Archives of Current Research International

Volume 25, Issue 4, Page 132-143, 2025; Article no.ACRI.132831
ISSN: 2454-7077

Ozone's Antimicrobial Potential: A Review Article

Matéus Simplício Araújo [a*], Yann Nobre Viana [a], Joelson Pessoa Dantas [a], Antônio Evandro de Sousa Silva [a], Guilherme Salles Ottoboni [a], Poliana Lima Bastos [a] and Francisco César Barroso Barbosa [a]

[a] Dentistry Course at the Federal University of Ceará - Sobral Campus, Brazil.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/acri/2025/v25i41143

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/132831

Review Article

Received: 17/01/2025
Accepted: 21/03/2025
Published: 26/03/2025

ABSTRACT

Objective: The importance of investigating new products with antimicrobial activity (AA) is based on the constant increase in the frequency of reports of antimicrobial resistance that hinder the treatment of human infections. This integrative literature review aimed to investigate the potential antimicrobial activity (AA) of O3 and elucidate its importance in the context of the need for bioprospecting of new antimicrobial agents.
Methodology: For this purpose, a search for articles published between July 2014 and July 2024 was carried out in the PubMed, Scielo and Cocharne databases. Four keywords were established and verified on the DeCs - Health Sciences Descriptors website, namely "ozone", "antimicrobial

**Corresponding author: Email: mateusodonto90@alu.ufc.br, mahttewss21@gmail.com;*

Cite as: *Araújo, Matéus Simplício, Yann Nobre Viana, Joelson Pessoa Dantas, Antônio Evandro de Sousa Silva, Guilherme Salles Ottoboni, Poliana Lima Bastos, and Francisco César Barroso Barbosa. 2025. "Ozone's Antimicrobial Potential: A Review Article". Archives of Current Research International 25 (4):132-43. https://doi.org/10.9734/acri/2025/v25i41143.*

activity", "antibacterial" and "antifungal". The search and critical reading of studies related to the AA of ozone in 3 databases led to the inclusion of 11 articles.
Results: ozone is a molecule that indeed has antimicrobial potential and its use occurs in different physical forms, such as the application of ozone in gas, in aqueous form, in oily vehicles or even in nanoparticles.
Discussion: It was observed that there is a need for more clinical studies and animal models to evaluate the applicability of O3 in infectious conditions in vivo, such as dentoalveolar abscesses, skin infections and respiratory and digestive tract infections, since the vast majority of articles found belonged to laboratory-based in vitro assays.
Conclusion: Ozone has a wide AA, therefore representing an important product for bioprospecting in the context of antimicrobial agents. The need for more clinical studies is highlighted.

Keywords: Ozone; antimicrobial activity; anti-bacterial; antifungal.

1. INTRODUCTION

The evolution of drug resistance mechanisms by bacteria and fungi is one of the best documented processes in the scientific community, as its consequences affect both developed and developing countries. This scenario leads to a major problem due to the pharmaceutical industry's constant need to develop new drugs that can be used effectively to treat fungal and bacterial infections in humans. Some research already points to serious prospects regarding the effectiveness of antibiotics, given that the frequency of antimicrobial resistance (AR) genes increases every year (IDSA, 2011). In addition, the incidence of fungal infections has increased in recent decades (Cambium, 2005).

Currently, Antimicrobial Resistance (AMR) is considered one of the biggest problems for global public health. It is estimated that approximately four million people acquire healthcare-associated infections every year in the European Union. European Union (EU), and that around 37,000 people die as a result of resistant infections acquired in hospital environments. The majority of these deaths (67.6%) are caused by bacteria that are multi-resistant to antibiotics (European Center for Disease Prevention and Control, 2020).

Thus, given the need to obtain more drugs with antimicrobial properties, new molecules are being studied with the aim of promoting the bioprospecting of new products with the prospect of clinical application in the treatment of infections (O'Neill, 2016). In this scenario, ozone stands out for its ability to suppress the growth of pathogens, since it is already known that ozonated vegetable oils have antibacterial activity, with studies proving their effectiveness against gram-positive (Sechi et al., 2001, Silva et al., 2021) (2024) pointed out the efficacy of applying ozonized sunflower oil against *Candida albicans* (Araújo et al., 2024).

The literature describes that ozone is generally used with a vehicle. This substance carries the ozone molecules and helps maintain its useful life, giving it its properties. Among the vehicles used, vegetable oils such as sunflower (Araújo et al., 2024) and olive (Khachatryan et al., 2022) stand out. The process of adding O3 to these compounds, ozonation, occurs in the unsaturation of the hydrocarbon chains present in the oil, leading mainly to the formation of cyclic ozonated species (Díaz et al., 2012). The ozonolysis mechanism is called the Criegee oxidation reaction, in which ozone reacts chemically on an unsaturated bond to form an unstable initial primary ozonide. It is then rapidly decomposed into carbonyl fragments that can combine to generate cyclic trioxolane compounds in anhydrous environments (Criegee, 1975). From this reaction, ozonides, hydroperoxides, aldehydes, peroxides, diperoxides and polyperoxides are produced, promoting antibacterial, fungicidal and antiviral properties of ozonated oils, which can therefore be applied in the cosmetic and pharmaceutical areas (Cirlini et al., 2012). After the ozonation process, vegetable oils undergo a drastic change in chemical composition, leading to alterations in their physical appearance, with a slight change in taste and smell and an increase in viscosity (Jacinto et al., 2023).

Ozone (O3) is a highly reactive molecule made up of three oxygen atoms that act as oxidizers (Jorge and Gonçalves, 1998). When bacteria are exposed to ozone in vitro, the phospholipids and lipoproteins of the bacterial cell envelope are oxidized. This mechanism disrupts the integrity of the cytosolic membrane, causing ozone to

infiltrate the microorganisms and oxidize glycoproteins and glycolipids, blocking enzymatic function. In addition, evidence has shown that ozone interacts with the cell walls of fungi as well as bacteria (Piola, 2022, Elvis and Ekta, 2011). Another interesting aspect related to the use of ozonides in the field of medical sciences is the absence of cytotoxicity, since in cell culture tests they showed no cytotoxic effect on fibroblasts or keratinocytes and induced fibroblast migration, which could help in the wound healing process (de Moraes and Teixeira, 2022).

In this context, this work aimed to analyze the antimicrobial activity of ozone in its different applications, formulations and vehicles, as well as to elucidate whether there are reports of antimicrobial resistance associated with this agent. Therefore, the analysis of the data presented in this study is of great importance because it reflects a possibility for the future application of ozone in human infections, especially in infections caused by resistant bacteria.

2. METHODOLOGY

After establishing the research's focal question, this integrative literature review was conducted by searching for articles in the PubMed, Scielo and Cocharne databases, published from July 2014 to July 2024 in the PubMed, Scielo and Cocharne databases. Four keywords, “ozone”, “antimicrobial activity”, “antibacterial” and “antifungal”, were established and verified on the DeCs website - Health Sciences Descriptors.

2.1 Criteria for Considering Studies for this Analysis

The selection of articles for analysis in this review was based primarily on the inclusion of articles that evaluated the AA of ozone using a well-described method, including any formulation, vehicle substance or physical state of the molecule (gaseous or aqueous). Only articles published in the last 10 years were selected, with no language restrictions.

2.1.1 Types of studies and inclusion criteria

To include studies that answered and met the focal question, the inclusion of studies that belonged to the following methodological delimitations was delimited.

(i)- *In vitro* studies
(ii)- Animal studies
(iii)- Clinical trials
(iv)- Cohort studies

2.1.2 Exclusion criteria

Studies that did not involve quantitative and qualitative analysis of the AA of ozonated compounds, studies without full text or that did not clearly describe the method or the microbial species studied, and literature reviews were also excluded. No exclusion criteria were applied to the type of microorganism with which the tests were carried out.

2.2 Data Collection, Extraction and Management

After critically reading the titles and abstracts, articles that met the inclusion criteria were downloaded to read the full text. At the end of this stage, 27 articles were obtained, as described in Table 1 and Fig. 1. In addition to the exclusion criteria already mentioned, duplicate studies were excluded, so this literature review was carried out using 11 articles. Fig. 1 shows how many articles were selected.

3. RESULTS

The process of data management, study selection, inclusion and exclusion of studies is described and illustrated in Fig. 1. The search and critical reading of studies related to ozone AA in 3 databases led to the inclusion of 11 articles, the main results of which are described in Table 1. Of this amount, most studies dealt with *in vitro* laboratory tests, and there was a lack of clinical trials and cohort studies.

4. DISCUSSION

The analysis of 11 articles included in this integrative review led to the conclusion that ozone is a molecule that does indeed have antimicrobial potential. Its application and use takes place in different physical forms, such as the application of ozone in gas (Shu et al., 2021, Piletić et al., 2022, Rangel et al., 2022) aqueous (Britton et al., 2019, Sabancı et al., 2022, Takizawa et al., 2023). or even in nanoparticles (Khachatryan et al., 2022, Lenart-Boroń et al., 2024), as well as in oily vehicles (Salaie et al., 2024, Donato et al., 2024). However, there is a need for more clinical and animal model studies to assess the applicability of O3 in infectious conditions in vivo, such as dento-alveolar abscesses, skin infections and infections of the

respiratory and digestive tracts, since the vast majority of the articles found were laboratory-based *in vitro* tests. Broth microdilution and agar diffusion tests were the most frequently used to assess the antimicrobial activity of O3.

It was found that the application of gaseous ozone was effective in reducing standard strains of *S. aureus, S. enterica, E. coli* and *P. aeruginosa* and was also able to reduce the cell viability of some clinical strains isolated from healthcare-related infections (HAIs), such as *S. aureus* methicillin-resistant (MRSA), *K. pneumoniae* carbapenase-producing (KPC+), *A. baumannii* PDR carrying the bla OXA gene. aureus (MRSA), carbapenemase-producing *K. pneumoniae* (KPC+), *A. baumannii* PDR carrying the bla OXA-23 gene and an environmental strain of *P. aeruginosa* (XDR) from hospital effluent (Rangel et al., 2022). This finding is clinically relevant, as it offers good prospects for the application of this compound in cases of infections caused by microorganisms resistant to the antibiotics commonly used to treat HAIs, given the growing global problem of AMR (IDSA, 2011). Other studies have also shown similar results with the application of gaseous O3 in *in vitro* tests, with an effective reduction in standard strains of K. pneumoniae ATCC 700603 and clinical isolates of K. pneumoniae producing OXA-48 (Piletić et al., 2022). Shu et al. (2022) investigated and proved the efficacy of ozone gas against *E. coli* and *L. monocytogenes*, highlighting that its effect is dose-time-dependent, making it a viable alternative for disinfecting foodstuffs such as tomatoes (Shu et al., 2021). Even so, it is important to highlight the antifungal activity of the gas, which showed a 99.9% reduction in viable C. albicans cells (Donato et al., 2024).

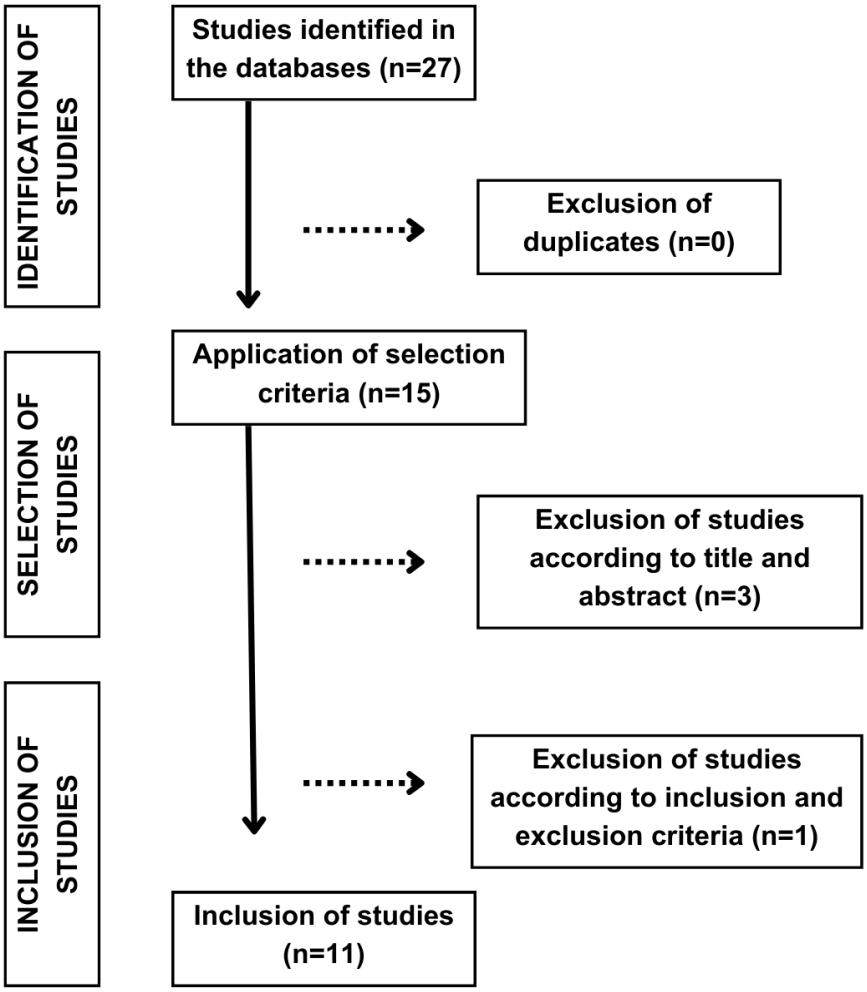

Fig. 1. Illustration of the methodology for managing, selecting and including studies in the work

Table 1. Synthesis matrix used in this integrative review

Reference	Study design	O3 formulation/use vehicle	Microorganism (s) studied	Method for evaluating O3 AA	Results
Britton et al., (2019)	Laboratory study and *in vitro* test	The antimicrobial effects of aqueous ozone were studied in combination with short-chain fatty acids (SCFA) of acetate, propionate or butyrate, as well as citrate or oxalate buffer formulations	*Salmonella enterica* and *Klebsiella pneumoniae*	Agar diffusion method	All buffer systems tested had a significantly greater reduction in CFUs after treatment with the combination of buffer and ozone, compared to treatment with buffer or ozone alone, which has not previously been reported for hard surfaces
Shu et al., (2021)	Laboratory study and *in vitro* test	Ozone gas	*Escherichia coli* and *Listeria monocytogenes*	Bacterial growth assay (log CFU/g) was determined by comparing O3-treated samples with the control according to standard procedures. The reduction in the viable cell count was calculated as the log change in the bacterial population expressed as log UFC/g recovered from tomato fruit treated with O3 compared to that recovered from the untreated control	For *E. coli*, low (1 µg O3 /g fruit) and moderate (2 µg O3 /g fruit) doses caused an insignificant reduction in survival, while high doses (3 µg/g fruit) caused a significant reduction in survival in a time-dependent manner. For *L. monocytogenes*, a moderate dose caused a significant reduction even with short-term exposure. Distinct responses to O3 xenobiosis between *E. coli* and *L. monocytogenes* are probably related to differences in the

Reference	Study design	O3 formulation/use vehicle	Microorganism (s) studied	Method for evaluating O3 AA	Results
					structure and components of the cytoplasmic membrane
Sabanci et al., (2022)	Laboratory study and *in vitro* test	Liposomal solution loaded with ozonized hyaluronic acid with nanobubbles (NAHAL)	*Staphylococcus aureus* (ATCC 6538), *Streptococcus pneumoniae* (ATCC 49619) and *E. coli* (ATCC 25922)	Broth microdilution assay	Bacterial growth was inhibited by the NAHAL solution in a time/dose dependent manner
Piletić et al., (2022)	Laboratory study and *in vitro* test	Ozone gas	Standard strains of *K. pneumoniae* ATCC 700603 and *K. pneumoniae* NCTC 13442. Clinical isolates of *K. pneumoniae* producers of OXA-48	Bactericidal activity was analyzed using methods for quantifying mature biofilm.	Total biomass reduction was observed for all *K. pneumoniae* strains tested after treatment with 25 ppm ozone for 1 h of exposure. The reduction was statistically significant compared to the control group for all *K. pneumoniae* strains tested ($p < 0.05$)
Rangel et al., (2022)	Laboratory study and *in vitro* test	Ozone gas	Standard strains *S. aureus* (ATCC 6538), *Salmonella enterica* (ATCC 10708), *E. coli* (ATCC 25922) and *Pseudomonas aeruginosa* (ATCC 15442). Four clinical strains isolated from IRAS: *S. aureus* resistente à meticilina (MRSA), *K.*	Bacterial inactivation (growth and cultivability) was investigated using colony counts and resazurin as metabolic indicators. Scanning electron microscopy (SEM) was performed	Exposure of the culture to a high level of O3 inhibited the growth of all bacterial strains tested with a statistically significant reduction in colony count compared to the control group. The cell viability of *S. aureus* (MRSA) (99.6%) and *P.*

Reference	Study design	O3 formulation/use vehicle	Microorganism (s) studied	Method for evaluating O3 AA	Results
			pneumoniae producer of carbapenemase (KPC+), *Acinetobacter baumannii* PDR gene carrier *bla* OXA-3 and an environmental strain of *P. aeruginosa* (XDR) of hospital effluent		*aeruginosa* (XDR) (29.2%) was considerably reduced, and SEM showed damage to the bacteria after treatment with O3
Khachatryan et al., (2022)	Laboratory study and *in vitro* test	Hydrogel based on hyaluronic acid containing ozonized olive oil micro/nanocapsules	*Candida albicans*	Broth microdilution assay	The Hyal/O3 leaves examined exhibited a very weak inhibitory effect against the commensal bacterial microbiota of the skin and pathogenic yeasts
Takizawa et al., (2023)	Laboratory study and *in vitro* test	Ozone ultra fine bubble water (OUFBW)	*S. pneumoniae* susceptible and resistant to antibióticos, *P. aeruginosa, Streptococcus mutans, Streptococcus sobrinus, Fusobacterium nucleatum, Prevotella intermedia and Porphyromonas gingivalis*	The bactericidal activity of OUFBW against planktonic cells was analyzed using standard plating methods.	Results indicated that OUFBW exerts a bactericidal effect instantly and non-specifically against all the bacteria studied
Salaie et al., (2024)	Laboratory study and *in vitro* test	Ozonized olive oil gel	*S. mutans* and *Granulicatella adiacens* isolated from peri-implantitis	Agar diffusion method	The results showed that ozonized olive oil applied to microbial biofilms grown on titanium implants significantly inhibited the growth of *G. adiacens*, but showed no significant effect against *S. mutans*. The same result was obtained

Reference	Study design	O3 formulation/use vehicle	Microorganism (s) studied	Method for evaluating O3 AA	Results
					when testing the antibacterial activity of ozone using the agar diffusion method.
Donato et al. (2024)	Laboratory study and *in vitro* test	Different formulations of ozone, either as a gas or dissolved in liquid matrices, specifically distilled water or oil	*E. coli, S. aureus, Streptococcus equi subsp. zooepidemicus, P. aeruginosa, K. pneumoniae and C. albicans*	Disc diffusion method, Minimum inhibitory concentrations (MICs) and minimum bactericidal/fungicidal concentrations (MBCs/MFCs) were determined by the broth dilution method according to CLSI.	The results showed a reduction in the microbial count of more than 99.9% for each pathogen. Ozonated oil showed bactericidal/fungicidal activity against all strains tested (MIC range 12.5-25% v/v, MBC/MFC range 12.5-50% v/v), while ozonated distilled water did not show an observable antimicrobial effect, discouraging its use as an antimicrobial agent
Puxeddu et al., (2024)	Laboratory study and *in vitro* test	Commercial olive oil (OOO) and sunflower seed oil (OSO) ozonized	*C. albicans, Enterococcus faecalis, S. aureus, K. pneumoniae, P. aeruginosa and E. coli*	Agar diffusion and broth dilution methods	Results revealed that both OOO and OSO showed a potent microbicidal effect, especially against C. albicans (IC50 = OOO: 0.3 mg/mL and OSO: 0.2 mg/mL) and E. faecalis (IC50 = OOO: 0.4 mg/mL and OSO: 2.8 mg/mL), while also exerting a certain effect

Reference	Study design	O3 formulation/use vehicle	Microorganism (s) studied	Method for evaluating O3 AA	Results
					against *S. aureus and E. coli*.
Lenart-Borón et al., (2024)	Laboratory study and *in vitro* test	Ozonized olive oil nano/microencapsulated in a hyaluronan matrix	*E. faecalis, S. aureus, P. aeruginosa, E. coli, Acinetobacter, Bacillus pumilus, Microbacteum maritypicum, Macrococcus luteus or Sporosarcina luteola, Aeromonas media, Citrobacter freundi, Kocuria rhizophila, Psychrobacter sanguinis*	Disk diffusion method	Nano/microencapsulated ozonated olive oil in a hyaluronan matrix was effective against a variety of bacteria, not only opportunistic and mild pathogens, but also those with a high potential for pathogenicity and resistance to antimicrobial agents, such as *Enterococcus* and *Acinetobacter*

The transport of O3 particles in oily substances, especially plant-based ones, has also been described. In this perspective, results showed that ozonized olive oil applied to microbial biofilms developed on titanium implants significantly inhibited the growth of G. adiacens, but showed no significant effect against S. mutans isolated from peri-implantitis. The same result was obtained when testing the antibacterial activity of ozone using the agar diffusion method (Salaie et al., 2024, Puxeddu et al., 2024). It is suggested that aerobic gram-positive bacteria have greater resistance to ozone, given their better tolerance to radical species of oxygenated products. (2024) investigated the applicability of ozonized commercial olive oil (OOO) and sunflower seed oil (OSO) against *C. albicans, E. faecalis, S. aureus, K. pneumoniae, P. aeruginosa* and *E. coli* and the results revealed that both OOO and OSO showed a potent microbicidal effect, especially against *C. albicans* (Donato et al., 2024). A similar result was also obtained by Araújo et al., (2024)

Studies have also reported the application of nanomolecular modifications of these compounds. Ozonated olive oil nano/microencapsulated in a hyaluronan matrix is effective against a variety of bacteria, not only opportunistic and less virulent pathogens, but also those with a high potential for pathogenicity and resistance to antimicrobial agents, such as Enterococcus and Acinetobacter (Lenart-Boroń et al., 2024). Also noteworthy in this field is the use of a liposomal solution loaded with ozonized hyaluronic acid with nanobubbles (NAHAL), developed using nanotechnology, which was able to prevent bacterial growth in a time/dose-dependent manner for *S. aureus, Streptococcus pneumoniae* and *E. coli*. (Lenart-Boroń et al., 2024).

These data show that ozone may be a future alternative in combating infections caused by the aforementioned microorganisms. Araújo et al., 2024 studied the application of ozonated sunflower oil and demonstrated the efficacy of this product against multiple strains of *c. albicans,* highlighting its future application as an antifungal for oral candidiasis (Araújo et al., 2024). This scenario becomes more fruitful when considering the absence of reports of antimicrobial resistance to this molecule in combination with its benefits, such as absence of cytotoxicity and relatively low cost (Bastos et al., 2022, Puxeddu et al., 2024). Thus, these findings allow us to infer that ozone may be an interesting alternative for application in the field of public health, highlighting the need for further studies, especially clinical trials.

5. CONCLUSION

As a result of this review, it can be concluded that ozone has a great capacity to inhibit the growth of various microbial species, such as gram-positive and gram-negative bacteria, as well as fungi. These findings have a major impact in the context of the increased occurrence of antimicrobial resistance, since the results of the articles analyzed point to the efficacy of this molecule against pathogens carrying antibiotic resistance genes. Another relevant characteristic observed about O3 is its versatility of application, varying in physical form and vehicles. This characteristic favors its clinical applicability. Thus, this article gathers and analyzes data that point to ozone's potent antimicrobial action and reinforces the need for clinical trials to evaluate its effect on pathogens in vivo and thus promote good prospects for clinical application.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENT

Thanks to the Federal University of Ceará and the O3 Extension Project.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Araújo, M. S., Prado, J. C. S., Aguiar, F. L. L. D., Silva, F. D. A., Viana, Y. N., Dantas, J. P., ... & Barbosa, F. C. B. (2024). Antifungal and antibiofilm activities of ozonated sunflower oil against *Candida albicans* strains: A pilot study and clinical perspectives. *Archives of Current Research International, 24*(5), 494–502.

Bastos, P. L., Ottoboni, G. S., Karam, A. M., Sampieri, M. B. d. S., & Araújo, E. F. D. (2022). Ozonioterapia na odontologia:

Revisão sistemática de literatura. *Research, Society and Development, 11*(4), e46711427474.

Britton, H. C., Draper, M., & Talmadge, J. E. (2019). Antimicrobial efficacy of aqueous ozone in combination with short-chain fatty acid buffers. *Infection Prevention in Practice, 2*(1), 100032. https://doi.org/10.1016/j.infpip.2019.100032

Cambium, I. I. F. N. (2005). *Fungemia in patients with Human Immunodeficiency Virus (HIV) and physiological characterization of isolated fungi* (Master's thesis, Universidade Federal de Pernambuco).

Cirlini, M., Caligiani, A., Palla, G., De Ascentiis, A., & Tortini, P. (2012). Stability studies of ozonated sunflower oil and enriched cosmetics with dedicated peroxide value determination. *Ozone: Science and Engineering, 34*(4), 293–299.

Criegee, R. (1975). Mechanism of ozonolysis. *Angewandte Chemie International Edition in English, 14*(11), 745–752.

de Moraes, C. M., & Teixeira, A. W. B. C. (2022). Ozone therapy in the healing of chronic lower limb wounds: A case series. *Global Academic Nursing Journal, 3*(2), e254–e254.

Díaz, M. F., Sánchez, Y., Gómez, M., Hernández, F., & Veloso, M. D. C. (2012). Physicochemical characteristics of ozonated sunflower oils obtained by different procedures.

Donato, G. G., Nebbia, P., Stella, M. C., Scalas, D., Necchi, D., Bertero, A., Romano, G., Bergamini, L., Poletto, M. L., Peano, A., Robino, P., & Nervo, T. (2024). In vitro effects of different ozone preparations on microorganisms responsible for endometritis in the mare. *Theriogenology, 219*, 132–137. https://doi.org/10.1016/j.theriogenology.2024.02.011

Elvis, A. M., & Ekta, J. S. (2011). Ozone therapy: A clinical review. *Journal of Natural Science, Biology, and Medicine, 2*(1), 66.

European Center for Disease Prevention and Control. (2020, September 18). Antimicrobial Resistance and Health Care Associated Infection Programme. European Union. Retrieved from https://ecdc.europa.eu/en

Infectious Diseases Society of America (IDSA). (2011). Combating antimicrobial resistance: Policy recommendations to save lives. *Clinical Infectious Diseases, 52*(Supplement 5), S397.

Jacinto, G. S., Benvenutti, L., Santin, J. R., de Freitas, R. A., Bella Cruz, A., Corrêa, R., & Bresolin, T. M. B. (2023). The effect of ozone dosage of sunflower and olive oils on their biological activities and chemical properties. *Ozone: Science & Engineering*, 1–20.

Jorge, N., & Gonçalves, L. A. G. (1998). Behavior of high oleic sunflower oil in thermooxidation and frying. *Food Science and Technology, 18*, 335–342.

Khachatryan, G., Khachatryan, L., Krystyjan, M., Lenart-Boroń, A., Krzan, M., Kulik, K., Białecka, A., Grabacka, M., Nowak, N., & Khachatryan, K. (2022). Preparation of nano/microcapsules of ozonated olive oil in hyaluronan matrix and analysis of physicochemical and microbiological (biological) properties of the obtained biocomposite. *International Journal of Molecular Sciences, 23*(22), 14005. https://doi.org/10.3390/ijms232214005

Khachatryan, G., Khachatryan, L., Krystyjan, M., Lenart-Boroń, A., Krzan, M., Kulik, K., Białecka, A., Grabacka, M., Nowak, N., & Khachatryan, K. (2022). Preparation of nano/microcapsules of ozonated olive oil in hyaluronan matrix and analysis of physicochemical and microbiological (biological) properties of the obtained biocomposite. *International Journal of Molecular Sciences, 23*(22), 14005. https://doi.org/10.3390/ijms232214005

Lenart-Boroń, A., Stankiewicz, K., Bulanda, K., Czernecka, N., Heliasz, M., Hunter, W., Ratajewicz, A., Khachatryan, K., & Khachatryan, G. (2024). In vitro antibacterial activity of ozonated olive oil against bacteria of various antimicrobial resistance profiles isolated from wounds of companion animals. *International Journal of Molecular Sciences, 25*(6), 3557. https://doi.org/10.3390/ijms25063557

O'Neill, J. (2016). *Combating drug-resistant infections globally: Final report and recommendations*. Retrieved from https://www.gov.uk/government/publications/combating-drug-resistant-infections-globally-final-report-and-recommendations

Piletić, K., Kovač, B., Perčić, M., Žigon, J., Broznić, D., Karleuša, L., Lučić Blagojević, S., Oder, M., & Gobin, I. (2022). Disinfecting action of gaseous ozone on OXA-48-producing *Klebsiella pneumoniae* biofilm in vitro. *International Journal of*

Environmental Research and Public Health, 19(10), 6177. https://doi.org/10.3390/ijerph19106177

Piola, N. X. (2022). Application of ozone therapy within the small animal clinic. *Multidisciplinary Journal of Health*, 1–12.

Puxeddu, S., Scano, A., Scorciapino, M. A., Delogu, I., Vascellari, S., Ennas, G., Manzin, A., & Angius, F. (2024). Investigação físico-química e eficácia antimicrobiana de óleos ozonizados: O estudo de caso de óleos comerciais ozonizados de oliva e semente de girassol refinados. *Molecules (Basel, Switzerland), 29*(3), 679. https://doi.org/10.3390/molecules29030679

Rangel, K., Cabral, F. O., Lechuga, G. C., Carvalho, J. P. R. S., Villas-Bôas, M. H. S., Midlej, V., & De-Simone, S. G. (2022). Potent activity of a high concentration of chemical ozone against antibiotic-resistant bacteria. *Molecules (Basel, Switzerland), 27*(13), 3998. https://doi.org/10.3390/molecules27133998

Sabancı, A. U., Erkan Alkan, P., Mujde, C., Polat, H. U., Ornek Erguzeloglu, C., Bisgin, A., Ozakin, C., & Temel, S. G. (2022). Nanobubble ozone stored in hyaluronic acid decorated liposomes: Antibacterial, anti-SARS-CoV-2 effect and biocompatibility tests. *International Journal of Nanomedicine, 17*, 351–379. https://doi.org/10.2147/IJN.S328090

Salaie, R. N., Hamad, S. A., & Meran, Z. D. (2024). Efficacy of ozonated olive oil against peri-implant microbes isolated from peri-implantitis. *Cellular and Molecular Biology (Noisy-le-Grand, France), 70*(6), 1–6. https://doi.org/10.14715/cmb/2024.70.6.1

Sechi, L. A., Lezcano, I., Nunez, N., Espim, M., Duprè, I., Pinna, A., ... & Zanetti, S. (2001). Antibacterial activity of ozonized sunflower oil (Oleozon). *Journal of Applied Microbiology, 90*(2), 279–284.

Shu, X., Singh, M., Karampudi, N. B. R., Bridges, D. F., Kitazumi, A., Wu, V. C. H., & De Los Reyes, B. G. (2021). Responses of *Escherichia coli* and *Listeria monocytogenes* to ozone treatment on non-host tomatoes: Efficacy of intervention and evidence of induced acclimation. *PLOS One, 16*(10), e0256324. https://doi.org/10.1371/journal.pone.0256324

Silva, K. H. G., Cunha, E. V., Galdino, V. L., & Hipolito, A. F. (2021). In vitro evaluation of the antimicrobial activity of gaseous ozone and ozonized oil. *Master-Teaching, Research and Extension Journal, 6*(11), 179–189.

Takizawa, F., Domon, H., Hiyoshi, T., Tamura, H., Shimizu, K., Maekawa, T., Tabeta, K., Ushida, A., & Terao, Y. (2023). Ozone ultrafine bubble water exhibits bactericidal activity against pathogenic bacteria in the oral cavity and upper airway and disinfects contaminated healthcare equipment. *PLOS One, 18*(4), e0284115. https://doi.org/10.1371/journal.pone.0284115

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/132831