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OXYGEN PLASMA AS A MICROBICIDAL TECHNOLOGY IN ELECTRIC HAND DRYERS

PLASMA DE OXIGÊNIO COMO UMA TECNOLOGIA MICROBICIDA EM SECADORES DE MÃOS ELÉTRICOS

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ABSTRACT: Objective: To evaluate the microbicidal efficacy of different models of hand dryers installed on a university campus focusing on the microbicidal performance of different filters and technologies. Method: Three models of dryers manufactured with different technologies were tested, such as HEPA filter, UV-C light, and oxygen plasma. Analysis of environmental heterotrophic bacteria and tests with standard strains of *Staphylococcus aureus* and *Escherichia coli* were carried out. Results: The results demonstrated that dryers without microbicidal technologies can disperse bacteria and models with oxygen plasma had a superior bactericidal effect, especially when used for 30 seconds. Conclusion: It was concluded that implementing microbicidal technologies in dryers, such as oxygen plasma, can significantly reduce bacterial contamination, making these equipment safer for public use.
KEYWORDS: Plasma gases; Hand Sanitizers; Heterotrophic Bacteria.

RESUMO: Objetivo: Avaliar a eficácia microbicida de diferentes modelos de secadores de mãos instalados em um campus universitário, quanto à eficácia microbicida de diferentes filtros e tecnologias. Método: Testaram-se três modelos de secadores fabricados com distintas tecnologias, como filtro HEPA, luz UV-C e plasma de oxigênio. Foram realizadas análises de bactérias heterotróficas ambientais e testes com cepas padrão de *Staphylococcus aureus* e *Escherichia coli*. Resultados: Secadores sem tecnologia microbicida podem dispersar bactérias e os modelos com plasma de oxigênio apresentaram efeito bactericida superior, especialmente quando utilizados por 30 segundos. Conclusão: A implementação de tecnologias microbicidas em secadores, como o plasma de oxigênio, pode reduzir significativamente a contaminação bacteriana, tornando esses equipamentos mais seguros para uso público.
PALAVRAS-CHAVE: Gases em plasma; Higienizadores de Mão; Bactérias Heterotróficas.

INTRODUCTION

Atmospheric air is composed of gases, water vapor, dust, impurities, and microorganisms. Poorly ventilated indoor environments that contain dirt and particles in the air can cause contamination (by bacteria, fungi, and viruses). As people are spending more time indoors, air quality has become an increasing concern.[1]

Hand dryers are increasingly used in public restrooms due to their cost-effectiveness and environmental friendliness since electric dryers do not consume excessive amounts of paper. A survey showed that a person consumes about 6 tons of paper in five years drying their hands and, to offset this environmental impact, 48 trees for every 1,000 users should be planted to replace the used paper.[2]

Hand dryers are commonly used in communal restrooms, environments where, in addition to the impurities naturally present in the atmospheric air mentioned above, microbial particles from fecal matter are also present. In other words, when a toilet is flushed with the lid open, bacterial particles are released into the air, contaminating the environment.[1]

The most common bacteria found in bathrooms are those belonging to the group of thermotolerant coliforms (fecal) and also those originating from the skin microbiota of individuals. In a previous study, the following microbial species were identified in hand dryers installed in bathrooms on a university campus: *Staphylococcus aureus, coagulase-negative Staphylococcus, Bacillus sp., Streptococcus sp., Escherichia coli, Pseudomonas aeruginosa* and several species of fungi. Of these, *S. aureus* was present in 100% of the dryers analyzed.[1]

When hand dryers lack microbicidal technology in their air outlets, they can become vectors for infections, as they may release contaminated air onto the clean hands of users. The dispersion and transmission of bacteria, as well as the potential for cross-contamination, can be exacerbated by the air movement generated by the dryers, which capture and recirculate ambient air. As a result, users and nearby individuals face an increased risk of exposure to airborne bacteria, which can either be inhaled or deposited onto clothing or skin, turning them into potential carriers of infection. Studies estimate that bacterial contamination on the hands of individuals using hand dryers increases by 4.5 times compared to drying with paper towels.[3]

Various filters and technologies have been implemented in hand dryers to reduce or minimize impurities and microbial particles in the air outlets. Among these technologies, oxygen plasma stands out. It is produced by ionizing atmospheric oxygen, which generates reactive oxygen species (ROS) capable of exerting microbicidal effects on a wide range of microorganisms. ROS exist in many forms, such as the hydroxyl radical (OH), hydroperoxy radical (HOO), superoxide anion radical (OH^-), or hydrogen peroxide (H_2O_2). Of these, OH and O_2– have been reported to have the ability to inactivate microorganisms.[4]

Previous studies have evaluated the use of low-temperature plasma in water and found a microbicidal effect against *Staphylococcus epidermidis* and *Escherichia coli*. This effect remained largely unchanged for four weeks of storage of the tested water samples, even though H_2O_2 had nearly disappeared.[4,5]

Therefore, the objective of this research was to assess the microbicidal efficacy of different hand dryer models installed in bathrooms on a university campus, focusing on the various filters and technologies employed.

METHODOLOGY

This experimental study was conducted between July and November 2023 in the laboratories of the Centro Universitario Integrado. For its development, three models of hand dryers, manufactured by a company in Campo Mourão, Paraná, were tested. Each dryer model incorporated one or more technologies, as shown in Table 1.

Table 1. Identification of the different hand dryer models used in the experimental procedures.

Identification	Model	Technology
A1	K2020 (INOX)	Filter High-Efficiency Particulate Arrestance (HEPA) + Light UV-C
A2	K2020 (INOX)	Filter HEPA + Light UV-C + O_2 Plasma
B1	AIRES	—
B2	AIRES	O_2 Plasma
C1	SPEED	O_2 Plasma
C2	SPEED	Dust Filter

The researchers received the equipment without identification. Each model was installed in pairs, with one placed in the women's bathroom and the other in the men's bathroom of a higher education institution. Both bathrooms were located in the same area and experienced the same flow of people. The equipment remained under testing for the same duration.

ANALYSIS OF HETEROTROPHIC BACTERIA

In the first stage of the tests, the amount of heterotrophic bacteria present in the air was compared to the amount of bacteria released by the hand dryer blower. To achieve this, Plate Count Agar (PCA) plates were placed open for 30 minutes on the floor and sink of each bathroom. Simultaneously, other PCA plates were positioned at the air outlet of the hand dryers, which were activated for three experimental durations: 15, 30, and 60 seconds. All plates were incubated at 37ºC for 48 hours, and the experiment was conducted in triplicate.

ANALYSIS OF KNOWN BACTERIA

In the second stage of testing, standard strains (Newprov) of *Escherichia coli* and *Staphylococcus aureus* were activated in Brain Heart Infusion (BHI) broth and used to contaminate the hands of volunteers. Sterile swabs were then used to collect samples from the hands at four different time points: immediately after contamination, after washing the hands with soap and water, and after drying the hands using the dryers under test for 15 seconds and 30 seconds, respectively. The collected samples were plated on MacConkey agar for *E. coli* and Mannitol Salt Agar for *S. aureus*, and incubated at 37ºC for 48 hours. All tests were performed in triplicate.

STATISTICAL ANALYSIS

After the incubation periods for all experiments, colony-forming units (CFU) were quantified, and the results were expressed as the mean ± standard deviation. The means were compared statistically using analysis of variance (ANOVA) followed by Tukey's post-hoc test, with the GraphPad Prism software version 5.0. A p-value of <0.05 was considered statistically significant.

RESULTS

ANALYSIS OF HETEROTROPHIC BACTERIA

Analysis of Figure 1 reveals a high bacterial density (> 100 CFU) in the areas of the floor and sink in the bathrooms analyzed. When the hand dryers were activated, regardless of the technology used, for 15 seconds, the bacterial count passing through the equipment was lower compared to the 30 and 60-second activation times. None of the filter types used resulted in a significant reduction in the environmental bacteria released by the air from the equipment.

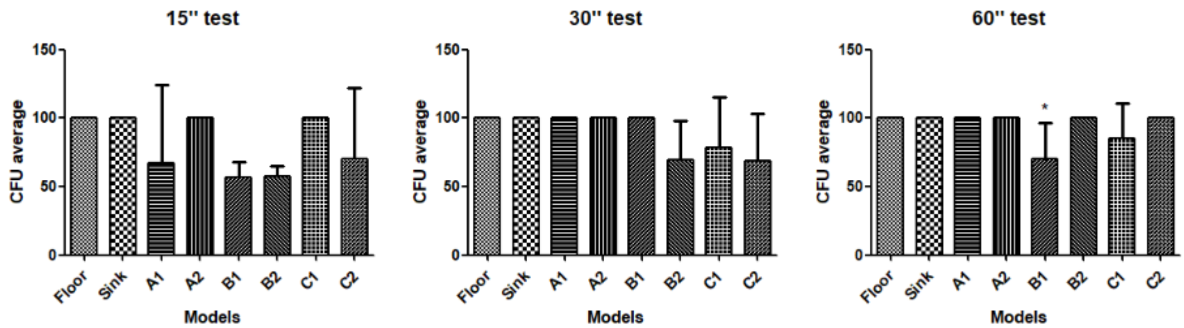

Figure 1. Bacterial growth was expressed as the mean and standard deviation of colony-forming units (CFU) for each collection location and hand dryer model analyzed.

ANALYSIS OF KNOWN BACTERIA

STAPHYLOCOCCUS AUREUS

In the tests with *S. aureus*, it was observed that hand washing slightly reduced the bacterial load on the hands of users; however, significant reductions were only achieved after the use of hand dryers. The different models tested (A1, A2, B1, B2, C1, and C2) exhibited varying efficiency rates based on the technology used. Nevertheless, it was noted that in all cases, allowing the hands to dry for 30 seconds enhanced the decontaminating effect of the equipment. Furthermore, it is important to highlight that for all models with oxygen plasma emission, the results were significantly superior ($p<0.05$) compared to the same models without plasma emission (Figure 2).

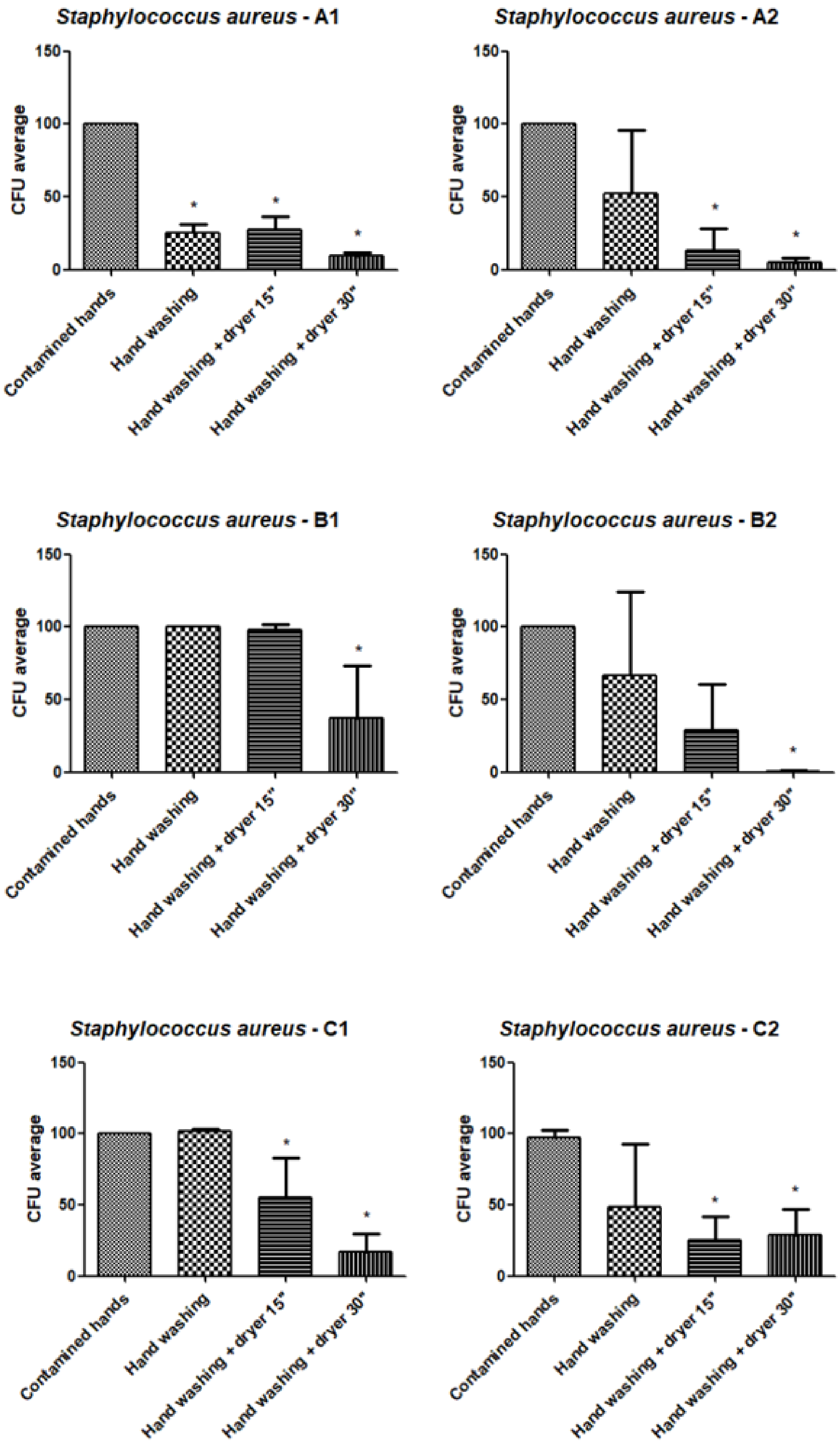

Figure 2. Bacterial growth of *Staphylococcus aureus* expressed as the mean and standard deviation of colony-forming units (CFU) for contaminated hands, hand washing with soap and water, and use of hand dryers for 15 and 30 seconds.

*Significant difference ($p < 0.05$) compared to the “contaminated hand” column.

ESCHERICHIA COLI

For the tests with *Escherichia coli* (*E. coli*), the results were similar in terms of the time of use of the hand dryer, with 30 seconds being effective for all equipment. Regarding the bactericidal effect of the plasma, it was observed that this effect was more pronounced for *E. coli* compared to *Staphylococcus aureus* (Figure 3).

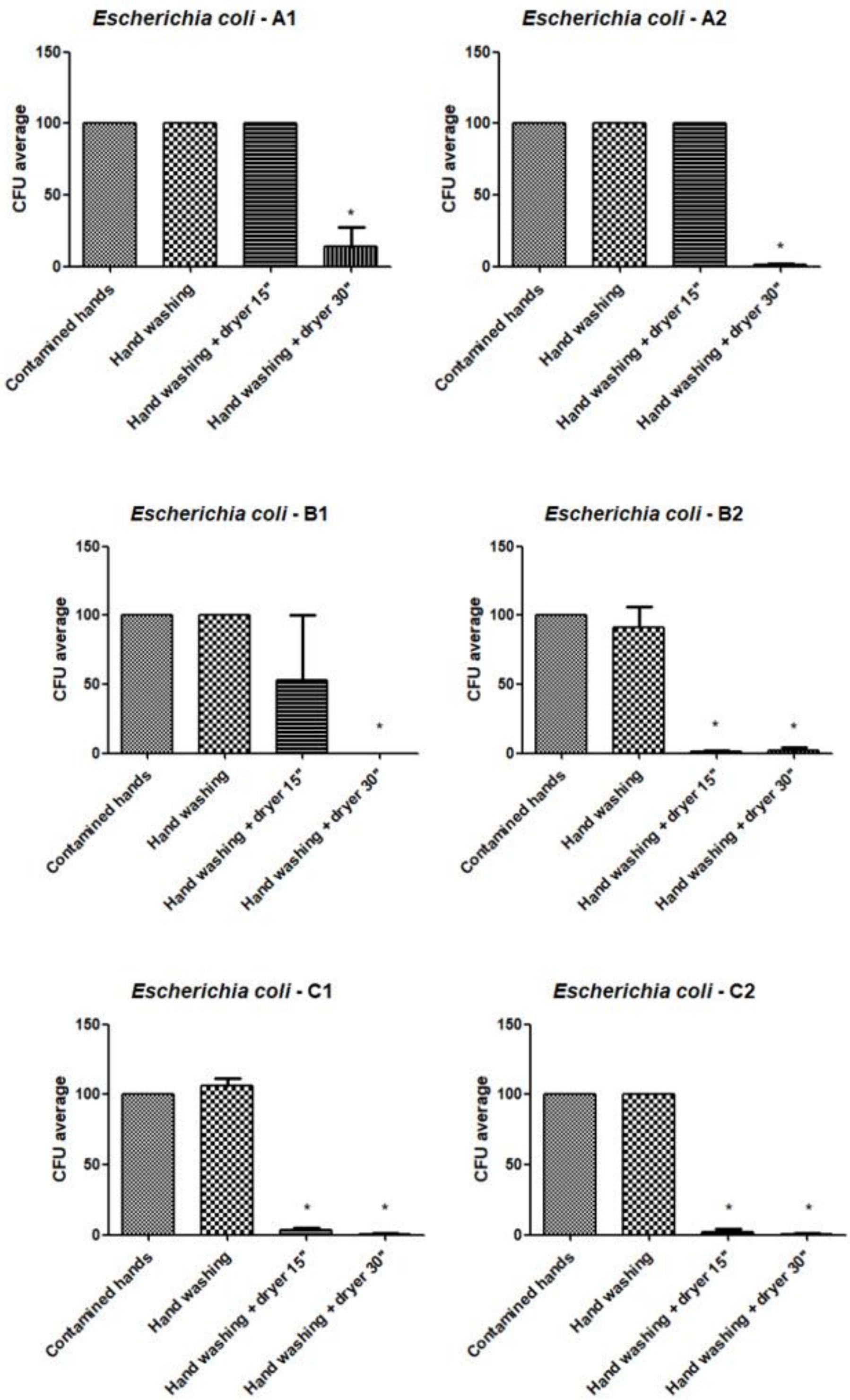

Figure 3. Bacterial growth of *Escherichia coli* expressed as the mean and standard deviation of colony-forming units (CFU) for contaminated hands, after hand washing with soap and water, and after using hand dryers for 15 and 30 seconds.
*Significant difference ($p < 0.05$) in relation to the “contaminated hand” column.

DISCUSSION

The use of electric hand dryers has become increasingly common today, however, few studies analyze the technologies used in filters to have a microbicidal effect, since they can disperse dirt, particles, bacteria, and fungi onto users' hands.[1] In this study, the dispersion of heterotrophic bacteria from the environment was verified, as well as the microbicidal action on known bacteria (*Staphylococcus aureus* and *Escherichia coli*).

In the first test, which focused on heterotrophic bacteria from the environment, it was demonstrated that hand dryers can disperse bacteria present in the air and direct them into the hands of users. These findings emphasize the importance of using effective microbicidal technologies to reduce bacterial contamination. In this study, equipment with the following technologies was tested: HEPA filter, which, due to its composition of fiberglass mesh, allows the separation and retention of small particles through three mechanisms: interception, impact, and diffusion; [6,7] ultraviolet light, which, after being absorbed by the nucleic acids (DNA), hinders its replication, or if replication occurs, causes mutations in the copies that render them incapable of further replication; and O_2 plasma, which promotes the oxidation of both aerobic and anaerobic microorganisms due to their vulnerability to free radicals.[4,8]

The equipment with O_2 plasma emission demonstrated a superior bactericidal effect compared to its counterparts without plasma emission. This action was most effective when the plasma was released for 30 seconds, highlighting that the exposure time to the plasma significantly influences its microbicidal potential.

Plasma is recognized in physics as a state of matter, similar to the solid, liquid, and gaseous states. In this state, atoms are ionized, containing charged particles (OH^-, H_2O^+, electrons), reactive compounds (ROS, which includes the hydroxyl radical, superoxide anion, hydrogen peroxide, and reactive nitrogen species – RNSs), molecules in both excited and ground states and ultraviolet (UV) photons.[9] Plasma has been employed for several years in the medical field for various purposes, one of which is material sterilization.[10, 11]

There are several conventional sterilization methods such as heat, irradiation, and chemical gases, but most of these methods have significant drawbacks, as they can alter the material's intrinsic properties. Plasma, on the other hand, has several advantages such as efficiency in reducing the load of viral particles and bacterial cells, formation of non-toxic by-products, and a relatively low operating cost.[9]

When compounds derived from oxygen or nitrogen come into contact with biological material, their high reactivity triggers several effects. Notably, these include the oxidation of lipids and proteins, the generation of electrostatic particles, and electroporation, which increases the number of micropores in the cell membrane. All of these effects ultimately lead to dysfunction and the rupture or disintegration of the microorganism's plasma membrane, causing cell death.[9]

To assess the physicochemical processes occurring during a plasma sterilization cycle, survival curves are plotted, represented by a logarithmic graph of the number of surviving microorganisms as a function of exposure time to the plasma. Generally, the number of surviving microorganisms decreases over time, but the rate of decrease varies at different stages of the process.[12] In this study, exposure to plasma for 30 seconds showed a significantly higher bactericidal effect compared to exposure for 15 seconds for both bacteria tested.

For this research, the action of O_2 plasma was tested on two well-known and morphologically different bacteria: *S. aureus* (Gram-positive) and *E. coli* (Gram-negative). The bactericidal effect of the plasma was found to be superior against *E. coli*, possibly due to its thinner cell wall compared to Gram-positive bacteria. Gram-negative bacteria have an additional outer membrane composed of phospholipids, lipoproteins, and lipopolysaccharides, but their cell wall has a lower peptidoglycan content, making them thinner and more susceptible to the deleterious effects of the plasma.[13]

Plasma has been increasingly employed in experimental research due to its cost-effectiveness, safety, and broad range of potential applications. Reports highlight its use in various sectors, including medicine, food, and agriculture, as well as for air, water, and sewage purification, food preservation, and decontamination.[13-15]

A study in the field of dentistry examined the sterilization of endodontic files with oxygen plasma, exposing them to Gram-negative bacteria (*Pseudomonas aeruginosa* and *E. coli*) and Gram-positive bacteria (*S. aureus*). The study found that the oxygen plasma particles oxidize and destroy bacterial cell structures. The primary mechanism of action involves targeting the cell wall, with greater efficacy observed in Gram-negative bacteria. This is due to the thinner peptidoglycan layer, which allows the passage of ions, free radicals, and electrons generated by the plasma, along with the interaction with membrane lipids that are abundant in Gram-negative bacteria.[16]

The study also demonstrated that exposure to plasma resulted in a reduction of 6 logarithmic cycles in the number of colony-forming units (log CFU) when stainless steel surgical material was subjected to decontamination. A similar reduction was observed when polypropylene materials contaminated with *E. coli*, *S. aureus*, *Mycobacterium tuberculosis*, *P. aeruginosa*, *Clostridium perfringens*, and *Clostridium tetani* were exposed for 30 seconds.[16] These results highlight the importance of standardizing exposure time and demonstrate the bactericidal potential of O_2 plasma across different material types and bacterial species.

Another study investigated the sterilization of medical hospital products using different types of plasma, using *Bacillus subtilis* and *Bacillus stearothermophilus* inoculated in plates. The results showed that the efficiency of O_2 plasma was five to six times greater than that of ambient air plasma, which contains additional elements in its composition, such as (CO_2, H_2, Ar e N_2).[17]

Washing hands before using a hand dryer is a crucial step in the hand decontamination process. Effective hand hygiene helps reduce Healthcare-Associated Infections (HAIs) and the spread of multidrug-resistant microorganisms.[18] This is a very important process in the National Program for the Prevention and Control of Infections Related to Healthcare (PNPCIRAS) established by the National Health Surveillance Agency (ANVISA).[19] According to the guidelines of the World Health Organization[20], the process for effective hand washing consists of six steps and should take an average of 20 to 30 seconds. In addition, washing hands with soap leads to a 60% reduction in the total bacteria count, highlighting the importance of washing hands before using hand dryers, so that these mechanisms work synergistically and complementary in removing bacteria. [21].

CONCLUSION

It is concluded that hand dryers without microbicidal technology can contribute to the dispersion of microorganisms in the environment. The release of O_2 plasma in hand dryers demonstrated bactericidal action that complemented hand washing, effective against *Staphylococcus aureus* and *Escherichia coli*. It was observed that the exposure time of contaminated hands to the air released by the equipment is crucial for achieving the microbicidal effect since after 30 seconds there was a significant reduction in bacterial growth compared to just 15 seconds of exposure.

Given the above, the implementation of filters or technologies that eliminate microbial particles, in addition to other impurities, is essential for the hand dryer to be an alternative that is not only economically and environmentally favorable but also a safe one for public health. The use of O_2 plasma as a microbicidal agent should be further explored and studied in other scenarios, to be implemented to assist in infection control and, ultimately, contribute to the promotion of public health.

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