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Effectiveness of Gaseous Ozone as a Disinfectant for Nosocomial Pathogens

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Abstract

Introduction: Ozone is a potent oxidizing agent and is characterized as a highly rapid and effective microbicide. This review is aimed to discuss ozone administration and disinfection strategies in both air and surface applications.

Methods: A literature review is one of the methods used in evidence-based practice that includes the analysis of studies relevant for decision-making and improving care practices. A literature search was conducted through October 2022 without restrictions concerning language or period of publication in the following databases: MEDLINE, SCOPUS, and COCHRANE, using the descriptors ozone and sterilization from the Medical Subject Headings Section (MeSH). Only primary studies addressing the use of O3 as a sterilizing agent for health products were included. These were selected by the title and abstract and only those that met the inclusion criteria were fully read. Papers identified in more than one database were analyzed only once.

Results: Recent studies have also demonstrated equal efficacy of ozone treatments of samples in a wet and dry state. Continual monitoring of the ozone concentration in the operator area confirmed that no ozone toxicity. Given the urgent need for new processing methods and the continuous development of new technology added to the large diversity of shapes and raw materials, the O3 gas is, according to the analyses, a promising method. In order to quickly reduce the ozone level to the safe level for humans working in the room after ozonation, an amount of fresh air is added to the room through a filter as substitutes for the highly ozonated air.

Conclusions: Ozone is considered to be an environment-friendly disinfectant that leaves no residual or by-products after the disinfecting process. Ozone with concentration higher than 1 ppm has adverse effects on human health and the use of ozone for air disinfections generally is not recommended if people are around. Nonetheless, further research of an experimental nature is required to gather evidence concerning its possibilities and limitations.

Keywords: Ozone, Disinfection, Germicide, Hospital, Viruses

Introduction

Ozone has gained hype in the world of disinfection/sanitization technologies due to its outstanding ability to inactivate all kinds of microorganisms in liquid, air, and dry phases. Being strong oxidizing and diffusible, the microbicidal application of ozone has been utilized in water treatment, food and agriculture, and healthcare [1, 2]. Although water disinfection is considered as the cradle of ozonation, coronavirus inactivation by ozone has voiced after it had been successfully used against SARS-CoV-1 and theoretically demonstrated as a potential solution against SARS-CoV-2. Ozone can damage the lipid membrane, capsid protein, and genome of the virus through oxidation, thereby disrupting its infection mechanism. Ozone, a potent virucide, is inexpensive, feasible to administer due to its gaseous nature, and is easy to produce, requiring only an electrical generator and air. Though, recently an appreciable volume of work aiming to combat COVID-19 spread by utilizing ozone has started to emerge [3].

Ozone is a potent oxidizing agent and is characterized as a highly rapid and effective microbicide. Thus ozone has been extensively used globally to disinfect drinking water, wastewater, air, agriculture processing, laundry, and healthcare, as well as enclosed spaces [4]. Amongst microorganisms, ozone is particularly proven to be extremely effective against viruses and bacteria as it inactivates them via oxidation of unsaturated aliphatic and aromatic units [5]. Viruses are unable to repair the oxidative damages and hence are highly susceptible to ozone than bacteria, fungi, and spores as reported by several groups of researchers concluding the order of microbial vulnerability to ozone, particularly virus and bacteria and to a lesser extent yeast and spores [5]. Viral inactivation as peroxidation of its constituents can take place either is through direct reaction of molecular ozone with the virus or indirectly through the reaction of a variety of primary reactive oxygen radicals (ROS), produced as a result of ozone decomposition in air or water medium, with viral components [6]. To illustrate the effect of ozone gas concentration (CAG) on the disinfection efficiency, the time required for attaining >99% inactivation at RH60-70% was measured. Similar viral disinfection results in various directions on the studied surfaces such as top, interior, sides, and bottom, revealing effective penetration of ozone gas and its efficacy over liquid disinfectants. More than 4-log inactivation was achieved against both viral strains regardless of surface material type within 60 min at 80 ppm ozone gas exposure [7]. The structure of coronavirus' envelop, as described in Supplementary Information (SI-1), is rich in amino acids and lipids, both of them being highly susceptible to ozone attack, make the virus vulnerable to ozonation.

Ozone oxidizes the thiol groups (R-S-H) in cysteine units of its spike protein to R-S-S-R which makes spike proteins incapable of binding to the host ACE2 receptors and henceforth penetrate it. It have been also postulated that the inactivation of SARS-CoV-2 by ozone proceeds through a mechanism targeting the structure of the virus rather than its genome (0.6 mg/L ozone in water, 1 min exposure time) [8]. For this, the authors assumed in this study that the local intrinsic ozone concentration (q A) is proportional to the ozone gas concentration in air surrounding the virus medium (C AG). In addition, upon drying, substances such as inorganic salts crystallize which may occlude the virus thereby preventing ozone attack. Although these variables are significant, studies on their effects on ozone disinfection of SARS-CoV-2 and other viruses in general are lacking. SARS-CoV-2 inactivation was investigated in more details by , on its surrogate

Influenza Virus A (RSV), by finding the effects of RH, temperature, and ozone dose on inactivation efficacy. Another study on a SARS-CoV-2 surrogate (Human Coronavirus HCoV-229E) led by , confirmed total viral inactivation within 1 min by exposure of 120 ppm gaseous ozone (i.e. Another group tested the virucidal activity of ozone-based dry-sanitizing device (FATHHOME's) against inactivation of human coronavirus (HCoV-OC43), model of SARS-CoV-2 on N95 facepiece filter respirators (FRR) and a glass surface [8]. The presence of water in the virus sample during ozone disinfection facilitates ozone mass transfer and consequently increases the effective ozone concentration in contact with the virus as opposed to a dried sample [9].

The preference of ozone reactivity toward lipids renders enveloped viruses to be least resistant to ozonation compared to non-enveloped viruses as confirmed by experimental findings of work on a comparative study of ozone inactivation of bacteriophage viruses T MS2, uX174, and u6 (surrogate of Norovirus Adenovirus Human Immunodeficiency virus HIV, and Influenza). Several studies have reported that ozone impairs the binding ability of virus to the host through oxidation of their lipid envelop and/or protein capsid constituents, thus, the damaged virus ultimately turns inactivated due to lack of self-healing mechanism like living-cells [10, 11]. Similar findings of ozone-mediated viral denaturation and oxidation of its constituents have been confirmed for coronaviruses (SARS-CoV-1/SARS-CoV-2) [12]. This review is aimed to discuss ozone administration and disinfection strategies in both air and surface applications and highlighted gaps and suggest correlations useful for a growing research and application fields.

Methods

A literature review is one of the methods used in evidence-based practice that includes the analysis of studies relevant for decision-making and improving care practices. It enables the synthesis of knowledge acquired on a given subject and indicates gaps that need to be filled in with further research. A literature search was conducted through October 2022 without restrictions concerning language or period of publication in the following databases: MEDLINE, SCOPUS, and COCHRANE, databases using the descriptors ozone and sterilization from the Medical Subject Headings Section (MeSH). Only primary studies addressing the use of O3 as a sterilizing agent for health products were included. These were selected by the title and abstract and only those that met the inclusion criteria were fully read. Papers identified in more than one database were analyzed only once. The included studies were classified according to the identification of the publication (author(s), title, periodical, year, country of origin, language) and data from the experiment concerning: scope, type of study, methodological procedures, results, considerations of this review, conflicts of interest, and score concerning quality of methodological rigor.

Results and discussion

In this review, ozone (O3) is presented in the triatomic form of oxygen (O3) and has been used as a chemical element to control microorganisms in various segments of the health sector, particularly in hospital waste treatment, pre-treatment of dental cavities, disinfection of hemodialysis machines and disinfection of operating rooms, among others. In the food sector, the sanitization process has been structured by ozone generators, resulting in adequate environments for cheese ripening processes. In terms of antimicrobial action O 3 acts in the oxidation of glycopeptides, glycoproteins and amino acids of the cell wall, modifying permeability and causing cell lysis. Although ozone has been widely used in food and industrial sterilization protocols, it has only recently been implemented in healthcare disinfection protocols and studies. The activity of ozone against bacteria, fungi, and viruses has been widely documented [4].

In a gaseous phase, ozone has a half-life of approximately 20 min, which has restricted some previous applications to low-concentration exposures over prolonged periods, with limited efficacy [13]. However, ozone has been applied to the cleaning of hospital laundry[14], and a recent study demonstrated resolution of persistent methicillin-resistant Staphylococcus aureus carriage in a nurse following ozone decontamination of her home [15]. Gaseous ozone at relatively high concentrations (25 ppm) has also been used to inactivate norovirus and bacteria in office and hotel room environments with the ozone being removed using a scrubber system [1]. in the United Kingdom has developed a device for disinfection of food preparation areas using gaseous ozone. The approach includes the addition of a quench gas at the end of a treatment cycle to rapidly reduce ozone concentrations to safe levels, thus removing the protracted decomposition periods that have compromised development of ozone disinfection processes in the past. In support of this, recent studies have also demonstrated equal efficacy of ozone treatments of samples in a wet and dry state [16]. Continual monitoring of the ozone concentration in the operator area confirmed that no ozone escaped from the test area. Escherichia coli appeared to be the most susceptible organism, with the greatest decrease seen when using 15 ppm ozone for 30 min [17]. It indicates that many conditions gave a greater than 3 log reduction for this organism.

The effect of changing ozone concentrations, with increasing concentrations leading to generally greater treatment effects. This can be seen to be statistically significant when site 5 is used as an example: with a fixed 30 min treatment time, significant differences in treatment effects were seen at different concentrations of ozone (10 and 20 ppm) for both E. coli and S. aureus. Exposure of organisms to increased humidity followed by quench gas (i.e., no ozone treatment) gave counts that did not vary significantly from those on the control plates [18]. An experiment was done to determine the optimal ozone concentration that causes significant reduction of the K. pneumoniae biofilm. Ozone has proven antimicrobial properties, but there is lack of scientific data on its effect on the K. pneumoniae biofilm; therefore, the aim of this study was to investigate the antimicrobial effect and mechanism of action of gaseous ozone on the K. pneumoniae biofilm [19]. During the determination of the optimal ozone concentration, the tested K. pneumoniae strains Kp NCTC 13442 and Kp ATCC700603 showed a slow progression in biofilm reduction after the ozone dosage increased. The minimum effective dose of gaseous ozone was determined at 25 ppm, with a statistically significant difference in comparison to the control and a 99% inhibition rate [20]. Interestingly, after 25 ppm of the ozone concentration, the increase in dose did not cause any further biofilm reduction. Moreover, during the two-hour exposure time, the biofilm reduction with different concentrations of gaseous ozone (25, 50 and 75 ppm) remained similar to the reduction obtained during the one-hour exposure [20].

The effect of increasing ozone concentrations on bacterial kill by exposing the MRSA strain to ozone was investigated in increasing concentrations without hydrogen peroxide at 80% humidity for 90 minutes. The ozone hydrogen peroxide vapor system provides a very high level of disinfection of steel and gauze surfaces against health care-associated bacterial pathogens. The system is an advanced oxidative process providing a rapid and effective means of disinfecting health care surfaces and spaces [21]. In the context of the COVID-19 pandemic, air and space disinfection with ozone has grown significantly in the last two years. Recent studies have confirmed the effectiveness of ozone against covid-19 virus; a concentration in the range of 1-25 ppm and contact times lying between 10 minutes and 3 hours are able to inactivate different types of viruses at room temperature and medium relative humidity [22]. The ozone generators in the market are mainly used for disinfection in different spaces, such as hospital rooms and in the food industry [23]. However, since ozone is toxic and a potent oxidizer that corrodes metals, it has not been widely investigated in the hospital environment. An exposure limit over 15 min has been set at 0.2 ppm at which concentration some people can still experience respiratory symptoms, but at which concentration, ozone has limited microbicidal efficacy. A few studies have investigated the potential for ozone as a gaseous decontaminant for the reduction of environmental C. difficile, with mixed results. At humidity of >80%, ozone will attack and degrade rubber and therefore compatibility with local materials should be considered [24].

Conclusions

Ozone is considered to be an environment-friendly disinfectant that leaves no residual or by-products after the disinfecting process. Ozone with concentration higher than 1 ppm has adverse effects on human health and the use of ozone for air disinfections generally is not recommended if people are around. In order to quickly reduce the ozone level to the safe level for humans working in the room after ozonation, an amount of fresh air is added to the room through a filter as substitutes for the highly ozonated air. Given the urgent need for new processing methods and the continuous development of new technology added to the large diversity of shapes and raw materials, the O3 gas is, according to the analyses, a promising method. Nonetheless, further research of an experimental nature is required to gather evidence concerning its possibilities and limitations.

Conflict of interests

The authors declared no conflict of interests.

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