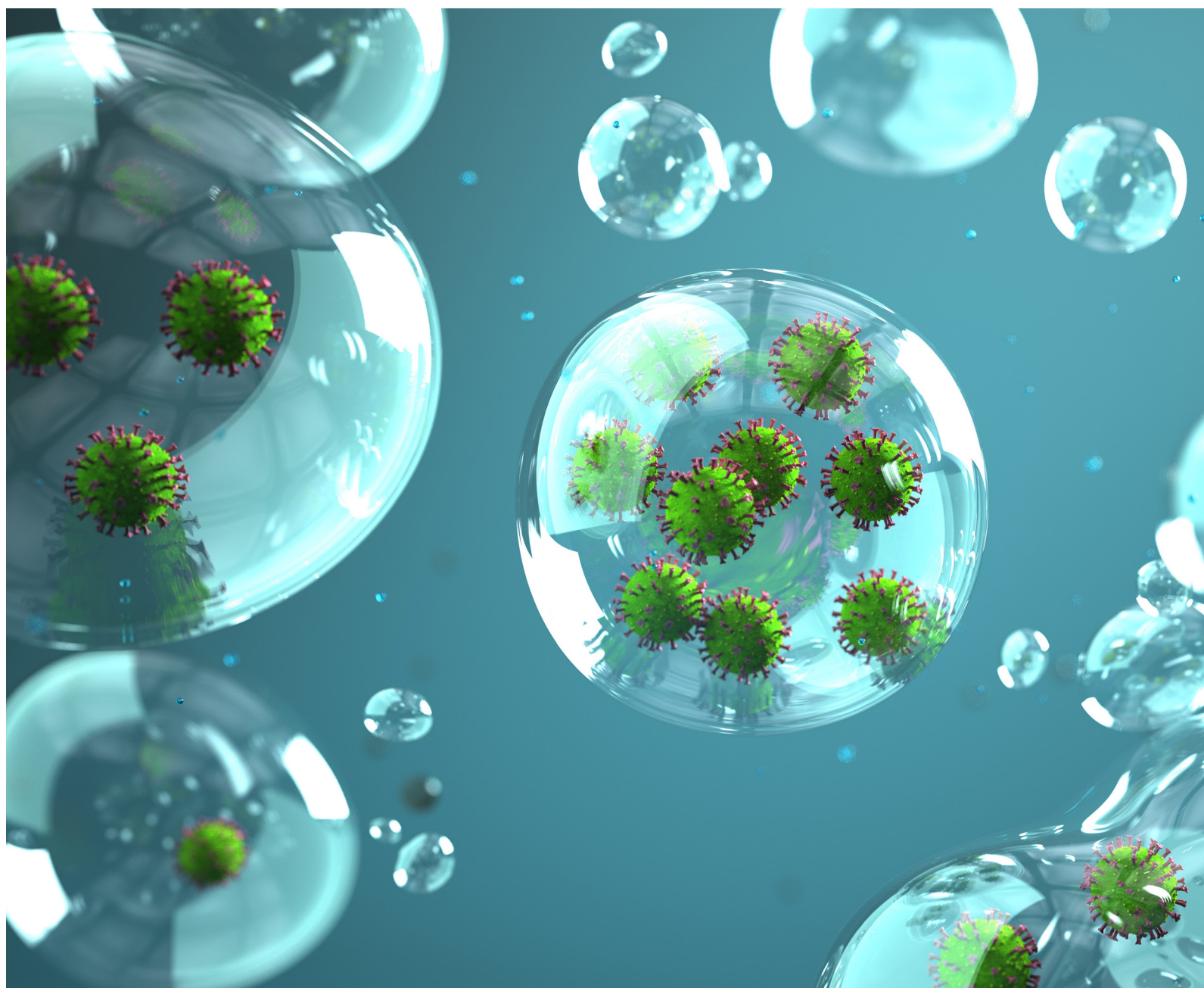




WHITE PAPER
AEROSOL MANAGEMENT DURING DENTAL PROCEDURES,
IN AND AROUND THE ORAL CAVITY



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NOTE/DISCLAIMER

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In reference to potential equipment solutions and methods described in this white paper: various combinations of different devices available today may improve the capture of aerosols and droplets, but depend on user needs, objectives, and how the procedure is performed. No single approach or device discussed within this paper can eliminate the risk of infection to dental health care professionals and patients. The intent is to offer information about dental aerosols and measures to control against the hazards they present.

ABSTRACT

Aerosol management in dentistry is reviewed with current knowledge on the subject including sources, suspension time, aerosol composition and particle sizes, dependence upon procedure, and exposure risks of both droplets and aerosol particles. Centers for Disease Control and Prevention (CDC), American Dental Association (ADA) and World Health Organization (WHO) guidance documents related to aerosol controls for dental healthcare settings pertaining to aerosol controls are reviewed. Aerosol reduction and control approaches including Engineering Controls are presented and discussed with focus on the practitioner and clinic infection control implementation.

Keywords

Dental aerosol, aerosol management, high-volume evacuation, high-volume evacuator (HVE), saliva ejector (SE), supplemental vacuum, dental splatter, COVID-19, SARS-CoV-2, droplet nuclei, healthcare-associated infections, bacteria, viruses, vacuum, CDC Guidelines, ADA, WHO, dental dam, infection control, source control, engineering control, pre-procedural mouth rinse, third hand, high speed handpiece, air/water syringe, ultrasonic scaling, sonic scaling, polishing, *Mycobacterium tuberculosis*, TB, *Legionella pneumophila*.

ABBREVIATIONS

ADA – *American Dental Association*

AGP – *aerosol generating procedure*

AORN – *Association of periOperative Registered Nurses*

CADR – *clean air delivery rate*

CDC – *U.S. Centers for Disease Control and Prevention*

CFU – *colony-forming unit*

COVID-19 – *Coronavirus disease 2019*

DHCP – *Dental Health Care Personnel*

EPA – *U.S. Environmental Protection Agency*

HAI – *healthcare associated infection*

HEPA – *high-efficiency particulate air*

HBV – *hepatitis B virus*

HICPAC – *Healthcare Infection Control Practices Advisory Committee*

HVAC – *heating, ventilation, air-conditioning*

HVE – *high-volume evacuation or high-volume evacuator*

NIOSH – *National Institute of Occupational Safety and Health*

OSHA – *Occupational Safety and Health Administration*

PPE – *personal protective equipment*

PPMR – *preprocedural mouth rinse*

SARS-CoV-2 – *Severe acute respiratory syndrome coronavirus 2 (the virus that causes COVID-19)*

SCFM – *standard cubic feet per minute*

SE – *saliva ejector*

TB – *tuberculosis (a disease caused by Mycobacterium tuberculosis bacteria)*

UVGI – *ultra-violet germicidal irradiation*

WHO – *World Health Organization*

INTRODUCTION

The transmission of pathogenic microorganisms by way of airborne droplets and aerosol particles containing infectious agents may pose a significant risk in dental clinics [1]. Concerns over airborne transmission of pathogenic bacteria including *Legionella pneumophila* and *Mycobacterium tuberculosis*, and viruses including Measles, Mumps, Rubella, and respiratory viruses in a wide range of settings are long standing. Recently due to SARS-CoV-2, the virus that causes COVID-19, more attention has been directed towards understanding transmission risks of respiratory viruses via droplets and aerosols. Dental clinics face particular challenges due to the considerable amount of aerosols and droplets generated during dental treatment. The potential for transmission of other diseases by airborne particulates and droplets produced in aerosol generating procedures (AGPs) in dentistry has been recognized for years, providing a foundation of knowledge and established control measures on which to develop further insights for effectively managing new exposure risks including those associated with COVID-19 transmission.

This paper reviews evidence-based information concerning the generation of aerosols and droplets in dentistry, their potential for transmitting disease and effective measures to mitigate the risks due to aerosols and droplets. Guidance from the U.S. Centers for Disease Control and Prevention (CDC), American Dental Association (ADA), and World Health Organization (WHO) related to dental aerosols and droplets are also discussed.

BACKGROUND

Aerosols and Their Sources

An aerosol is formally defined as a suspension of fine solid particles or liquid droplets in a gas or air [2]. Aerosolized particles composed of liquids, solids, or mixtures become suspended in air for several seconds to much longer periods of time, or even indefinitely under some indoor conditions [3]. The composition of aerosolized particles depends on the source processes in which they are formed. In dental healthcare settings, aerosols and droplets with infectious material can be introduced through a number of source processes, including (and as shown in **Figure 1** on page 6):

- physiological processes (breathing, coughing, sneezing, talking)
- facility environmental processes (heating, ventilation, air-conditioning (HVAC) systems; airflow movement), and
- dental treatment processes (which generate airborne fluids and particulates from the patient along with coolant or irrigating solutions from instrumentation)

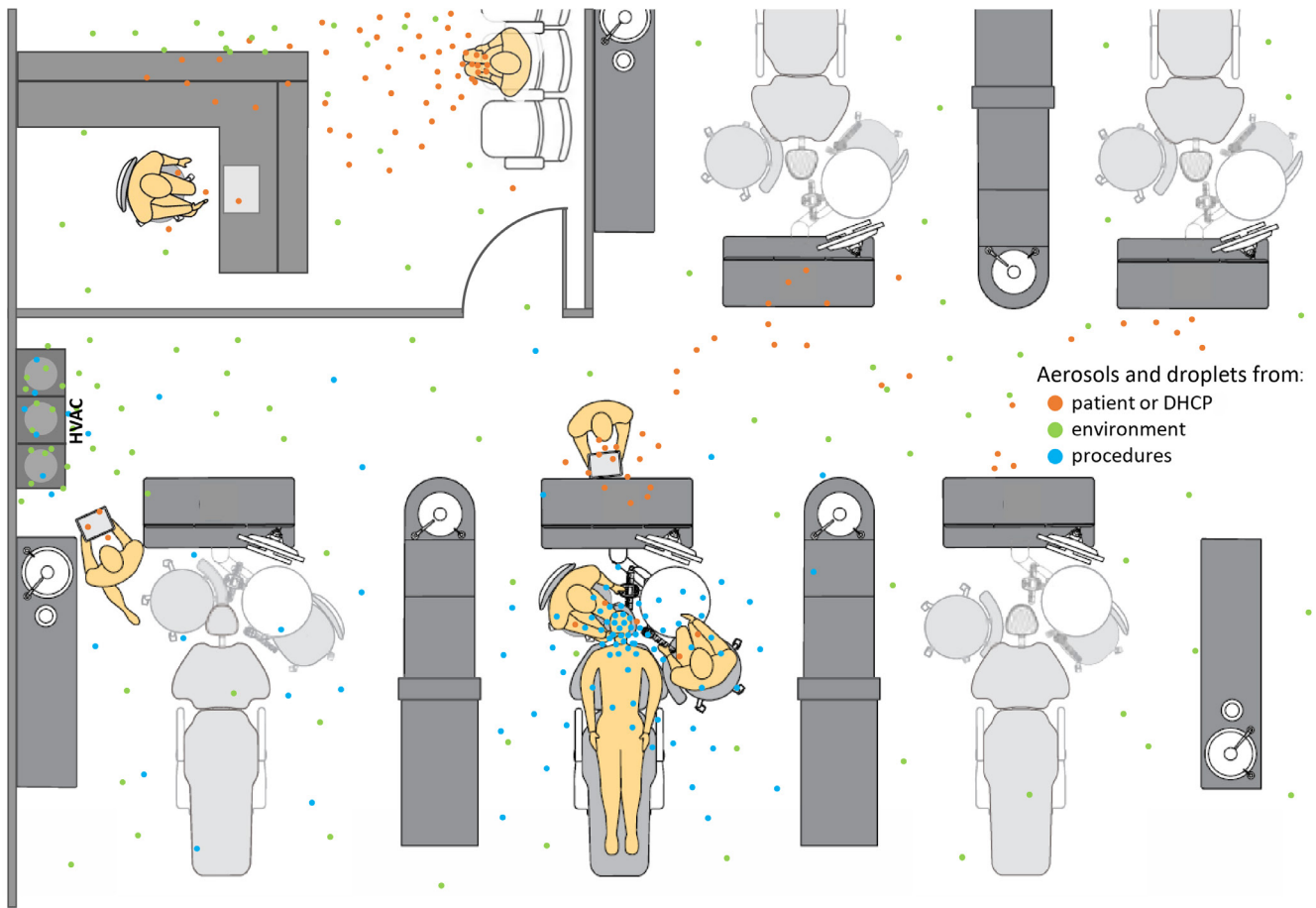


Figure 1. Three potential sources of aerosol particles and droplets in the dental clinic.

In dental clinics, these aerosol source processes may also take place at the same time, each contributing incrementally to the total amount of suspended particles and resulting in mixtures from multiple sources and AGPs. The increased prevalence of AGPs in dentistry, presents a heightened challenge for dental clinics in managing the transmission risks of various infectious diseases, such as COVID-19.

Physiologically produced aerosols and droplets that contain infectious microorganisms are generated through talking, respiration, sneezing, and coughing by infected patients and dental health care personnel (DHCP) in the clinical environment [4]. The aerosol and droplet spray patterns from these source processes can vary greatly, including cone-shaped jets (from speaking) or turbulent clouds (from coughing or sneezing) that can travel up to 8 m (26') [4]. With the close proximity of patient and the DHCP during treatment (which is typically closer than 60 cm [2']), exhalation is a high-risk factor for both airborne spread and direct droplet exposure, even in the absence of any AGPs [5].

Environmental sources of aerosols from both outside and inside of the dental treatment room are present in dental healthcare facilities. Aerosolized bacteria and viruses from the outdoor environment can be brought inside through heating and cooling systems as well as compressed air systems. Aerosolized particles originating from adjacent rooms can be transported through ducting or air currents into a dental treatment room. The treatment room environment may also contain previous aerosol particles

and droplets that settled on work surfaces, equipment, furniture, flooring, and other locations and subsequently became re-aerosolized.

Through visual observations and some limited quantitative measurements, many dental treatment procedures are known to be aerosol and droplet generating. Treatment procedure aerosols and droplets are composed of coolant water, patient saliva and nasopharyngeal secretions, dental plaque, blood, tooth components, dental materials used in the procedure, and patient exhaled air mixtures [6, 7, 8]. There are multiple mechanisms responsible for aerosolized and droplet particles exiting the patients' mouth: fluid mixtures splash against the soft and hard palate, tooth, tongue or gingiva to create droplets; the fluids contact high rotational speed instruments causing rapid directional changes in the fluid flow and droplet momentum; and turbulent mixing of air and fluid, and disruption of fluid surface tension generating large numbers of aerosol and droplet particles [9]. These mechanisms typically occur whenever handpieces and other powered dental instruments are used in procedures [8, 9, 10].

Particle Sizes and Suspension

Particle sizes are critical to defining physical behavior and exposure routes for both aerosols and droplets, as well as for risk assessments for cross-transmission of pathogens. Various size ranges have been used to define and describe the terms 'aerosol' and 'droplet' and are commonly expressed in units of micrometers (μm). Size classification based on aerodynamic diameter is the most frequently used method for defining and describing particle behavior concepts: aerosols remain suspended and droplets quickly fall out of the air indoors [2, 3]. For this paper, we consider aerosol particles to have a diameter of less than $10 \mu\text{m}$ and droplets to have a diameter larger than $10 \mu\text{m}$ [11].

It is visually observable during patient treatment involving dental AGPs that a range of droplet sizes are produced. Particles in the range of $1 - 10 \mu\text{m}$, which are too small to see, have been detected in the spray generated from an air/water syringe, electric high-speed handpiece, air-driven high-speed handpiece, low-speed handpiece with water, and ultrasonic scaler [12]. Based on these measurements and data for suspension time and distance traveled, particle size ranges from AGPs potentially span ultra-fine particles (below $1 \mu\text{m}$) to large droplets ($500 \mu\text{m}$).

In reality, there is not a precise size cut-off differentiating suspended particles from settling particles since factors other than size also influence whether a particle remains suspended or quickly settles. Dynamic behavior of droplets found in dental clinics is affected by evaporation, agglomeration, de-agglomeration, charge effects, and release from surfaces [2, 13]. Evaporation of droplets is driven by factors including room temperature, relative humidity, velocity, and air currents. There is a critical droplet size above which the evaporation does not occur quickly enough, and the droplet continues to fall. Below this critical droplet size, evaporation is sufficiently rapid so a particle that was initially settling becomes a sufficiently small particle (or droplet nuclei) to remain suspended for a measurable time [14]. The historic work of Wells showed that droplets less than $100 \mu\text{m}$ can reduce in size into infectious droplet nuclei while falling from a height of 2 m [3]. The discussion of particle sizes is critical to the understanding how diseases may be transmitted, how long particles are suspended, and where contamination spreads.

Aerosol particle sizes are relevant to infectious disease transmission. From a disease transmission perspective, aerosol size ranges may be classified based on where particles contact within the respiratory system (see Figure 2): respirable aerosols that reach bronchioles and alveoli are $< 2.5\text{-}5\ \mu\text{m}$; thoracic aerosols that reach into the trachea and large intrathoracic airways are $< 10\text{-}15\ \mu\text{m}$; inhalable aerosols that contact the mouth, throat, and nose are $100\text{-}200\ \mu\text{m}$; and droplets $> 200\ \mu\text{m}$ that may splash into mucus membranes [15]. These contact areas may all be transmission sites for infectious aerosols or droplets. Aerosols less than $5\ \mu\text{m}$ in size have the greatest penetration to all areas of the respiratory system, including the lower respiratory tract, and have been associated with transmission of pathogens including *Mycobacterium tuberculosis* [16]. Due to a lack of sufficient evidence specific to the SARS-CoV-2 transmission pathways, airborne aerosol particle and droplet transmissions must both be considered relevant [11, 16, 17].

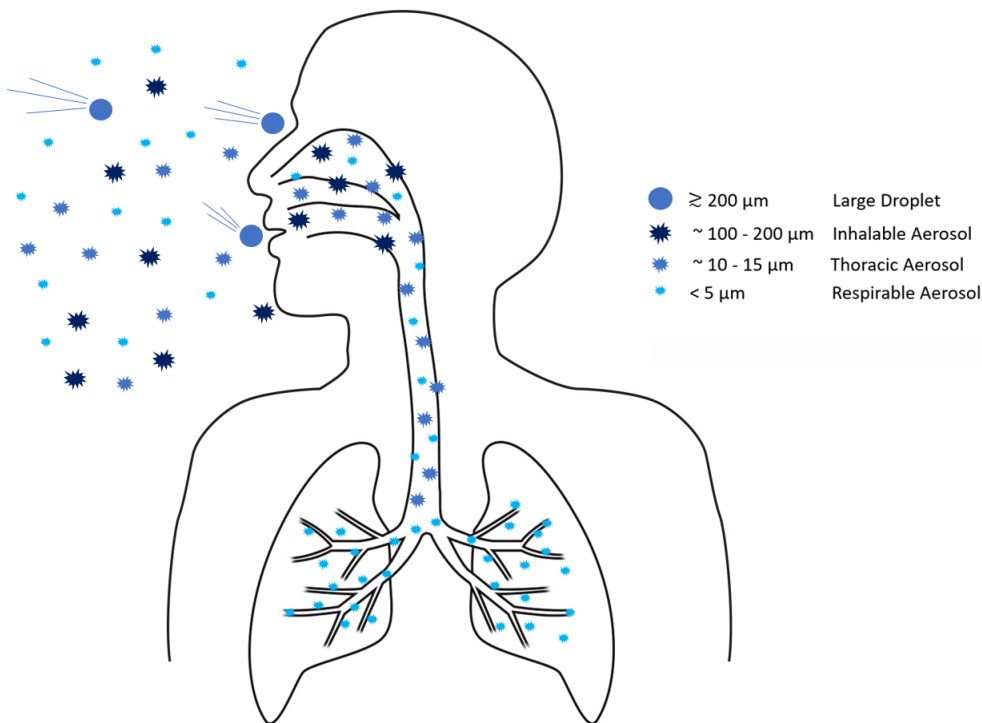


Figure 2. Aerosol particle and droplet sizes and potential high-risk contact areas [15].

Dental aerosols can remain suspended in the dental clinic air for several minutes up to a much longer period of time and travel great distances depending on environmental conditions (see **Figure 3** on page 9).

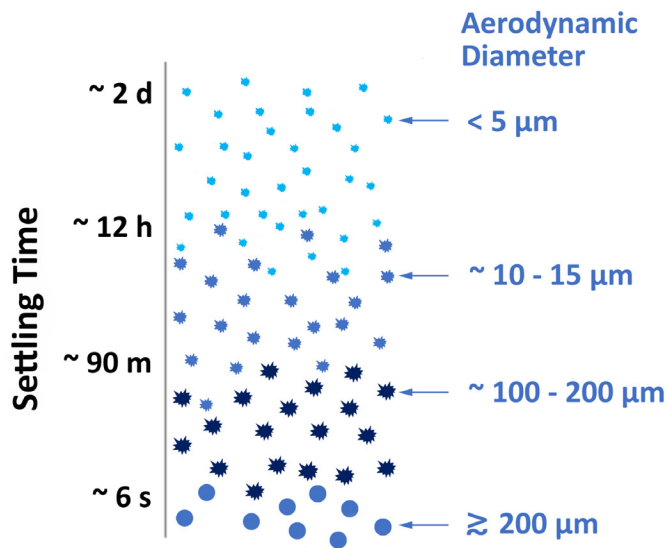


Figure 3. Estimated particle settling times in turbulent air of an 8' (244 cm) high room [13].

Particles from AGPs can remain suspended long after the procedure is completed, so a higher risk of exposure may persist. Studies using spectrofluorometric analysis reported particle settling from AGPs up to 2 - 4 m (6.6 - 13') away from the patient's mouth [15]. Appropriate methods for isolating and detecting smaller AGP-generated particles classified as respirable and thoracic aerosols, which may be transported even further distances, have not been applied in dental clinics. The long settling times of smaller particles poses even greater challenges for controlling infectious airborne and settled contaminants in dental clinics with open floor plans. In these layouts, small particles can be transported between patient sites and settle outside of the vicinity of the dental chair where they were generated.

Aerosol Formation – Dependence on Procedure

The amount, size distribution, and composition of aerosols and droplets generated by various dental procedures varies according to the type of instruments involved and the nature of the procedure. The main sources of dental aerosols and droplets that are known or suspected include procedures that utilize ultrasonic and sonic scalers, air polishing and abrasive devices, low and high-speed handpieces (electric and air-driven), air/water syringes, and lasers [8, 9, 12, 18]. Ultrasonic scalers have been studied more extensively and have been shown to produce sprays of aerosols and droplets that present an exposure risk [10]. As Kumar and Subramanian have identified gaps in research, only limited evidence on air/water syringe sprays is available, and it is unknown if all particle sizes (associated with infection exposure risks) result in relevant quantities [9]. Air abrasion and air/water syringe contamination levels are unknown due to lack of studies available. See **Table 1** on page page 10 for a summary of known or potential AGPs based upon literature sources and the World Health Organization (WHO) definition of AGPs in oral healthcare. A definitive and comprehensive list of AGPs for dentistry has not been possible due to lack of data.

Table 1. Dental procedures known or suspected to be aerosol generating and clinical evidence.

Dental Procedure	Clinical or Literature Evidence
Ultrasonic scaling and polishing (dental cleaning)	Dye indicator and bacterial growth studies
3-Way Air / Water Spray (Individually)	Particle size measurement
Periodontal treatment with ultrasonic scalar	Indicator and bacterial studies
Any preparation with low or high-speed handpieces	Indicator and bacterial studies
Direct and indirect restoration and polishing	Indicator and bacterial studies
Definitive cementation of crown or bridge	None found
Mechanical endodontic treatment	None found
Surgical tooth extraction and implant placement	None found

Procedure-Generated Aerosol Composition

Procedure-generated dental aerosols are composed of saliva, coolant water, blood, dental materials, dust, and other atmospheric particles present in the clinic [9]. Estimates put the ratio of saliva to water coolant in dental aerosols from all devices between 1:20 and 1:100 [9]. This could potentially mean 95-99% of aerosols are composed of water coolant. The implications of this are that coolant water contamination should not be overlooked and that oral or respiratory pathogen content is diluted from levels found in saliva or blood if the mixture is homogenized.

Exposure Risks

With numerous interacting factors, assessing exposure risk in the dental clinic is difficult. There is a lack of quantitative data available on saliva-sourced respiratory infections to determine the biologically relevant infectious dose for specific pathogens. In addition to saliva as a source of contamination in airborne particles, there is also evidence that blood in aerosols and droplets can potentially increase risks of cross-transmission of some pathogens, including the hepatitis B virus (HBV) [7]. See **Figure 4** on page 11 for a summary of potential factors that impact transmission risk in the dental clinic.

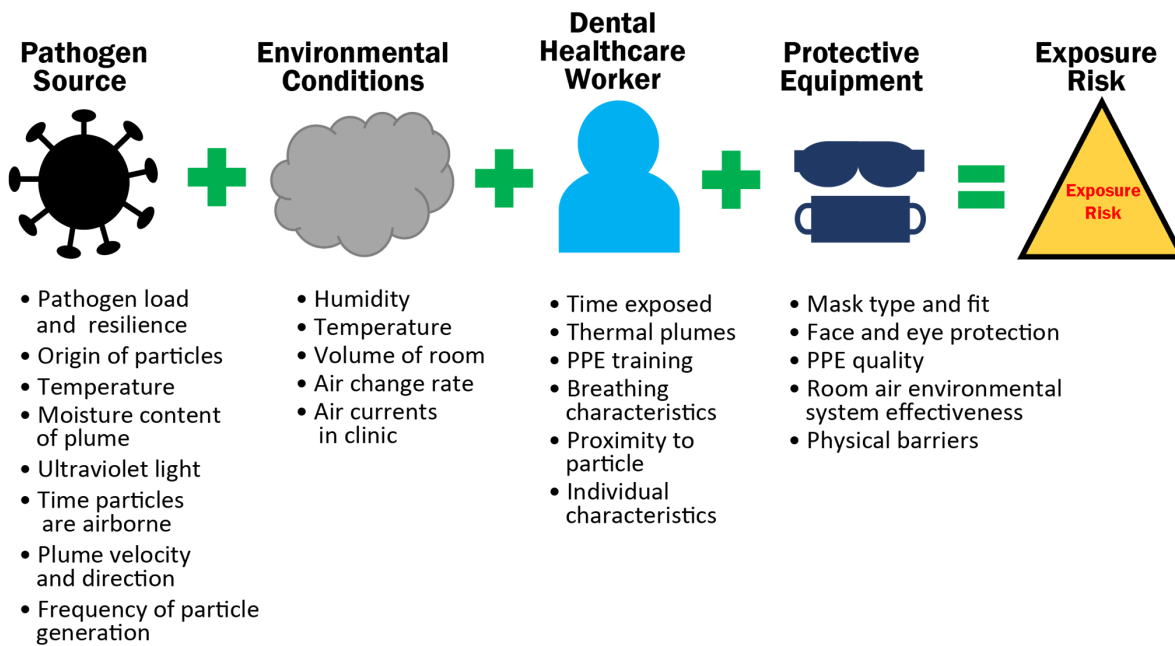


Figure 4. Factors for aerosol transmission in the dental environment.

There are a number of pathogenic bacteria and viruses that potentially can be transmitted in dental clinics by aerosols and/or droplets through direct contact, indirect contact, or contact with dental unit water [8, 20, 21]:

- *Mycobacterium tuberculosis* (TB)
- Respiratory viruses (influenza, rhinovirus, adenovirus, SARS, SARS-CoV-2, MERS)
- *Legionella pneumophila*
- Herpes simplex virus types 1 and 2 (HSV)
- Varicella-zoster virus (VZV)
- Cytomegalovirus
- Human immunodeficiency virus (HIV)
- Hepatitis B virus (HBV)
- Hepatitis C virus (HCV)
- Hepatitis D virus (HDV)
- Measles virus
- Mumps virus
- Rubella virus
- *Pseudomonas aeruginosa*
- *Streptococcus pyogenes*
- Multi-resistant bacteria (MRSA, ESBL, and other)

Currently there is no direct evidence reported of transmission of SARS-CoV-2 virus associated with any specific dental procedures. However, the SARS-CoV-2 virus and antibodies have been found to be present in saliva [19]. With saliva being a constituent in aerosols and droplets generated during dental procedures, and with the close proximity between patient and dental health care personnel during treatment where exposure directly from respiratory droplets occurs, this suggests there is a plausible risk of SARS-CoV-2 transmission associated with dental treatment.

Modes of Exposure in the Dental Clinic

A recent review of transmission in dental clinics shows evidence of four basic routes that pathogenic viruses and bacteria may be transmitted [22]:

- inhalation of airborne microorganisms suspended in air
- direct contact with blood, oral fluids or other materials
- conjunctival, nasal, or oral contact with aerosols or droplets containing pathogens
- indirect contact with contaminated surfaces or instruments

Evidence shows that respiratory viruses including SARS-CoV-2 can be transmitted through small and large droplets [22]. Transmission of respiratory viruses and pathogenic bacteria through contact of droplets with oral, nasal, and eye mucous membranes is also plausible [23]. As mentioned previously, long-range airborne transmission of the COVID-19 disease through fine and ultra-fine airborne particles associated with aerosols as well as the infectious dose is unknown at the time of this writing, although other diseases have been confirmed to be transmitted by way of aerosols.

Persons Potentially Exposed

Those in the dental clinic who have symptomatic or asymptomatic respiratory infections, or carry bloodborne pathogens, may readily cause healthcare associated infections by infecting others in the clinic. However, infected patients present a greater risk due to the aerosols generated during treatment. Dental health care personnel treating the infected patient face the greatest exposure risk, but lack of effective aerosol controls and clinic design may expose more personnel to infectious aerosols than just those working directly with the patient. Airflows may put anyone in a waiting room or reception area also at risk if particles travel from treatment rooms to other areas of the facility.

GUIDANCE FOR AEROSOL INFECTION CONTROL MEASURES

Background

The CDC, ADA, and WHO have provided infection control guidance and recommendations related to control of dental aerosols before the COVID-19 pandemic. With the concerns over transmission of SARS-CoV-2 in dental clinics, these organizations have issued interim guidance specific to COVID-19. However, these are recommendations and local government health authorities ultimately control the dental procedures that are allowed to be performed. In short, always follow the guidelines of your local health authorities first, as they may vary from or even supersede recommendations in other regions.

CDC Guidance

CDC guidance and recommendations related to the prevention and control of infectious dental aerosols are found in several publications. These include the “Guidelines for Infection Control in Dental Health-Care Settings – 2003” [21], “Interim Infection Prevention and Control Guidance for Dental Settings During the Coronavirus Disease 2019 (COVID-19) Pandemic” [18], and “Guidelines for Preventing the Transmission of *Mycobacterium tuberculosis* in Health-Care Settings, 2005” [24]. The latter reference related to *Mycobacterium tuberculosis* (TB) will not be discussed directly in this document. The pre-COVID-19 guidelines continue to apply to the overall infection control program required to reduce infection risks in a dental clinic. An abridged review of the guidelines and relevancy to dental aerosols and splatter is discussed below. The complete guidelines should be reviewed periodically due to updates during the COVID-19 pandemic as new information becomes available.

The CDC’s position on aerosols and splatter appears in the “Guidelines for Infection Control in Dental Health-Care Settings – 2003.” This position states that aerosols and splatter is generated from surgical instruments and air/water syringes and that these procedures generate mostly large droplets of water, saliva, blood, microorganisms, other debris, and, to a lesser amount, aerosols [21]. This guidance defines aerosols as particles <10 µm and cites studies that show oral fluids can be retracted into instruments and patient materials can then be transferred intraorally, including viral DNA, when using high-speed handpieces and prophylaxis angles [21]. The recommended CDC infection control approach is to minimize droplets, splatter, and aerosols by use of dental dams and high-velocity air evacuation. The CDC cites studies that show preprocedural mouth rinses (PPMRs) reduce the level of oral microorganisms in aerosols and splatter generated during routine dental procedures with rotary instruments, but also states that no evidence of reduction in clinical infections has been reported [21]. Because of the insufficient data, the CDC makes no recommendation for PPMRs.

These guidelines discuss a number of pathogens including cytomegalovirus (CMV), HBV, HCV, herpes simplex virus types 1 and 2, HIV, *Mycobacterium tuberculosis*, staphylococci, streptococci, and other viruses and bacteria that colonize or infect the oral cavity and respiratory tract [21] – all of which can be transmitted by splatter droplets and aerosols. In the United States, dental clinics are still advised to follow these (along with the Occupational Safety and Health Administration’s [OSHA]) standards. Recommendations in the 2003 guidelines are categorized using the CDC and Healthcare Infection Control Practices Advisory Committee (HICPAC) system. These recommendations minimize risks of exposure of dental health care personnel and patients to aerosols and droplets from splatter. Guidelines and recommendations related to aerosols and droplet exposure that are applicable in this paper include the following topics:

- Infection controls for surfaces, including clinical contact surfaces directly exposed to aerosols and splatter generated from dental procedures.
- Controls for cross-contamination caused by contact with surfaces exposed to splatter and aerosols.
- Proper use of protective barriers and coverings in the presence of splatter and aerosols.
- Sterile instrument or device packaging storage.

- Cleaning and disinfection guidelines for surfaces or items exposed to aerosols and droplets.
- Laser plume and electrosurgery recommendations by NIOSH and AORN.
- Information on the level of protection offered by surgical masks.
- Exposure management and risks related to aerosols to be included in a written health program for dental health care personnel.
- Guidance for Dental Healthcare Professional health monitoring and vaccinations for diseases transmitted through aerosols and droplets.
- Annual dental clinic review of new devices or tools with engineering safety features.
- Work-practice controls.
- Hand hygiene.
- Personal Protective Equipment (PPE) and protective clothing.
- Dental unit water treatment to reduce aerosol risks.
- Equipment decontamination from splatter and aerosols.
- Protection for parenteral medications and syringes.

The complete guidance and recommendations should be reviewed and followed due to critical infection control information that is not included in this paper.

Recent interim CDC infection control guidelines related to the COVID-19 pandemic provide additional infection prevention and control recommendations for dental settings. Guidelines are found in the “Interim Infection Prevention and Control Guidance for Dental Settings During the Coronavirus Disease 2019 (COVID-19) Pandemic,” which is periodically updated [18]. These interim guidelines continue to evolve based on current knowledge and should be consulted directly. These guidelines recognize that dental settings have unique concerns that require specific infection control considerations beyond other healthcare settings. Emphasis is placed on considering the postponement of certain procedures and visits; screening, monitoring and exposure response processes; and various exposure risk mitigation measures.

The CDC cites the main risks of dental treatment during the pandemic as the use of rotary dental and surgical instruments, including handpieces, ultrasonic scalers, and air/water syringes [18]. These instruments are utilized in AGPs where surgical masks only offer limited protection from aerosols (droplet nuclei). While there is currently no data available to quantify unique transmission risks of SARS-CoV-2 during dental practices, it is believed to be significant.

CDC’s COVID-19 guidance provides recommendations on universal source control measures, universal use of PPE, equipment considerations, environmental infection controls, and other practices for the COVID-19 pandemic that address risks of aerosols and droplets from splatter. Administrative controls and work practice recommendations provide additional considerations to the 2003 guidelines, including:

- Limiting the number of personnel and patients in the dental treatment room.
- Segregation and isolation of sterile supplies in areas away from potential contamination.

- Avoidance of AGPs, whenever possible, that include the use of high-speed dental handpieces, air/water syringes, and ultrasonic scalers.
- Where AGP's are necessary, the use of four-handed dentistry, high evacuation suction, and dental dams to minimize droplet splatter and aerosols.
- Use of an N95 respirator or respirator with equivalent or higher levels of protection when performing necessary AGPs.
- Though still not formally recommended, use of PPMRs to potentially reduce viral loads found in aerosols and droplets.

The CDC does not formally provide guidance on dental clinic design, including HVAC controls, due to the lack of data showing virus contamination in facility systems [18]. Additional recommendations in the CDC's COVID-19 guidance related to engineering controls for aerosol and droplet reduction are:

- Maintain ventilation systems.
- Consult with facilities staff or HVAC professionals to address risks.
- Use portable high-efficiency particulate air (HEPA) air filtration units when performing AGPs to reduce aerosol concentrations.
- Use upper-room ultraviolet germicidal irradiation (UVGI) as an adjunct decontamination method.
- Use individual patient rooms.
- For open floor plans:
 - Separate patient chairs.
 - Implement a physical barrier.
 - Orient treatment rooms parallel to the direction of airflow.
 - Optimize patient orientation to effectively utilize air vent flow directions.
- Adjust patient volume to provide sufficient time for disinfection and/or air-handling.
- With respect to environmental infection controls, the CDC's 2003 guidelines recommend the cleaning and disinfection of surfaces and equipment exposed to aerosols and splatter. The interim COVID-19 guidance adds new information specifically to disinfection: Disinfectants that are qualified for use should be found on the EPA's List N (<https://www.epa.gov/coronavirus/about-list-n-disinfectants-coronavirus-covid-19-0>).
- Alternative disinfection methods, including ultrasonic waves, UV radiation, and LED blue light have not been evaluated for effectivity against the SARS-CoV-2 virus nor for inactivation of pathogens containing aerosols and splatters.

There are no additional recommendations for sterilization protocols for respiratory pathogens, and the guidance in the 2003 Dental Health-Care Settings document should be followed.

ADA Guidance

The American Dental Association's "Summary of ADA Guidance During the COVID-19 Crisis and Return to Work Interim Guidance Toolkit" provides guidelines for aerosol control measures that closely align with the CDC's interim COVID-19 guidance. Additional recommendations provided by the ADA include [20, 25, 26]:

- Use of manual hand scaling tools, instead of ultrasonic scalers, when cleaning teeth.
- Use of high velocity suction whenever possible.
- Use of rubber dental dams whenever possible.
- Take extra-oral radiographs whenever possible.
- N95 masks should be worn in combination with full face shields when treating patients at close proximity.

The ADA also provides numerous other dentistry specific resources for COVID-19, including what constitutes a dental emergency. These resources can be found on the ADA Coronavirus (COVID-19) Center for Dentists website shown in **Table 2** on page 17.

WHO Guidance

In August 2020, the World Health Organization (WHO) recommended delaying routine nonessential oral health care during the COVID-19 pandemic [27]. The position provided on AGPs is that they present risks of airborne transmission and that COVID-19 cannot be excluded. WHO defined AGPs in oral healthcare as:

- All clinical procedures that use spray-generating equipment, such as:
 - Air/water syringes.
 - Ultrasonic scalers for cleaning and polishing.
- Periodontal treatment with ultrasonic scaler.
- Any dental preparation with high- or low-speed handpieces.
- Direct and indirect restoration and polishing.
- Definitive cementation of crown or bridge.
- Mechanical endodontic treatment.
- Surgical tooth extraction and implant placement.

WHO recommends delaying non-urgent oral healthcare, including oral health check-ups, dental cleanings, and preventative care, until community transmission or clusters of the disease have been reduced to safer levels as recommended by the applicable government level.

Urgent or emergency oral healthcare interventions are recommended to be provided. WHO includes interventions to address acute oral infections, swelling, systemic infection, significant or prolonged bleeding, severe pain not controllable with analgesia, oral healthcare pre-interventions to other urgent procedures, and dental or orofacial trauma. When urgent oral healthcare treatment is needed, WHO's recommendations (directly related to aerosols and droplets) include:

- Increase ventilation and airflow.

- Avoid use of split air conditioning or other types of recirculation devices.
- Consider installing filtration devices including HEPA filters.
- Use fluid resistant disposable gowns.
- Use face shields that cover front and sides of the face or goggles
- Wear a fit-tested N95 or FFP2 respirator (or higher).
- Have patients rinse their mouth with 1% hydrogen peroxide or 0.2% povidone iodine for 20 seconds prior to examination or starting any procedure.
- Avoid or minimize AGPs and prioritize minimally invasive procedures using hand instruments.
- When AGPs are required:
 - Ensure assistance during procedures (four-handed dentistry).
 - Use high speed suction.
 - Use a rubber dam when possible.
 - Avoid use of the spittoon (i.e., cuspidor) and instead use a disposable cup or high-speed suction.

Regulatory guidance documents from health organizations around the world will continue to be revised as new information becomes available. To stay informed of the most recent updates, be sure to regularly review these resources (see **Table 2**), as well as other guidance documents from your local health authorities.

Table 2. Common worldwide health resources related to aerosol and droplet controls.

Resource	Website
CDC- Guidelines for Infection Control in Dental Health-Care Settings - 2003	https://www.cdc.gov/mmwr/preview/mmwrhtml/rr5217a1.htm
CDC- Interim Infection Prevention and Control Guidance for Dental Settings During the Coronavirus Disease 2019 (COVID-19) Pandemic	https://www.cdc.gov/coronavirus/2019-ncov/hcp/dental-settings.html
WHO - Considerations for the provision of essential oral health services in the context of COVID-19	https://www.who.int/publications/i/item/who-2019-nCoV-oral-health-2020.1
ADA – COVID-19 Center	https://success.ada.org/en/practice-management/patients/infectious-diseases-2019-novel-coronavirus
OSHA COVID-19 Control and Prevention	https://www.osha.gov/coronavirus/control-prevention/dentistry
DHHS - Control of Smoke from Laser/Electric Surgical Procedures	https://www.cdc.gov/niosh/docs/hazardcontrol/hc11.html

APPROACHES FOR IMPROVED AEROSOL AND DROPLET SOURCE CONTROLS

Hierarchy of Controls

While there are currently no practical or economical source controls that completely contain dental aerosols and droplets, various improved techniques, work controls, and engineering controls have been developed to reduce exposure risk. According to the National Institute for Occupational Safety and Health (NIOSH), controls closer to the source are generally more effective. As shown in **Figure 5**, “elimination” controls, which involve physically removing the hazard, are effectively at the source, while engineering controls are intermediately located, and PPE is the farthest from the source, positioned just before an individual’s body is exposed to the hazard.

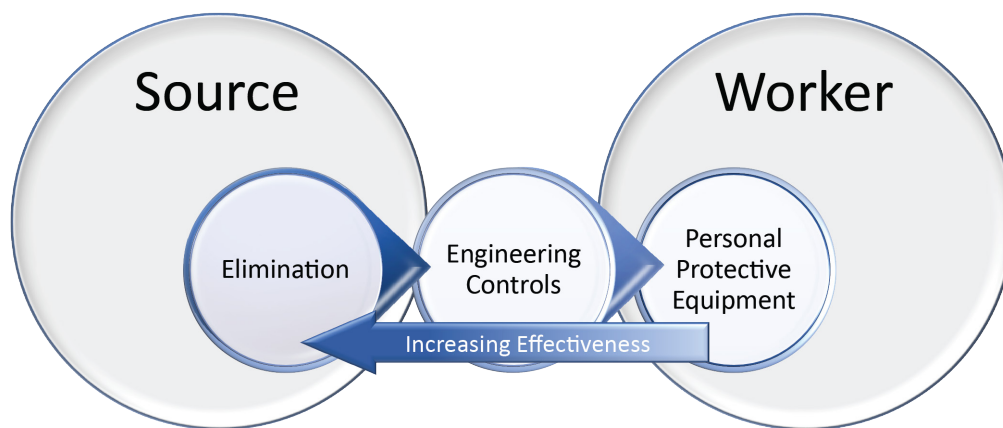


Figure 5. Proximity of various types of control measures to the hazard source and the worker.

Controls at or near the aerosol and droplet source will be the most effective, as they stop aerosol and droplet clouds from dispersing over larger clinical areas and settling on clinical surfaces with which dental health care personnel or patients make direct contact. Environmental controls, including HVAC systems and air-quality controls, are not considered source controls for AGPs and are only discussed briefly here. Supplemental suction devices, including portable suction equipment, are also not in the scope of this paper. Other dental healthcare and literature should be consulted for facility environmental controls, supplemental suction, air-purification methods, PPE, and surface cleaning and disinfection.

Pre-Treatment Processes

Various measures for controlling against disease transmission can be practiced before a patient’s visit to the clinic. During pre-treatment screenings for COVID-19, patients can be instructed to brush, floss, and use mouthwash prior to their visit and as close to the appointment time as possible. Evidence exists that patient brushing, flossing, and rinsing with mouthwash prior to procedures reduces the bacterial counts found in aerosols and droplets [28]. Administering a PPMR is another measure aimed at controlling oral microflora. There is evidence that PPMRs can reduce the level of oral microorganisms found in aerosols and droplets generated during ultrasonic scaling, air-polishing device use, and air-turbine handpiece use [29, 30, 31]. Most clinical studies have shown that PPMRs significantly reduce the total number of colony forming units (CFUs) in aerosol and droplet samples taken after AGPs have occurred [25]. PPMRs used in these clinical studies included four types: chlorhexidine (CHX), cetylpyridinium chloride (CPC), and

continued

essential oils (EO) and herbal [32]. It is currently being investigated if CHX and CPC have sustained anti-viral activity toward SARS-CoV-2. It should also be noted that CDC guidance states that there is no clinical evidence that PPMRs prevent infections. And while an epidemiological link between PPMRs and infection rates has yet to be established, dental health care personnel may still wish to consider using PPMRs.

Environmental Considerations

There are a number of environmental considerations that influence aerosols in the dental clinic. Start-stop conditions with facility heating and air-conditioning controls may create air turbulence across the treatment rooms and processing areas, challenging the aerosol source capture methods in place and making them less effective. While not a true source control, treatment room layout can help improve this. For instance, if feasible, orienting the dental chair so the patient's head is near the return air vents and away from pedestrian corridors will allow the flow of air from the HVAC system to more effectively reduce the risk of aerosols escaping the treatment room. This is consistent with the CDC COVID-19 interim guidance that also recommends continuous running of bathroom fans, consultation with HVAC professionals on facility airflows, and airflow directions for portable HEPA units.

HEPA filtration helps improve indoor air quality and reduce airborne pathogens. A portable HEPA unit can be used as an adjunct control in combination with other aerosol capture methods including an HVAC HEPA system for greater cleaning performance. For facilities that do not have central HVAC HEPA systems or have systems that do not include adequate fixed HEPA filters to capture airborne pathogens, portable air purification units (including HEPA filtration UVGI) are a lower cost option that require no facility redesign, HVAC system improvements, or significant maintenance effort. Portable HEPA units are available with and without UVGI. One example of a portable air purification unit is JADE by Surgically Clean Air™ (see **Figure 6**). This unit uses filtration, UV irradiation, and other capture methods to improve indoor air quality.



Figure 6. JADE by Surgically Clean Air™ portable air purification unit.

Portable HEPA units provide aerosol removal in treatment rooms or office areas and can be easily relocated and positioned according to the CDC guidance. This offers an advantage over facility HVAC systems where redirection of airflows is more difficult. Disadvantages of portable HEPA units are a smaller size that could provide lower clean air delivery rates (CADR) than a larger facility environmental system. Effectiveness of portable units depends upon several factors including the filtration efficiency, CADR, unit design specifications, maintenance, and room air-flow characteristics. Proper maintenance and following regular filter and UV lamp replacement protocols are important for ensuring reliable performance.

Room humidity and temperature settings influence the effectiveness of source controls as well. For example, SARS-CoV-2 can remain infectious from 2 hours up to 9 days at room temperature and has been observed to persist better at 50%, compared with 30%, relative humidity [22]. To determine if your indoor air quality can be improved, review your environmental control settings for dehumidification and temperature. Cleaning and disinfection in the treatment room is also important. Research has shown that high levels of bacterial contamination, caused by aerosols and droplets not captured during dental treatment, were found within 80 cm (31") around the head of the patient [33, 34]. This underlines the importance of thorough cleaning and the use of an approved disinfectant after each patient—especially on surfaces near the patient.

Dental Unit Water and Air

Dental unit water and dental unit air are both potential sources of microorganisms that may become aerosolized, although there are no reports at this time indicating SARS-CoV-2 can be transmitted directly through contaminated dental unit water or air (see **Figure 7** on page 21). When measures to control against biofilm in dental unit waterlines are not taken, high levels of environmental bacteria in dental unit water have been widely reported, sometimes exceeding 10^5 CFU/ml [35]. Under such conditions, dental unit water may contribute more to dental aerosol and droplet bacteria levels than saliva or oral secretions. It is well established that chemical treatments added to dental unit waterlines reduce bacterial counts in dental unit water. A consistent routine of daily waterline maintenance, water quality monitoring, and intermittent shock treatment is a proven, effective approach to successfully achieve acceptable dental unit water quality [36, 37]. At a minimum, facility managers should follow dental unit manufacturer instructions for waterline maintenance.

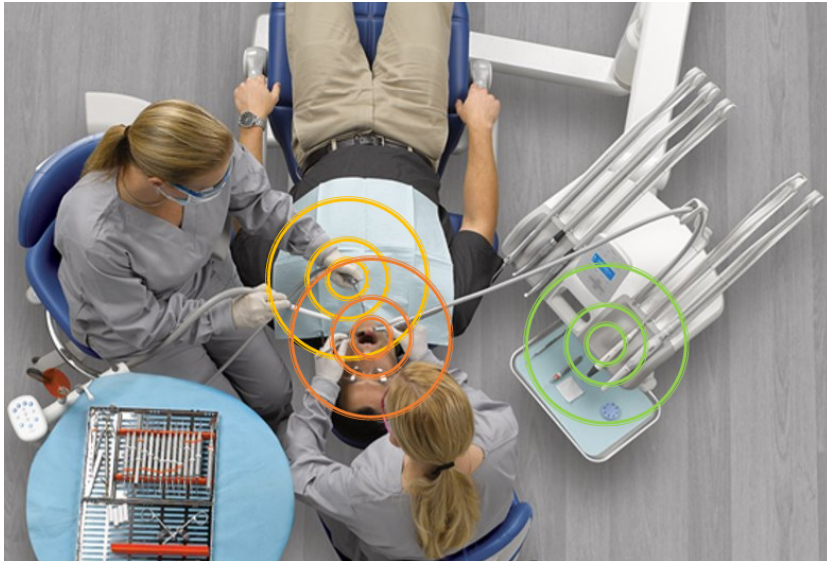


Figure 7. Microbial contamination from dental unit waterlines may become aerosolized by the instruments that use dental unit water for coolant or irrigation.

In addition to dental unit water, the air delivered by rotary handpieces and air/water syringes is also an important contributor to the formation of aerosols. Since contaminated compressed air can contribute to the bioload in aerosols, the compressed air supply should be both clean and dry to avoid contamination. This begins with the air compressor itself. Air compressors require properly designed, integrated dryers to effectively control air quality.

Likewise, the air plumbing system design needs to minimize moisture condensation, which can create a collection point for bacteria and mold. A thorough review of the plumbing system design is essential prior to installation and can also identify where improvements are needed to help minimize condensation in existing installations.

The compressed air system should also be reviewed for potential contamination sources, including condensation points, moisture, and the air-intake. Bacteria and viruses can potentially enter the system if the air-intake is near other sources of contamination, such as building air exhaust. As specified by ANSI/ADA Standard No. 94, the air intake must also be at least 10 m (33') away from sources of hazardous gas or vapor.

Like all clinical equipment, the air compressor, plumbing system, and related devices should be regularly maintained to reduce contamination risks. Guidelines for system maintenance are found in the manufacturer's instructions for use and other product support materials. For ANSI/ADA and ISO requirements around dental compressed air quality and contamination controls, see **Table 3** on page 22.

Table 3. Standards for dental compressed air quality and contamination controls.

Requirement	Standard		
	ANSI/ADA 94*	ISO 22052*	ISO 7494-2*
Bacterial filter (rating)	Not specified	0.22 µm > 99.99 %	0.22 µm
Humidity (pressure dew point)	≤ +5 °C at 20 °C (7 bar constant system pressure)	≤ +3 °C at 20 °C (0.7 MPa constant system pressure)	< -20 °C at 1 atm
Condensate drain	Not specified	Must be equipped	Not specified
Oil content	0.05 ppm	≤ 0.1 mg/m ³	≤ 0.5 mg/m ³
Particle Size (filtration)	< 5 µm	Particle size Particles per cubic meter 0.1 µm < d ≤ 0.5 µm ≤ 400 000 0.5 µm < d ≤ 1.0 µm ≤ 6 000 1.0 µm < d ≤ 5.0 µm ≤ 100	1 µ Particle size Particles per cubic meter m ≤ d ≤ 5 µm ≤ 100

* ANSI/ADA 94 Dental Compressed Air Quality
 ISO 22052 Dentistry – Central compressed air source equipment
 ISO 7494-2 Dentistry – Dental units – Part 2: Air, water, suction and wastewater systems

Instrument Air and Water Coolant Adjustments

Once controls in the dental unit air and water lines are reviewed and if necessary improved to reduce contamination levels, the next high impact control that should be addressed is the handpiece settings. Handpiece manufacturers should be consulted for reducing aerosols during use. Handpieces that may be adjusted to minimize aerosol and droplet production include ultrasonic scalers, electric and air-driven handpieces, and air/water syringes. Correct device usage, along with proper air and water coolant settings, should help minimize aerosol generation while still maintaining effective temperature management of the tooth.

Sonic and Ultrasonic Scalers

Sonic and ultrasonic scalers are among the most significant sources of aerosols and airborne droplets. To minimize aerosols, consideration should be given to using hand instruments instead of powered sonic or ultrasonic scalers [10]. If an ultrasonic device is necessary:

- Consult with the manufacturer for recommendations on settings to minimize aerosol spray while assuring effective performance for the application.
- Use a high-volume evacuator (HVE) during scaling to achieve high aerosol capture rates [8].

Air/Water Syringes

Air/water syringes can produce a significant amount of aerosols as well – nearly equal to that of ultrasonic scalers [8]. And although the air/water syringe is used in most dental treatment procedures, there are some ways to limit its potential impact on aerosol generation.

continued

Here are two considerations:

- **Reduce air/water flow rates** – if the dental unit includes air/water syringe adjustment controls, reduce the flow rate to minimize excessive air/water flow. If an adjustment control is not available, attach a pinch valve to the syringe air/water lines to adjust the flow rate.
- **HVE** – An HVE can significantly reduce aerosols, especially during hygiene procedures. HVE/mirror combination instruments, such as the Nu-Bird® Suction Mirror, provide the additional function of a mirror which can be useful for a hygienist working without an assistant. Optimal capture of spray from the air/water syringe requires both correct positioning of the HVE and adequate airflow. The optimal position of the device will be as close to the aerosol generation source as possible without contact on the patients tongue or oral tissues.

High-Speed Handpieces

Anti-retraction features built into the dental unit water system and in some high-speed handpieces as well as adjusting air coolant and water coolant settings may reduce the number of contaminated aerosol and droplet particles.

- Consult with handpiece manufacturers on settings to reduce water and aerosols formation without negative impacts to cooling and performance.
- Consider and test coolant water individually without air coolant.
- Optimize air and water coolant flow to reduce excess spray and splatter while still providing sufficient cooling to avoid thermal damage to oral tissue.
- Consider using electric contra-angles instead of air-turbines.
- Maintain handpieces including following all cleaning and disinfection procedures.

Vacuum Systems and Instrumentation

Since minimizing aerosol generation cannot completely eliminate aerosols in the dental clinic, capturing aerosols at or near the source is a critical control measure for reducing aerosol exposure risks. The dental clinic central vacuum system is foundational to that effort, as it supplies suction to all vacuum instruments in the clinic. The system should include a robust vacuum pump and plumbing system appropriately sized and designed to meet the current and future needs of the practice. Annual maintenance checks and testing should confirm that the vacuum system provides adequate flow capacity for the clinic. If it doesn't, the vacuum pump should be replaced or upgraded to a larger flow capacity. The building plumbing should also be reviewed regularly for deficiencies, leaks, restrictions, or other problems that reduce vacuum pressure and/or flow capacity. If any sources of vacuum loss are found they should be corrected immediately to restore aerosol capture.

Facility Vacuum System Capacity and Capability

Vacuum instruments require adequate flow from a central vacuum source to operate as designed and effectively capture aerosols and droplets. Sizing of the vacuum source equipment should be done by

someone with experience in designing dental clinic suction systems in consultation with the manufacturer of the vacuum source equipment and someone with knowledge of how vacuum will be used in the clinic, including number of concurrent users, types of vacuum instruments and use patterns. Use pattern considerations include factors such as whether multiple vacuum instruments will be used simultaneously while treating a patient and whether instruments will be used continuously or only intermittently. Consideration for the facility piping system and dental equipment vacuum lines are also important in sizing the vacuum source equipment (discussed further below).

A well-designed and constructed system will provide effective flow at each instrument over the full range of anticipated concurrent users. Typical target flow rates for common vacuum instruments are provided in **Table 4**. For specifications of your vacuum instruments, refer to the instructions for use that came with your dental equipment. Upon installation or upgrade of a vacuum system, performance of the complete system should also be verified to meet airflow targets by measuring the flow at the instruments in the dental treatment room.

Table 4. Typical minimum airflow recommendations for high performance of vacuum instruments.

Attachment	Typical Airflow Target
15 mm HVE (Large Bore HVE)	10 SCFM (283 NL/min)
11 mm HVE	7.5 SCFM (212 NL/min)
Supplementary HVE attachments (i.e., HVE-mirror)	6 SCFM (170 NL/min)
Saliva Ejector	2 SCFM (57 NL/min)

Multiple vacuum units used in tandem offer the advantages of extending the life of the system and reducing the risk of losing all vacuum in the clinic if a unit fails. Vacuum manufacturers can provide performance and sizing guidelines to help determine the best vacuum configuration that meets the clinic's current and future needs.

Facility and Dental Unit Vacuum Plumbing and Maintenance

An effective central dental vacuum system also requires facility plumbing that is both correctly designed and properly maintained. A number of plumbing issues can restrict airflow to the vacuum pump, creating choke points. Choke points that diminish vacuum system flow include undersized piping, too many bends, tight-radius elbows, and excessive fittings. A progression of properly sized piping is also important to achieving acceptable vacuum flow with smaller diameter piping for branch lines at individual treatment rooms and progressively larger diameter piping as these branches merge along the flow path to the central vacuum source (see **Figure 8** on page 25). Because it is difficult to modify the vacuum piping after a clinic is built and outfitted, it is critical to have the piping system designed by someone with experience in dental vacuum systems. It is also advisable to design the system conservatively, as there are no drawbacks from a performance perspective to a piping system that offers less flow resistance.

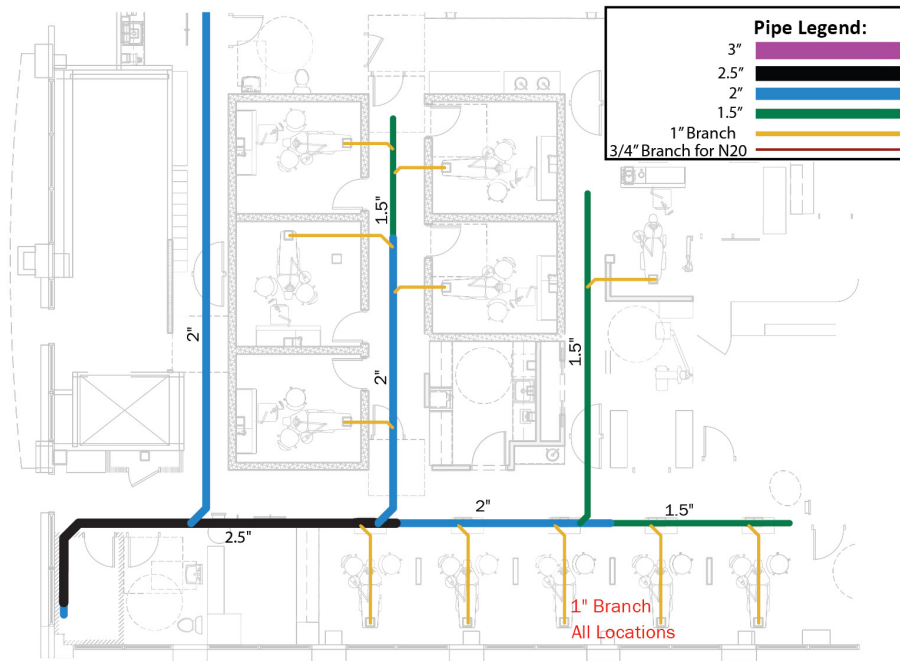


Figure 8. Example of dental clinic vacuum piping schematic designed to supply adequate flow to all treatment rooms.

Similarly, choke points can occur within the dental equipment. Small diameter vacuum tubing and tight bends within the dental chair, for example, can restrict airflow, resulting in reduced performance at the vacuum instruments. A-dec dental chairs promote airflow by using 25 mm (.98") diameter hose throughout the chair from the connection to the facility vacuum piping to the vacuum solids collector, where the handheld instrument tubing attaches (see **Figure 9**).

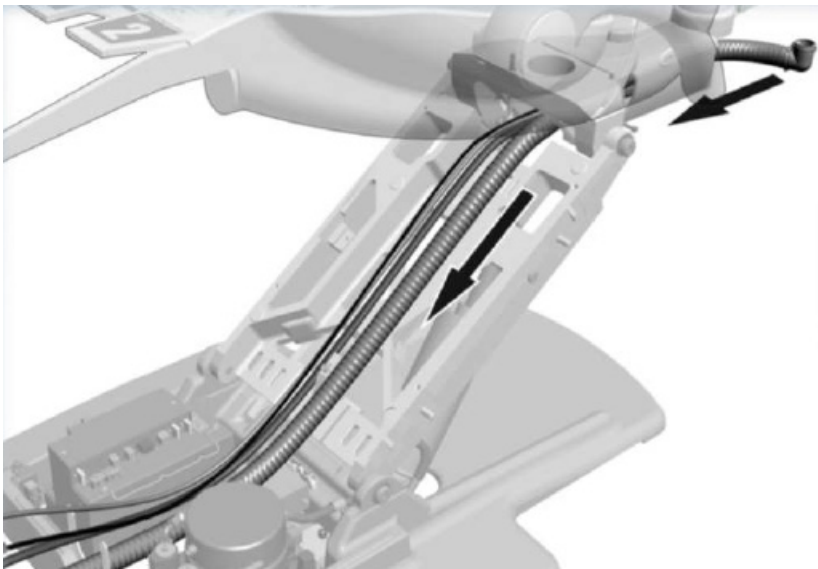


Figure 9. Example of large diameter vacuum hose and gradual bends to promote increased vacuum flow through the dental chair.

Poorly maintained dental vacuum systems can also lead to reduced performance. Daily cleaning of the suction lines in each treatment room with a vacuum line cleaning solution compatible with your vacuum system helps prevent build up in the dental equipment vacuum lines as well as facility piping.

System leaks in the dental equipment or facility piping will also bleed pressure and reduce the vacuum's ability to provide adequate airflow for the clinic. Since leaks can occur at any time, the facility plumbing system should be inspected regularly. An annual vacuum maintenance service by your dental equipment dealer can reveal issues impacting the vacuum performance, as well as potential plumbing improvements that may be needed. For new installations, most manufacturers provide facility design guides that detail all of the vacuum, plumbing, and exhaust components required for a well-designed facility plumbing system.

Vacuum Instruments

Conventional HVEs and saliva ejectors (SEs) are the primary control for aerosols and splatter during dental procedures. Each instrument serves a different function. The HVE directly targets solid debris and airborne particulates, while the SE collects pooled saliva and water that can become aerosolized if not removed. Different tip configurations are available for both instruments and allow for adjustments for different procedures. Additional devices to control against vacuum backflow or "suck back" may also be used, and include disposable designs, alternate parallel flow path designs, and integral anti-backflow valves. These designs can negatively impact flow rate, which is important to consider before purchasing any new vacuum device or accessory.

High-Volume Evacuators (HVEs)

The HVE provides an efficient way to capture aerosols for two reasons:

1. The large diameter tubes and larger internal diameters offer less resistance to airflow, so the vacuum flow rate can be higher.
2. The tip of the HVE can be placed close to the location where aerosols are generated.

Some HVEs feature larger diameters than standard HVEs to increase volumetric flow and improve particle collection capability when paired with an appropriately sized vacuum system. The A-dec 15 mm Large Bore HVE (see **Figure 10** on page 27), for instance, removes up to 45% more air from the oral cavity than standard 11 mm diameter HVEs when used under the same vacuum system conditions.



Figure 10. A-dec large bore HVE with saliva ejector and air/water syringe.

The type of cannula or tip used with the HVE can also affect the flow rate and effectiveness. Some HVE tips, such as Dürre Universal Cannula Tips, are designed to reduce the noise generated by the HVE.

Saliva ejectors (SEs)

Saliva ejectors are designed to be used to remove pooled saliva or other fluids. Some techniques used with saliva ejectors involve a hook shaped tip that retains the SE in the patient's mouth. This frees up a hand to use an HVE in the oral cavity in conjunction with the SE, improving overall aerosol and droplet collection. It is generally recommended that patients should not close their lips on a saliva ejector to avoid the possibility of backflow.

Other Complimentary Methods/Practices:

When used in combination with HVEs, the dental dam (or rubber dam) has been shown to reduce total CFU counts of microorganisms in air samples when compared to procedures without the use of a dam [38]. In fact, six studies have shown that dental dams provide, on average, a 30% reduction in splatter [39]. However, there are concerns that dental dams may also deflect spray or splatter onto dental health care personnel [40]. One potential way to mitigate this concern would be to reduce the quantity of air/water spray (as earlier described in this paper) when using a dental dam.

Additional methods and designs that may offer improvements in aerosol capture include hygienist HVE hand-hold techniques and hands-free designs. The hand-hold technique involves using the non-dominant hand to hold both the HVE and mirror while performing hygiene procedures. Hands-free designs may be appealing in two- and four-handed procedures by allowing for multiple suction points and freeing up one hand for other tasks. Adec's Third-Hand HVE holder, for instance, can securely position the HVE tip within 1" (25.4 mm) of the oral cavity, which helps improve aerosol capture and allows the operator more flexibility to use both hands (see **Figure 11** on page 28).



Figure 11. A-dec Third-Hand HVE Holder (shown with secure position of HVE tip to assist with aerosol collection during two-handed dentistry).

Dental isolation systems, like the Zyris® Isolite® or DryShield®, provide another option for removing pooled saliva and aerosols from the oral cavity. These systems provide continuous suction by way of a hands-free device with a mouthpiece having a series of vacuum intake ports that connects to a dental unit HVE tubing. The mouthpiece is also intended to provide some of the isolation benefit of dental dams by covering portions of the back of the mouth.

CONCLUSION

Research has been conducted and published in various dentistry journals over the years concerning aerosols generated during dental procedures. Still, there are many gaps in knowledge about the transport and persistence of aerosol particles and droplets of varying sizes, as well as the exposure risks associated with these various airborne particles. Further questions remain regarding the degree of effectiveness of current tools and methods to capture aerosols under the wide range of conditions and procedures that occur within the dental clinic. More research is needed to understand the properties of dental procedural sprays, including the fluid dynamics of the spray patterns and the immediate movement of the aerosol and droplet plume. However, there is evidence that suggests that HVEs and other engineering controls discussed in this paper greatly reduce aerosol and airborne droplet emissions. As more insights from research on aerosols and airborne pathogens continue to emerge, health authorities worldwide continue to evolve the current thinking on dental healthcare settings and guidelines for worker safety, and newly issued guidance should be monitored and implemented regularly.

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