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The Evolution and Efficacy of Disinfection Methods in Dental Practices: From Traditional to Advanced Technologies – A Review Article

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ABSTRACT

Ensuring effective disinfection in dental clinics is crucial for safeguarding patient health and preventing cross-contamination. Traditional disinfection practices have been widely used to maintain a sterile environment. However, these methods often encounter limitations and necessitates finding alternative methods.

Objectives

This review aims to provide an overview of existing disinfection methods used in dental clinics and focuses on evaluating the efficacy and versatility of advanced technologies, specifically vaporised hydrogen peroxide (VHP) and hypochlorous acid (HOCl). The review also examines the effectiveness of these methods as well as the operational benefits and potential limitations associated with the use of VHP, HOCl, and vaporizers in dental settings.

Methods

This review involved analysing and synthesizing findings from various published articles and studies on disinfection practices in dental clinics. It focused on their efficacy, application methods, and impact on microbial decontamination in clinical environments.

Results

The articles reported the mechanisms of action, effectiveness, and practical applications of these advanced disinfection technologies such a vaporiser in dental clinics. It highlights recent research and case studies demonstrating the superior performance in achieving thorough microbial decontamination, reducing environmental contamination, and enhancing overall infection control protocols. Additionally, the review explores the operational benefits of these technologies, such as reduced application time and lower toxicity risks compared to conventional agents.

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Conclusion

Advanced technologies like VHP and HOCl show superior microbial reduction and practical advantages over traditional methods. Their integration into dental settings can strengthen infection control, though further research and clear guidelines are needed to support widespread adoption.

INTRODUCTION

Surface decontamination in dental clinics presents unique challenges due to the presence of high-touch areas, diverse surfaces, and constant movement of people, all of which complicate effective disinfection. Effective surface disinfection is critical to minimise the risk of cross-contamination and protect both patients and dental staff. Over the years, methods have evolved from manual cleaning to advanced automated technologies, enhancing efficacy, coverage, and safety.

Mechanical disinfection

Mechanical disinfection, or physical decontamination, is the crucial first step in the disinfection process. It involves the physical removal of visible debris, organic matter, and contaminants from dental instruments, equipment, and environmental surfaces, allowing the active ingredients of disinfectants to work effectively.[1,2]

The primary goal of pre-cleaning is to reduce the microbial load on surfaces by eliminating larger particles and residues that could otherwise shield microorganisms from subsequent disinfection efforts. This process typically involves physical actions such as scrubbing, wiping, or rinsing, which are essential for effectively dislodging and removing contaminants. Other methods of physical disinfection include steam, heat, ultraviolet-C (UV-C) radiation, and filtration. 1Steam sterilisation uses high pressure steam to penetrate and kill microorganisms while UV-C radiation is an efficient method used to reduce microbial contamination by disinfecting the air and environmental surfaces. Plasma sterilisation and gas sterilisation use ionized gas, ethylene oxide and formaldehyde respectively to sterilise dental instruments and equipment by.[1,5]

The significance of mechanical disinfection lies in its ability to enhance the efficacy of chemical disinfectants. This step is vital because the presence of organic matter can inhibit the effectiveness of disinfectants, potentially leading to incomplete or ineffective disinfection.[1,2]

In dental settings, where precision and cleanliness are paramount, effective mechanical disinfection sets the

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stage for the success of subsequent chemical disinfection processes. It helps in ensuring the intended antimicrobial action by disinfectants on surfaces and instruments, thus significantly contributing to infection control and patient safety. Mechanical disinfection is not merely a preliminary step but a foundational practice that underpins the entire disinfection process.

Chemical disinfection

Chemical disinfectants can be classified based on their chemical composition, spectrum of activity, and practical applications in dental settings. Alcohols (ethanol, isopropanol) are effective against bacteria, fungi, and enveloped viruses but are not sporicidal, and they act rapidly with low residue.[6] Aldehydes (glutaraldehyde, formaldehyde) are high-level disinfectants capable of inactivating bacteria, viruses, fungi, and spores, but require careful handling due to toxicity and potential corrosiveness.[9] Halogen-releasing agents (chlorine and iodine compounds) are broadly effective, including against mycobacteria, and are often used for surface disinfection.[6] Quaternary ammonium compounds are low- to intermediate-level disinfectants that are effective against bacteria and enveloped viruses but have limited activity against spores and some non-enveloped viruses.[6] Hydrogen peroxide and peracetic acid are potent oxidizing agents with broad-spectrum activity, including bacteria, viruses, fungi, and spores, and are increasingly used as environmentally friendly alternatives.[6,9] Other agents, such as phenolics, acids, alkalis, and heavy metals, provide additional options depending on the clinical setting and the type of surface or instrument being disinfected.[9] Selecting the appropriate chemical disinfectant requires consideration of the target microorganisms, compatibility with materials, safety for staff and patients, and environmental impact.[7,8]

Surface disinfection can be one-step (direct chemical application) or two-step (pre-cleaning followed by chemical disinfection). Two-step methods ensure removal of organic matter but are time-consuming, while one-step methods are more practical in high-throughput dental settings.[7]

Disinfectant wipes offer a convenient alternative, providing targeted application with reduced chemical exposure and improved coverage, while saving time.[8] However, the efficacy of the disinfectant wipes is dependent on the correct storage of the wipes.

The spray-and-wipe method remains the most commonly used approach in dental clinics, supported by a wide range of formulations. The chemicals that could potentially be used in surface disinfection include formaldehyde, glutaraldehyde, hydrogen peroxide, aldehydes, halogen-based biocides, quaternary ammonium compounds, phenolics, acids/alkalis, heavy metals, and alcohols, each with its unique properties and applications.[9]

The various types of disinfectants

Maintaining hygiene and preventing cross-contamination in dental settings requires the careful selection of disinfectants. The wide array of disinfectants available, each with specific mechanisms of action and target pathogens, underscores the need for a tailored approach to infection control. From the potent oxidative effects of hydrogen peroxide and sodium hypochlorite to the broad-spectrum efficacy of alcohols and quaternary ammonium compounds, understanding the strengths and limitations of these agents is essential. Additionally, considerations such as potential corrosiveness, toxicity, and shelf life play a significant role

Table I: summarizing the disinfectants used in dentistry along with their target pathogens or indications:

Disinfectant	Pathogens/Indications	Environmental Considerations
Sodium Hypochlorite	Bacteria, viruses, fungi, spores; used in endodontics for root canal disinfection; also dissolves organic tissues. [1,2,]	Corrosive; toxic fumes if misused. Must avoid mixing with other chemicals.
Hydrogen Peroxide	Bacteria, viruses, fungi, spores; used for root canal disinfection in endodontics; effective at 0.5% for disinfection against SARS-CoV-2; recommended for mouth rinse. [,6-8,11,]	Oxidative; safe residues. Can reach hard-to-clean areas.
Chlorine Compounds	Bacteria, viruses, fungi, spores; includes sodium chlorate(I), sodium dichloroisocyanurate, and chloramine; used for surface disinfection; sodium hypochlorite recommended for SARS-CoV-2. [1,2,6-8,]	May form toxic by-products, and corrosive.
Ethanol	Bacteria, fungi, viruses (excluding spores); used in disinfecting surfaces, skin disinfection, and hand sanitizers; recommended in 62-71% concentration for SARS-CoV-2. [1,11,13]	Flammable; low environmental impact Fast acting; limited residual effect
Isopropyl Alcohol	Bacteria, fungi, viruses; used for surface disinfection and hand sanitisation; recommended in 70% concentration for surface disinfection; combined with silver nanoparticles for enhanced adhesion. [1,2,6-8]	Highly flammable; evaporates quickly, minimal long-term environmental impact.
Povidone-Iodine	Bacteria, fungi, viruses; effective as mouth rinse; recommended for SARS-CoV-2 at 0.2%; acts by oxidizing cell components; also used for skin disinfection. [1,2,8,11,13]	Safe when used in small amounts; avoid large-scale disposal.
Chlorhexidine	Bacteria, fungi; ineffective against spores and mycobacteria; used for hand disinfection, oral gels, and endodontic final irrigant; not effective against SARS-CoV-2 unless combined with alcohol. [1,2,6-8,]	Low biodegradability.
Quaternary Ammonium Compounds (QACs)	Bacteria (especially gram-positive), enveloped viruses, fungi; used for disinfection of noncritical surfaces and undamaged skin; less effective against mycobacteria. [1,2,6-8,]	Low toxicity Less effective on spores/mycobacteria.

Glutaraldehyde	Bacteria, fungi, viruses, spores; high-level disinfectant; used for disinfection of medical equipment; activated in alkaline pH; potential toxic effects. [1,2,6-8,1]	Toxic; requires ventilation High-level disinfection.
Aldehydes (OPA)	Bacteria (including mycobacteria), fungi, viruses, spores; high-level disinfectant; stable across a wide pH range; used for disinfecting medical equipment. [-8,11,13]	Proper waste management required.
Phenolic Compounds	Bacteria, fungi; used for disinfecting surfaces; includes eugenol and thymol; ineffective against spores; used as antiseptic in endodontics and dental treatments. [1,2,6-8,13]	Toxicity varies Limited antiviral activity
Silver Compounds	Bacteria; used for preventing infections in wounds and treating eye infections; includes silver sulfadiazine. [1,2]	Toxicity varies Limited antiviral activity

in ensuring safe and effective disinfection practices. This section discusses the disinfectants commonly used in dentistry, their applications, and the regulatory guidance that shapes their clinical use. [1,2,10,11]

Guidelines from the centres for Disease Control and Prevention (CDC) and the World Health organisation (WHO) provide universally accepted principles for surface disinfection. Regulatory requirements for environmental disinfectants vary by country, but the WHO and dental regulatory bodies recommend that an ideal surface disinfectant should demonstrate broad-spectrum antimicrobial activity, rapid action, and effectiveness in the presence of organic matter. It must also be non-toxic, non-corrosive, compatible with dental materials, easy to use, and environmentally safe. Additionally, it should comply with regulatory safety standards and show proven efficacy against bacteria, viruses, fungi, and spores commonly encountered in dental settings.[28]

Challenges associated with surface decontamination.

During dental procedures, both direct and indirect contact with instruments, equipment, and environmental surfaces is unavoidable, frequently involving saliva, blood, biological fluids, or bioaerosols, and consequently exposing dental staff and patients to infectious microorganisms present in the oral cavity. Kchaou et al. (2020) and Tzoutzas et al. (2022) highlight several challenges associated with effective surface disinfection in dentistry, including the wide range of pathogen exposure, the constant interaction between patients and dental staff, the diversity of surface types, high levels of movement within confined clinical spaces, and the emerging resistance to existing disinfectants.[21-23] In addition, dental procedures inevitably generate splatter and subvisible blood droplets that further increase the risk of pathogen transmission.[15, 16] These factors underscore the importance of prioritising high-touch and frequently contaminated areas during routine disinfection.[1,17] However, manual cleaning alone may leave residual microorganisms on hard-to-reach surfaces, contributing to persistent contamination, while workflow constraints in busy clinics often hinder strict adherence to recommended disinfection protocols. Identifying zones with consistently high contamination risk and directing targeted cleaning efforts toward these areas can therefore enhance overall efficacy and significantly reduce cross-contamination.

Objectives of Surface Disinfection

The primary aim of surface disinfection is to eliminate and neutralize pathogens on environmental surfaces in a dental clinic.[17,18] However, the lack of comprehensive data on nosocomial infections in dental clinics poses challenges for developing effective infection control strategies. Studies suggest that optimal surface disinfection should eliminate and deactivate microorganisms present, prevent the spread of infection, and avoid any idiopathic harm to staff or patients.[8,12,19,20]

Routes and Sources of Contamination

During dental procedures there is direct and indirect contact with instruments, equipment, and environmental surfaces. This can occur by contact with saliva, blood, biological fluids or bioaerosols and by default with various infectious microorganism present in the oral cavity during dental treatment. Kchaou et al. (2020), and Tzoutzas et al. (2022), reported several challenges facing surface disinfection in dentistry ranging from the range of pathogen exposure, direct and indirect contact by patients and dental staff, the variety of surfaces, continuous movement of individuals in a short space of time in the same environment and the development of resistance to existing disinfectants.[21-23]

Selecting the Appropriate Disinfectant

Based on the above-mentioned factors, the disinfectant of choice should be broad-spectrum in nature to effectively eliminate a wide range of pathogens and prevent transmission through direct or indirect contact.[20] It must also be effective against biofilm-producing microorganisms and contribute to reducing cross-contamination by adequately managing most, if not all, areas of contamination. Manual disinfection methods, although widely used, are often time-consuming and may not reach all contaminated areas – particularly hard-to-reach surfaces or those that are difficult to clean – resulting in incomplete coverage and allowing pathogens to persist on surfaces within the dental clinic.[24] Furthermore, manual disinfection relies heavily on human consistency and is therefore prone to variability.[18]

Dental clinics comprise a wide range of materials, equipment, instruments, and environmental surfaces, all of which can retain bacteria, viruses, and fungi, serving as reservoirs for microbial contamination.[1,25] The challenge, therefore, lies in selecting a disinfectant that is compatible with these diverse surfaces, does not degrade materials, and is environmentally safe while posing no harm to staff or patients. It is essential that the disinfectant of choice prevents damage to equipment and materials and does not compromise their functionality or longevity.[12]

Resistance to Disinfectants and Biofilm Formation

One of the most current challenges faced by the dental fraternity is the development of resistance to existing disinfectants which is often as a result of noncompliance with infection control protocol.[27] Pathogens, like *E. faecalis* and

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C. albicans, can develop resistance to certain disinfectants, reducing their effectiveness. Furthermore, biofilms formed by these organisms can inhibit disinfection efforts. This trend is increasing the risk of nosocomial infection amongst dental staff and patients and poses a significant threat.

Sterilisation and Disinfection Methods

The CDC has proposed guidelines and protocols for disinfection of environmental surfaces in order to combat the development of antimicrobial resistance.[28] In order to prevent or hinder the transmission of infectious diseases, strategies that aid in the reduction or elimination of microorganisms including bacterial spores should be selected based on the needs of the dental clinic. The strategies can be categorised as either sterilisation or disinfection. Sterilisation and disinfectants are fundamental processes in dentistry to prevent the transmission of infectious diseases.[23]

The aim of sterilisation involves the complete elimination or deactivation of microorganisms, resilient bacterial spores. The sterilisation process is closely associated with disinfection.[1] Disinfection is an essential part of the infection control protocol in a dental clinic. The aim of the disinfection process is to completely eliminate trace of all microorganisms but there is a possibility that some may survive the disinfection process.[1,23] Disinfection is divided into high, intermediate and low-level disinfection and is used depending on the item and its level of contamination.[29]

There are various methods of disinfection namely mechanical, and chemical. Mechanical disinfection involves physical actions such as wiping, scrubbing, and removal of organic matter. This process is typically the first step before the application of a chemical disinfectant.[30] Chemical disinfection uses chemical agents to eliminate or inactivate microorganisms. Lastly physical disinfection uses agents to disinfect surfaces or equipment namely: ultraviolet germicidal irradiation (UVGI) and moist heat sterilisation.[29] The end result of the aforementioned methods is to eliminate or reduce the number of microorganisms on instruments, equipment, and environmental surfaces.

However chemical-based disinfectants can have an environmental impact as well due to harmful residues or toxic by-products.[24] This consequently will impact the safety of the dental team and patients, as well as a long-term environmental fallout. Lastly, traditional disinfection methods might require special disposal methods for certain chemicals, which aids to the intricacy of bio decontamination techniques.[1]

Compliance and Human Factors

Adherence to infection control guidelines can be challenging due to several factors. Members of the dental team often work in high-pressure environments with limited time, which may result in inadequate disinfection.[11] This can be as a result of noncompliance, negligence, or inadequate training. The dental clinic has equipment and materials with various compositions and often have areas that are hard to reach that influences the complete removal of pathogens. In light of these challenges an alternative disinfection technique like the use of vapor provides an effective alternative.[31]

Alternative Approaches: Vapor-Based Disinfection

Advancements in technology have developed infection-control techniques which include equipment and surfaces that have materials within it which enhance infection control measures in dental practices. Despite the advancements in the field of infection control, the ideal disinfection and technique that meet all requirements has not been developed.[31]

The manual spray-wipe-spray-wipe surface disinfectants can be used in various concentrations for a variety of surfaces in the dental practice.[24] Due to the configuration of the dental practice with many inanimate items and surfaces, the need for an all-room disinfection protocol that is not reliant on the dental staff member completing the tasks.[31] The use of a vaporiser will be able to reach multiple surfaces that rarely get disinfected in the treatment room and could possibly lead to cross contamination.[1]

A vaporiser or fogger offers a practical and efficient solution for disinfecting dental clinics, especially in areas that are hard to reach through manual cleaning methods. These devices can disperse disinfectant solutions as aerosols or steam, and in doing so disinfect the majority of the surfaces and equipment.[24] The non-touch bio-decontamination have been successfully implemented to decontaminate enclosed areas, like incubators, medicine trolleys, laboratory cabinets, operating rooms, isolation room, general medical wards, and intensive care units.[24,31]

The development of a vaporised disinfection technique offers several benefits for infection control in the dental clinics.4 It provides an automated, fast acting, comprehensive coverage in a shorter period of time that can impact both air and surfaces and in doing so reduces the risk of contamination.[24] It reduces the impact of human error by providing uniform disinfection across all surfaces and is less reliant on manual methods and reduces the workload of the dental team members. This method of infection control allows for adaptability, which is advantageous especially in light of the recent COVID 19 pandemic.[1,11]

There is a need for advancement of technology that can use various products quickly, efficiently, and is cost effective. A collaboration between dental health care workers and researchers will positively influence disinfection protocols that addresses the growing concern of the development of microbial resistance and the other challenges faced by the dental team.[32] vaporised disinfection provides an alternative that can penetrate biofilms and effectively inactivate resistant pathogens. This can possibly overcome the resistance issues associated with traditional disinfection methods.[32] Vaporised disinfection devices often use less harmful chemicals and minimise residues, reducing the environmental impact.[24] This makes it a safer option for disinfection within a dental clinic and the environment. Vaporising devices is a possible disinfection solution by providing automated, consistent, and comprehensive decontamination, the challenges associated with traditional methods.[18]

Vaporising devices

The vaporisation of the active ingredient into a vapour or fog is termed a vapour generator or a fogger in the medical / hospital health care industry. A vaporising unit has a generator that uses a four-stage cycle: conditioning, gassing, gas dwell and aeration.[24] During the conditioning phase, the air from the cabinet is passed through the generator where moisture is removed reducing the relative humidity of the air returned to the.[20] A chemical like liquid hydrogen peroxide is then vaporised and injected into the cabinet during the gassing phase and allowed to form micro-condensation on the surfaces, and this is then held in the chamber for the duration of the gas dwell phase.[24,33] The dwelling phase is the time that the gaseous vapour is allowed to be suspended in the room air before removal with the aeration phase.[31] Studies have reported the efficacy of vaporised hydrogen peroxide (VHP) and vaporised hypochlorous acid as the active ingredient in non-touch bio decontamination units.[4]

The review study by Ahmed & Mulder (2021) highlighted that dental environments are prone to contamination risks, and VHP's effectiveness suggests its potential as a valuable decontamination tool achieving significant pathogen reduction, including bacteria, fungi, and viruses. Falaise et al. reported that VHP is highly effective in decontaminating a range of hazardous microorganisms, including bacterial spores, HG3 bacteria, and viruses like SARS-CoV-2.[35] It is deemed a safer alternative to formaldehyde fumigation since it leaves no harmful residues and requiring no post-process neutralisation. Mickelson et al. (2019) tested low-concentration VHP (3% hydrogen peroxide) over a long duration and reported effective decontamination of Bacillus anthracis spores. Mead et al. (2022), demonstrated effective decontamination of N95 filtering respirators with VHP, providing a low-cost alternative for PPE decontamination.[36,37] The disadvantage of VHP is the potential oxidative damage to certain materials and might require careful laboratory preparation to mitigate risks. Overall, these studies demonstrate that VHP decontamination is a viable solution for achieving effective decontamination in various settings. However, there are limitations and challenges, such as potential material damage, and the need for accurate sensor calibration. These findings suggest that while VHP is effective, careful planning, standardization, and safety protocols are necessary to ensure optimal results.[4]

HOCl is emerging as an alternative disinfectant in a dental clinic due to its effectiveness against a range of pathogens and safety profile when used according to the manufacturer's instructions. Guan et al. (2022) reported that HOCl can reduce viral transmission in dental practices. HOCl at 100 ppm effectively destroys aerosolized viruses, like SARS-CoV-2 and HSV1, within 30 seconds, and provides an alternative for reducing infection risks in dental settings.[38] Boecker et al. (2021) reported that aerosolized HOCl can deactivate various microbial contaminants at safe concentrations, making it a useful method for controlling airborne contamination, especially in public indoor spaces.[39] Mehendale et al. (2023), emphasises the importance of safely using chlorine- based disinfectants.[40] It distinguishes between hypochlorous acid (HOCl) and other chlorine-based solutions. HOCl is a safe alternative for clinical applications, while hypochlorite (OCl-) is more suitable for surface disinfection. The study highlights the dangers of mixing chlorine-based solutions with other chemicals and calls for proper storage, handling, and safety protocols to prevent hazardous outcomes.[38-40]

Safety Considerations and Guidelines – Vaporising device
Staff should be trained on how to use disinfectants, including vaporised forms. It is important to label all disinfectants clearly, indicating the chemical composition and safety warnings.[24] It is essential to follow the manufacturer's instructions and to adhere to Occupational Safety and Health Administration (OSHA) guidelines and Environmental Protection Agency (EPA) standards, along with local and national health department requirements.[11] Inhalation of high concentrations of disinfectant fumes or being exposed for extended periods can cause respiratory irritation, eye discomfort, and other adverse effects. The use of PPE during disinfection, especially when vaporised chemicals are used, is recommended.30 In order to mitigate these risks, ensure sufficient ventilation is in place with appropriate filtration systems, like HEPA filters, to maintain air quality.1,24

CONCLUSION

The growing concern of microbial resistance to disinfectants, often stemming from noncompliance with infection control protocols, underscores the critical need for strict adherence to recommended guidelines. Ensuring consistent and proper use of disinfectants is essential to prevent resistance and maintain the efficacy of disinfection practices. Moreover, the selection of disinfectants must also consider environmental safety and sustainability, aligning with the broader goal of minimising the ecological impact in healthcare settings. Balancing effectiveness with environmental responsibility is key to fostering a safer and more sustainable approach to infection control.

Modern disinfection techniques offer significant benefits in enhancing infection control within dental settings, providing more efficient, effective, and targeted solutions to reduce microbial load and prevent cross-contamination. By embracing these advanced methods, dental practitioners can ensure a safer environment for both patients and staff. It is crucial for dental professionals to consider upgrading their disinfection practices to leverage the full potential of these innovations, ultimately leading to improved patient outcomes and a higher standard of care.

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CPD questionnaire on page 52

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.