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LITERATURE REVIEWS

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LITERATURE REVIEWS

Dental Bioaerosol Literature Review April 2020

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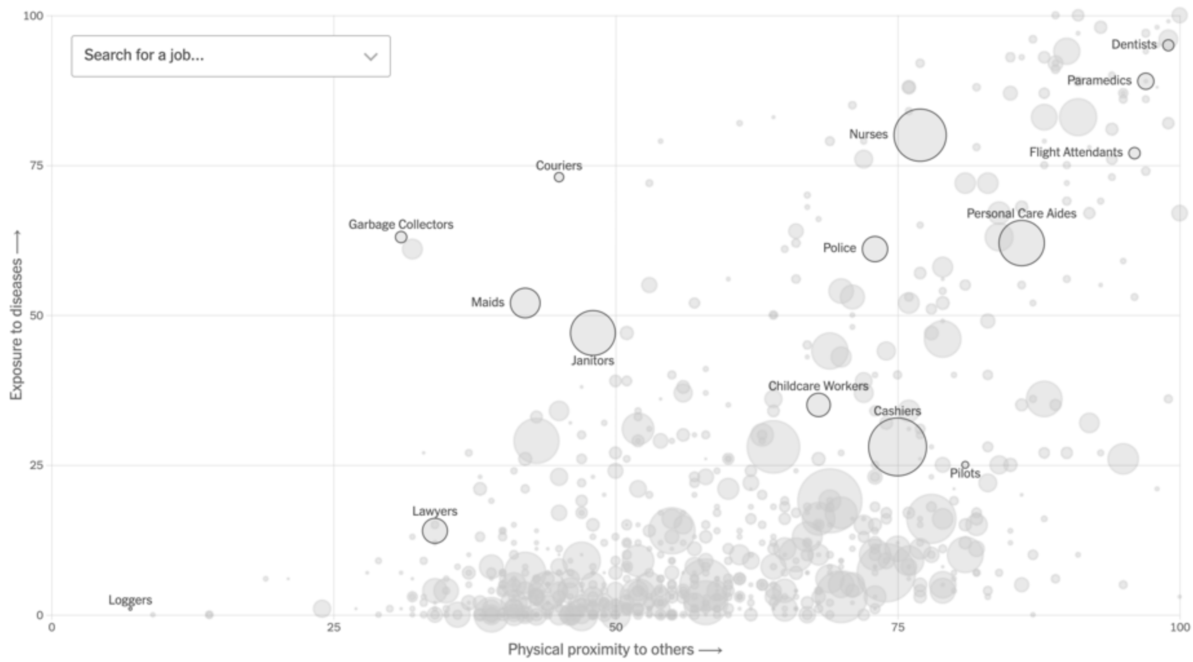
Table of Contents

Executive Summary

Low air quality in dental practises: a significant yet avoidable threat to dental professionals and their patients

Of 974 different occupations considered by O*NET Bureau of Labor Statistics for their health-related risks in 2018, four of the top 5 were found to be in the dental industry[1]. Amidst the outbreak of coronavirus in March of this year, The New York Times released a visible representation of this data, highlighting dentists, Dental assistants and dental hygienists all ranking amongst the top for their occupational exposure to disease and proximity to others[2] (see graph below). The occupational hazard, therefore, to dental professionals is comparatively high versus other professions and occupations. The main risks to dental professionals are expossure to contaminants, disease and infection. The purpose of this white paper is to provide the reader with a greater understanding of the ways in which low air quality within a practice can lead to significant exacerbation of these exposures and thus increased risk not only to themselves, but to their team and their patients.



Source: Gamio, L., 2020. The Workers Who Face The Greatest Coronavirus Risk. [online] Nytimes.com[3].

[1] Business Insider, 2020
[2] Gamio, L., 2020
[3] Gamio, L., 2020

The risks

The recent outbreak of novel coronavirus (COVID-19) in late 2019 and into 2020 has reinforced the need to mitigate air quality risks within dental practises both during this outbreak and thereafter. It has become clearer than ever that viruses capable of spreading via 'direct contact… droplet and possible aerosol transmissions'[4] require improved mitigation, beyond current measures, in order to ensure the safety of dental professionals and their patients alike. This paper will provide a 'deep dive' into the creation of particulate matter we might expect to find in dental practises, explaining how they find their way into the air within a dental practise and the associated health risks to those breathing them in.

The solution

This white paper will then consider the various ways it has become possible, through technology, to remove these impurities from the air through capture and elimination. Due to the variety of particulate matter, we can expect to find, based on prior research, we can comment on the different types of filters and technologies needed to effectively purify the air within such high-risk environments. Further, the paper will explore the most optimal solution to this dilemma by way of introducing the concept of 'Air Purification Units'. Finally, the paper will outline the considerations important to account for when deciding on the optimal air purification product for surgeries. Such implementations will significantly improve the wellbeing of all who spend time inside these dental practices.

Low Air Quality in Dental surgeries

Introduction

An occupational hazard can be described as the risk to a person deriving from their line of employment[5]. Those within the profession of dentistry are widely considered to be exposed to a variety of occupational hazards; from their proximity to infections to the vulnerability of developing musculoskeletal disorders to their exposure to radiation[6]. Amongst the most serious risks to any health practitioner is that of transmitting infectious diseases. A prominent method by which such transmissions are likely to occur is via airborne methods[7]. Within the context of the recent worldwide outbreak of the 'Novel Corona Virus' pandemic, the susceptibility of those within a high-risk dental setting are highlighted as of particular concern[8].

When an individual in the surgery sneezes, coughs, or even talks, both small splatter and even smaller 'aerosols' are released. In aerobiology, the larger of the two,

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[4] Ge, Z., et al. 2020
[5] Anjum et al. 2019
[6] Ardekani, A et al. 2012
[7] Harrel, S. and Molinari, J., 2004.
[8] Ge, Z., et al. 2020

namely 'splatter' (>50 μm diameter), fall toward the ground on a rather steep trajectory (an arc shape) after leaving the individual, this means proximity is required for transmission person to person[9]. However, the release of aerosols (≤50 μm diameter) from an individual can travel much larger distances through the air and remain suspended within it for extended periods- only to be breathed in by unsuspecting and potentially susceptible individuals. These Bio Aerosols are described as 'airborne particles of liquid or volatile compounds that contain living organisms or have been released from living organisms'[10]. Understanding exactly how a given virus spread is difficult. In the example of MERS-CoV, it was concluded that both contact and airborne precautions were therefore necessary[11]. This is similarly the case with the latest outbreak of COVID19. Furthermore, the reproductive number (R0) of 'COVID19' is widely found to exceed that of SARS[12] and MERS CoV [13] indicating it is even more important to take measures to remove associated aerosols from the air in the present as COVID has a very high tendency to transmit from person to person.

Why are dental practises particular high risk for spread of infectious diseases?

In one study the researchers consider the possible aerosol transmission of infectious diseases (with a focus on COVID-19) within the context of the dental setting. It is explained that because of the nature of dental procedures, notably the use of water as a coolant during the use of high-speed handpieces and in the removal of debris, those spending time in these environments are more likely to contract such viruses[14].

The 'bio-aerosols' that are released during such procedures are 'commonly contaminated with bacteria, fungi, and viruses' and due to their small size tend to remain suspended in the air for long periods[15]. Building on this premise, it is explained that use of such equipment exacerbates the usual level of aerosols released into the air through coughing or sneezing by causing 'several thousand droplets' to be 'aerosolized'[16]. Particularly dangerous are the smaller particles of aerosols, those that are between 0.5 μm and 10 μm. These aerosols are capable of lodging themselves in deeper and smaller passageways of the lungs and are believed to carry the greatest risk of transmission of infections[17]. Not only are the airborne aerosols present within the surgery itself but via convection currents, they can move freely around the entire dental practice.

'Any dental procedure' that causes the potential for aerosolization of saliva in a patient's mouth will lead to contaminated air[18]. Another study claims the use of 'dental handpieces, air-water syringes, ultrasonic scalers, and air polishing units' are

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[9] Ge, Z., et al. 2020
[10] James, R. and Mani, A., 2015
[11] Chavis, S. and Ganesh, N. 2020
[12] Liu, Y. et al. 2020
[13] Al-Tawfiq, J. et al. 2014
[14] Ge, Z., et al. 2020
[15] James, R. and Mani, A., 2015
[16] James, R. and Mani, A., 2015
[17] Harrel, S. and Molinari, J., 2004
[18] Harrel, S. and Molinari, J., 2004

all widely known to lead to aerosolization, and thus form 'many-fold increases in colony-forming units (CFUs) when compared to pre- and post-operative' measurements[19].

As part of the oronasopharynx, the mouth is home to bacteria and viruses from the nose, throat and respiratory tract, all of which have the potential to end up in the air following dental procedures. One study used a passive air sampling method to conclude that microbial aerosols created as a by-product of the use of high-speed rotating instruments are significant and underestimated by practitioners. This study found significant contamination of the dental surgery at all distances measured (including at over 1.5 meters away from the patient!) Such a study concluded that the extent of the contamination resulting from aerosolization of the substrate in the oral cavity was much more extensive than previously thought and 'practically encompasses the whole room'[20].

Other reasons for poor air quality in dental surgeries

The strong cleaning products used in dental surgery, including disinfectants used to wipe down surfaces, have been found to contribute significantly to low air quality in dental offices. A study found that TVOC (total volatile organic compound) concentrations were seen at their highest (2000–5500 μg m− 3) when detergent products such as Bacillol were used to disinfect surfaces. Furthermore, three distinct peaks in TVOC concentration within the dentistry clinic were found to be heavily associated with the utilisation of products for cleaning in the morning, at lunchtime and the end of the working day[21].

Volatile methyl methacrylate, a key component of resin materials commonly used for temporary prosthetics, is also found to be a heavy contributor to the levels of VOCs in the surrounding air as the monomer seeps into the surrounds following polymerisation and incomplete setting[22].

A lack of ventilation within dental practices can also contribute to low air quality. One study associated the 'very high concentrations of TVOCs' (exceeding acceptable level by a factor of 20) to be not only a result of dental activities but also a result of insufficient ventilation[23]. Commonly used 'natural' ventilation systems (for example where the surgery door is an air inlet and windows are air-outlets) have also been found to offer insufficient air renewal, leading to the clustering and trapping of air pollutants in certain areas of the surgery[24].

[19] James, R. and Mani, A., 2015
[20] Rautemaa, R., et al. 2006
[21] Helmis, C, G., et al. 2007
[22] Liu, M., et al. 2017
[23] Helmis, C., et al. 2008
[24] Helmis, C, G., et al. 2007

Air quality will become a growing issue as current hygiene regulations are insufficient

The number one historic respiratory hygiene method is simply to 'avoid contact with others while a person is having symptoms'[25]. Thus, those showing symptoms are encouraged not to visit the surgery. However, in the context of the current pandemic, such a school of thought is unlikely to be deemed sufficient post-pandemic as many realise such a method has so far proved ineffective at stopping the spread of COVID-19. Furthermore, simply encouraging sneeze-etiquette in the dental practice such as covering your nose and mouth with your elbow when sneezing, cannot be sufficient to ensure respiratory hygiene. Despite the partial effectiveness of dental professionals PPE, the patient remains exposed to the low-quality air at all times. Researchers call for increased attention from environmental safety and health departments regarding the air quality within health practises, including dental practises for the benefit of professionals and patients alike[26]. The nature of the emergency COVID19 infection prevention and control guidelines might suggest the possible future introduction of air quality audits within UK practises. These emergency guidelines currently draw the link between the ability to decontaminate the air within a room and the safety of an individual to enter a room without an FFP respirator[27].

What is the solution?

Air Purification

The solution suggested by much of the literature involves the use of an air purification unit to filter the air for a vast range of harmful impurities. Studies have concluded the need for ventilation and purification of 'air-borne' microbial pollutants to drive up the air quality within the dental surgery environment [28][29]. Many studies have found air purification systems/units to be effective at improving indoor air quality within short time frames through reducing odour, particulates, microorganisms and dangerous substances such as mercury and formaldehyde[30].

Air Purifier technology

[25] Chavis, S. and Ganesh, N. 2020.
[26] Liu, M., et al. 2017
[27] Public Health England, 2020.
[28] Chen, C., et al. 2009
[29] Sawhney, A., 2015.
[30] Erdingerl, L., et al.

Due to the many impurities likely to be found within the dental practise environment any suitable air purification unit requires the integration of many different filters and additional technologies to purify the air thoroughly.

Filters used within air purification units

Pre-filters

A pre-filter is required to remove large impurities from the air and acts as an initial purification step before the engagement of subsequent processes.

Carbon Filters

Carbon filters (or 'activated carbon') are an advanced type of filter that allow volatile compounds to be removed from the air as well as odours and other potentially present gas pollutants. These filters enable gases to become trapped on a highly porous bed of charcoal and are particularly effective in removing mould and dust from the air. The pores in the charcoal enjoy a large surface area, allowing large amounts of gas to be held upon them. Whilst a key filter, no sanitisation or elimination of living organisms occur within this filter[31].

HEPA (High-Efficiency Particulate Air) Filters

A HEPA filter is widely defined as follows: a filter capable of capturing 99.97% of dust particles and other microbes in the air (down to a size of 0.3 microns diameter). The filter structure involves an outer filter stopping and trapping larger particles, prior to the air approaching a second filter in which the more microscopic bacteria and debris are captured. Despite, by definition, HEPA filter's remarkable efficiency- these filters are unable to kill germs or mould spores, instead they become trapped and unable to continue within the flow of air through the purification unit. Studies recommend the implementation of HEPA filters to filter contaminated air in treatment rooms within the current COVID 19 context[32] because despite the COVID 19 virus being smaller than the HEPA filter, virus aerosols often agglomerate together making them large enough to become trapped by the HEPA filter. Smaller particulate material that passes through the HEPA will be killed by UV-C exposure in units with this technology implemented in a subsequent part of the purification unit.

Furthermore, the potential breeding ground associated with the accumulation of microbes within the HEPA[33] is insignificant for two reasons. Firstly, viruses trapped within the HEPA are unable to multiply due to their biological make-up and therefore die soon after becoming trapped. Secondly the build-up on the HEPA will remain safely withheld within the unit until the filter is changed. In order to prevent against possible transmission upon changing HEPA filters it is important to wear the appropriate PPE when doing so. Readers should also be aware of marketing tools used by companies to advertise their air purifiers as being "HEPA-type," "HEPA-

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[31] Myers, P., 2020.
[32] Ge, Z., et al. 2020
[33] Al-abdalall, A, D et al. 2019

like," or "99% HEPA," as these refer to HEPA filters which perform below industry standards outlined above[34].

UV-C filter:

A UV-C filter is not a filter at all, once the air has travelled through the above filters, it travels through a small chamber and during this time is exposed to UV-C light.

UV light refers to ultraviolet light, an invisible form of electromagnetic radiation just outside the visible spectrum to humans (with a shorter wavelength than visible violet humans can see). More specifically, UV-C waves refer to an obscure part of the ultra-violet section of the spectrum and are distinctive from UV-A and UV-B both due to their comparatively greater energies and shorter wavelengths[35].

Most importantly, however, UV-C can be created artificially by humans and is extremely effective at destroying genetic material. It is hence that UV-C emitting bulbs are crucial to any effective air purification units' internal technology. UV-C waves are able to destroy cells by disrupting their DNA - deeming them unable to go on performing their vital functions following extended exposure. This means UV-C can effectively kill bacteria, viruses and mould particles passing through the chamber. This disinfectant process is called 'germicidal irradiation'. Importantly, UV-C emitting bulbs within air purification units are not released externally (outside the constraints of the unit's internal infrastructure) meaning their use is considered safe to the user[36].

Titanium dioxide Catalyst

During the UV-C exposure stage of the air purification, the use of a catalyst (often in the form of titanium dioxide) can be utilised to accelerate the chemical reaction between the various particles in the polluted air and the UV-C waves[37]. When UV-C light shines on Titanium dioxide (or 'titania'), electrons are released at its surface. These electrons interact with the h20 in the air forming hydroxyl radicals (OH·), these highly reactive radicals then react with the organic impurities/pollutants in the air and form inoffensive substances such as Co2 and h20. This type of catalyst causes a speedup of the throughput of the air purification unit whilst ensuring more of the through-putted air is processed with its first pass.

[34] Yadav, N., et al. 2015.
[35] WHO, 2020.
[36] Nardell, E. et al. 2008.
[37] Goswami, D, Y., et al. 1997

Factors to consider when purchasing an air purifier for a dental surgery
Important considerations

Due to the range of harmful pollutants likely to be suspended within the air of a given dental surgery, it is extremely important that all of the above filters and technologies are integrated into the design of an air purification unit. This will ensure you avoid exposing any users of the dental practise environment to potentially detrimental health risks associated with breathing in harmful particulate matter.

Traditional air purification units tend to rely upon a small number of the above solutions, usually focusing upon HEPA filters as their primary defence against suspended particulates, alongside a carbon filter to remove odours. Despite HEPA filters being described as 'highly effective technology'[38], these two filters alone are unable to kill bacteria and viruses. One study found that because HEPA filters do not kill microorganisms proliferate and instead retain them trapped in the filter, the particulates may re-enter the filtered air at a future time[39].

Secondly, one should consider the size of the room they intent to purify the air within. Many products claim to be able to purify the air within rooms up to 24 m^2, however important to understand is the lack of a **standard measure** by which to verify or disprove this purification capacity claim. For example, a unit expressing the above claim may only be capable of 'turning-over' the air within the said room of 24 m^2 – three times an hour. One study, however, concluded that to drive down the risk to those breathing the contaminated air, a dental surgery should have its air 'turned-over' (or 'air changed') more than 15 times per hour[41]. Current COVID infection prevention and control guidelines issued by the UK government indicates there should be a minimum of 6 air changes per hour in general wards to ensure safe entry without the need for a class 3 filtering face mask[42].

To avoid such confusion, a more informative metric by which to measure the maximum capability of a unit to purify the air would be to measure its potential throughput by m^3 per hour (UK) or feet^3 per hour (US), it is, therefore, possible to calculate how many times your dental surgery would have its air changed per hour based on the dimensions of the room and quoted maximum throughput of the purifier.

[38] Yadav, N., et al. 2015
[39] Chuaybamroong, P., et al. 2010
[41] Fuji, K and Mizuno, J., 2011.
[42] Public Health England 2020.

The maximum capability of a unit is extremely important to consider for two reasons. Firstly, for noise-related reasons, your unit should be working at merely a derivative of its maximum capacity for large portions of the day. Otherwise, the noise generated by an over-stretched unit shall be distracting to its user. Secondly, a powerful unit shall have to be run at full capacity for less time than that of a weaker product when it gauges new pollutants in the air. The air will also be cleared of impurities much quicker as well as more thoroughly.

A further consideration might be the number of air purifier units required throughout a dental practice to ensure the wellbeing of all who work there and visit. Due to the ability of suspended particulate matter to travel via convection currents from one room to another[43], it is necessary to implement air purification units in each surgery facility within the practice. Furthermore, a detailed study found that positioning of air purification units within the surgery itself could have an extremely significant impact on the quantity of potentially harmful droplets/aerosols entering a DHCW's (Dental Healthcare Worker's) 'breathing zone'[44]. With this in mind, it is not only important to have a unit in each surgery, but the unit must also be located in a strategic position within the surgery to reduce risk most effectively.

'Dent-air'

If after reading this report, you feel like you need a degree in mechanical engineering to understand what is going on with the air in your surgery - then perhaps the most important factor to consider when making your purchase decision should be ease of use. As is always the case with products here at Bryant Dental – that's not something you're going to have to worry about with the 'Dent-air'. All the unit requires its user to do is simply press one button and the built-in intelligence ('reactive air kinetic technology') will scan the surrounding air and adjust the throughput respectively, no further user-input required. Such a feature means the unit will never be operating at a noise level beyond what is necessary to provide healthy purified air in the surgery.

The thoughtful design of the 'Dent-air' also allows you as the user to pre-empt a release of aerosols into the air by way of adjusting your unit's throughput of air via a wireless remote. For example, before the use of a high-speed instrument, you might decide to increase the throughput speed in order to accelerate the elimination of the resultant aerosols you are about to release into the air.

For our clients with an interest in technology, we have also engineered a mobile app that seamlessly syncs to your 'Dent-air' allowing you to monitor your air automatically.

[43] James, R. and Mani, A., 2015
[44] Chen, C., et al. 2009

Concluding remarks

This white paper is intended to highlight the reasons for low air quality found within dental practises. Within the current context of a global COVID-19 pandemic, the dangers posed to dentists are more apparent than ever. This paper supports the use of air purification units as the solution for such a potentially dangerous issue as low-quality air within practices. It considers the different types of filters, and other technologies required to not just remove impurities in the air, but to kill them. It also considers the various questions one should ask when making decisions regarding purchasing suitable air purification products and de-bunks some of the marketing jargon introduced by companies trying to oversell their offerings. It is hoped that this white paper will contribute towards an improvement in air quality within dental practices through the more widespread adoption of air purification units, thus providing a safer environment for employees to work in and for patients to visit.

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LITERATURE REVIEWS

The Efficacy of Existing Air Purification Technologies in the Dental Environment

The Efficacy of Existing Air Purification Technologies in the Dental Environment; A Brief Literature Review.

Background

That several dental procedures generate aerosols is a fact established widely both amongst dental professionals and their patients. This cloud is often clearly visible when performing interventions such as those involving the high speed handpiece or the ultrasonic scaler. The aerosol visible consists of particulate matter and liquids aerosolised both from the dental water lines, and the site of treatment; making a more apt description of the resultant aerosol a bioaerosol, which contains microorganisms and other organic substances such as blood and saliva alongside dental material particulates.

Given the ubiquitous nature of bioaerosol production within dentistry, dental professionals are understandably familiar with universal protection measures such as masks and visors to prevent, at least to some extent, the inhalation of the bio aerosol generated during practice, with the potential inhalation rate of bioaerosol when unimpeded by masks reported to be as high as 0.12microlitres of aerosolised saliva in a 15-minute period (Bennet et al 2000), and although the efficacy of the face masks routinely used in dentistry is contentious, with the reduction in aerosol inhalation varying greatly between reports, it is clear that they have some effect. In conjunction with visors and high-volume evacuation suction during the procedure, the bioaerosol released into the environment or inhaled can be greatly minimalised (Micik et al 1969) (Harrel and Molinari 2004).

In their pioneering studies, Micik et al postulated that in the dental environment, we should divide the general aerosol produced into true aerosols which are particles of a diameter of less than fifty micrometres in size, and 'splatter' which consists of larger particles. There is a wide consensus that when we consider the risk of airborne infection and inhalation of particulate contaminants in dentistry, it is mainly from the true aerosol particles, due to their ability to remain airborne for an extended period, reportedly up to thirty minutes (Hinds 1982), and the ability of the smaller aerosol particles within this subset- zero point five to ten micrometres in size- to penetrate the respiratory tract.

With the widespread use of resin composites in dentistry, comes a new risk associated with dental aerosol. The sensitisation of dental professionals to methacrylates, the major constituent of resin composites, has been well documented (Schedle et al 2007) (Syed et al 2015), and though patients show few adverse effects, dental professionals due to their increased exposure to these materials have been shown to develop contact dermatitis and airway related disease (Hamann et al 2005) (Piirila et al 2002) (Jaakkola et al 2007), the latter being the focus here. One vector for inhalation of particle associated methacryclates is in the respirable 'dust' (Cocik et al 2020) aerosolised by dental procedures, and parts of this fall into the size category of <10 micrometres, which allows them to penetrate deeply into the respiratory system (Nilsen et al 2019). This particulate matter, if inhaled, not only has the potential to cause some airway diseases, such as adult onset asthma (Jaakkola et al 2007), but in an in an alarming *in vitro* study on the effects of the respirable fraction of composite dust on human bronchial cells showed that even in sub-toxic levels, the particulate matter was capable of causing genotoxic changes (Cocik et al 2020).

The spread of the ‘splatter’ also becomes a matter of concern given the advent of infectious diseases such as SARS, and the resurgence of tuberculosis in some areas, as these diseases are usually spread via droplet nuclei). These droplet nuclei are larger than the aerosol particles and behave in a ballistic manner, meaning that they are ejected with a greater momentum than aerosols from the site of propagation, and continue until they contact a surface or fall to the floor (Micik et al 1969) (Micik et al 1971) (Micik et al 1978). This behaviour is preferable to aerosol suspension as surfaces are consistently cleaned between patients in a dental environment, unfortunately, in the case of droplet nuclei, as the droplet starts to evaporate its constituent microorganisms gain the ability to remain airborne as aerosols (Harrel et al 2004).

That the bioaerosol generated in dental procedures, which potentially contains infectious microorganisms or contaminants such as methacrylate particulates, is able to remain airborne for up to 30 minutes is alarming considering that many dental practitioners remove their masks following a procedure to converse with their patient, exposing themselves to airborne pathogens and adverse respiratory effects. There is also the risk of this potentially infectious aerosol entering ventilation systems and therefore spreading to ‘clean’ zones and areas where personal protection is not used.

A published example of a virus spreading throughout a medical practice via the ventilation system was seen when a 12-year-old boy with measles was reported coughing in one room, and several people who had no close contact with the patient, and had in fact never been in the same room as him, developed measles (Bloch et al 1985). Coughing, as seen in this case, and sneezing are common methods of aerolisation of pathogens and are reported to be a common method of transmission of several illnesses, including SARS and influenza, as well as the common cold. Dental aerosol production in comparison, by virtue of the high speed of the motor within the dental unit, and the duration of its use in certain procedures, has the capability to generate a far greater volume of aerosolised pathogen when treating an infectious patient (Micik et al 1969) and this risk to patients and practitioners should be taken very seriously.

Furthermore, although bodies such as the American dental association state that taking the proper universal protections in personal protective equipment should eliminate much of the danger of the immediate aerosol and splatter propagated by operative procedures , a study in 1988 showed an elevated serology for legionella in dentists (Reinthaler et al 1988). Legionella is a bacterium that is commonly found in dental unit water lines left stagnant, and good practice in dentistry currently is frequent flushing of the dental unit water lines. The salient information we can take from this study is related to the fact that several studies show that legionella is a bio-aerosol dependent hazard to elderly patients and those with respiratory difficulties (Zemouri et al 2017). The increased level of exposure to dental aerosols by the dental team suggests that presence of legionella in the aerosol would affect them before the patients, and this was reflected in the elevated serological levels of antibodies for legionella in dentists, 11% compared to 5% in the general population (Reinthaler et al 1988). The relevance here is the evidence in this study of bio- aerosol related spread of infectious disease in the dental environment despite the use of personal protective equipment. A more recent study found this serology to be inconsistent with dentists surveyed in London in 2003, however, in this study in only one practice surveyed were they able to isolate legionella in the water supply, and the serology was perhaps consistent with this (Pankhurst et al 2003).

This suggests that with the advent of widespread resin composite use, and in light of the novel threat of airborne respiratory diseases such as SARS and the coronavirus, in addition to the existing protective protocols in place in the dental environment, novel strategies to minimise aerosol inhalation and spread should be adopted. A strategy that has been suggested in previous literature on the subject of dental bioaerosol (Harrel et al 2004), and subject of this literature review, is the use of air purification technologies in the dental environment to mitigate the risk of aerosol related spread.

Types of purification technologies

In this review, we will consider the comparative and synergistic efficacy of the following air purification technologies, which are frequently used either in isolation or in combination in several commercially available air purifiers.

Mechanical filtration:

This is the integral part of air purification which focusses on the removal of particulate matter from the air, and these filters can be subdivided by particle filtration efficiency and the size of particles removed. Commonly used filters are pre-filters which remove larger particles, and are usually used in conjunction with high efficiency particulate air (HEPA) filters. The latter are the most commonly used type of mechanical filtration method in commercial air purifiers. True HEPA filters have a standardised efficiency of 99.7% (Schroth 1996) rating for removing particles equal to 0.3 micrometres and above, which should mean for every 10,000 particles of 0.3 micrometres or larger only 3 should be able to pass unimpeded through the filter. Rutala et al showed that when in room portable purifiers were used, 90% of particles with a size of more than or equal to 0.3 micrometres were cleared within 5-8 minutes, a great reduction from both the value quoted in Hinds' study of 30 minutes (Hinds 1982), and the control value in this study in a non-ventilated chamber of 120 minutes (Rutala et al 1995).

The mechanism of action of HEPA filters is threefold: larger particles, i.e. those of a size over 10 micrometres are filtered in the traditional sense, in that in they do not fit the holes in the filter's fibre meshwork and so are directly intercepted. Inertial impaction is employed to remove particles between 0.5 and 10 micrometres, these include typical bacteria, and due to their density, which is greater than that of air, they deviate from the normal laminar flow of air and adhere to the filter by virtue of their inertia. Particles much smaller than this, those less than around 0.1 micrometre behave differently, by merit of their reduced size, the effect of Brownian motion is far stronger on these particles and so their typical course through air can be likened to a zigzag. Therefore, although they can fit through the pores in the filter, their non-laminar flow causes them to be caught on the fibres which constitute the filter, this is known as diffusional interception. A study conducted at the university of Minnesota showed that HEPA filters had a 99.99% efficacy when removing particles below 5 nanometres. The reason that the focus is placed on particles 0.3 micrometres in size is because at this size, they are less susceptible to Brownian motion and inertial impaction,

and so have the greatest potential to pass through the filter. A true HEPA filter must therefore be tested using di-octyl phthalate to show 99.97% efficiency for these most difficult to capture particles.
When placed into the dental context, in theory these filters should remove most particulate content, as well as most microbial content as bacteria tend to fall into the size bracket of 0.5 to 1.5 micrometre and viruses between 0.01 and 0.4 micrometres in size, although the HEPA filter does not in itself have any mechanism for sterilisation once these microorganisms have been captured.
Ultra-low particulate air (ULPA) filters may have an efficiency even higher than that of the HEPA filter, with reported values at 99.999% (Jamriska et al 1997), but these are not yet in widespread use.

Adsorption:
This technology involves the use of solid adsorbent materials, such as the commonly used activated carbon, and is particularly suited to removing volatile organic compounds and other contaminants in the gaseous phase, which attach themselves to the surface of the adsorbent. However, its efficiency is variable and VOCs attach to the filter so over time its efficiency reduces and the filter requires regular replacement. Humidity has also been shown to reduce the efficacy of carbon filters (codony et al 2014).

UVC Irradiation:
UV light can be divided into different categories based on its wavelength, with the wavelengths of UVC waves ranging between 100-280 nm (Green and Scarpino 2001). It is used in purification units in the form of one or many UVC emitting mercury lamps, or LEDs, within the unit, and its mechanism of action is through the damage of the DNA or RNA of microorganisms such as viruses and bacteria, and its efficacy is largely dependent on the intensity of the light, the duration of exposure of the microorganism and the humidity of the room. This UVC is usually used in conjunction with another filtration technique as it has no effect on particulate matter.

Methods

Given that the particulate matter of concern in dental aerosols tends to be less than fifty micrometres in size, due to their ability below this size to remain in airborne for up to thirty minutes (Hinds 1982), with respirable particles being between less than 10 micrometres in size, when evaluating the efficacy of air purification technologies, studies will be included which detail the ability of each technology to effectively remove particulate matter of this size from the air. Another consideration when evaluating efficacy in the dental environment is the antimicrobial properties of the purification technology, considering the potentially infectious bio aerosol created during dental procedures. We may also consider the ability of these technologies to remove volatile organic compounds from the air, these include malodourous constituents of bioaerosol and are often present in dentistry due to the nature of some procedures.

A particular difficulty encountered when conducting this literature review was the paucity of literature on the efficacy of air purification in the dental environment. However, as the purpose of this review is to assess the efficacy of the purification technologies in essence on bio-aerosols, studies were included which assessed the technologies for removal of particulate matter, antimicrobial efficacy, and ability to remove malodourous and toxic VOCs.

Given the particular nature of the different filtration methods above and their different methods of action, they also have different targets, as shown generally in table 1 (Lui et al 2017). Pollutants can be subdivided into three main categories, larger particulate matter such as respirable dust, VOCs such as ammonia and microorganisms such as bacteria and viruses. Respirable dust and microorganisms are most pressing in the dental environment.

Purification Technique	**Pollutants**			
	Suspended particles	**Volatility organic contaminants**	**Microorganism**	
	Dust, pollen, secondary pollutants, lampblack, etc.	**Formaldehyde, benzene, ammonia, etc.**	**Bacteria**	**Virus**
	Diameter 0.01–100 µm	**Diameter 0.0001–0.001 µm**	**Diameter 0.2–10 µm**	**Diameter 0.01–0.3 µm**
Filtration	Effective	Non-effective	Effective	Non-effective
Adsorption	Partially effective	High-efficiency	Partially effective	Non-effective
Ion generations	Effective	Not obvious	Partially effective	Non-effective
Ultraviolet radiation	Non-effective	Non-effective	High-efficiency	High-efficiency

it would follow that certain types of filters are used for removal of particulates and others have primarily antimicrobial effects, and reviewing the efficacy of each for both functions is beyond the scope of this review on dental efficacy. More in depth reviews have been conducted on these topics (Zhang et al., 2011) (Bahri and Haghighat, 2014) (Luengas et al., 2015) (Zhong and Haghighat, 2015) (Siegel, 2016).

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In this review, we will focus on HEPA filters and ionising purification technologies and their efficacy in removal of particulate matter. For their reported antimicrobial effects, we reviewed ionising purification systems and UVC irradiation.

Studies were reviewed which assessed both clean air delivery rate (CADR) and first pass efficacy. 36 studies were returned in various literature searches and of these 15 were retained.

Results

n.b. Although adsorption methods such as activated carbon filters do not remove particulates or have anti-microbial effects in any notable way, and are not the focus of this review they have been shown to have great efficacy in removing volatile organic compounds (VOCs) which can cause unpleasant odours in a dental setting. This system has been shown to have an efficacy of 70-80% by Sidheswaran et al (2012) and 90% by Jo and Yang (2009). This could be a useful adjunct to any major purification technology.

A Review of Efficacy of Air Purification Technologies in Removing Particulate Matter

Study	Study Design	Reported Efficacy of Ionising Filters in Removing Particulate Matter
Lee et al 2004	Chamber test	97% efficacy in particles 0.1 micrometre, 95% in particulate matter 1 micrometre
Offerman et al 1985	Field test	207m3/h clean air produced by ion generators, compared to 306m3/h HEPA
Macintosh et al 2012	Field test	Ionic purifiers took 0.5 hours to clear all particulate matter less than 2.5 micrometres with the use of three portable ion generators, however, the increase of sub fine particles increased. A single HEPA filter took 1.4 hours to achieve this result

Study	Study Design	Reported Efficacy of HEPA Filters in Removing Particulate Matter
Dee et al 2006	First pass efficacy test	In this study, a porcine respiratory virus was used as an allegory for viruses in bioaerosol. HEPA filters had over 95% efficacy in removing particles from the air, and were the only filter which prevented transmission
Reisman et al 1990	Long term study on changes in particulate matter compared to control	An 85% reduction in particle number count was recorded with the use of HEPA filters, and 73% in particles >0.3micrometres
Xu et al 2010	Long term study on changes in particulate matter compared to control	A 72% reduction of particles 0.5-10 micrometres in size was found
Du et al 2011	Long term study on changes in particulate matter compared to control	A standalone HEPA filtration system reduced particulate matter by 64-80%

Review Of The Efficacy Of Antimicrobial Efficacy Of Air Purification Technologies

Study	Study Design	Reported Efficacy in Reducing Microbial Content of Air of UVC Irradiation
Green et al 2002	First pass efficiency of different UVC filters with different numbers of UVC lamps	Five different pathogens were used to evaluate the efficacy of UVC filters which had different numbers of internal lights and no HEPA filters. All were found to be 99% effective in removing all types of pathogens
VanOsdell and Foarde 2002	First pass efficiency at different room humidity	UVC irradiation was 99% effective in removing *S. epidermis* at a room humidity of 55%, but decreased to 74% at 85% room humidity, showing that efficacy is greatly dependant on ambient conditions
Kujundzic et al 2007	First pass efficiency at different airflow speeds	Single pass efficacy of removing vegetative bacteria reported to be 87% at 2.2.m/s air flow, however, at 5.5.m/s air flow there was no removal of bacteria, possibly due to reduced exposure of organisms to the UVC rays.

Kim and Kang 2018	Measurements taken at first pass with different intensities of UVC	UVC irradiation reduced the viral load of the air passed through the filter in the case of all three viruses used. Efficacy was related almost linearly to increased dose of UVC, 4.7 log reduction in virus particles with 46mJ/cm2

Study	Study Design	Reported Efficacy in Reducing Microbial Content of Air of Ionisation technology
Sunday et al 2019	First pass efficiency	Microbes such as *E. Coli* were used as allegories for those present in bioaerosols. Positive ions showed greater efficacy in clearing colony forming units from the air than negative ions, with positive ions having an efficacy of 88.5% in first pass measurements, compared to 62.85%. however, this dropped to around 40% in both when air flow speed was increased. There was also a marked decrease in increased humidity.
Zhou et al 2018	First pass efficiency	Reported efficacy of 30% for *S. marcescens* at an inlet air flow of 3.0m/s, disinfection efficacy reduced to 9.5% and 7.7% when airflow was increased to 5.0m/s and 6.0m/s respectively.
Gabbay et al 1990	First pass efficiency	Use of ionisation reduced microbial content of air by 40-50%
Jafari 2018	First pass efficiency	Reported efficiency of ion generator as excellent and microbial disinfection as very good, making it comparatively if not quantifiably better performing than the other methods evaluated which included HEPA, UVC and photocatalysis

Discussion

HEPA filtration systems showed consistently increased efficacy independent of ambient conditions when removing particulate matter of all sizes in comparison to ion generating purification systems, however, values were generally lower than those quoted by manufacturers which suggests not all HEPA filters are ‘true’.

UVC irradiation shows consistently higher antimicrobial efficacy when compared to ion generating systems. Both systems are affected by room humidity and rate of airflow, and both have a diminishing effect on efficacy. There is a suggestion that increased humidity is protective in some way for microorganisms. In light of this, it could be postulated that the adjunctive use of a dehumidifier or desiccant in a purifier which contains either of these biocidal technologies could improve efficacy.

In the current climate, the efficacy of these technologies on the novel coronavirus is likely to be a question of some urgency, however, there is little in the literature on this subject. However, UVC irradiation is in use in sterilisation of N95 masks and has shown efficacy in SARS, a virus very similar in structure to COVID-19.

Emerging Technologies and Adjunctive Technologies

Photocatalytic Oxidation:

Photocatalytic oxidation is the process of promoting, at ambient temperatures, the stepwise free radical decomposition of several organic compounds in a stepwise reaction and producing water and carbon dioxide as by products. UV light is used on a semi-conductor, often titanium dioxide (Zhong and Haghighat 2015) (Huang et al 2016). The appeal of this technology is clear, as then use of photocatalysis as s viable means of purifying air and water has long been considered. In theory, this technology requires little maintenance and are cost effective (Shirasishi et al 2009), and it has also been shown to have an antiviral and bacterial effect. However, this process has been shown to produce some undesirable products which can deactivate the catalyst, making it ineffective over longer periods of time. Performance is also usually less than other methods of filtration. However, tests outside of lab conditions have yielded greatly different results and suggest that perhaps the technology is not ready to be used in isolation, but could be useful as an adjunctive method of filtration once the by products are better understood (Hay et al 2015).

Cold plasma:

This method of purification relies on the use of high voltages to eliminate particulate matter and microorganisms using redox reactions and precipitation. There have been reports of an efficacy of up to 95% (Liang et al 2012) in the elimination of bacterial and fungal species. However, this is not yet commonly found in commercial units due to poor energy efficiency and the formation of nitrous oxides and ozone (Mista et al 2008).

Zeolites With Metallic Silver Adsorbent Technology

Cheng et al (2012) impregnated zeolite with metallic silver and found that it had an antimicrobial efficacy of up to 95% in two hours and around 90% at one hour.

Conclusions

Given the specific concerns with airborne contaminants, it follows that the purification technology most effective in the dental environment is the one which is most efficient in removing particulate matter from at least zero point five micrometres and larger from the air, and which has an antimicrobial effect to reduce the bioaerosol effect generated by dental procedures.

In the context of this, the combination of HEPA filters and UVC technologies seems to be the best synergistic technology to improve safety in the practice of dentistry. The HEPA filter was shown in all studies to be effective in removing the largest proportion of particulate matter from the air and greatly reducing the time interval in which these contaminants remain airborne (Rutala et al 1995). It has also shown efficacy in removing micro-organisms from the air, however it is not able to inactivate them and this could lead to a risk of accumulation of bacterial colony forming units and viruses on the filter and redistribution. In combination with UVC irradiation, HEPA filtration is able to eradicate microorganisms which pass through the unit. However, neither is effective in the removal of VOCs such as odours from the air which can be unpleasant for both practitioner and patient, the addition of a carbon filter to this base technology could resolve this issue.

Notably, one study found that the use of
a ULPA filter in conjunction with UVC had a 99.9995% efficacy in removing contaminants from the air, which could be an area for further exploration (Marrier et al 1993). Another area of emerging interest is the increased use of nanotechnologies in filtration which appears to show promising results in current trials, and photo catalysis using titanium dioxide, which has shown efficacy in removing VCOs but is as yet no commonly used in indoor air purification.

A clear finding of this review was the lack of literature focussing on the effects of air purification in reducing the risk of respiratory disease and spread of airborne pathogens, although it has been identified as a possible solution (Harrel et al 2004); given the aerosolising nature of dental procedures and the occupational risk of respiratory ailments from inhalation of these aerosols, this is an area into which there is a clinical need for further exploration.

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+44 (0)1932 320064 | +44 (0)7990 113723

dentair.co.uk

Bryant Dental, The Barns, Hilltop Farm, Lyne Lane, Lyne, KT16 0AW

IFU_EN1_0/IF April 2020