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The Dynamics of Bioaerosol Contamination in Dental Clinics: Patterns, Risks, and Preventive Measures - A Review Article

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ABSTRACT

Dental procedures, particularly those involving aerosol-generating techniques (AGPs), pose significant challenges in infection control due to the potential spread of bioaerosols. These aerosols, consisting of particles of varying sizes, can contain pathogenic microorganisms and settle on surfaces within the dental clinic, posing a risk of cross-contamination and infection.

Objective

This review aims to examine the extent and implications of bioaerosol contamination in dental clinics, focusing on the factors influencing aerosol dispersion, surface contamination patterns, and strategies for mitigating risks.

Methods

A comprehensive review of recent studies was conducted, analysing the spatial distribution of bioaerosols, particle size and settling times, contamination of environmental surfaces, and the effectiveness of various infection control measures.

Results

Bioaerosols generated during dental procedures can settle on surfaces after a certain period. The dispersion and settling of aerosols are influenced by particle size, type of dental procedure, and environmental factors such as ventilation.

Conclusion

Proper management of bioaerosol transmission in dental settings is crucial for preventing nosocomial infections. Continued research and improved infection control measures are essential to ensure a safe environment for both patients and dental professionals.

Spatial distribution of bioaerosols in dental clinics

Bioaerosol contamination is a critical concern in dental settings, particularly in light of the significant adaptations that health professionals had to implement during the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) pandemic. The pandemic underscored the importance of understanding bioaerosol transmission dynamics and their implications for infection control practices. This article explores key factors influencing bioaerosol dispersion in dental environments and discusses potential mitigation strategies. [1,2]

Dental procedures involving instruments like the fast hand piece, ultrasonic scalers, and micromotors generate aerosols containing particles of biological matter, contributing to surface contamination.[1,2] Aerosol-generating procedures (AGPs) can release increased microorganism counts into the air by aerosolizing saliva, blood, and other biological materials present in the oral cavity.[3] This rise in aerosol concentration leads to bioaerosol dispersion within the dental clinic.[4] Settling of bioaerosols on environmental surfaces, dental equipment, furniture, and floors can lead to contamination, with these items, known as fomites, potentially acting as vectors for disease transmission. [5-7]

Environmental surfaces in close proximity to the patient exhibit higher contamination levels.8 While the immediate treatment site is a primary source of bioaerosol generation, aerosols can disperse to areas farther from the patient, such as countertops, equipment, and dental unit waterlines (DUWL), influenced by airflow patterns and ventilation systems.[2,9] Proper ventilation and air circulation within the clinic can affect the dispersion and concentration of aerosols, impacting overall contamination levels.[10]

Studies assessing aerosol contamination in dental clinics consistently highlight the significant risks associated with AGPs. While results vary, these studies emphasize the need for effective management strategies.[11,12] For instance, Watanabe et al. (2018), used ATP bioluminescence analysis to detect high levels of ATP on personal protective equipment (PPE), indicating considerable aerosol dispersion towards the face.[13] Similarly, Al-Eid et al. (2018), employed luminol to detect blood contamination on PPE and clinical subsites, supporting findings from Watanabe et al. (2018).

Comparative studies reveal varying degrees of bioaerosol spread. Zemouri et al. 2020 found high contamination levels within 80 cm of the patient's head, especially on surfaces like the dental chair's headrest and arms.[15] Florez et al. (2021), reported contamination extending to surfaces 45–360 cm from the aerosol source, indicating a broader potential spread.16 Mirhoseini et al. (2021) suggested that microbial aerosol levels are higher at 0.5 meters compared to 2 meters, recommending a minimum 2-meter distance

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to reduce exposure risk.[17] Holliday et al. (2021), noted that contamination can extend up to 4 meters from the source, albeit at lower levels, reinforcing the need for comprehensive infection control measures.[4]

Effective infection control measures, including proper PPE, ventilation, and spatial management, are essential for reducing aerosol spread and contamination in dental settings.[18] Understanding and mitigating the impact of these factors is crucial for maintaining a safe clinical environment.

Puljich et al. (2022), conducted a study that corroborated earlier findings, identifying specific sites within a dental clinic contaminated by bioaerosols.[19] The study meticulously assessed bioaerosol exposure and contamination risks at various key areas around the dental treatment area. The positions where the dentist typically stands during procedures, about 30 cm from the patient's mouth, were evaluated to determine the level of bioaerosol exposure risk for the dentist, given their proximity to the primary source of bioaerosols.

The areas corresponding to the positions of the dental assistant, situated on the left side of the patient and approximately 40 cm away, were assessed to evaluate the exposure risk to the dental assistant, who is in close contact with the patient during treatment.

Areas selected to assess bioaerosol dispersion in close proximity to the patient, at a distance of 20 cm, were crucial in evaluating the extent of patient-generated bioaerosols, which pose a direct risk to both the dental team and other patients.[19]

A position situated 90 cm from the patient's mouth was used to evaluate the effectiveness of the dental suction system in removing bioaerosols. This spot was strategically chosen to assess how well the suction system could minimize bioaerosol presence during procedures.[19]

Another area, where dental instruments and equipment were stored during procedures and located 80 cm from the patient, was assessed to evaluate the potential for bioaerosol contamination on these surfaces, which could contribute to cross-contamination if not adequately controlled. Finally, a control point, situated 200 cm away from the patient's mouth, was critical for differentiating between bioaerosols generated by the dental procedure and ambient bioaerosol levels in the clinic environment, providing a baseline for comparison.[19]

Suspension and Settlement of Bioaerosols During Dental Procedures

Bioaerosols suspended in the air during dental procedures can pose significant health risks by potentially being inhaled by dental staff or patients or by settling on environmental surfaces.[20] Large particles (>10 micrometres [µm]) tend to settle quickly and are less likely to reach the lower respiratory tract. They are often filtered out by the upper respiratory system. Small particles, ranging between 2.5 and 10 µm, can penetrate deeper into the lungs but are still more likely to be trapped in the upper respiratory tract. Fine particles (<2.5 µm) can reach the lower respiratory tract and are more likely to be inhaled deeply into the lungs, while ultrafine particles (<0.1 µm) can penetrate even further into the lungs.[10,20]

It is important to note smaller bioaerosol particles, due to their lower settling velocity, can remain suspended in the air for extended periods, increasing the likelihood of inhalation. This persistence in the air makes it crucial to understand the impact of various dental procedures and the airflow dynamics within the clinic, as these factors directly influence the level of bioaerosol contamination.[10,20]

A comprehensive analysis by Liu et al. (2022), investigated bioaerosol distribution and associated infection risks in a compartmentalized dental clinic.[9] The study provided valuable insights into the extent of contamination and the associated risks for both dental staff and patients. During the active treatment phase (0-30 minutes), the study found that the source compartments—typically the surgery rooms—presented a high risk of infection for dental staff, even with protective measures in place. This risk was particularly pronounced for patients, especially those in adjacent compartments, highlighting a critical need for more effective protective strategies and improved infection control measures.

Immediately after treatment (30-60 minutes), the risk of infection in the source compartments remained elevated due to the persistence of bioaerosols. For patients treated immediately after, the infection probability could rise up to 10%, underscoring the necessity for effective ventilation systems to reduce the bioaerosol load. Adjacent compartments were also at risk, with the potential for significant exposure if patient appointments were scheduled too closely together. This emphasizes the importance of strategic patient scheduling and robust ventilation systems to minimize the risk of cross-contamination.[1,5,6]

By thirty minutes post-treatment (60-90 minutes), the risk of infection in the source compartments significantly decreased, with probabilities falling to below 0.05%. This reduction in risk also extended to adjacent compartments, provided that proper ventilation was maintained. The study's findings recommend a 30-minute safety interval between patient appointments to ensure both dental staff and patient safety. Maintaining effective ventilation during this period is crucial to reducing overall infection risk and ensuring a safe clinical environment.[1,2,6]

Holliday et al. (2021) reported the majority of dental aerosol contamination settles onto surfaces between 1- 5 min and by 10 minutes most aerosols have settled. 4,21 This indicates that bioaerosols generated by AGP can have various settling times due to several factors such as the size of the particle, type of procedure and environmental factors which include the clinic ventilation.[4,8]

Aerosols generated during dental procedures consist of particles of varying sizes, from very fine aerosols to larger droplets and splatter. Smaller particles range from 0.001 µm to 50 µm in diameter and particles greater than 100 µm are classified as splatter which settle quickly on surrounding surfaces and the floor.[8,10,12,16] The particle size influenced the behaviour of these aerosols, including how long they remain suspended in the air and how quickly they settle on surfaces.[12] Aerosolized particles as small as 1µm can contain sufficient volume to harbour various respiratory pathogens and can lead to contamination up to a distance of one meter thereby posing a risk of infection.[8,10,12] Aerosolized particles smaller than 10 µm are considered ultrafine particles, which can stay suspended in the air for several hours and spread up to 3 meters from the source.[15,16]

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In summary, the study by Liu et al. (2022), highlights the critical role of effective ventilation and strategic scheduling in managing bioaerosol contamination in dental clinics.9 Proper ventilation systems are essential for dispersing and diluting bioaerosols, while a 30-minute safety interval between patient appointments helps mitigate the risk of infection from residual aerosols. Implementing these strategies can significantly enhance infection control practices and ensure a safer environment for both dental staff and patients.

Contamination Sites and Cleaning Protocols in Dental Clinics

Studies have established that bioaerosols generated during dental procedures can disperse beyond the immediate vicinity of the patient, affecting various surfaces throughout the dental clinic and posing a risk of infection.1 Innes et al. (2021), identified several contaminated areas within the dental surgery, emphasizing the importance of rigorous cleaning and disinfection protocols to prevent the transmission of infectious agents, as further supported by Polednik (2021).[1,2,20]

Work Surfaces: Countertops, dental chairs, instrument trays, and other surfaces directly involved in dental procedures are particularly prone to contamination. These surfaces are exposed to splatter, and aerosols generated during treatment and may also come into contact with contaminated instruments, making them critical for targeted disinfection.[5,6,7]

Floors: Areas around the dental chair and pathways where personnel move are significant contamination sites. Contaminants can result from dropped instruments, splatter, bioaerosols, and foot traffic, highlighting the need for regular and thorough cleaning of these areas.[11,13]

Dental Equipment: Instruments, devices, and machinery in the dental clinic's immediate vicinity are potential contamination sources. These items can be contaminated directly through contact with surfaces or indirectly via splatter and aerosols from procedures.[12,13,18]

Personal Protective Equipment (PPE): Gloves, masks, and face shields worn by dental personnel are exposed to bioaerosols and may become contaminated during procedures or through patient contact. Proper handling and disposal of PPE are essential to prevent cross-contamination.[9,10]

Patient-Related Areas: Surfaces near the patient, such as dental chair armrests and adjacent tables, are vulnerable to splatter, aerosols, and direct contact with the patient. These areas require careful disinfection to manage contamination risks effectively.[5,6,8]

These findings underscore the extensive potential for contamination within a dental clinic, reinforcing the need for comprehensive cleaning and disinfection protocols to mitigate the risk of infectious agent transmission effectively.
The detailed assessment at these various locations offered valuable insights into bioaerosol distribution and the associated contamination risks in dental clinics, underlining the importance of targeted infection control measures. This assists in identifying potential hotspots for bioaerosol deposition and informs the implementation of infection control measures to mitigate transmission risks.

Strategies for Mitigating Bioaerosol Transmission in Dental Clinics.

Bioaerosols serve as a major concern in relation to the transmission of pathogenic microorganisms. Cross-contamination from environmental surfaces that have microbial deposits is known to be a vector for the transference of infection from one individual to another.[22] Great emphasis is placed on following stringent infection control measures in order to manage all forms of contamination. To ensure patients safety and provide a hygienic and pathogen-free environment, it is crucial to prioritize the identification and addressing of risk factors. Together with the implementation of proper decontamination protocols and disinfection practices, dental clinics can mitigate the risk of infections associated with dental treatments.[8,23]

As previously described the volume and spatial distribution of bioaerosols in a dental clinic can vary depending on the type of procedure performed and is managed by the implementation of various strategies and mitigating measures.[24] This study by Dey et al. (2023), concludes that the risk of exposure of dental personnel is significant but various factors such as air quality, and an effective ventilation system mitigate the risks.25 Environmental factors such as dental clinic design, room ventilation, air currents, influence the spatial distribution pattern of bioaerosols in a dental clinic.[3,26,27]

Poor ventilation and high humidity levels increase the survival of pathogens within bioaerosols, increasing the risk of transmission and contamination.[28] The implementation of a cross-ventilation system in the clinic can reduce concentration of particles in the air by 80-89%.[4] This knowledge should influence the surgery design. Weijden (2023) reported inadequate ventilation systems may result in the retention or recirculation of aerosols.[12] Moreover, aerosol particles that have previously settled on surfaces in the treatment room can be disturbed and reintroduced into the air, contributing to potential contamination.[6,17]

An effective ventilation system, the use of air purifiers, high-efficiency particulate air (HEPA) filters, and the use of dental suction devices to minimize aerosol spread during procedures.[29] Proper ventilation in the dental clinic promotes air exchange and reduces the concentration of bioaerosols or removes smaller aerosol particles that may contain viruses.[27] HEPA filters in the ventilation system can trap or remove particles or bioaerosols.[25] Dental suction used during procedures can significantly reduce contamination and high-volume evacuators (HVE) and dental suction devices can efficiently capture and remove aerosols generated by dental instruments when positioned close to the oral cavity.[30] Dual suctioning significantly reduces particle concentration and microbial load, emphasizing the role equipment and techniques play in mitigating aerosol exposure.[8,16] Another method of mitigating aerosol spread, and contamination is the use of a high-speed suction and saliva ejectors. This combination can significantly reduce aerosol levels during dental procedures. However, it is important to note that these methods may not be entirely effective at eliminating aerosols outside the patient's mouth.[31]

Continuous monitoring of the air quality by using active sampling methods allows for monitoring of the microbial load. This allows for early detection of contamination and aids in implementing corrective measures can minimize the risk of microorganism transmission.[32] The studies by Dey

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et al.2023, and Monoil et al.2023, focused on improving air quality in dental clinics through a combination of aerosol reducing system, high efficiency air filtration, and targeted ventilation.[25,33] The study recommended the use of HEPA filters, air purifiers, high volume evacuations (HVE)systems, and anti- microbial solutions to control contamination.[25]

In addition, Tzoutzas et al. (2022), recommended an increase in ventilation systems and the use of extra-oral suction devices for capturing aerosols near the oral cavity.[32] The room ventilation with higher air changes per hour (ACH) and HEPA filtration units are effective in reducing particulate matter, while extra-oral suction devices with sufficient flow rates can achieve 100% aerosol removal efficiency.[33]

Dey et al. 2023 recommended the use of UV-C radiation for sterilization, indicating its germicidal properties and potential limitations.[25] Tzoutzas et al. (2022) addressed best practices for infection control in dental clinics, emphasizing personal protective equipment (PPE), regular disinfection, and careful clinic design to facilitate proper air flow.32 The study recommended continuous operation of air purifiers during and after dental procedures to maintain a safe environment. The CDC's October 2016 summary on infection prevention in dental settings recommends using ventilation and air filtration systems with high-efficiency filters to capture airborne viruses, alongside portable air evacuation carts equipped with HEPA filters and continuously operating fans.[34]

In addition, the utilisation of mechanical suction minimizes aerosol spread from the oral cavity. The use of UV-C lighting or in- duct UV systems to eradicate airborne viruses has proven to reduce microbial load. Maintaining a relative humidity between 40 -60 % assists in reducing virus transmission, inhibits mould proliferation. Together these factors ensure optimal air quality.[23]

Despite the implementation of evidence-based strategies to manage bioaerosol transmission surface contamination remains a persistent challenge. This highlights the importance of not only focusing on bioaerosol control but also maintaining stringent surface cleaning and disinfection protocols. Effective management of surface contamination is crucial to ensuring comprehensive infection control, as pathogens can still spread through contact with contaminated surfaces, emphasizing the need for a dual approach to infection prevention.[30]

Management of surface contamination

Effective management of surface contamination is essential for preventing the spread of nosocomial infections in dental settings. The following key measures should be adhered to:

Proper Hand Hygiene: Hand hygiene is a cornerstone of infection prevention. Dental health care workers should wash their hands thoroughly with soap and water for at least 20 seconds before and after each patient encounter. This includes after touching any surfaces, handling equipment, and removing gloves. Proper hand washing involves rubbing all areas of the hands, including between fingers and under nails, to ensure complete cleanliness.[35-37]

Hand Sanitiser: The CDC and WHO recommend alcohol-based hand sanitisers with an alcohol content between 60%-95% for effective disinfection. Common alcohols include ethanol and isopropanol. While effective, pure alcohol can dry the skin and lacks residual antimicrobial activity. To mitigate this, hand sanitisers with increased glycerine concentration and 70% ethanol are preferred, balancing efficacy with skin care.[38]

Mouthwash Role of Mouthwashes: In summary, clinical evidence supports the use of preprocedural mouthwashes containing antiseptic agents as an effective measure for temporarily reducing bacterial or viral load in the oral cavity and dental aerosols. Their inclusion as part of a comprehensive protection strategy for dental healthcare professionals (HCPs) is recommended, despite some remaining ambiguities and potential side effects. When selecting an antiseptic, agents like chlorhexidine (CHX), cetylpyridinium chloride (CPC), essential oils (EO), and combinations of these are supported by the most extensive data. Preprocedural rinsing with antimicrobial agents such as chlorhexidine or povidone-iodine is shown to reduce microbial levels in saliva, limiting cross-contamination during aerosol-generating procedures. These agents disrupt bacterial membranes and provide sustained antimicrobial effects, along with virucidal and fungicidal properties, significantly contributing to infection control in dental settings.[39]

Regular Cleaning and Disinfection: All environmental surfaces in the dental clinic, including countertops, dental chairs, light handles, doorknobs, equipment, and frequently touched surfaces, should be cleaned and disinfected regularly between patients. Use disinfectants that are registered and follow the manufacturer's instructions for proper use, including contact time and dilution. A documented cleaning schedule helps ensure thorough coverage and consistency.[18,35,39]

Disposable and Single-Use Items: Use disposable and single-use items wherever possible to reduce the risk of surface contamination. These items, such as gloves, suction tips, and barriers, should be properly disposed of after use. Safe disposal practices help prevent cross-contamination and maintain a sterile environment.[40]

Proper Waste Management: Dispose of all items that come into contact with bodily fluids, including disposable PPE and contaminated materials, according to appropriate guidelines. Dental health care workers should wear appropriate PPE when handling waste and maintain good hand hygiene. Proper segregation and disposal of waste, including sharps and biohazardous materials, are crucial for infection control.[41]

Ventilation and Air Filtration: Implement ventilation systems with HEPA filters and UV chambers to reduce aerosol-related contamination. Portable HEPA filters can be placed near patient chairs during treatment to capture airborne particles. Regular maintenance of these systems is crucial for effective air purification and reducing the risk of airborne infection.[25]

Zoning for Decontamination: Establish a zoning system to manage decontamination efforts effectively. Define areas that become contaminated during operative procedures and focus cleaning and disinfection efforts on these specific zones. This approach ensures that high-risk areas receive targeted attention and helps streamline the decontamination process.[43,44]

Two-Stage Decontamination Process: Surface decontamination should follow a two-stage process: cleaning followed by disinfection. Start with cleaning surfaces using

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detergent and water to remove organic matter and debris, followed by disinfection with an appropriate disinfectant to kill any remaining pathogens. This approach ensures thorough decontamination and reduces the risk of.[45,46]

Dental Unit Waterlines (DUWL): DUWLs are a major source of microbial contamination, with biofilm formation occurring rapidly due to the waterline structure and environmental factors. Biofilms provide a breeding ground for pathogens, posing a risk to patients, particularly immunocompromised individuals. Contamination primarily arises from patient saliva and microbial contamination from municipal water, with anti-retraction valves often ineffective in preventing backflow. Biofilm development is influenced by factors such as water flow, pH, temperature, and microbial characteristics, leading to higher resistance to disinfectants.[42] Despite the well-documented risks, many dental professionals remain unaware of the potential dangers, with studies showing only 30% recognize the infection risks posed by DUWL water. Water supplied to DUWLs often does not meet potable water standards, increasing health risks, especially for those with compromised immune systems. Therefore, improving infection control in dental clinics through regular cleaning, disinfectant use, and proper monitoring is essential to reduce microbial contamination and protect both patients and staff. Implementation of weekly shock treatments with high-level disinfectants can manage DUWL effectively. Proper maintenance is essential for preventing contamination and ensuring patient safety.[40,42]

Selection of Effective Disinfectants: Choose disinfectants effective against a broad spectrum of pathogens, including enveloped viruses. For surfaces in healthcare settings, use 70% ethyl alcohol for disinfecting reusable equipment and sodium hypochlorite at 0.5% concentration for surfaces. Chlorine-based disinfectants and hydrogen peroxide have shown efficacy against SARS-CoV-2 and other viruses, making them suitable for use in dental settings.[6,25,47,48] Aerosol particles interact dynamically with environmental surfaces, influencing pathogen persistence and potential transmission. The nature of the surface material significantly impacts surface contamination. Porous surfaces, such as textiles or unsealed wood, tend to trap and retain particles more effectively than non-porous surfaces like metal or plastic. This trapping effect can lead to prolonged viability of aerosolized pathogens, increasing the likelihood of surface-to-person transmission. Conversely, non-porous surfaces may facilitate easier cleaning and disinfection, potentially reducing the risk of pathogen persistence. Overall, the choice of surface disinfectant should be tailored to the specific surface characteristics and the nature of aerosol particle interactions to achieve optimal disinfection and reduce the risk of pathogen transmission.[6,25,47,48]

CONCLUSION

Addressing bioaerosol contamination in dental clinics is crucial for ensuring the health and safety of both patients and staff due to the high risk of aerosol transmission of infectious agents inherent in dental procedures. Understanding bioaerosol distribution allows for the implementation of effective control measures, which significantly reduces the risk of spreading infections such as COVID-19, monkeypox, and other pathogens. By enhancing infection control practices through improved ventilation systems, modified procedural techniques, and appropriate disinfection protocols, dental clinics can better protect vulnerable populations, including those with compromised immune systems or underlying health conditions. This knowledge also ensures compliance with infection control standards and regulations set by health authorities, thereby maintaining accreditation and avoiding legal issues. Furthermore, effective bioaerosol management can improve clinic efficiency and patient comfort, potentially reducing anxiety and enhancing overall operational effectiveness. Investigating bioaerosol distribution not only advances research and knowledge on infection transmission dynamics but also promotes sustainable practices by identifying control measures that minimize the need for excessive disinfectants and PPE. In summary, addressing bioaerosol contamination is essential for maintaining a safe, efficient, and compliant dental practice.

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Online CPD in 6 Easy Steps

The Continuing Professional Development (CPD) section provides for twenty general questions and five ethics questions. The section provides members with a valuable source of CPD points whilst also achieving the objective of CPD, to assure continuing education. The importance of continuing professional development should not be underestimated, it is a career-long obligation for practicing professionals.