Aerosol Remediation in Dental and Medical Practice

DESIGN ERGONOMICS / ERGONOMIC PRODUCTS

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I. HISTORY

Since the invention of the Borden air rotor in 1957, dental aerosols have been a concern for the health of dental practitioners, staff and – through circulation in the common air handling systems of the modern office – patients as well.[1]

II. CURRENT CONDITIONS

The invention of modern air conditioning systems has resulted in ducted air handling as the predominant solution for heating and cooling in virtually all healthcare facilities. While efficient, these systems admix all of the air in an office or office zone. This disadvantage can become problematic when dental aerosols are introduced into the system. Attempts to alleviate the problem of dental aerosols have been effective to varying degrees; however, none have succeeded in eliminating the potential threat of aerosol contamination to an acceptable standard of safety.

III. PROBLEM CONSIDERATIONS

The problems with dental aerosols can be divided into six distinct areas of occurrence and potential control:

1. **Post Circulation Cleanup**
2. **Entire Office Remediation**
3. **Operating Room Interventions**
4. **Treatment Zone Controls**
5. **Operating Field Controls**
6. **Immediate Capture**

IV. PROBLEM-SOLVING APPROACHES

***1. Problem Solving* – Post Circulation Cleanup:**

The most frequent area for the control of aerosols released in the treatment environment has been the disinfection of surfaces exposed to airborne agents. Surface disinfection is, and will remain, a critical component in all aspects of healthcare. However, compliance testing against national standards has fallen to the product manufacturers themselves and, as such, is subject to a certain degree of skepticism. To quote Rella Christensen in a recent Clinicians Report[2],

> *Both the Environmental Protection Agency (EPA) and Food & Drug Administration (FDA) specify tests and register disinfectants, but neither agency tests each product to validate effectiveness. Originally, there was a national test lab plus state labs that did this, but they were eliminated by government austerity programs in favor of registration based on data manufacturers choose to*

[1] MADDEN, R. M., HAUSLER, W. J., JR & LEAVERTON, P. E. (1969). Study of Some Factors Contributing to Aerosol Production by the Air -Turbine Handpiece. *Journal of Dental Research*, *48*(3), 341.

[2] CHRISTENSEN, R. (2020). Dental Office Infection Control Myths and Dangerous Beliefs. *Gordon J. Christensen Clinicians Report*, May 2020, Volume 13 Issue 5, 5

submit. Unfortunately, most companies choose to forego tests that include relevant human secretions/excretions. Even though the government long ago recognized this system is seriously flawed, it has not resolved the need to validate each product's kill claims (See Disinfectants:EPA lacks assurance they work. Government Accountability Office (GAO). Aug. 1990).

Mitigation at this stage, then, should be viewed as a final effort in infection control, not a primary one. Greater focus must be paid to mitigating the impacts of aerosols while suspended, and when possible, at their source.

2. Problem Solving **– Entire Office Efforts**

Recently a greater awareness of the infectious nature of aerosols in the common air handling systems has created an emphasis on reducing the level of agents returned through the common airway. Efforts to that end include the use of enhanced filtration, UVC duct sanitation and other means and it is now theoretically possible to retrofit many existing office air handling systems. Technology exists to bring office air to clean room specifications. System such as LifeAire[3] and Gordon Cleanroom Products[4] have emerged as potential candidates for upgrade.

Unfortunately, these systems, while very effective, suffer from a combination of non-universal applicability, installation complexity and significant expense. Costs for a typical five operatory retrofit installation can easily run in excess of $100,000 for true isolation. Alternative solutions, while less comprehensive, include the installation of more basic UVC disinfectors in existing HVAC plenums. Brands such Sanuvox[5] have been installed in many offices and have had moderate success in reducing bacterial and viral viability. UVC does provide one challenge for monitoring in that it does not kill viruses but rather interferes with their ability to reproduce and therefore becomes quite difficult to monitor installation success.

Another area of whole office retrofit possibility is the upgrading of existing HVAC systems to HEPA filtration standards. This option, while desirable can provide considerable complexity for HVAC balancing due to the substantial increase in resistance provided by very high MERV filtration. Systems that provide both filtration and significant fan boosting in conjunction with the existing HVAC system such as the Honeywell F116 series can be considered as useful adjuncts. Practice administrative controls need to be applied to such systems to ensure proper maintenance and filter changes.

A final consideration here is the use of electrostatics. Electrostatic units do not kill offending organisms however they facilitate particle binding thus, in effect, enlarging particle size making subsequent filter entrapment more successful. Most significantly, these units can increase the effectiveness of mid-range MERV filtration.

These solutions are far from foolproof. Further complications to retrofitting of both clean room systems and the less comprehensive enhancements result from the fact that that many heating and air-conditioning installation designs were not created as fully closed systems. It is very common to find that the return air plenums are open in design and thus susceptible to an extraordinary degree of cross contamination and may even force unconditioned air back into the finished treatment space. This is an area of intervention that requires a great degree of skill and detailed attention. A full majority of the

[3] https://lifeaire.com/
[4] http://www.gordoncleanroom.com/
[5] https://sanuvox.com/

litigation in commercial construction comes from the area of Heating Mechanical Engineering which indicates the difficulties in this realm, due in part to its high degree of technical and environmental variability and complexity.

***3. Problem Solving* – Operating Room Interventions**

In general, given the inability to control air purity within the entire office envelope with 100% certainty, attention has turned to the individual operatory. Control at the room level is attractive for a number of reasons:

1. It is conceptually a more approachable area of control.
2. It is visually inspectable on a routine basis, unlike whole office systems which require external monitoring or detailed administrative controls.
3. It can be phased into an existing practice in a more cost and time effective manner.

Complete operatory interventions include, but are not limited to; the filtration of all incoming airflow through the use of booster fan/filter units (FFU's), physical space restrictions (enclosure with doors, elimination of wall-less cabinet dividers), and self-contained heating and air-conditioning systems etc. These efforts, while important and partially effective, are not without their downfalls and limitations. In order to function safely for the benefit of the occupants in the non-filtered areas of the office, negative airflows must be maintained in these treatment spaces.

Negative airflow rooms create or increase certain challenges;

1. The assurance that adequate intake air is maintained becomes imperative. This becomes highly variable with the introduction of rooms without doors or even the frequent egress through closed door operatories. Adequate intake air must be maintained.
2. The use of analgesia and inhalation anesthetics must be very carefully monitored in the absence of open air flows. The NIOSH standard for scavenging system exhaust rate is 45 liters per minute.[6] This has not been addressed adequately in the dental environment even prior to the introduction of these proposed controlled treatment airflow operatories.
3. Disruptions to the overall office airflow can occur if the design does not permit sufficient make-up air to the remainder of the facility. Variable flow balancing systems exist for HVAC regulation[7]; however, these are often costly, and best suited to temperature control rather than air pressure maintenance, and thus must be carefully addressed by highly skilled professionals.
4. Leaks must be properly controlled from adjacent spaces in all dimensions.

Pursuing a negative room airflow strategy (at least on a one or two room basis) is an objective that should be strongly considered by all practitioners, and is a proposed requirement in the recently released OSHA 3990-03 2020 publication[8]. Despite the challenges previously mentioned, negative airflow rooms can be rapidly accomplished, and with a rather limited number of easily obtained components. Doing so will permit practices to reopen after COVID-19 shut down with a much greater

[6] CDC - NIOSH Publications and Products - Controlling Exposures to Nitrous Oxide During Anesthetic Administration (94-100). (2014, June 6). Retrieved from https://www.cdc.gov/niosh/docs/94-100/default.html

[7] As of January 1, 2016, ASHRAE Standard 90.1 requires all new equipment above 65,000 BTUs to include two speed fans (ie variable flow). Commercial systems have employed variable-capacity functions for decades." SEE ALSO ASHRAE HANDBOOK

[8] https://www.osha.gov/Publications/OSHA3990.pdf

confidence and safety – when accomplished in conjunction with new clinical and staff protocols such as; whole office social distancing, limited use of waiting rooms, implementation of temporary "sneeze" barriers at non-clinical interaction points, elimination of paper documentation, sensible PPE precautions non-clinical staff etc. Note that the advent of load balancing individual FFU's could provide a significant increase in office security.

4. Problem Solving **– Treatment Zone Controls**

There are three major strategies for the creation of a single or multiple operatory negative airflow environments:

1. ***Conversion of the treatment room HVAC ducting system to clean room specifications.***
   This strategy calls for the separation of the operatory HVAC system from the general office air handling and the installation of clean room filtration systems uniquely designed for that specific area. This approach would be considered the gold standard for room isolation and protection; however, the approach can be cost prohibitive and beyond the immediate realm of possibility for most offices – especially considering the economic disruption to dental practice during the COVID-19 epidemic.

   As mentioned previously, this room cannot be outfitted in what would be considered the standard Clean Room positive pressure environment. Rather, it requires clean room filtration in the presence of negative airflows which would be balanced through outside intakes when possible in order to minimize disruption to the remaining office HVAC system. One concern for this strategy is the relative scarcity of qualified personnel to install such systems in the tens of thousands of offices that would require such an upgrade should this become mandated.

2. ***Conversion of treatment room zone HVAC to a 4 pipe hydronic heating and cooling system.***
   This approach would include individual room zone controls and the modification or addition to the existing HVAC system to permit make up air to be exhausted preferentially from the treatment room environment – thus creating negative air flows. Airflow balancing in this situation can also be achieved through outside ducting where possible.

   There are advantages to this method; it is proven technology and the fan units on the specified heating and cooling coils can be upgraded to accommodate HEPA or high MERV filtration. This solution is most practical when the treatment room alignment is condensed and access for plumbing feeds either below or above the operatory spaces are readily available.

3. ***Through the use of dual function air conditioning "split systems".***
   Inverter powered split air conditioning and heating systems have become quite common throughout the industry in the last decade.[9] Their efficiency has increased markedly[10] and they are commonly used for additions to existing structures. Much as in the previous 4 pipe hydronic alternative, split systems can be used to isolate a certain segment of a dental office from the

[9] ACUMEN RESEARCH AND CONSULTING (2019, April 24). Split Air Conditioning Systems Market Size Worth Around USD 178 Billion by 2026. Retrieved from https://www.globenewswire.com/news-release/2019/04/24/1808897/0/en/Split-Air-Conditioning-Systems-Market-Size-Worth-Around-USD-178-Billion-by-2026-Acumen-Research-and-Consulting.html

[10] SKAER, M. (2011, August 10). Average SEERs Rise in Residential Sector. Retrieved from https://www.achrnews.com/articles/104536-average-seers-rise-in-residential-sector

remaining heating and air-conditioning system. The significant advantage for use of these systems is that they can be purchased and installed for a limited number of treatment rooms which allows for an incremental approach to office conversion or reopening. They can be purchased in configurations that allow for 1, 2, 3 or even an entire treatment suite to be converted rapidly at a moderate cost and with little disruption to the existing heating system.

An additional advantage of split systems is that they are generally well understood by local heating and air conditioning professionals and thus have a high probability of successful installation.

In order to complete the negative pressure flow desired, an additional room exhaust must be installed and balanced to maintain negative air pressures. This must be coordinated with the split duct system and one must be careful to assure that the additional controls can be added to the system purchased.

Unfortunately, there are disadvantages regarding the use of split system air flows. These include but are not limited to;

a. The inability to utilize HEPA filtration on through the wall units – which are the most common form of these in the marketplace. Increased filtration is possible with recessed (ducted) versions of these systems but they must be specifically design for this use.
b. The limitation of the length of run from the internal (room) outlet to the external condensing unit.
c. The final limitation to these systems is the fact that they are actually heat exchangers, and as a result, have a somewhat limited operating temperature range. Climate extremes, notably extremes of cold, can require these systems to utilize additional electric heating coils which can significantly increase operating expenses.

5. Problem Solving **– Operating Field Controls**

While the importance of both whole office intervention and individual room isolation in the effort to control pathogens in healthcare facilities should not be underestimated, there has been a recent increase in the understanding and awareness that control as close to the point source of contamination will have a greatly magnified effect on not only the immediate containment but additionally on the effectiveness of pathogen removal from all other less direct sources.

Operating Field Controls have traditionally fallen into two categories of extraoral equipment that might effectively be characterized as; containment boxes and vacuum devices.

Containment boxes
Many attempts at circumscribed containment have been pursued in keeping with work such as the handling of radioactive isotopes or in laboratory research. While effective as physical barriers, these devices ignore the simple reality of patient respiration and, due to the requirements of limited access for effectiveness, severely restrict operator access and thus the ability to function.

Vacuum systems
In the 1960s and the 1970s numerous vacuum systems were developed in dentistry primarily to rectify problems with many of the then emergent Dental Air Abrasion systems. A number of these abrasion

devices lacked fine spray control and thus required vacuum containment. Later, these extraoral vacuum units were redeployed for the purpose of "safe amalgam removal". With the advent of SARS in Asia in 2002-2004, these units were mated to higher levels of exhaust filtration; and they have recently entered the marketplace as solutions to cope with COVID 19 cross contamination. These devices do provide a certain, variable level of aerosol protection, due in large part to their relative proximity to the point source of infection. However, their overall effectiveness suffers from three vulnerabilities at present:

1. Protection effectiveness is significantly influenced by the proper placement of the suction orifice relative to the treatment zone. Without clear physical criteria for use it is quite easy to have a breakdown in operator utilization resulting in a false sense of safety and minimal effectiveness. Unlike the HVAC controls previously discussed it is rather more difficult to impose functional restrictions on these devices nor measure their real time effectiveness.

2. As currently configured the vast preponderance of these devices are designed as portable units with immediate filtration released back into the treatment space. Depending upon the filtration efficiency of a given device the net result can often be a churning of the pathogens that are intended to be trapped by the filter back into the immediate zone of the patient and care providers. A method providing a full exhaust of captured particles would be a recommended amendment to these systems, if they are to be considered. At least one unit currently on the market offers this as an option.

3. All current vacuum systems can be significantly affected by lateral airflow disturbances – for example, window or door opening, air conditioning cycles and even the placement of the operator's hands and instruments in front of the device. None of the devices can be considered a comprehensive solution to operator or patient safety.

Hybrid systems

Recently, patents have been applied for a system that combines the physical barriers envisioned with containment boxes with the use of proximity vacuum generated negative pressures in an effort to capture pathogens at high-efficiency, reliably, conveniently and without suffering significant variances due to air buffeting or placement errors. This device, which is able to readily remove contaminants directly from the treatment and operator zone without return, is known as the Safe-T-Shield™[11] due to the physical separation created between operator and patient.

The Safe-T-Shield™ gains its efficiency through a combination of its ability to hold and contain over seven times the patient's tidal volume (3700mL Shield volume vs 500mL tidal volume for an average male adult[12]) as it is processed in a laminar flow and evacuated. Protection provided is thus a combination of containment within the vessel, orientation due to a structured flow path, and the safe removal and disposal outside the facility. The physical barrier of the shield as designed allows operators to practice in their customary positions including, for example, standing for surgical procedures. It is also ambidextrous and suitable for both two and four hand use.

It is believed that the potential exists for shielding to develop a removal efficiency as high as 95% while containing 100% of the concentrated pathogen load found in droplet splatter due to its physical barrier.

[11] https://www.ergonomic-products.com/safe-t-shield/

[12] HALLETT, S.; ASHURST, J.V. *Physiology, Tidal Volume*; StatPearls Publishing: Treasure Island, FL, USA, 2019

Concerns regarding shield use have been found to be twofold at this point:

1. Cost for fixed installation required to fully outfit larger facilities may be met with resistance from non-owner operators.
2. The skill set variability for high volume evacuation among a wide range of dental assistants studied suggest that there is a potential gap in training and effectiveness for splatter control at the point of origin. This will be discussed in the subsequent section of this paper.

6. Problem Solving **– Immediate Capture**

While it has become abundantly clear that any action or mechanism utilized with high efficiency within the zone of Operatory Field Controls will have a magnified effect on the total containment of pathogens within the practice, the primary site of prevention and containment is, in fact, directly at the site of release – the patient oral and nasal airways. Studies have shown that effective oral airway isolation through the use of rubber dams where possible, and particularly through the timely and efficient use of high volume evacuation, has the capability to cut pathogen release from the oral by approximately 90%[13]. This is a significant result because, by definition, this capture mitigates all future release into the entire upstream system. Therefore, proper HVE use is considered fundamental and essential to all aerosol generating dental procedures. However, it is also estimated that during dental procedures approximately 70 to 80% of all respiration emanates from the patient's nasal airway. This indicates that an obvious gap in capture methodology exists.

Fortunately, recent studies have shown that the use of nasal respirators (for example, the placement of a nitrous oxide nosecone) have the ability to capture this flow. However, most dentists do not use devices that involve nasal air control and unfortunately the vast majority of offices are not equipped to supply regulated air to these devices. Neither is it appropriate to run 100% oxygen for extended time periods due to the potential for hyperoxic toxicity which is a real yet poorly understood phenomenon. The fact that oxygen, when used for convenience and without consideration for conditions such as COPD can lead to hypercapnia is a significant concern. A recent meta-analysis in Lancet 2018 by Chu, Kim et al found that liberal oxygen use in the care of patients with various illnesses increased mortality by 1 in 71 patients.[14]

However, the current pandemic has shifted the emphasis regarding pathogen containment. Previously, containment efforts have not emphasized removal of the pathogenic organisms in the immediate field of treatment. Given that we now have a more clearly defined recognition regarding the breadth of protection required, the need for nasal airway control has become much more obvious.

As a solution the author has found that the use of a simple and inexpensive self-adhesive nasal mask (Breathe-Safe™, pat. pend.) is able to effectively trap and remove up to 80% of the exhaled pathogens of nasal origin while both maintaining patient comfort and permitting the operator to have a clear field of view.

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[13] JACKS ME. 2002. A laboratory comparison of evacuation devices on aerosol reduction. J Dent Hyg. 2002 Summer;76(3):202-6.

[14] CHU, D. K., KIM, L. H-Y., YOUNG, P. J., ZAMIRI, N., ALMENAWER, S. A., JAESCHKE, R. et al. Mortality and morbidity in acutely ill adults treated with liberal versus conservative oxygen therapy (IOTA): a systematic review and meta-analysis. *The Lancet*, Vol. 391, No. 10131, p1693–1705, Published April 28, 2018

V. SUMMARY

In the review of dental and medical aerosol containment challenges, it is clear that control and mitigation as close to the source of release should be the primary focus for efforts. Prior difficulties, and perhaps the resistance of practitioners to adopting these measures, have resulted in pressure on regulatory agencies to enforce more elaborate and expensive methods of control[15]. These protocols are far removed from the source of contagion. As a result, they require much broader implementation, and are far more costly and ultimately invasive to the dental or medical practice - often demanding the complete physical rebuilding of the practice infrastructure itself.

The potential for a coordinated approach to this problem combining intensive control at the points sources of release with a physical barrier for protection and the subsequent direct removal of the offending organisms from the facility as a whole has the prospect for markedly reducing the level of remediation required on a whole office level while maximizing both staff and patient health.

[15] https://www.osha.gov/Publications/OSHA3990.pdf