory and WMAF in the MDC), the airborne particulate concentrations were reduced even further, often falling below background levels, leading to an estimated effectiveness of 100% at capturing PM₁₀. Thus, it is expected that the combination of the chairside ACD with the portable ambient ACD (in dental clinic operatory) or with the WMAF (in MDCs) would decrease the dental providers' exposure to SARS-CoV-2 containing aerosols while performing dental procedures.

In most assessed conditions in the MDC, the use of the negative pressure module increased exposure to PM₁₀ during AGPs. This observation suggests that achieving a lower negative pressure room closer to -0.01 inch wc at that particular location may be preferable to a highly negative pressure room.

The presence of uncaptured droplets and spatter on the surrounding environment indicates the need to complement the use of the chairside ACD with proper administrative controls and personal protective equipment, as recommended by governmental agencies and the scientific community for preventing the transmission of infection in health care settings.

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SUPPLEMENTARY MATERIAL

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CONFLICT OF INTEREST STATEMENT

None declared.

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