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Efficacy of an Extraoral Suction System in Reducing Aerosol Contamination

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Abstract

The dental setting is regarded as a high-risk environment for aerosol concentrations and transmission of respiratory infectious agents, especially in relevance to the COVID-19 pandemic. Though a number of approaches and practices have evolved to reduce the spread of pathogens in the dental setting, the risk of airborne infection remains a concern. Several new extraoral suction (EOS) devices have been marketed recently; further investigation is warranted to determine their clinical effectiveness. **Objective:** The aim of this study was to evaluate the efficacy of a chairside EOS device (PAX 2000 Extraoral Dental Suction System, pH Dental, Inc.) in reducing aerosol contamination from subjects receiving initial or supportive periodontal therapy with ultrasonic scaling by a registered hygienist. **Methods:** Colony-forming units (CFUs) were measured using passive sampling methods (aerobic, anaerobic, and room temperature agar plates) before, during, and after treatment at three different locations in the dental operatory. Forty subjects were randomly allocated into two test groups, with or without the use of the EOS device during treatment. Retrieved colony-forming units CFUs after incubation were quantified and identified into bacterial/fungal taxa. Data were analyzed with Mann-Whitney U tests (α=0.05). **Results:** Use of the EOS device reduced the number of CFUs during treatment at all three locations but was only statistically significant (P=0.018) at the patient's chest area, where the highest CFUs were present. The aerosols consisted of 74 different taxa of human origin. **Conclusions:** The EOS system may serve

to reduce aerosol contamination in the clinical dental setting, especially in proximity to the patient's head, where most aerosols were generated.

Introduction

The advent of the COVID-19 pandemic outbreak declared by the World Health Organization has markedly impacted the landscape of healthcare, especially the delivery of dental care services. (1) COVID-19, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has a predominant respiratory mode of infectious transmission via respiratory droplets. (2) SARS-CoV-2 has the capacity to remain infectious in airborne droplets. (3) Aerosols, composed of suspended solid or liquid particulates with less than 50 micrometers of diameter in a gas medium, are particularly worrisome. (3,4) Thus, for the safety and well-being of the federal service dental providers and DoD beneficiaries, it is essential that best evidence-based practices and protective measures are identified and prioritized to ensure optimal risk management.

Though the COVID-19 outbreak has re-highlighted the importance of effective infection control in dentistry, concerns regarding the threat of transmitting pathogenic microorganisms during dental treatment are certainly nothing new within the discipline. Many previous studies have demonstrated a significant increase in bacterial and fungal aerosol concentrations during dental treatment and, consequently, a commensurate increase in the transmission of respiratory infectious agents. (5) These bio-aerosols can impose great risks on patients who are immunocompromised. (5,6) The risk to otherwise healthy patients and dental professionals alike is undeniably present but is not considered to be statistically significant. (5,6) Nevertheless, there is an increased prevalence of respiratory conditions among dental professionals that may be attributed to contaminated air routinely generated in the dental operatory. (4)

Spatter, defined as airborne particles greater than 50 micrometers in diameter, is also generated in dental settings. Overall, spatter droplets are not considered to be as significant of an infection threat as compared to aerosols since they can only remain airborne transiently before falling onto a surface, from which they evaporate, leaving behind smaller particles. (7) Nevertheless, spatter droplets can be a source of possible

infection in the dental treatment setting and have been recorded to transmit diseases such as HIV, tuberculosis, SARS, measles, influenza, Legionnaire's disease, and hepatitis. (7, 8) The salivary gland, in particular, has been identified as a potential reservoir of SARS-CoV-2 infection by recent studies. (9) Spatter and aerosols alike are produced during the use of an ultrasonic scaler, which is heavily employed in modern dental practice to perform initial and supportive periodontal therapy to mechanically remove supra- and subgingival plaque and calculus. (10) Additionally, a previous investigation has concluded that the ultrasonic scaler can produce aerosols and spatter that are comparable to those generated from high-speed dental handpieces. (11)

To ensure patient and provider safety, a number of approaches and practices in reducing the spread of pathogens have evolved. Both high-volume suction and pre-procedural antiseptic mouth rinses have been proven to mitigate the risk of airborne infection. (4) Furthermore, personal protective equipment (PPE) in the form of gloves, masks, gowns, and protective eyewear has shown to be effective in preventing contamination. (4) However, protections cease as soon as PPE is removed, and unfortunately, bio-aerosols can remain suspended in the air as contaminants for up to 30 minutes after procedure completion. (12) The use of a rubber dam has been clinically proven to eliminate 98% of microbial contamination at the primary source. (13) Even so, not all dental procedures may be performed with a rubber dam—for instance, initial and supportive periodontal therapy—and not all patients are able to tolerate the use of a rubber dam.

Recently, it has been purported that the inclusion of extra-oral scavenging (EOS) device in conjunction with the traditional, high-volume evacuator can further reduce spatter contamination during dental aerosol-generating procedures. Further investigation is warranted in the clinical dental setting to provide evidence for the effectiveness of EOS devices in reducing airborne vector transmission of potential infection.

Several new EOS devices have been marketed recently. The PAX 2000 Extraoral Dental Suction System (pH Dental, Inc., Orange, CA, USA) has a unique, multi-stage carbon filtration system design that draws in dental aerosol and spatter particles, performs

plasma disinfection, and then releases the purified air back into the room. At 12.60 inches x 12.99 inches x 29.72 inches, the unit is compact enough to be incorporated into a dental operatory setup and is reported to generate noise below 70 decibels. The unit features a medical-grade H13 HEPA filtration system, 1000 W motor power, and a dual UV-C bulb light system that reportedly kills microorganisms greater than 0.3 microns at 99.95% efficiency. See Figure 1.

The aim of this study was to evaluate the efficacy of a chairside EOS device (PAX 2000 Extraoral Dental Suction System) in the reduction of spatter contamination during dental aerosol-generating procedures as well as contribute toward an optimal evidence-based protocol for safe delivery of dental treatment in a modern era of infection control precipitated by the COVID-19 pandemic.

The null hypothesis tested was that there would be no difference in microbial load, composition, or spatial distribution in the dental operatory with or without the use of the EOS device during ultrasonic cleaning of a dental patient.

Figure 1. PAX2000 Extraoral Dental Suction System

Materials and Methods

A random sample of 40 patients treatment-planned for initial or supportive periodontal therapy at Dunn Dental Clinic (Joint Base San Antonio-Lackland Air Force Base, TX) participated in this exempt human study. Each patient was consented using an Informational Informed Consent Document, in which the patient's willingness to participate in the study served as their "implied consent," and no identifiable information was obtained from the subjects for research purposes. The 40 patients were randomly allocated into two test groups — one group with exposure to the extra-oral suction device during the ultrasonic cleaning procedure and the other without — and each group was composed of 20 patients. The group of patients without exposure to the extra-oral suction device during ultrasonic cleaning served as the control group. A single-chair dental treatment room was used for each scheduled patient to minimize environmental bias. The saliva ejector was used during the ultrasonic cleaning procedure to control moisture. However, high-speed suction was not permitted for the purposes of this investigation since it was not an adjunct commonly used during routine ultrasonic cleaning. The PAX2000 EOS device inlet was placed in the same position throughout the study, 6-8 inches from the patient’s mouth during dental treatment. The filter of the PAX2000 was maintained per manufacturer instructions for use to ensure the proper functioning of the unit. All baseline and procedure sampling was performed with the clinic windows closed and no fans operating.

The microbial load, composition, and spatial distribution of aerosols and spatter generated during ultrasonic scaling were measured using passive sampling. This method involved exposing 90 mm diameter Petri dishes containing either trypticase soy agar with 5% sheep blood (TSA II) or R2A agar to the air for 30 minutes. The air was sampled at three specific time points during the course of the patient’s scheduled treatment: 1) 30 minutes before the procedure (the room was unoccupied for at least 1 hour); 2) during the dental treatment, and 3) 30 minutes after the final treatment. The plates were placed

at three designated locations 1) above the patient's chest suspended on a tray, at 12 in from the oral cavity; 2) next to the dental instruments on the unit, and 3) on the countertop at the foot of the dental chair (control). See Figure 2.

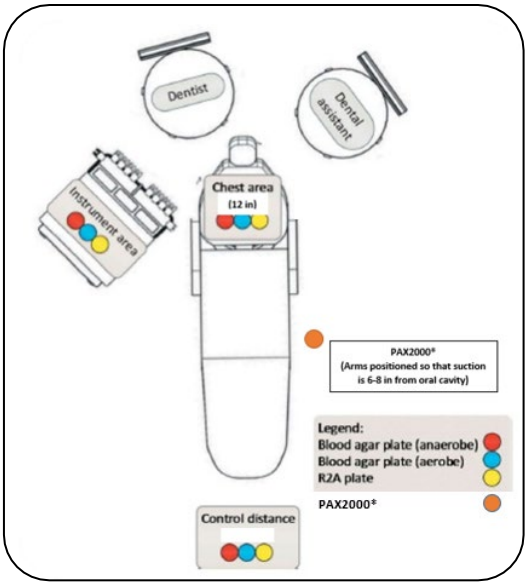

Figure 2. Floor Plan of Dental Operatory for placement of agar plates

Samples from the dental unit waterline (DUWL) were also collected from the air-water syringe of the dental unit before each patient's treatment for comparative analysis. The DUWL at Dunn Dental Clinic was continuously treated with the Sterisil system (Sterisil, Inc., Palmer Lake, CO, USA) to prevent the development of bacterial biofilm. The syringe was flushed for 30 seconds prior to sampling. A universal tube of 50 mL was filled with water, marked, and stored at 4°C upon transportation to the laboratory.

TSA II plates from passive sampling were incubated (Thermo Forma Steri-Cycle 370 CO_2 Incubator, Thermo Fisher, Waltham, MA, USA) at 37±2˚C aerobically and anaerobically upon arrival to the laboratory on the same day. The R2A plates were incubated aerobically at 23˚C. The number of colonies was counted after 7 days of incubation. Bacterial colonies on each plate were streaked for isolation onto TSA II plates. Clinically relevant bacteria were identified through gram staining, qualitative differential tests, and identification cards (Vitek 2, BioMerieux, Marcy l'Etoile, France). Executed qualitative differential tests included catalase, coagulase, oxidase, and indole. Fungal growth was subcultured onto Potato Flakes Agar plates. The fungal colonies were stained with Lactophenol-cotton blue stain and then identified microscopically. See Figure 3.

The sampled DUWL water was vortexed for 30 seconds; 500 µL was placed on R2A agar in triplicate, and plates were incubated aerobically at 23°C to determine the CFU of heterotrophic bacteria.

Figure 3. Sample laboratory report of bacterial/fungal species identification

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Data were analyzed to test the principal hypotheses that there would be no difference in microbial load, composition, or spatial distribution in the dental operatory with or without the use of the extra-oral suction device during ultrasonic cleaning of a dental patient. The number of taxa was counted per location/timepoint. The source of the taxa was assigned—either human or environmental/water—based on the best available evidence.

The outcome data (i.e., microbial load, composition, and spatial distribution in the dental operatory) were calculated for each location and time point. Continuous outcomes were assessed for normality by the Shapiro-Wilks test. Non-normally distributed data were presented as the median and interquartile range (IQR) and were analyzed using the Mann-Whitney U test with statistical analysis software (SPSS, Version 26, IBM, Chicago, IL, USA). Differences were considered significant when $p < 0.05$.

The power analysis was performed assuming the large effect size (Cohen's $d = 1.0$) for a 2-sided test with a significance level α of 0.05. The sample size of 20 per group achieved 87% power.

Results

DUWL microbiology

All collected dental unit waterline samples contained 0 CFU/mL. The DUWLs were maintained with routine disinfection using the Sterisil system (Sterisil, Inc) and with bleach every three months.

Microbial load in the air, passive sampling

During sample collection, the air-water syringe, ultrasonic scaler, and saliva ejector were all used by the dental hygienist while treating patients. The median CFUs per plate per location and time point ranged from 0 to 6, as reported in Table 1. The lowest CFUs/plate was found in samples collected before treatment from those placed on the countertop at the foot of the dental chair. Therefore, plates arranged on the countertop at the foot of the dental chair are considered to be controls for all passive measurements. All collected data were assessed by the Shapiro-Wilks test and found not to be normally distributed ($p < 0.001$).

Time	Location	**Colony Forming Units** Median (IQR)		
		No Suction Device	Suction Device[#]	P value
Before	Instrument Table	1 (3)	1 (2)	0.109
	Patient Chest	1 (2)	1 (2)	0.235
	Patient Foot	1 (2)	0 (1)	0.176
During[#]	Instrument Table	4 (3)	3 (3.75)	0.125
	Patient Chest	6 (10.75)	4 (5)	0.018*
	Patient Foot	3 (3)	2 (3)	0.071
After	Instrument Table	2 (2)	2 (3)	0.844
	Patient Chest	2 (2)	2 (3)	0.163
	Patient Foot	1 (1.75)	2 (3)	0.149
[#]Suction device was only active during treatment *Indicates significant difference				

Table 1. Colony Forming Units per location and time point with and without suction device

The highest CFUs/plate was retrieved from the patient chest location, followed by the instrument tray area during all time points. There were no significant differences between aerobic and anaerobic plates for all locations and time points ($p>0.05$). Microbial load after treatment was comparable but higher than before treatment at all locations. The use of the EOS suction device reduced the number of CFUs/plate during treatment at all three locations but was only statistically significant ($p=0.018$) in the patient's chest area.

Microbial composition

Bacteria and fungi of human origin were found in all sampled locations and time points, as summarized in Table 2. A total of 73 human-derived taxa (HDT) were identified. No bacterial or fungal taxa were identified in samples acquired from the DUWL due to no CFUs obtained in those samples. The HDT *Diphtheroid*, *Kocuria*, *Micrococcus*, *Staphylococcus*, and *Streptococcus* were present in all sampled locations and at all time points. The number of HDT ranged from between 16 and 38 taxa per location or time point. The greatest numbers of bacterial and fungal taxa were observed from samples collected during treatment, followed by those obtained after treatment.

Time	Location	**Total Number of Bacterial and Fungal Taxa**	
		No Suction Device	Suction Device[#]
Before	Instrument Table	19	16
	Patient Chest	20	19
	Patient Foot	19	17
During[#]	Instrument Table	32	37
	Patient Chest	38	36
	Patient Foot	23	32
After	Instrument Table	25	30
	Patient Chest	24	28
	Patient Foot	22	27
[#]Suction device was only active during treatment			

Table 2. Total number of bacterial and fungal taxa identified in samples per location and time point with and without suction device

Discussion

Past studies have demonstrated the utility but also limitations of adjunctive extraoral suction and filtration devices to minimize the spread of generated aerosols. Suyama et al. (1995) previously examined an extra-oral vacuum aspirator (EOVA) (Free Arm Type, Tokyo Giken, Inc., Tokyo, Japan), focusing on the prevention of secondary pollution caused by the discharge of scattered contaminants from the aspirator exhaust. They were able to demonstrate the utility of the EOVA device in preventing infection in the dental setting, as well as the importance of sufficient exhaust containment in its design to prevent secondary infection. (14) Holloman et al. (2015) compared an illuminated isolation system (Isolite, Zyris, Inc., Goleta, CA, USA) and a traditional saliva evacuator for aerosol and spatter reduction during ultrasonic scaling. As studied, neither Isolite nor the traditional saliva ejector reduced aerosols and spatter effectively, and there was no significant difference in reduction between them as well. (15) Graetz et al. (2014) conducted an in-vitro study of high-volume evacuation during ultrasonic scaling. Comparing various cannulas, they concluded that high-volume evacuation could significantly reduce spatter contamination produced during power-driven scaling. (16) More recently, Holliday et al. (2021) compared the use of low volume suction at 40L/min air and medium volume suction at 159 L/min air on the reduction of close and distant dental aerosol contamination in an open-plan clinic using fluorescein dye as a tracer. They found that the use of dental suction conferred a substantial positive effect on the mitigation of distant contamination but also that there was a low threshold for this effect, given that they recorded a minimal observed difference between low and medium suction. (17)

Some more recent studies have begun to use more sophisticated technology to filter and purify bio-aerosols generated during dental treatment. Hubar et al. (2014) sought to validate whether a germicidal air purifier unit (Ionic Breeze GP, Sharper Image, Inc., Farmington Hills, MI, USA) and a non-germicidal unit (Ionic Breeze Quadra, Sharper Image, Inc.) would be effective in filtering and destroying bacteria from dental aerosols generated in dental school operatories. Through collection, incubation, and analysis of the samples, they reported that the germicidal unit was able to kill more than 99% of *Staphylococcus aureus* collected on its stainless-steel blades, while the non-germicidal

unit was ineffective and collected numerous *Staphylococcus aureus*. (18) Nevertheless, the study was rather limited in scope since they focused solely on one strain of bacteria. Hallier et al. (2010) performed a pilot study of bio-aerosol reduction using an air-cleaning system (IQ Air Flex Vac, Goldach, Switzerland). The IQ Air Flex Vac boasts itself to have a long, flexible polypropylene plastic suction duct with three layers of filtration technology: a high-efficiency particulate air (HEPA) pre-filter capable of retaining particles less than 0.3 microns, a four-cylinder gas filter cartridge, and an electrostatically charged post-filter. In operating the device during four types of dental procedures — history and oral examination, ultrasonic scaling, cavity preparation, and extraction — it was demonstrated that the air cleaning system significantly reduced bio-aerosol load between 72-87% during dental procedures. (19) However, the researchers chose to sample bio-aerosol generation from different procedures in separate clinics with multiple dental student providers, hoping to control for residual bio-aerosol and assess increases in bio-aerosol based on the specific dental procedure performed, but introduced some confounding factors through this design. Zhao et al. (2020) contrasted two classes of air purifier filters, fine filters (F6) and high-efficiency particulate air (HEPA) filters, and their efficacy in removing aerosols in-vitro. They reported that HEPA filters were most effective at 83% removal compared to the fine filters at 54%. However, the study was only performed in the laboratory. (20)

Shahdad et al. (2020) conducted an innovative study with an EOS device (TM10, TopMed Dental Lighting Co. Ltd., Foshan, China) in a simulated study conducting dental procedures on a dental manikin. Their experimental design involved the use of citric acid in water lines so that chromatic change could be measured on universal indicating paper placed in locations throughout the operatory to record the intensity of splatter contamination. They found that the EOS device produced a 20% reduction in frequency and 75% reduction in mean intensity of contamination in the operatory, in addition to a 33% and 76% reduction in mean intensity contamination for the clinician and assistant, respectively. Nevertheless, their study was a simulation by design and was not able to account for numerous patient factors such as saliva, soft tissues, and patient compliance that would influence the efficacy of EOS systems in a clinical setting. (21) Graetz et al. (2021) built upon Shahdad et al.'s study with another simulated study, focusing on

measuring small particle concentrations using an air sampler (Lasair III 110, PMS Inc., Boulder, CO, USA). They chose to focus on small particle concentrations due to their frequency of generation during high-speed tooth preparation. They found that an EOS device (JakAir Mobile System, ULT, Lobau, Germany) equipped with an ultra-low penetration air filter significantly reduced the number of generated particles during dental procedures. However, their experimental study was only simulated with treatments conducted on a manikin head. (22) Previous studies had evaluated the utility of such devices in reducing microbial load during dental treatment but had tested the devices in simulated treatment and thus did not fully account for various factors in the clinical setting such as saliva, soft tissues, patient compliance, and practicality for use during dental treatment. (21,22)

Of particular note was a recent publication by Suprono et al. (2021) that detailed a pioneer investigation in evaluating and comparing the effectiveness of dental evacuation systems in reducing aerosols during oral prophylactic procedures in a large clinical setting. They performed a controlled clinical study using a split-mouth design on 93 student participants recruited with inclusion and exclusion criteria. During oral prophylaxis, either high volume suction or a combination of high volume suction and an intraoral suction device (Mr. Thirsty, Zirc, MN, USA) were used, and agar plates were arranged for aerosol collection in various locations around the room at four treatment periods: baseline, high-volume evacuation, combination (HVE and intraoral suction device), and posttreatment. They concluded from their study that the combination of devices resulted in significant reductions in CFUs and that the highest amounts of CFUs were present in the operating zone and on patients. (23)

This study was an effort to further evaluate the clinical efficacy of a modern, chairside EOS device in the dental operatory to reduce aerosol contamination. The null hypothesis that there would be no difference in microbial load, composition, or spatial distribution in the dental operatory with or without the use of the EOS device during ultrasonic cleaning of a dental patient was rejected. The use of the EOS device decreased microbial air contamination at all locations during treatment and was statistically significant at the patient's chest. Notably, the patient chest location also was identified with the highest number of identified bacterial and fungal taxa, mainly of human origin.

The results of this study are in line with previous studies, which also substantiated that the greatest aerosol contamination is found in close proximity to the patient's head and where the EOS device can have the most utility. (21-25) Similar reported patterns of higher mean CFUs during treatment compared to before and after treatment was also observed in other studies. (23,24) However, though in a previous study, bacterial taxa were able to be identified from DUWL samples and compared with HDT collected from passive and active sampling (24), all collected DUWL samples during this study contained 0 CFUs/plate. These results indicate that current infection control practices have been highly effective and reliable in meeting regulatory standards.

In comparison to previous studies, this study yielded notably lower CFUs from samples obtained through passive sampling. (23, 24) In their study design, Suprono et al. exposed plates for a longer duration of time at 50 minutes before and after treatment and for an additional 30 minutes after completion of ultrasonic cleaning to allow for additional aerosols to settle. (23) The particular positions and heights of the plates may have been an additional factor that influenced yield. Air ventilation in the dental treatment operatory may have affected aerosol patterns of flow as well. Finally, all participant subjects in this investigation were also required to rinse with an antibacterial rinse before undergoing ultrasonic scaling as a COVID-19 precaution. This practice was excluded in the study by Zemouri et al. and not evaluated by Suprono et al. According to Devker et al. (2012), pre-procedural mouth rinsing led to a significant reduction of CFUs in obtained aerosol samples from ultrasonic scaling. (26)

Additional limitations to this study ought to be considered when interpreting the results of this analysis. By design, the passive sampling method was not able to account for various microorganisms that did not settle on the plates, those that did not viably culture on blood agar/R2A medium, or those that became inactive when aerosolized. Furthermore, viruses were also of interest in this study initially due to the advent of the COVID-19 pandemic but were not able to be captured. Thus, the results are actually an underrepresentation of the true contamination that was generated during dental treatment.

The patient cohort involved in this study was another uncontrolled element. Patients who were treatment planned for initial or supportive periodontal therapy involving

ultrasonic scaling were randomly recruited, and no exclusion criteria were utilized. The severity and extent of gingivitis/periodontitis, oral hygiene, and medical history among patient subjects may have all served as confounding factors that influenced the results.

The unique logistical challenges in the dental operatory that the EOS system presented via occupation of physical space were not captured in this study. Although the arm of the EOS unit is highly adjustable and customizable, the hood of the device is most effective when positioned directly over the oral cavity. Unfortunately, this location may interfere with the provider's field of view when delivering care. In this study, although the dental hygienist was able to adjust short-term to working with the EOS system, its long-term usage may necessitate a significant change to traditional practices in terms of positioning and ergonomics that render its inclusion to be less practical.

Additionally, the EOS system was responsible for significant noise output during operation. Subjects in this study were offered earplugs during all trials conducted, and every subject opted to wear them for at least part of the dental procedure. Although noise levels in the dental office typically do not reach levels that can lead to hearing loss, recent studies suggest that dentists are at heightened risk when operating high-volume suction and handpieces for extended periods of time. (27) Routine use of the EOS device would thus potentially exacerbate existing occupational noise exposure in the dental operatory and further increase the risk of hearing loss.

Future studies should improve on collection methods of acquiring aerosol samples to better account for various bacteria, fungi, and viruses that may be potential vectors of disease transmission and demonstrate the utility of chairside EOS devices in the dental operatory.

Conclusion

The chairside EOS system may serve to reduce aerosol contamination in the clinical dental setting, especially in proximity to the patient's head, where most aerosols were generated.

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