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COMPARING ORTHODONTIC DEBONDING AEROSOL PRODUCTION WITH
VARIOUS HIGH-VOLUME EVACUATION SYSTEMS

by

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A Thesis submitted to the Faculty of the Graduate School,
Marquette University,
in Partial Fulfillment of the Requirement for
the Degree of Master of Science

Milwaukee, Wisconsin

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ABSTRACT
COMPARING ORTHODONTIC DEBONDING AEROSOL PRODUCTION WITH
VARIOUS HIGH-VOLUME EVACUATION SYSTEMS

Eric D. Moe, DMD

Marquette University, 2021

Objective:

The COVID-19 pandemic has placed a new emphasis on defining aerosol generating procedures and evaluating ways to reduce those aerosols. Both biocontaminants and particulate matter can potentially be transmitted with dental aerosols with negative health effects associated with each, especially aerosols with particulate matter of 2.5 micrometers or less (PM_{2.5}). This study aims to evaluate the PM_{2.5} aerosol production from orthodontic debonding with a high-speed, air-driven handpiece without water coolant and assess the effectiveness of traditional four-handed high-volume evacuation (HVE) and two commercially available hands-free high-volume evacuation (HFHVE) systems.

Methods:

Orthodontic debonding was simulated using a dental manikin and acrylic dental model with composite-based adhesive attachments bonded to 28 teeth, with a 4 mm x 2 mm x 1 mm rectangular aligner template. A high-speed, air-driven handpiece without water coolant was used to debond the composite attachments. PM_{2.5} aerosol concentration was measured with an air quality monitor suspended 6 cm above the maxillary central incisors. Seven trials were completed for all evacuation systems and controls. The mean PM_{2.5} aerosol concentrations for each evacuation system were compared with an analysis of variance and post-hoc test of multiple comparisons using the Bonferroni test. P value less than 0.05 was considered statistically significant.

Results:

Orthodontic debonding with no evacuation system produced a significantly elevated level of PM_{2.5} aerosol concentration compared to all three evacuation systems tested. There was no statistically significant difference between four-handed HVE and the two other HFHVE systems, however the trend of the data suggest four-handed HVE reduces aerosols more effectively.

Conclusion:

Orthodontic debonding with a high-speed, air-driven handpiece should be classified as an aerosol generating procedure, and some type of evacuation system should be used to reduce aerosol levels. Four-handed HVE is likely the most effective system for aerosol reduction, but the two other HFHVE systems evaluated in this study may be effective alternatives for a solo practitioner without an available assistant. All groups produced aerosol levels higher than baseline, so appropriate personal protective equipment (PPE) should be utilized.

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INTRODUCTION AND LITERATURE REVIEW

The COVID-19 pandemic caused by SARS-CoV-2 (Naming corona virus disease, 2020) has disrupted and changed both daily life and health care delivery. As of May 9, 2021, the United States has reported over 32 million total cases of COVID-19 and over 570 thousand deaths (COVID data tracker, 2021), and the world has reported over 157 million total cases with over 3.2 million deaths (Coronavirus dashboard, 2021). Dentistry has been widely affected during the pandemic due to both close distances between providers and patients for long periods of time (Peng et al., 2020) and numerous procedures that generate aerosols (Guidance dental settings, 2020; Innes et al., 2021). Highly relevant during a pandemic and moving forward, this study aims to evaluate aerosol production during orthodontic debonding with a high-speed, air-driven handpiece without water coolant and compare the effectiveness of aerosol reduction of traditional four-handed dentistry utilizing high-volume evacuation (HVE) and two commercially available hands-free high-volume evacuation (HFHVE) systems.

The mechanism of transmission of SARS-CoV-2 is not completely understood, but it has been suggested to spread at varying capacities directly and indirectly through fomites, splatter droplets (diameter $> 5 \mu\text{m}$), and aerosol droplets (diameter $< 5 \mu\text{m}$), with aerosol droplets having potential to remain suspended in the air over a period of time (Bahl et al., 2020; Cevik et al., 2020; Coronavirus how transmitted, 2021; Fennelly, 2020; Lewis, 2020; Modes of transmission, 2020; Ren et al., 2020; van Doremalen et al., 2020). SARS-CoV-2 has also been suggested to have receptors in salivary glands and be present in saliva of those infected, which could become aerosolized during dental procedures (Li et al., 2020; To et al., 2020). However, recently it was shown that during

aerosol generating procedures (AGPs), the irrigant used, not saliva, is the primary source of microorganisms that are aerosolized. Furthermore, of the participants in which SARS-CoV-2 was found in their saliva, none was found in the aerosol condensate in that study (Meethil et al., 2021).

Beyond SARS-CoV-2, other microorganisms (Bentley et al., 1994; Harrel and Molinari, 2004; Kohn et al., 2003; Toroğlu et al., 2001; Zemouri et al., 2017) and particulate matter (Cokic et al., 2020; Day et al., 2008; Din et al., 2020; Eliades and Koletsi, 2020; Iliadi et al., 2020; Ireland et al., 2003; Johnston et al., 2009; Llandro et al., 2021; Ravenel et al., 2020; Sotiriou et al., 2008) can potentially be transmitted through dental aerosols with negative health effects associated with each. Particulate matter alone, especially particulate matter less than 2.5 µm in size (PM_{2.5}), has been shown to have significant negative impact on human health including asthma, respiratory inflammation, jeopardized lung function, and promotion of cancers, because it can pass through the body's defense systems, such as nose hair, and navigate to, and accumulate at, the end of the respiratory tract (Xing et al., 2016). Aerosols generated from dental procedures have been shown to be reduced with HVE by more than 90% (Harrel and Molinari, 2004).

Due to the COVID-19 pandemic, a focus on researching and defining AGPs in dentistry has become much more prominent. It is widely accepted that many dental procedures produce aerosols and splatter droplets, including ultrasonic scaling, high-speed handpieces, slow-speed handpieces, oral surgery, air-water syringes, and hand scaling, but most studies found that high-speed handpieces and ultrasonic scalers produce the most (Innes et al., 2021). Unfortunately, guidelines defining AGPs during the pandemic have often been poorly defined with many categorizations being considered too

simplistic (Virdi et al., 2021). Adding to the complexity of the problem is that attempts to evaluate aerosol production follow many different techniques and protocols, not limited to different procedures in different areas of dentistry, high-speed vs slow-speed handpieces, water vs no water coolant, differences in measurement locations, and differences in the variable being measured including tracer dyes, bacterial contamination, and particulate matter (Llandro et al., 2021).

Orthodontic debonding has been shown to generate aerosols and splatter (Day et al., 2008; Din et al., 2020; Eliades et al., 2020; Eliades and Koletsi, 2020; Ireland et al., 2003; Johnston et al., 2009; Llandro et al., 2021; Toroğlu et al., 2001), especially PM_{2.5} aerosols (Ireland et al., 2003). Recently, it was suggested that orthodontic debonding with four-handed HVE produces splatter and settled aerosol mostly in the immediate vicinity of the procedure (Llandro et al., 2021), and aerosols were produced with both slow-speed and high-speed handpieces, with high-speed handpieces producing more (Din et al., 2020). No studies have compared orthodontic debonding with standard four-handed HVE to commercially available HFHVE systems and a positive control of no evacuation system. One study simulating restorative procedures did evaluate high-speed handpieces with no HVE system and compared that to eight HVE systems and found that all of the HVE systems had significant reduction in aerosols compared to the positive control of no evacuation system (Ravenel et al., 2020). However, this study utilized a bur with water coolant that was not cutting simulated acrylic tooth material or composite resin and was only directed into a previously made occlusal preparation. Studies with ultrasonic scalers have compared various HFHVE systems to saliva ejectors with various degrees of aerosol reduction (Jacks, 2002) or no reduction at all (Holloman et al., 2015). One HFHVE

system was shown to reduce aerosols effectively in simulated restorative procedures (Nulty et al., 2020), but no HFHVE systems have been evaluated in orthodontic debonding.

The aim of this study was to evaluate particulate matter aerosol production during orthodontic debonding with high-speed, air-driven handpieces without water coolant. A positive control of debonding with no evacuation system was compared to standard four-handed HVE and commercially available HFHVE systems. Such HFHVE systems may be highly applicable in residency programs or practices with limited assistant availability. While four-handed dentistry using standard HVE has been recommended for reduction in aerosols (Guidance dental settings, 2020), there are various HFHVE systems available that can be used as a solo provider without an assistant that claim to limit aerosols. The two HFHVE systems studied here were the Xuction HVE Dental Aerosol Reducer and the A~flexX HVE Advanced Extra-Oral Pump Kit, which to the best of our knowledge have not been evaluated in the literature for any orthodontic or dental procedures to date.

MATERIALS AND METHODS

Orthodontic debonding was simulated using a dental manikin and acrylic dental model (Columbia Dentoform Corp; Long Island, NY). Composite-based adhesive attachments were bonded to all 28 teeth, excluding third molars, with a 4 mm x 2 mm x 1 mm rectangular aligner template. Plastic conditioner (Reliance Orthodontic Products; Itasca, IL) was applied to each tooth and air-dried for 30 seconds, followed by a thin layer of Assure universal bonding resin (Reliance Orthodontic Products; Itasca, IL). Composite-based adhesive, Transbond XT (3M; Maplewood, MN) was used for the composite attachments. A high-speed, air-driven dental handpiece without water coolant (Dentsply Sirona; York, PA) was used to remove the composite attachments bonded to each tooth with a tungsten carbide debonding bur (Komet USA; Rock Hill, SC). An air quality monitor (Multifunctional Air Quality Monitor EG VOC-180, EG; Blackburn, UK) was suspended 6 cm above the maxillary central incisors to measure PM_{2.5} aerosol concentration throughout the orthodontic debonding procedures.

Five groups of trials were evaluated in the study. Room ambient air was used as negative (baseline) control. The positive control was debonding with no HVE system, with the set-up shown in Figure 1. The controls were compared to debonding with four-handed dentistry utilizing a standard HVE (F-HVE), shown in Figure 2, the Xuction HVE Dental Aerosol Reducer (X-HFHVE) (Xuction Dental; Midlothian, VA), shown in Figure 3, and the A~flexX HVE Advanced Extra-Oral Pump Kit (A-HFHVE) (A~flexX; Ft. Lauderdale, FL), shown in Figure 4. F-HVE was accomplished with an assistant closely following the bur removing the composite attachments. X-HFHVE was set up in its standard position with the evacuation attachment connected to its cheek retractors just

inferior to the lower lip. A-HFHVE was standardized to be stationary at one location just touching the upper and lower lips at the left side of the mouth. While the A-HFHVE can be moved, it was kept stationary for this study. Aerosol was measured by $PM_{2.5}$ concentration values recorded every five seconds throughout all trials. Seven trials were completed for each type of evacuation system and controls. The mean $PM_{2.5}$ aerosol concentrations for all trials of each evacuation system were compared with an analysis of variance and a post-hoc test of multiple comparisons using the Bonferroni test.



Figure 1. Debonding set-up for positive control, no evacuation system



Figure 2. Debonding set-up for F-HVE

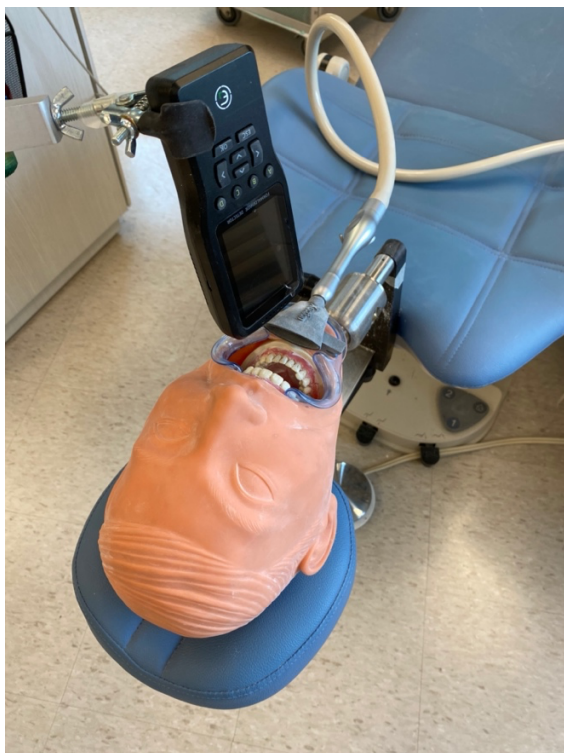


Figure 3. Debonding set-up for X-HFHVE



Figure 4. Debonding set-up for A-HFHVE

RESULTS

The mean PM_{2.5} aerosol concentration for each trial for each type of evacuation system and the positive and negative controls is shown in Table 1 and the overall results are shown in Figure 5. There was a statistically significant ($p < 0.05$) increase in mean PM_{2.5} aerosol concentration between baseline conditions, 1 $\mu\text{g}/\text{m}^3$, and the positive control of orthodontic debonding with no evacuation system, 267 $\mu\text{g}/\text{m}^3$. F-HVE had a mean PM_{2.5} aerosol concentration of 30 $\mu\text{g}/\text{m}^3$, a reduction of 89% from the positive control. X-HFHVE had a mean PM_{2.5} aerosol concentration of 87 $\mu\text{g}/\text{m}^3$, a reduction of 68% from the positive control. A-HFHVE had a mean PM_{2.5} aerosol concentration of 120 $\mu\text{g}/\text{m}^3$, a reduction of 55% from the positive control.

The mean PM_{2.5} aerosol concentration for each evacuation system was compared with an analysis of variance (ANOVA) and a post-hoc test of multiple comparisons using the Bonferroni analysis, and the results are shown in Table 2. All three types of evacuation systems provided statistically significant decreases from the positive control of debonding with no evacuation system in place. In fact, F-HVE and X-HFHVE were not statistically different from baseline conditions, indicating that these two means reduce aerosol down close to the baseline level; while A-HFHVE and the positive control were, indicating these reduce aerosol not as effectively as other two means. However, the trend in the data suggests there is still aerosol released from the debonding procedure compared to baseline even when F-HVE and X-HFHVE systems are utilized. There was not a statistically significant difference between any of the three evacuation systems used. However, the trend in the data suggests that F-HVE is likely the most effective at

reducing aerosols during orthodontic debonding in this study, and the two HFHVE systems may be effective, but potentially less so than F-HVE.

Table 1. PM_{2.5} aerosol concentration for all trials

Evacuation System	N	PM _{2.5} (µg/m ³)	Time (min)	Mean (µg/m ³)	SD (µg/m ³)
Negative Control	1	2	10:00	1	0
	2	1	10:00		
	3	1	10:00		
	4	1	10:00		
	5	2	10:00		
	6	1	10:00		
	7	1	10:00		
Positive Control	1	158	10:20	267	109
	2	126	8:05		
	3	220	7:15		
	4	361	5:10		
	5	429	3:45		
	6	315	4:55		
	7	262	4:30		
F-HVE	1	16	9:10	30	11
	2	25	7:40		
	3	34	6:55		
	4	46	6:40		
	5	41	4:40		
	6	23	4:05		
	7	28	3:45		
X-HFHVE	1	46	9:05	87	46
	2	54	8:30		
	3	117	6:00		
	4	72	6:10		
	5	172	3:35		
	6	95	3:45		
	7	49	3:20		
A-HFHVE	1	163	4:25	120	68
	2	91	5:00		
	3	237	4:45		
	4	124	4:40		
	5	131	4:35		
	6	44	4:05		
	7	48	3:30		

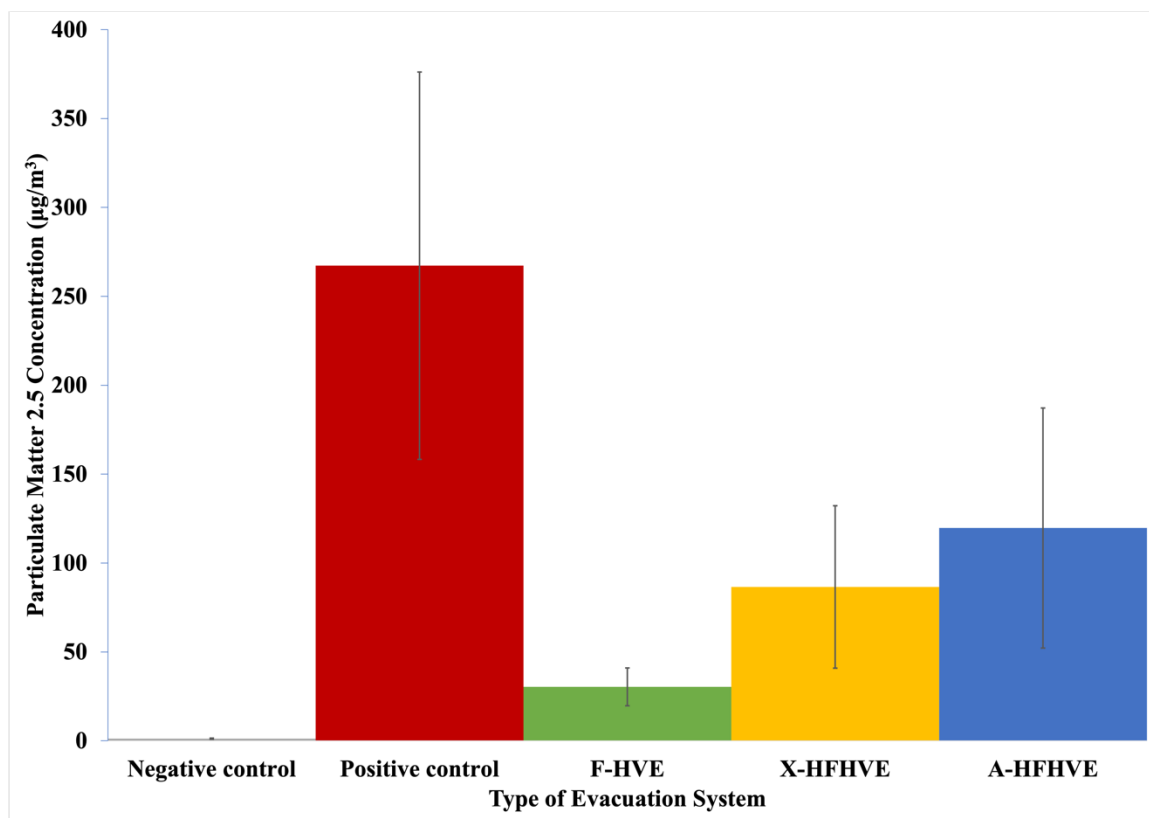


Figure 5. PM_{2.5} aerosol concentration average and standard deviation for each system

The average length of the debonding procedures across all trials was 5 minutes and 39 seconds with a range of 3 minutes and 20 seconds to 10 minutes and 20 seconds.

The negative control ambient room trials were evaluated for 10 minutes each.

Table 2. Multiple comparisons Bonferroni analysis

Evacuation System Pair	Mean Difference	Standard Error	Significance (p value)
Negative vs Positive	-266.0	32.6	.000 *
Negative vs F-HVE	-28.4	32.6	1.000
Negative vs X-HFHVE	-85.3	32.6	.138
Negative vs A-HFHVE	-118.4	32.6	.010 *
Positive vs F-HVE	237.6	32.6	.000 *
Positive vs X-HFHVE	180.7	32.6	.000 *
Positive vs A-HFHVE	147.6	32.6	.001 *
F-HVE vs X-HFHVE	-56.9	32.6	.916
F-HVE vs A-HFHVE	-90.0	32.6	.098
X-HFHVE vs A-HFHVE	-33.1	32.6	1.000

DISCUSSION

This study demonstrated a significant increase in PM_{2.5} aerosol concentration at 6 cm above the maxillary central incisors during a simulated orthodontic debonding protocol compared to the negative control ambient air at the same location. This suggests, like others (Day et al., 2008; Din et al., 2020; Eliades et al., 2020; Eliades and Koletsi, 2020; Ireland et al., 2003; Johnston et al., 2009; Llandro et al., 2021; Toroğlu et al., 2001), that orthodontic debonding should be considered an AGP and appropriate precautions such as personal protective equipment (PPE) and an evacuation system should be utilized.

In regard to evacuation systems, the data and statistical analysis suggested that F-HVE, X-HFHVE, and A-HFHVE all significantly reduced the PM_{2.5} aerosol concentration compared to the positive control of debonding with no evacuation system. The 89% reduction provided by F-HVE was consistent with prior research into high-volume evacuation with four-handed dentistry, which showed 90%+ reduction in aerosols (Harrel & Molinari, 2004). While there was no statistical significance between F-HVE and the two HFHVE systems, the 68% reduction in PM_{2.5} aerosol concentration for X-HFHVE and the 55% reduction for A-HFHVE suggest a trend that for the simulated orthodontic debonding protocol here, they may not be as effective as traditional four-handed dentistry. This may be due to the HVE in four-handed dentistry being closer to the handpiece and bur at all times during the debonding procedure, whereas the HFHVE systems used here were positioned slightly extra-oral in one fixed location, allowing the produced aerosols to disperse more with a lesser amount being evacuated.

The effectiveness of X-HFHVE and A-HFHVE at aerosol reduction have not previously been reported in the literature for orthodontic debonding or any other dental-related procedures. To the best of our knowledge, no HFHVE systems have been evaluated for orthodontic debonding. Various other HFHVE systems and combination HVE with HFHVE systems have been evaluated for use with ultrasonic scalers and general dental procedures with various degrees of success (Holloman et al., 2015; Jacks, 2002; Nulty et al., 2020; Ravenel et al., 2020). However, these studies and their results may not translate completely to orthodontic debonding. Orthodontic debonding involves every tooth in the mouth, whereas previous studies about restorative procedures involved just one tooth and location, with some utilizing rubber dam isolation and combinations of evacuation systems. With the ability to focus evacuation systems on a single, isolated area, it may be reasonable to expect more effective aerosol reduction compared to orthodontic debonding, where the location of aerosol production is frequently changing. Similarly, results of other studies evaluating HFHVE systems should not be automatically generalized to all HFHVE systems, as they can vary in numerous ways including design, shape, intraoral vs extraoral placement, and ability to change locations. For example, even within the design of this study, the A~flexX HVE system was kept stationary in one set location touching the lips on the side of the mouth, for standardization. However, moving it throughout the debonding procedure to the quadrant or side of the mouth being worked on could potentially increase its effectiveness.

There are several limitations of the debonding protocol utilized in this study. As debonding was simulated on a manikin, there was a lack of respiration and saliva or blood production that human patients would provide. The effectiveness of the HFHVE

systems used here could be further evaluated and compared to traditional four-handed HVE using tracer dyes to evaluate splatter control with a manikin, or by studying orthodontic debonding on human patients that measures aerosol concentration, splatter droplets, and microbiological contamination for a more complete understanding of their effectiveness.

Debonding was only performed here with a high-speed, air-driven handpiece without water coolant, and the amount of composite adhesive on each tooth was more than a fixed appliance case and most clear aligner cases. Din et al. showed that high-speed handpieces produced higher aerosol levels than slow-speed handpieces in orthodontic debonding, so the effectiveness of the evacuation systems in this study was likely challenged with a high amount of aerosol production due to the type of handpiece (high-speed) and amount of composite adhesive (more) compared to real patient debonding scenarios. It is possible that both the traditional HVE and the HFHVE systems may perform even better with less composite on each tooth, such as after fixed appliance removal, or when removing fewer or smaller attachments after clear aligner treatment.

Another limitation of this study design was only measuring aerosol concentrations at one location, 6 cm above the maxillary central incisors. This location was chosen because it was as close to the oral cavity as the air quality monitor could be while allowing adequate space for all of the evacuation systems used, and Llandro et al. demonstrated that splatter and settled aerosol during orthodontic debonding was mostly localized to the immediate area of the procedure. This study does not evaluate other potential areas of interest like the mouth and nose of the orthodontist or other patients outside the general vicinity of the procedure.

Unfortunately, the infective dose for COVID-19 in humans is not well understood for any of its potential routes of transmission (Karimzadeh et al., 2021), and it is certainly not understood specifically related to transmission through dental aerosol production. However, the U.S. Environmental Protection Agency has standards for PM_{2.5} aerosol concentration called the Air Quality Index, which is used for outdoor air quality. The standard maximum for long term exposure is 12.0 µg/m³, and the standard maximum for short term exposure (24 hours) is 35 µg/m³. The Air Quality Index has a scale for PM_{2.5} aerosol concentrations in µg/m³, including “Good” (0-12), “Moderate” (12.1-35.4), “Unhealthy for Sensitive Groups” (35.5-55.4), “Unhealthy” (55.5-150.4), “Very Unhealthy” (150.5-250.4), and “Hazardous” (250.5-500) (Revised air quality index, 2016). Utilizing this classification system with the understanding that these aerosol levels are not experienced for 24 hours, but predominantly just when AGPs are occurring, the positive control of debonding with no evacuation system was “Hazardous”, traditional four-handed HVE was “Moderate”, and both HFHVE systems were “Unhealthy”. There are not specific standards available for indoor air quality.

The results of this study may be potentially applicable to orthodontic residency programs or any orthodontic practices with limited availability of dental assistants. These are scenarios in which providers may not have an assistant to provide traditional four-handed HVE. This study suggests that orthodontic debonding is an AGP, and debonding without an evacuation system can subject the provider to substantially elevated particulate matter aerosols. While traditional four-handed HVE is potentially more effective, this data suggest that the Xuction HVE Dental Aerosol Reducer and the A~flexX HVE Advanced Extra-Oral Pump Kit may be attractive options for an

orthodontist without an assistant to try to replicate the effectiveness of four-handed HVE aerosol evacuation during debonding, and they are certainly more effective options than using no evacuation system at all.

CONCLUSION

The COVID-19 pandemic caused an emphasis on defining AGPs and evaluating aerosol reduction in dentistry. We demonstrated that orthodontic debonding with a high-speed, air-driven handpiece with no water coolant should be classified as an AGP, and that traditional four-handed high-volume evacuation is largely effective at reducing those aerosols. In scenarios such as orthodontic residency programs in which assistants may not be readily available to perform four-handed dentistry at every debonding procedure, we showed that two commercially available hands-free high-volume evacuation systems can be utilized as a solo practitioner to reduce these aerosols compared to not utilizing any evacuation system at all. While all evacuation methods evaluated reduced aerosols compared to no evacuation system, there were still elevated aerosol levels, so appropriate personal protective equipment (PPE) should be used. Further understanding on the effectiveness of these hands-free high-volume evacuation systems could be obtained by repeating this study with human subjects.

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