ORIGINAL ARTICLE

Ultrasonic scaling in COVID-era dentistry: A quantitative assessment of aerosol spread during simulated and clinical ultrasonic scaling procedures

Alexandra C. Pierre-Bez[1] 🔵 | Gina M. Agostini-Walesch[1] | P. Bradford Smith[1] | Qing Hong[1] | David S. Hancock[1] | Megan Davis[1] | Gina Marcelli-Munk[2] | John C. Mitchell[1]

[1]College of Dental Medicine-Arizona, Midwestern University, Glendale, AZ, USA

[2]Dental Institute-Glendale, Midwestern University, Glendale, AZ, USA

Correspondence
Alexandra C. Pierre-Bez, College of Dental Medicine – Arizona, Midwestern University, 19555 N. 59th Avenue, Glendale, AZ 85308, USA
Email: apierr@midwestern.edu

Abstract

Objective: Healthcare agencies recommend limited use of aerosol-generating procedures to mitigate disease (COVID-19) transmission. However, total dispersion patterns of aerosols, particularly respirable droplets, via dental ultrasonic units is unclear. The purpose of this study was to characterize and map total spatter, droplet and aerosol dispersion during ultrasonic scaling in simulated and clinical contexts.

Methods: Ultrasonic scaling was performed on dental simulation units using methylene blue dye-stained water. All resultant stain profiles were photoanalysed to calculate droplet size and travel distance/direction. Airborne particle concentrations were also documented 0–1.2 m (0–4ft.) and 1.2–2.4 m (4–8ft.) from patients during in vivo ultrasonic scaling with a saliva ejector.

Results: Stain profiles showed droplets between 25 and 50μm in diameter were most common, with smaller droplets closer to the mouth. In-vivo particle concentrations were uniformly low. The smallest (<1 μm, PM1) and largest (>10 μm, PM10+) particles were most common, especially within 1.2 m (4ft.) of the patient. Respirable particles (PM2.5) were uncommon.

Conclusions: Tests showed the highest concentration of small droplets in zones nearest the patient. While uncommon, particles were detected up to 2.4 m (8ft.) away. Furthermore, observed particle sizes were consistent with those that can carry infectious agents. Efforts to mitigate the spread of inhalable aerosols should emphasize proximate regions nearest the procedure, including personal protective equipment and the use of evacuation devices.

KEYWORDS
dental hygiene, dental hygiene research, instrumentation: hand, sonic, ultrasonic, professional practice

---

1 | INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is transmitted via contact with infected saliva.[1] Oropharyngeal viral loads in symptomatic patients can be similar to those in asymptomatic patients, indicating potential viral spread by asymptomatic individuals. SARS-CoV-2-containing aerosols can travel over 1.8 m (6 ft.).[2] Studies show virus-laden aerosols may cause surface contamination, though results on this conclusion are mixed.[3,4] For example, one recent study found that SARS-CoV-2 was not detected in settled dental aerosols, perhaps due to a dilution effect of irrigation solution.[5] They further found that few microbiota detected in dental aerosols arise from patient saliva and that most biological contaminants found within 1.8m (6 ft.) of the patient are bacteria sourced to the irrigation system.[5] However, most dental aerosol studies have relied on limited-sampling, close-proximity methods to infer the likelihood of viral contamination. This means that viral transmission via dental aerosols cannot be ruled out until more comprehensive studies are performed to assess the patterns of total aerosol dispersion in different clinical environments, as well as the ability for these aerosols to transport viruses like SARS-CoV-2.

Spatter (>100 μm in diameter),[6,7] droplets (5–100 μm diameter)[7,8] and aerosols (particles <5 μm)[7,8] can travel well beyond the zones immediately surrounding a patient's mouth depending on droplet or particle size. Spatter typically follows a bullet-like trajectory away from the operative site until surface contact.[9] These larger salivary droplets tend to settle quickly onto the patient's chest and other proximate locations.[10] Aerosols, however, can remain suspended for longer periods, with their small aerodynamic diameter increasing the likelihood of inhalation. Particles under 10μm can reach deep in the respiratory tract where viral transmission may occur.[11,12] SARS-CoV-2 has been detected in airborne particles ranging from 0.25 μm to over 4 μm.[13,14] A recent study evaluating the particle size produced during various dental procedures showed that ultrasonic scaling produced both spatter (median diameter of 300 μm) and aerosols (median diameter of 1.38 μm) up to 100 cm (39.37 in) from the mouth, the furthest point at which data were collected.[6]To date, most research

on dental aerosols, including the real-time studies cited above, use fluorescent dyes[15-17] or bacterial colony-forming units (CFUs) to understand aerosol spread following dental procedures.[4,18] These methods typically rely on 'spot collection' wherein contamination is assessed at relatively few surface locations in an examination room, on personal protective equipment (PPE), or other limited areas.[5,11,19] Furthermore, the direction that a droplet or particle travels is often not included in the study design. These points are important given that the pattern of aerosol concentration (and associated contamination risks) is a product of both travel distance and direction.[20] Therefore, the placement of sampling points likely has a considerable effect on subsequent results.

Here, two complimentary tests were used to determine particle and droplet size and dispersion during ultrasonic scaling: [1] A simulation showing cumulative droplet distributions on *all surfaces* proximate [<1.2 m (4 ft.)] to the operator and patient in a controlled environment (hereafter referred to as 'simulation test') and [2] a real-time assessment of airborne particle concentrations at a broader [0–2.4 m (0–8 ft.)] distance range during multiple *in vivo* ultrasonic scaling sessions in a dental clinic ('real-time test'). This study design allowed for a comprehensive evaluation of aerosols, including the travel range, travel direction, concentration and size distribution of droplets and particles ≥0.1 μm that are produced during ultrasonic scaling. When combined with other emerging studies, this provides important context for viral transmission risks.

2 | STUDY POPULATION AND METHODOLOGY

2.1 | *Simulation test*

2.1.1 | Experimental parameters and protocols

This test was conducted in a simulation clinic equipped with a dental simulation unit or DSU (KaVo Dental, Brea, CA). The DSU was
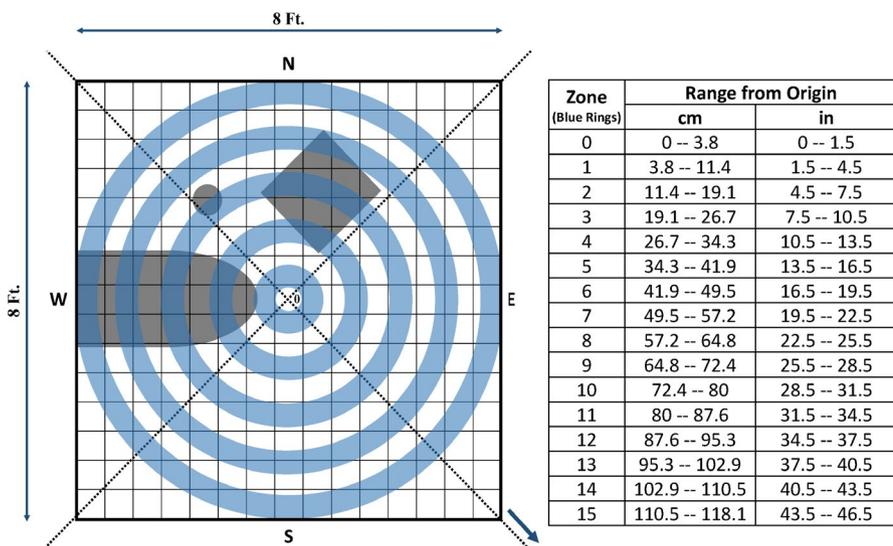

Zone (Blue Rings)	Range from Origin	
	cm	in
0	0 -- 3.8	0 -- 1.5
1	3.8 -- 11.4	1.5 -- 4.5
2	11.4 -- 19.1	4.5 -- 7.5
3	19.1 -- 26.7	7.5 -- 10.5
4	26.7 -- 34.3	10.5 -- 13.5
5	34.3 -- 41.9	13.5 -- 16.5
6	41.9 -- 49.5	16.5 -- 19.5
7	49.5 -- 57.2	19.5 -- 22.5
8	57.2 -- 64.8	22.5 -- 25.5
9	64.8 -- 72.4	25.5 -- 28.5
10	72.4 -- 80	28.5 -- 31.5
11	80 -- 87.6	31.5 -- 34.5
12	87.6 -- 95.3	34.5 -- 37.5
13	95.3 -- 102.9	37.5 -- 40.5
14	102.9 -- 110.5	40.5 -- 43.5
15	110.5 -- 118.1	43.5 -- 46.5

FIGURE 1 Diagram of the floorplan and layout showing the zones used to organize the data with 7.6cm (3-in.) grid and quadrant system. Square: operator chair; Arch: DSU; Plus sign: origin (open mouth of DSU).

positioned in full recline with the mouth 71.1cm (28in.) above floor level atop a 2.7 × 2.7 m (9 × 9 ft.) section of white paper on which a 2.4 × 2.4m (8 × 8 ft.) perimeter was drawn. After the procedure, the paper was marked with a grid, quadrants and key landmarks to facilitate later digitization (Figure 1). The water reservoir of a Dentsply Cavitron was filled with 500cc reverse osmosis (RO) water and 0.5 g methylene blue dye, after which an experienced operator performed ultrasonic scaling on typodont teeth #6–11 for 5 minutes using a saliva ejector continuously (50% power and lavage, water flow rate 18 mL/min). Afterwards, the paper was left undisturbed for 10 minutes to allow stain-bearing droplets and spatter to settle and dry.

2.1.2 | Data collection

Pilot tests were conducted using variably sized floorplan grids containing droplets of different sizes and concentrations. These confirmed that a series of five overlapping photographs of each box in a 7.6 × 7.6 cm [3 × 3in.] grid system [camera height 30.5 cm (12in.)] were necessary to acquire high-resolution images (preservation of smallest droplets) and a sufficient number of landmarks to facilitate undistorted composite photograph creation (Fig. S1). The floorplan was systematically photographed using a Nikon D3400 series DSLR camera and zoom lens (AF-P DX NIKKOR 18-55mm) with flash and lens perpendicular to the floor. High-resolution composite images of large floorplan regions were generated with Photoshop version 20.0.9 (Adobe, San Jose, CA, USA). Composite images were exported as uncompressed TIFs. ImageJ[21] was used to scale and threshold the images to isolate stain profiles of blue droplets. Regions of interest (ROIs) were created to demarcate specific zones corresponding to the distance from origin (patient's mouth) (Figure 1). Particles in each ROI were counted using the Analyze Particles feature. Each image was inspected for obvious non-stain particles (eg hair, dust and debris). Associated data points and highly elongated stains were removed to ensure isolation of true droplets and spatter.

Stain profiles produced by droplets upon surface contact are a product of speed, direction upon impact, droplet properties (viscosity, density and surface tension) and substrate (surface roughness).[22] To calculate droplet diameter, the minimum Feret diameter for each stain profile was applied to published formulae to estimate droplet diameter for water on paper using the Swath Kit™ system, whose imaging technology had a resolution most comparable to ours.[23] Based on the resolution limits of our camera, the smallest reliably detectable stain profile had a diameter of 23.26 μm. This corresponded to a droplet diameter of 9.07 μm as estimated by the Swath Kit™ formula [Droplet = − 4.42 + (0.583*Stain Diameter) – (0.000132*Stain Diameter2)].[23] As droplet velocity was unknown, droplet size predictions are approximations that convey a general idea of airborne droplet size. However, values are generally faithful when stain profiles are not scalloped (indicating low-velocity impact) as was true here.[18]

2.2 | *Real-time test*

2.2.1 | Experimental parameters and protocols

Aerosolized particle concentrations were quantified in real time during full mouth ultrasonic scaling on 6 volunteers in a large dental clinic. All procedures were performed by a single licensed, registered dental hygienist using a saliva ejector. A light-scattering laser photometer aerosol monitor (AM) (DustTrak 8533; TSI Incorporated, Shoreview, MN) measured airborne particle concentrations throughout the procedures during clinic closure to eliminate the inclusion of particles from unrelated procedures. The AM quantified real-time mass concentration and size range of particles under 15 μm (ie smaller than can be detected photographically) at distances beyond the 1.2 m (4 ft.) in the simulation test.

To assess real-time particle spread, particle concentrations were documented every second during ultrasonic scaling in two zones: [1] 0–1.2 m (0–4 ft.) from the patient's head at various locations and [2] 1.2–2.4 m (4–8 ft.) from the patient's head [data were not collected in the 0–1.2 m (0–4 ft.) range for one patient]. Baseline clinic particle concentrations were collected over two 7-hour periods of clinic closure. Particle concentrations were reported in 5 size ranges (Table S1) up to concentrations of 150mg/m³ with a sensitivity of 0.001mg/m³ (Table S2). To capture data commensurate with the stain tests and to control for differences in procedure length between participants, data were extracted from a standardized, 5-minute timeframe at the midpoint of each procedure.

3 | RESULTS

3.1 | Simulated test: droplet size and dispersion

The mean laboratory temperature was 21.1°C (range 19.9–22.0°C). An ANOVA with post hoc Tukey showed significant interaction between zone and quadrant, indicating a significant effect of distance (zone) and direction (quadrant) on droplet size distributions (SE: *P*-value < 0.001, *F* = 269.4). No stain droplets were detected beyond zone 15 [beyond 1.2 m (46.5in)].

The sizes of droplets and spatter produced across all tests ranged from 9.1 to 605.4 μm, with considerable variation in mean droplet size depending on zone. The smallest droplets were seen in zones 4–6 [25.4–50.8 cm (10–20in.) from the patient's mouth] and larger droplets at zone 10 and further [72.4+cm (28.5+in.)] (Table 1). Of the four smallest sizes observed, droplets with diameters between 25 and 50 μm were most prevalent in each zone (Fig. S2).

3.2 | Real-time test: particle concentration and dispersion

Baseline particle concentrations were very low, with just 0–98 seconds during which particles were detected across 51,043 individual

TABLE 1 Descriptive information on stain and droplet size[a]

Zone	Stain diameter		Droplet diameter	
	Mean size ± SD (µm)	Range (µm)	Mean size ± SD (µm)	Range (µm)
0	82.93 ± 29.45	23.26–399.57	42.9 ± 16.35	9.07–207.45
1	95.5 ± 42.46	23.26–1378.91	49.5 ± 22.22	9.07–548.5
2	104.29 ± 65.28	23.26–3730.81	54.38 ± 33.03	9.07–599.69
3	84.69 ± 69.07	23.26–1429.89	43.38 ± 34.73	9.07–559.32
4	73.92 ± 48.81	23.26–1075.39	37.64 ± 24.1	9.07–469.88
5	66.05 ± 31.72	23.26–802.64	33.38 ± 16.42	9.07–378.48
6	64.32 ± 40.96	23.26–1342.1	32.31 ± 19.03	9.07–540.26
7	123.69 ± 184.3	46.51–1000	61.2 ± 89.03	22.41–446.58
8	74.71 ± 113.06	46.51–1413.34	36.72 ± 47.53	22.41–555.88
9	181.13 ± 405.51	46.51–1464.64	76.95 ± 155.16	22.41–566.3
10	834.92 ± 124.93	746.57–923.26	389.29 ± 45.3	357.26–421.32
11	835.11 ± 134.52	740–930.23	389.2 ± 48.77	354.71–423.68
12	1504.73 ± 16.18	1493.29–1516.17	573.94 ± 3.01	571.82–576.07
13	NA	NA	NA	NA
14	NA	NA	NA	NA
15	1504.75 ± 257.65	1213.18–1701.77	568.12 ± 52.11	508.59–605.44

[a]Size is based on stain minimum Feret diameter. Note that 23.26µm is the minimum stain diameter that can be reliably detected given the camera resolution. This was, therefore, set as our bottom threshold.

TABLE 2 Average particulate concentration (mg/m^3) and total detection count[a] by distance from patient's mouth.

Distance	PM1		PM2.5		PM4		PM10		PM10+	
	Conc.	Count	Conc.	Count	Conc.	Count	Conc.	Count	Conc.	Count
<1.2m (4 ft.)	0.0010	722	<0.0001	8	<0.0001	60	0.0004	218	0.0017	241
>1.2m (4 ft.)	0.0003	303	<0.0001	1	<0.0001	35	0.0002	145	0.0008	141

[a]Total number of seconds for which a non-zero particle concentration count was observed at a 5-minute midpoint sample taken during ultrasonic scaling.

readings (1/second) (Table S2). It was, therefore, unnecessary to normalize data against the baseline as in other studies.[24] Real-time particle mass concentrations during scaling procedures were also low (Table 2), though there was marked between-subject variation for PM1, PM10 and PM10+ particle sizes (Table S3). PM1 (the smallest detected) and PM10+ (largest) particles were highest in overall concentration (Table 2). PM1 particle concentrations dropped 70% as the distance from patient increased beyond 1.2 m (4 ft.), while PM10 particle concentrations decreased by 50% and PM10+ decreased by

53%. Particles in the intermediate PM2.5 (fine) and PM4 (coarse) size categories were uncommon at all distances, in the frequency of detection and in mass concentration, averaging <0.0001mg/m^3 across participants.

In terms of detection frequency, results showed PM1 (submicron) particles were the most common, followed by the largest (PM10+) (Table 2). PM1 particles were detected within 1.2 m (4 ft.) from the patient's mouth at an average of 144.4 (±122.8) seconds out of the total 5-minute (300 seconds) time interval

sampled (Table S4). In contrast, PM1 particles were detected only 65 seconds out of the 51,043-second baseline (clinic closure) readings. PM10+ particles were detected at an average of 48 seconds (±31.78) out of 300 seconds within 1.2 m (4 ft.) from the patient. However, they were only detected 14 seconds of the 51,043 seconds of clinic closure. These results show marked particle increases during ultrasonic scaling. As with particle mass concentrations, there is marked variation in detection frequency across subjects (Table S4).

4 | DISCUSSION

4.1 | Dispersion of spatter and droplets produced during ultrasonic scaling

Droplets with diameters between 25 and 50 μm were most prevalent in each zone during the simulation test, followed more distantly by 50–75 μm and 0–25 μm diameter droplets. Detectable droplet sizes for both tests, therefore, meet the criteria for 'spatter' (>100 μm in diameter), 'droplet' (5–100 μm in diameter) and 'aerosolized particle,' (diameters less than 5 μm).[7,8] This supports the use of stain profiles on paper as an effective means to study droplet size and dispersion during dental procedures.

Our simulated tests identified quadrants opposite the operator working hand (south and east quadrants) as regions with the highest droplet concentrations, particularly within 0.6m (2 ft.) of the patient (Figure 1). While there was no assistant in these tests, results corroborate those by Veena et al.[17] whose pilot study showed contamination on the dental assistant's chest and left hand during ultrasonic scaling. Assistants typically work opposite the operator in these regions (ie zones with the highest droplet concentrations). The assistant zone contained the highest concentration of settled droplets, consistent with what Veena et al. termed the 'maximum aerosol contamination' zone.

The results of both simulated and real-time tests confirm regions proximate to the source have the highest concentration of surface contamination and airborne particle concentrations. This is consistent with other studies showing the greatest contamination within 0.3 m (1 ft.) of the operative site, and that contamination/particle load decreases with increasing distance.[17] Veena et al.[17] found that contamination decreased by 50% at distances over 0.6m (2 ft.), and Bentley et al.[10] found uniform bacterial contamination 0.6m (2 ft.) from the source. Collectively, these conclusions indicate that most particles generated during ultrasonic scaling are found within 0.6m (2 ft.) of the patient's mouth.

While multiple prior studies show microbe-bearing spatter and aerosols generated during dental treatment often land in proximate regions (eg patient's chest or provider PPE), recent research shows aerosols generated by ultrasonic scalers can travel up to 3.96m (13 ft.)[16] While overall particle concentrations measured in this study were very low (<0.001mg/m^3 for most particle sizes), our real-time tests detected particles at distances up to 2.4 m

(8 ft.) in all directions and our simulation test detected droplets nearly 1.2m (4 ft.) from the source—the maximum distances for each study. Other studies using bacterial quantification and contamination mapping show viable bacteria spread throughout dental operatory spaces, likely due to transport by aerosols containing irrigants and lower levels of patient saliva.[5,25] In total, the results of these studies and ours show aerosolized particles produced during ultrasonic scaling decrease as distance from the source increases, but that there is potential for distant contamination by aerosol spread.

4.2 | Contextualizing real-time data

PM1 particles were most prevalent in overall detection frequency. While PM1 particles are unlikely to transport larger bacteria, they can transport smaller virus particles (eg 70-120 nm SARS-CoV-2).[26,27] However, their small size and low travel velocity means they may be exhaled before settling in the respiratory tract, though this claim is the subject of ongoing debate due to many extenuating physiological and environmental factors that influence particle movement trajectories.[28,29] This is not true of PM2.5 particles, which can enter and settle in deeper parts of the respiratory system where they may absorb into the bloodstream and pose infection risk.[30] However, these particles were uncommon in our real-time tests. This may indicate ultrasonic scaling produces comparably less PM2.5 particles, or that they are disproportionately captured by standard saliva ejectors.

Aerosols produced via ultrasonic scaling contain a mixture of irrigation solutions, saliva, blood, bacteria and other respiratory or oropharyngeal debris that can cause surface and PPE contamination or disease transmission via inhalation.[4,5,31,32] Our real-time test showed that a 30kHz magnetostrictive ultrasonic unit produced more PM1 particles during dental prophylaxis than any other particle size. Similar results were reported for tooth preparations by Liu et al.,[33] wherein 96.78% of total suspended particles were PM1 when no evacuation was used. As a result, the authors conclude that almost all particles generated during drilling and grinding of extracted natural teeth were PM1. Results are similar for *in vivo* tooth preparations, which primarily produce particles <3.0 μm, but do so at higher concentrations.[24] Further investigation into the production of ultrafine particle concentrations during ultrasonic scaling is needed to include smaller, potentially contaminated aerosols, as existing evidence predicts that any PM1-, PM2.5- or PM10-sized particles could transmit COVID-19 and other viruses.[34]

4.3 | Implications for COVID-era dentistry

The minimum droplet size necessary to transport SARS-CoV-2 is unknown, but coronaviruses range from 70 to 120nm in size.[26,27] A recent study of Wuhan Province hospitals during the COVID outbreak showed that out of five size ranges, the highest concentration of SARS-CoV-2 particles was 0.25–1.0μm (submicron) and 2.5μm+

(fine or supermicron). They propose both likely came from resuspension, the former from contaminated staff clothing and the latter from surface dusts and particulates.[14]

Insight can also be gleaned from literature on influenza transmission. About 90% of influenza A-laden particles are <4.7 μm.[35] Expirated droplets contained detectable influenza RNA in 83% of infected subjects, with 75%+ patients having detectable RNA in all three droplet size ranges evaluated (>4.0 μm, 1.0–4.0 μm and <1.0 μm) and over half of respirable particles containing viral RNA.[36] The exhaled breath of influenza patients showed 'the infectious dose via aerosol [was] about two orders of magnitude *lower* than via large droplets' [emphasis added] but that risks associated with larger (>5μm) droplets were strongly mitigated by surgical mask use.[37] The size range for influenza A (80–120 nm) largely encompasses that of SARS-CoV-2,[37,38] suggesting that under similar conditions, most droplets detected in our simulated and real-time tests were capable of transporting SARS-CoV-2 (with larger droplets/spatter being of greater concern than aerosols for viral transmission).

Altogether, the work by our group and others on droplet and particulate contamination indicate that multiple barriers are necessary to reduce the risk of viral spread during dental procedures. Our prior work shows marked reduction in detectable droplets with high-volume evacuation (HVE) use during ultrasonic scaling for all droplet size ranges, indicating this is a critical tool for removing potentially virus-laden particles at the source.[39] This corroborates similar studies that show a reduction in dental handpiece-generated aerosols with the use of HVE or extraoral scavengers.[34,40] While HVE was not used in our real-time test, the 99% reduction in particles identified with HVE use during ultrasonic scaling would significantly reduce particle concentration and spread.[39] Evacuation devices are, therefore, necessary to protect the health of dental healthcare providers (DHCPs).

Other spatter mitigation strategies include personal protective equipment to limit the risk of inhalation and exposure, and protective barriers to limit potential transmission via contact with contaminated surfaces. Preprocedural mouth rinses, such as chlorhexidine and cetylpyridinium chloride, can reduce bacterial load in dental aerosols by 68.4%.[41] Pre-appointment toothbrushing can also reduce airborne contamination during dental procedures.[10] The best protocols to protect against viral transmission via aerosols and spatter is likely to be one that uses myriad, multilevel strategies to protect both DHCPs and their patients.

COVID-19 has raised concerns regarding aerosols generated during dental procedures, including the length of time these aerosols remain airborne and the distance they can travel. Our tests identified areas closest to the patient as those with the highest density of small, potentially respirable particles, that this concentration decreases with increased distance, that droplets disproportionately travel in directions opposite the operator working arm, and that all five particle size groups evaluated can be detected up to 2.4m (8 ft.) away from the patient's mouth during ultrasonic scaling with a saliva ejector. This demonstrates the importance of aerosol and spatter mitigation strategies for all dental procedures, including those associated with dental ultrasonic use.

5 | CLINICAL RELEVANCE

5.1 | *Scientific rationale for study*

Few studies have used whole room mapping to measure the distance and direction of droplet and aerosol spread from ultrasonic scaling instruments.

5.2 | *Principle findings*

Concentrations of droplets and spatter produced during ultrasonic scaling decrease at distances further from the source; however, distant surfaces in all directions can become contaminated. Significant contamination was observed opposite the operator, in the dental assistant zone.

5.3 | *Practical implications*

Due to the maximum potential spread of contaminated droplets and aerosols, dental healthcare professionals must use appropriate personal protective equipment and aerosol mitigating strategies to reduce contact with contaminated aerosols and surfaces.

CONFLICT OF INTEREST
The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS
APB and GA had primary responsibility for conceptualization, clinical and simulation data collection, analysis and writing. QH and MD assisted with project development and photoanalytical data collection. DH was involved in project development and data collection. BS and JCM were responsible for supervision, resources, conceptualization and manuscript review. GMM assisted with project execution.

ORCID
Alexandra C. Pierre-Bez https://orcid.org/0000-0003-2533-291X

REFERENCES
1. Peng X, Xu X, Li Y, Cheng L, Zhou X, Ren B. Transmission routes of 2019-nCoV and controls in dental practice. *Int J Oral Sci.* 2020;12(1):9. https://doi.org/10.1038/s41368-020-0075-9
2. Kutter JS, Spronen MI, Fraaij PL, Fouchier RAM, Herfst S. Transmission routes of respiratory viruses among humans. *Curr Opin Virol.* 2018;28:142-151.
3. Liu Y, Ning Z, Chen Y, Guo M. Aerodynamic characteristics and RNA concentrations of SARS-CoV-2 aerosol in Wuhan hospitals during COVID-19 outbreak. 2020;bioRxiv. https://doi.org/10.1101/2020.03.08.982637

4. Gund M, Isack J, Hannig M, et al. Contamination of surgical mask during aerosol-producing dental treatments. *Clin Oral Invest*. 2021;25(5):3173-3180. https://doi.org/10.1007/s00784-020-03645-2

5. Meethil AP, Saraswat S, Chaudhary PP, Dabdoub SM, Kumar PS. Sources of SARS-CoV-2 and other microorganisms in dental aerosols. *J Dent Res*. 2021;100(8):817-823.

6. Han P, Li H, Walsh LJ, Ivanovski S. Splatters and aerosols contamination in dental aerosol generating procedures. *Appl Sci*. 2021;11(4):1914. https://doi.org/10.3390/app11041914

7. Leggat PA, Kedjarune U. Bacterial aerosols in the dental clinic: a review. *Int Dent J*. 2001;51:39-44.

8. Infection Prevention and Control of Epidemic- and Pandemic-prone Acute Respiratory Infections in Health Care. World Health Organization; 2014 (available at https://apps.who.int/iris/bitstream/handle/10665/112656/9789241507134_eng.pdf;jsessionid=41AA684FB64571CE8D8A453).

9. Harrel SK, Molinari J. Aerosols and splatter in dentistry: a brief review of the literature and infection control implications. *J Am Dent Assoc*. 2004;135:429-437.

10. Bentley CD, Burkhart NW, Crawford JJ. Evaluating spatter and aerosol contamination during dental procedures. *J Am Dent Assoc*. 1994;125:579-584.

11. AMEC Power. Review of Respirable Particle Size Range. Nuclear Decommissioning Authority. 2013 [cited 2021 March 12]. Available from: https://rwm.nda.gov.uk/publication/review-of-respirable-particle-size-range/

12. Thomas RJ. Particle size and pathogenicity in the respiratory tract. *Virulence*. 2013;4:847-858.

13. Chia PY, Coleman KK, Tan YK, et al. Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients. *Nat Commun*. 2020;11(1):2800. https://doi.org/10.1038/s41467-020-16670-2

14. Liu Y, Ning Z, Chen Y, et al. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature*. 2020;582:557-560.

15. Teichert-Filho R, Baldasso CN, Campos MM, Gomes MS. Protective device to reduce aerosol dispersion in dental clinics during the COVID-19 pandemic. *Int Endod J*. 2020;53:1588-1597.

16. Allison JR, Currie CC, Edwards DC, et al. Evaluating aerosol and splatter following dental procedures: addressing new challenges for oral healthcare and rehabilitation. *J Oral Rehab*. 2021;48(1):61-72. https://doi.org/10.1111/joor.13098

17. Veena HR, Mahantesha S, Joseph PA, Patil SR, Patil SH. Dissemination of aerosol and splatter during ultrasonic scaling: a pilot study. *J Infect Public Health*. 2015;8:260-265.

18. Pelleu GB Jr, Shreve WB, Wachtel LW. Reduction of microbial concentration in the air of dental operating rooms: I. High-efficiency particulate air filters. *J Dent Res*. 1970;49(2):315-319.

19. Zemouri C, Volgenant CMC, Buijs MJ, et al. Dental aerosols: microbial composition and spatial distribution. *J Oral Micribiol*. 2020;12(1):1762040. https://doi.org/10.1080/20002297.2020.1762040

20. Agostini-Walesch GM, Pierre-Bez AC, Hancock DS, Hong Q, Davis M, Smith B, Mitchell JC. Whole-room mapping of aerosolized spatter. Poster presented at: International Association of Dental Research; July 21–24, 2021; Virtual

21. Abramoff MD, Magalhaes PJ, Ram SJ. Image processing with ImageJ. *Biophotonics Int*. 2004;11(7):36-42.

22. Hulse-Smith L, Mehdizadeh NZ, Chandra S. Deducing drop size and impact velocity from circular blood stains. *J Forensic Sci*. 2005;50(1):54-63.

23. Hoffmann WC, Hewitt AJ. Comparison of three imaging systems for water-sensitive papers. *Appl Eng Agric*. 2005;21(6):961-964.

24. Sotiriou M, Ferguson SF, Davey M, et al. Measurement of particle concentrations in a dental office. *Environ Monit Assess*. 2008;137:351-361.

25. Ionescu AC, Cagetti MG, Ferracane JL, Garcia-Godoy F, Brambilla E. Topographic aspects of airborne contamination caused by the use of dental handpieces in the operative environment. *J Am Dent Assoc*. 2020;151(9):660-667.

26. Cascella M, Rajnik M, Cuomo A, Dulebohn SC, Di Napoli R. *Features, evaluation and treatment coronavirus (COVID-19)*. 2020.

27. Kim J, Chung Y, Jo HJ, Lee N, Kim MS, Woo SH. Identification of Coronavirus isolated from a patient in Korea with COVID-19. *Osong Public Health Res Perspect*. 2020;11(1):3-7.

28. Jabbal S, Poli G, Lipworth B. Does size really matter? Relationship of particle size to lung deposition and exhaled fraction. *J Allergy Clin Immunol*. 2017;139(6):2103-2104.

29. Deng Q, Ou C, Chen J, Xiang Y. Particle deposition in tracheobronchial airways of an infant, child, and adult. *Science Tot Environ*. 2018;612:339-346.

30. Centers for Disease Control and Prevention. Air quality: Particle pollution. [cited 2021 March 12]. Available from: https://www.cdc.gov/air/particulate_matter.html

31. Harrel SK, Barnes JB, Rivera-Hidalgo F. Aerosol and splatter contamination from the operative site during ultrasonic scaling. *J Am Dent Assoc*. 1998;129:1241-1249.

32. Dias I, Delgado E. Bacterial aerosols released during dental ultrasonic scaling in dogs. *Dent Oral Biol Craniofac Res*. 2020;3(3):2-5.

33. Liu M, Chen C, Chuang L, Lin W, Wan G. Removal efficiency of central vacuum system and protective masks to suspended particles from dental treatment. *PLoS One*. 2019;14(11):e0225644.

34. Nulty A, Lefkaditis C, Zachrisson P, Van Tonder Q, Yar R. A clinical study measuring dental aerosols with and without a high-volume extraction device. *Br Dent J*. 2020. https://doi.org/10.1038/s41415-020-2274-3

35. Leung NHL, Zhou J, Chu DKW, et al. Quantification of influenza virus RNA in aerosols in patient rooms. *PLoS One*. 2016;11(2):e0148669.

36. Lindsley WG, Blachere FM, Thewlis RE, et al. Measurements of airborne influenza virus in aerosol particles from human coughs. *PLoS One*. 2010;3(11):e15100.

37. Milton DK, Fabian MP, Cowling BJ, Grantham ML, McDevitt JJ. Influenza virus aerosols in human exhaled breath: particle size, culturability, and effect of surgical masks. *PloS Pathog*. 2013;9(3):e1003205.

38. Vajda J, Weber D, Brekel D, Hundt B, Muller E. Size distribution analysis of influenza virus particles using size exclusion chromatography. *J Chromatogr A*. 2016;1465:117-125.

39. Agostini GM, Pierre-Bez AC, Marcelli-Munk G, et al. Aerosols in ultrasonic scaling: comparing particle spread using saliva ejectors and high-volume evacuation. *J Dent Hyg*. 2021;95(3):18-25.

40. Shahdad S, Patel T, Hindocha A, et al. The efficacy of an extraoral scavenging device on reduction of splatter contamination during dental aerosol generating procedures: an exploratory study. *Br Dent J*. 2020. https://doi.org/10.1038/s41415-020-2112-7

41. Ge Z, Yang L, Xia J, Fu X, Zhang Y. Possible aerosol transmission of COVID-19 and special precautions in dentistry. *J Zhejiang Univ Sci B*. 2020;21(5):361-368.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.