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KEY WORDS
Aerosols; high-volume suction; extraoral evacuation device; endodontic access preparation, endodontics
Abstract:

Introduction: COVID-19 has caused many concerns in the dental field regarding aerosol production and the transmission of the SARS-CoV-2 virus during dental procedures. Because of the abrupt arrival of COVID-19 there has little to no published research on the efficacy of dental suction devices in the removal of aerosols related to COVID-19 or the impact extraoral suction devices have on patient experience. Therefore, the aim of this study was to measure the amount of aerosol produced during endodontic access preparation for root canal therapy (RCT) with and without the use of an extraoral dental suction device, and to gather information through a survey regarding the patients’ experience.

Methods: Aerosol measurements were recorded in 8 closed-door resident operatories each morning prior to procedures, 1 minute during procedure, and 15 minutes after access complete. The CICADA DTO KN99 Extraoral Dental Suction Device (Foshan Cicada, Guangdong, China) was placed in 4 operatories while no DTO extraoral suction device was used in 4 control operatories. Twenty cases with DTO and 20 cases without it were completed and data analyzed.

Results: Aerosols 1 minute after access was higher with and without DTO. Significant reduction after 15 minutes when DTO and high-volume suction. Composite and zirconia produced most aerosols at 1 minute.

Conclusion: The results show that the reduction of aerosols is enhanced when the extraoral suction device is used in combination with traditional high-volume evacuation. However, the increased noise level when using the device can have a negative impact on the patient’s dental experience.
Introduction:

The practice of dentistry has many biological risks that pose a daily challenge for the dental team. Dentists and dental assistants work in close proximity to their patients, which puts them at higher risk for microbial infections via aerosols. Major concerns have been raised regarding the working environment, and efforts continue to be made to minimize the dissemination of the microbial pathogens in generated aerosols. (1)

The SARS-CoV-2 virus, which is responsible for COVID-19, and many other infectious agents can be transmitted in the dental operatory via aerosols through inhalation, fomites and/or non-intact skin and mucous membranes. In addition, particulate dust and aerosols from composites and other restorative materials, such as amalgam, zirconia, porcelain, and different metals, may be detrimental to health, if inhaled. These microscopic particles may become aerosolized and could penetrate deep into the lungs surpassing the natural defense mechanism of mucus and cilia. Existing studies have revealed that chronic inhalation of respirable dust and microscopic particles may cause local and systemic toxicity when absorbed, or even provoke more serious conditions such as pneumoconiosis (2). With the increase in cases of COVID-19 throughout the world, there is a concern of transmission via respiratory droplets and aerosols during dental procedures. Droplets are classically described as larger entities (>5 µm) that rapidly drop to the ground by force of gravity, typically within 3 to 6 feet of the source. Aerosols are smaller particles (<5 µm) that rapidly evaporate in the air, leaving behind droplet nuclei that are small enough and light enough to remain suspended in the air for hours (3). Realistic management of all dental procedures that generate aerosols in everyday practice, in the era of a pandemic, is more pertinent than ever. (2)
To address the transmission of COVID-19 and microscopic particles via aerosols, the protocol for dental personnel has changed to reduce exposure to the virus by using preprocedural mouth rinses (4), and using additional technologies to enhance evacuation protocols (5).

Increased use of N95/KN95 respirators has been recommended by the Center for Disease Control (CDC) and other state and national regulatory bodies to help reduce transmission. Protective eyewear with side-shields (including goggles and face masks), high-volume evacuators, appropriate positioning of the patients, and dental dams were recognized as the foremost engineering protection strategies (1). However, if SARS-CoV-2 is carried by aerosols that can remain suspended in the air for prolonged periods, these measures would provide only partial or temporary protection, and six feet of separation would not provide protection from aerosols that remain suspended in the air or are carried by currents. (3) Studies have demonstrated that these aerosols can travel up to 27 feet (3, 6-8).

Several studies illustrate the contamination of surfaces in endodontic offices via aerosol (8, 9). These and other studies have demonstrated that every surface in the dental operatory was contaminated after the use of an air-turbine (6, 10). It has also been shown that dental operatories are at a much higher level of contamination than public spaces. A systematic review by Laheij et al, (11) concluded that bio-aerosols are generated from multiple sources in the dental office, which include dental instruments and human activity. Reducing the transmission of the infections due to aerosol production is a very important area of concern in these times. One classic study indicated that, together with a preprocedural mouth rinse and the rubber dam, a high-volume evacuator should be used during dental treatment (12).

Dental dam usage during endodontic procedures is considered the standard of care.
However, there is controversy over their effectiveness in clinical practice. In two older studies, there was a significant reduction in bacterial airborne contamination when dental dams were used. (13, 14) Conversely, another study found that the use of a dental dam was associated with significantly higher bacterial aerosol levels despite its purported clinical benefits. (6).

One recent study showed the efficacy of extra-oral evacuation, especially when combined with preprocedural mouth rinse, close to the patient and the provider during periodontal scaling (15). However, the degree to which aerosol dissemination from different surfaces and at different times during endodontic access preparation, and the need for additional technologies, such as extra-oral evacuation, have not been fully explored.

Several studies have been done using patient survey responses to certain aspects of dental treatment, including quality of life studies before and after treatment, patient preferences regarding treatment plans, and patient experiences during treatment. (4,12) There is a multitude of factors involved with studying patient responses to dental treatment, and different models have been adapted to best record patient experiences. A study by Azarpazhooh et al. (2013) first published an attempt to apply the Gelberg-Andersen Behavioral Model to investigate patients' preferences during the treatment of teeth with apical periodontitis (16). In this model, the authors highlighted the importance of evaluating demographics, financial situation, education level, and especially dental health behavior patterns when developing patient surveys related to specific experiences.

One survey used to assess quality of life in relation to oral disease is the Oral Health Impact Profile, developed by Slade and Spencer (1994). (17) It is based on a model of disease and associated consequences, derived from the International Classification of Impairments, Disabilities and Handicaps. It measures self-reported dysfunction, discomfort, and disability
The recognition of the importance of patient satisfaction has led to the development of specific dental treatment-related patient satisfaction measures, which apply scaling methods such as visual analogue scales, adjectival scales, or semantic differential scales (19, 20). A visual analogue scale is a way to measure subjective characteristics or attitudes that cannot be directly measured. An adjectival scale is a method where the individual is measured against a set benchmark. A semantic differential scale measures a person’s subjective perception of and affective reactions to the properties of concepts, objects, and events by making use of a set of bipolar scales. Some studies have chosen to use a mail-out survey design, with varying levels of participation. (16) However, enhanced aerosol control measures, especially ones that generate noise during operation, have not been sufficiently evaluated relative to their direct effect on the patients’ experience during the endodontic appointment, which is a part of their overall experience with the endodontic treatment.

Therefore, the purpose of this study was to measure the levels and particle sizes of aerosols produced during endodontic access preparations while using an extraoral dental evacuation device, in tooth structure, as well as different restorative materials through which the access was created. A patient survey was obtained at the end of the procedure to evaluate patient experience with the use of this device. Our hypothesis was that there would be no change in recorded aerosol levels and particle sizes while using an extraoral evacuation unit when compared to a control with traditional high-volume evacuation alone during endodontic access. We further hypothesized that patients will not rate their dental treatment experience negatively when the extraoral evacuation device was in operation during the endodontic procedure.
Materials and Methods:

Extraoral Evacuation Device and Experimental Conditions
This study was approved by the IRB at the University of Alabama at Birmingham, (protocol #300006944). In this study, the CICADA DTO KN99 Extraoral Dental Evacuation Device (Foshan Cicada, Guangdong, China) was used. All procedures and measurements were performed and recorded in closed-door operatories. Prior to initiating root canal therapy, the patients were required to rinse with 50/50 hydrogen peroxide/water for 60 seconds due to institutional guidelines. Forty adult patients were randomly assigned to one of two equal groups: experimental group had the extraoral evacuation device activated and a control group without the device. The unit was placed in the same position for each procedure; at the foot of each patient, six feet from the operator with the evacuation hood eight inches from the patient’s mouth. The sample size was determined using G*Power (version 3.1.9.6, Universität Kiel, Germany) based on an effect size of 0.4, alpha error of 0.05 and power or 1-beta error of 0.8. The minimal total sample using these parameters was 34, and so we selected 40 patients, which increased the power to 0.85. Once anesthesia had been implemented, a dental dam was placed to isolate the tooth requiring treatment. A pre-operative aseptic swab of 4% sodium hypochlorite was used to disinfect the field. A Kavo high- speed handpiece with water spray coolant was used to access all teeth. Traditional high- volume evacuation was used on all endodontic accesses. The extraoral dental evacuation device was activated on power setting #3, which is the setting recommended by the manufacturer, for the experimental group.

Measurement of Aerosol Production
The Temtop PMD 331 Air Quality Handheld Particle Counter 7 Channels (Temtop, San Jose, CA) was used to evaluate the particle size and the number of particles in the droplets and aerosols produced. The Temtop Particle Counter was placed 4 feet away from the patient’s oral cavity and a sampling time of 60 seconds was used as recommended by the manufacturer. Three recordings were done for each case: a pre-operative aerosol measurement of 60 seconds was recorded in the operatory each morning prior to beginning any procedure, another was recorded 1 minute after initiation of the access preparation, and a third postoperative recording 15 minutes after the access was completed.

Patient survey
A survey was given to each patient at the end of the procedure to help in assessing patient experience and the feasibility of using the extraoral evacuation in the current dental practice environment. It was important to keep the survey brief and direct, because patients were in variable emotional and physical conditions directly following their respective procedure(s). The aim of this survey was in evaluating the patient response to the noise and intrusion level of the extraoral evacuation unit in conjunction with endodontic treatment. No protected health information (PHI) was collected on the patient.

The patients were administered a list of 5 questions and asked to answer with a scale of 1-10, using a semantic differential scale, with labeled end-points (21):

1. How satisfied were you with your dental treatment?
2. How painful was your dental treatment?
3. Would you consider your treatment time-consuming or fast?
4. Would you consider your treatment unpleasant or pleasant?

5. How would you rate the noise level of the dental treatment?

Statistical Analysis:

Sample means, and standard deviations (SD) were summarized by time, evacuation method, bur type, and tooth or restorative material cut. Due to the repeated measurements of airborne particles during a procedure (preoperative, at one minute, and at fifteen minutes), we utilized repeated measures ANOVA treating time as a within subject factor. We examined three between factors: surface material being cut, bur type used, and evacuation method used during the procedure. Separate repeated measures ANOVA models were built for each of the between subject factors. P-values are reported for the significance of the between subject factors, within subject factors, and their interaction. A p-value less than 0.05 was considered significant. Normality assumption was examined using histograms and normal probability plots. The normality assumption was deemed reasonable. Finally, a repeated measures ANOVA model including all three between factors simultaneously was constructed to examine their adjusted p-values. All tests were conducted using SAS 9.4 or R 4.1.2.

Analyses of the patient survey data were done by comparing the results of patients who had the extraoral evacuation device used during their procedure, and those who did not, using unpaired t-test.
Results:

Total levels of aerosol production

The levels of aerosol production increased at 1 minute into the access preparation compared to baseline levels, and then decreased at 15 minutes, with the only difference by bivariate analysis at 15 minutes (p<0.0001) (Fig. 1).

A similar pattern in the levels of aerosols produced from each surface material was produced at the different time points (Fig. 2). Composite and zirconia produced the most aerosols at the 1-minute mark, but both also had a high standard deviation compared to the other materials.

Data on the particle sizes produced in the aerosols is shown in Figs. 3 and 4. The data showed that the highest levels of particle sizes detected were the smallest, and progressively lower levels of the larger particle sizes were detected, with all surface materials. A comparison of the levels of particles detected with tooth versus restorative materials is shown in Fig. 5.

The table shows the statistical models for the analyses that included time of measurement, surface material, and bur type. These analyses indicated that, in addition to significant variation across preoperative, 1-minute, and 15-minute times (p-value <0.001), the between factor of evacuation type and the interaction of evaluation type and time were statistically significant (p-values 0.0022 and 0.0023 respectively). However, a separate Repeated Measures ANOVA examining the effects of bur type and the interaction of bur type with time did not demonstrate statistical significance (p-values 0.4539 and 0.2292 respectively), though the within factor measuring variation due to time was significant (p-value < 0.001). A Repeated Measures ANOVA examining the
effects of material type produced similar results, with material type and the interaction of material type with time not demonstrating statistical significance (p-values 0.4496 and 0.8168 respectively), though the within factor measuring variation due to time was significant (p-value < 0.001). One final Repeated Measures ANOVA was built including all three between factors (evacuation method, bur type, material type). This model again indicated variation due to time (p-value < 0.001), evacuation type (p-value = .0043), and the interaction between time and evacuation type and time (p-value = 0.0087). All other effects and interactions did not achieve statistical significance. The test of evacuation type and time was significant, follow-up tests were conducted at each timepoint producing p-values of 0.6590, 0.0405, and .0002 for preoperative, 1-minute, and 15-minute comparisons respectively.

A t-test was used to evaluate the results of the patient survey. The results indicated that there was a statistical significance only for question 5, which was the question regarding the noise level (Fig. 6) (p<0.0001). Very little variation was noted among the survey results for the other four questions (p >0.05).

Discussion

Aerosol generation during routine endodontic access is a concern in that it may contribute to the cross-infection risk, especially in the era of COVID-19. In endodontics, the use of high speed and low speed handpieces with coolant, ultrasonics and lasers, produce spatters, droplets and aerosols that can reach a considerable distance, carrying potentially infective agents.(7) Previous investigations highlighted the pathogenic load of bio-aerosols in dentistry.(8, 9, 22) The findings of the present study
showed that aerosols are measurable pre-operatively, significantly increase at 1 minute into the access preparation, and decrease at 15 minutes after completion of the procedure. This study also showed that there was a significant difference in the presence of aerosols 15 minutes after access when an extraoral dental evacuation device was used. The authors are not aware of other studies that compared the aerosol levels at different times during endodontic access preparation, with control for the surface material, and the type of bur used.

The randomization of patients used in this study resulted in the inclusion of different surface materials and bur types in both groups, however, the study was only powered for the effect size of the main variable of interest. Future studies should evaluate whether restorative materials result in higher amounts of aerosols, which was not revealed to be statistically significant in this study. Some of the particles present in aerosols generated during endodontic procedures would be expected to be larger and heavier compared to others, and therefore should not remain suspended in the air as long as the smaller particles. This study showed that endodontic access preparations through composite or zirconia had a much higher particle content in the aerosols at the one-minute time frame compared to tooth structure, with that number being dramatically reduced by the fifteen-minute measurement, however, these differences were not statistically significant. Variations in surface material aerosols may be due to larger particle sizes dropping out of the air much more quickly, or from the high evacuation systems running for fifteen minutes post access.

Another finding in this study was that there was a much higher concentration of 0.3um and 0.5um particles in the aerosols than any other sizes at both reading times.
This is to be expected and supports other studies that show the smaller the particle size in the aerosols, the longer they will remain suspended in the air, and the longer it takes for them to settle on a surface. The smaller size also allows them to drift much farther away from the patient and clinician before settling on surfaces. (8) and so they were much more likely to be detected at four feet away from the source of production. Studies have shown that they can be carried by currents up to 27 feet away. (5, 17) Therefore, it is critical to try and eliminate as much of the aerosols as possible in the dental operatories during endodontic procedures.

When comparing the difference in the number of particles in the aerosols generated when accessing natural tooth structure versus accessing through restorations, the main difference was seen at the one-minute measurement after access began. Accessing through a restoration produced a higher concentration of particles in the aerosols, however, this difference was not statistically different (data not shown). This supports the Iliadi study (2), and shows that the water can mix with the dust generated from cutting restorative materials and produce a much higher concentration in the aerosols. This can be detrimental for the dental personnel, who are at risk of inhaling this daily, and shows the value of removing the particles from the air and wearing adequate respirators and face shields.

In this study, the extra-oral evacuation device had its evacuation hood eight inches (~20 cm) from the patient’s mouth. In this location, it reduced the amount of aerosol by 16%, 1 minute into the procedure, and by 46%, 15 minutes after the procedure (Fig. 1). In a recent study, placement of an extra-oral evacuation device 10 cm away from the mouth resulted in negligible bacterial contamination by aerosols compared with 20 cm away, where more dental
aerosols containing bacteria were detected (15). Taken together these data provide the clinician with the relative efficacy to be expected of this technology.

Regarding the patient survey, the results of this study indicate that patients viewed the noise negatively. The extraoral dental evacuation device generates a high level of noise, registering about 45 decibels even on setting 3. This noise level makes communicating with the patient more difficult, yet not impossible. Another incidental finding that may be important to some patients and clinicians was the generated of heat by the machine. This study was conducted in closed-door operatories, and by the 15-minute mark, a large amount of heat was generated by the extraoral dental evacuation device. This was associated anecdotally with high level of discomfort for the providers performing the procedures. Further studies may need to include a survey question regarding the level of discomfort associated with the heat produced by the extraoral dental evacuation device. Taken together, the effects of the noise and the heat generation may dissuade many practitioners from using these devices, especially that it is not known whether the reduction of aerosol with these devices is clinically significant.

Conclusions

This study showed that aerosols may remain suspended in the air for extended periods of time. The surface material cut, and the bur type were not statistically significant in the amount of aerosol generated. Currently, high-volume evacuation alone has been the primary way that most clinicians have attempted to remove the aerosols produced while practicing dentistry. The results of our study demonstrate the
value of the high-volume evacuation plus the extraoral dental evacuation device and allow the clinician to determine whether the extra cost, noise and possibly heat generation with the use of the extraoral dental evacuation device is warranted. The reduction of aerosols is of paramount importance to the health and well-being of the clinician and staff in a dental practice, as they are at constant risk of exposure to aerosols which may carry infectious diseases. This study adds more data to assess the risk and benefit of using one additional technology available to the practitioner.

**Acknowledgement**

The authors would like to gratefully thank Drs. David Clanton and Nathan Nunnelee for their assistance with the conception and execution of the study. All authors deny any conflict of interest related to this study.
References:
### Within Factor

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### Bur Type

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### Surface Material

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Table: Analysis of the data with all variables: HVE (high volume evacuation), EVE (extraoral evacuation)
**Figure legends:**

**Figure 1:** Aerosol production with and without extra-oral evacuation

**Figure 2:** Surface material for all patients in the study

**Figure 3:** Mean aerosol production in each group by surface material and particle size at 1-minute

**Figure 4:** Mean aerosol production in each group by surface material and particle size at 15-minutes

**Figure 5:** Surface material for all patients in the study

**Figure 6:** Comparison of survey results with and without extra-oral suction
Surface material for all patients in the study

- Amalgam
- Composite
- PFM
- Tooth
- Zirconia

Legend:
- Control
- Total 1-Min
- Total 15-Min
Mean aerosol production in each group by surface material and particle size at 1-Minute.

- Amalgam
- Composite
- PFM
- Teeth
- Zirconia
- EOE-Amalgam
- EOE-Composite
- EOE-PFM
- EOE-Tooth
- EOE-Zirconia

Legend:
- Total 1-Min
- 0.3 μm
- 0.5 μm
- 0.7 μm
- 1.0 μm
- 2.5 μm
- 5.0 μm
- 10 μm
Surface material for all patients in the study

- **Tooth**
  - Control
  - Total 1-Min
  - Total 15-Min

- **Restoration**
  - Control
  - Total 1-Min
  - Total 15-Min

 Axes:
 - Y-axis: 0 to 12,000
 - X-axis: Tooth and Restoration

Legend:
- Blue: Control
- Orange: Total 1-Min
- Gray: Total 15-Min
Comparison of Survey Results with and without Extra-oral Suction

- Mean Without
- Mean With

* denotes a significant difference.
Credit Author Contribution Statement

**Barton Barrett**: Conceptualization, Data acquisition, Data curation, Writing –original draft, Writing – review & editing. **Jason McGovern**: Conceptualization, Data acquisition, Data curation, Writing –original draft, Writing – review & editing. **William Catanzaro**: Conceptualization, Data acquisition, Data curation, Writing –original draft, Writing – review & editing. **Shandra Coble**: Data curation, Writing – review & editing. **David Redden**: Data analysis, writing, editing. **Ashraf F. Fouad**: Conceptualization, Methodology, Data acquisition, Data curation, Data analysis, Writing – review & editing.