Perception of Professionals from Different Healthcare Units Regarding the Use of Spray Technology for the Instantaneous Decontamination of Personal Protective Equipment during the Coronavirus Disease Pandemic: A Short Analysis

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Abstract: Within the context of the coronavirus disease (COVID-19) pandemic, different disinfection technologies have been developed to efficiently exercise microbial control, especially to minimize the potential risks that are associated with transmission and infection among healthcare professionals. Thus, the aim of this work was to evaluate the perception of professionals regarding the use of a new technology (chamber) for the instantaneous decontamination of personal protective equipment before the doffing stage. This was a cross-sectional descriptive study where the study data were obtained by using a questionnaire with qualitative questions. In total, 245 professionals participated in the study in three hospitals. Healthcare professionals represented 72.24% (n = 177) of the investigated sample. Approximately 69% of the professionals considered the disinfection chamber as a safe technology, and 75.10% considered it as an important and effective protective barrier for healthcare professionals in view of its application before the doffing process. The results found in this study demonstrate that the use of spray technology in the stage prior to the doffing process is acceptable to professionals, and that it can be an important tool for ensuring the additional protection of the professionals who work directly with patients who are diagnosed with COVID-19.

Keywords: contamination; disinfection; personal protective equipment; biocidal agent; COVID-19; SARS-CoV-2; healthcare workers

1. Introduction

Surface disinfection procedures represent one of the main types of interventions against pathogenic microorganisms and aim to prevent, avoid, or intervene to control the transmission of pathogenic microorganisms [1,2]. Currently, there is a growing concern that the hospital environment may be an underestimated source for the dissemination of pathogens [3], such as bacteria [4], fungi [5], and viruses [6], including the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [7]. SARS-CoV-2 is the causative agent of the 2019 coronavirus disease (COVID-19) that was isolated and first identified in patients in the city of Wuhan, China, in December 2019 [8]. However, within 60 days of the first reported case, the disease spread globally, predominantly in Asia, Europe, and the Middle
East [9,10]. In Brazil, more than 31.3 million cases were reported by the beginning of June 2022, resulting in more than 667,000 deaths [10]. Brazil has reported the third largest number of cases worldwide, next only to the number of cases reported by the United States and India [10]. Even with the rapid development and availability of vaccines [11,12], the high transmission rate of SARS-CoV-2 associated with other factors has made COVID-19 the major public health concern in recent human history [13].

In the context of outbreaks and epidemics that are caused by infectious agents, new technologies and protocols have been proposed to efficiently exercise microbial control and reduce the infection rate [14,15]. Previous studies have shown the benefits of using ultraviolet light devices for disinfecting hospital environments [16,17], portable devices with spray systems for surface decontamination [3], and disinfection chambers using different biocidal agents [14,18]. Due to the high transmission potential of SARS-CoV-2 [19,20], the use of disinfection chambers has gained popularity for responding to the global demand for controlling the COVID-19 pandemic [21,22].

In India, the Defense Research and Development Organization (DRDO) has developed disinfection chambers to be used by individuals during the COVID-19 pandemic, called Personal Hygiene Equipment. The equipment is for use in controlled access areas with heavy footfall, such as the entrance and exit areas of hospitals, malls, and business buildings [23]. Disinfection chambers using ozonized water, ozone, or other biocidal agents have been employed in different countries during the COVID-19 pandemic to reduce transmission between individuals, especially in areas with heavy pedestrian traffic [24–27].

Previously, during the outbreak of the Ebola virus in Africa, a proposed alternative was the spraying of chlorine at a concentration of 0.5% (5000 ppm) on animate and inanimate objects, including humans, to reduce the infection potential of this virus [28]. However, some mild or moderate adverse clinical effects have been reported, mainly by nurses and cleaning professionals, after prolonged exposure to this agent [28].

In Brazil, the National Health Surveillance Agency (Anvisa) does not recommend the use of disinfection chambers for direct use with individuals, regardless of the biocidal agent used [29]. However, the Anvisa and the Directorate of Sanitary and Environmental Surveillance of the State of Bahia (Divisa BA) [30] authorize the use of chambers and devices with regulated pulverization or spraying systems of biocidal agents for the disinfection of surfaces in controlled environments, such as hospitals and healthcare units, and for the decontamination of personal protective equipment (PPE) [29,30].

The use of chambers in hospitals and healthcare units during the COVID-19 pandemic for the instantaneous disinfection of PPE before the doffing process can be an important tool for the additional protection of professionals working directly with patients who are diagnosed with COVID-19. Healthcare workers are considered worldwide as one of the most vulnerable groups to pathogen infections, including SARS-CoV-2 [31,32]. This may be due to their close contact with patients and contaminated environmental surfaces, which may also be responsible for high mortality rates in this group [33,34]. Considering only the numbers associated with COVID-19, more than 3000 health professionals were infected in China, with a mortality rate of 1.1% [35,36]; the infection rates in Italy and Spain were 20% and 26%, respectively [37,38]. In Latin American countries such as Ecuador and Bolivia, this rate reached 10% [39], while in Brazil more than 257,156 healthcare professionals were infected [40]. Currently, the incidence of COVID-19 among this population is related to vaccination and the appearance of new variants of SARS-CoV2-2, which usually have a greater capacity for infection [41,42].

In this context, the use of PPE is considered to be the main option for the protection of health professionals, since such equipment provides a physical barrier against infectious agents [43]. However, the PPE doffing process should be performed following strict biosafety protocols [44]; PPE doffing is characterized as a critical step, and cases of self-contamination have been reported [45]. Different studies have pointed out the high bioburden, especially the molecular detection of SARS-CoV-2, in places that are targeted for PPE doffing [46]. This condition has mainly been related to the contact that healthcare
workers have with aerosols that are generated from the care of patients who are diagnosed with COVID-19 [47]. Therefore, different initiatives to prevent self-contamination of healthcare workers during the COVID-19 outbreak were discussed and considered [48]. In a recent study of our group [49], the efficacy of the chamber for the instantaneous disinfection of seven different types of PPE using a low concentration sodium hypochlorite solution as a biocidal agent was demonstrated [50–52]. The potential for its use during the COVID-19 pandemic in one step prior to the PPE doffing process was also reported [53].

The use of chambers and other technologies for disinfection can be considered as promising options, provided that their effectiveness, as well as their safety, are proven [29,30,54]. However, in addition to the analysis of the effectiveness for inactivating microorganisms or for reducing microbial load, evaluating the perception of professionals regarding the use of these new technologies is also of fundamental importance. Most of the studies are focused on evaluating the performance of new devices, being limited to the evaluation of technical parameters, such as the ability to reduce the bioburden on the surface, the time required for this action, and what is the best biocide agent, among others [55]. Nevertheless, knowledge about the perception of professionals about new technologies is important for adherence to the proposed method, the evaluation of safety parameters, and the determination of possible adverse effects, which are relevant when carrying out studies with this proposal [56].

Thus, the aim of this work was to evaluate the perception of various professionals regarding the use of a new technology (chamber) for the instantaneous decontamination of PPE before the PPE doffing process. The professionals were selected from different hospitals and reference healthcare units designated for the treatment of COVID-19 in a region of Brazil.

2. Materials and Methods

This study was conducted among professionals from hospitals and reference healthcare units designated for COVID-19 treatment in the state of Bahia (Brazil). Figure 1 shows the general methodological scheme that was applied in this study. We evaluated the perception of different professionals regarding the use of a disinfection chamber with a biocidal agent (0.25% sodium hypochlorite solution) spray technology. The perception regarding the use of this chamber for the instantaneous decontamination of PPE and the potential for its use as a barrier to reduce the risk of contamination by SARS-CoV-2 during the deworming stage were evaluated.

![Figure 1](image.png)

**Figure 1.** Stages of the study conducted to evaluate the perception of different professionals in hospitals and health units regarding the use of the disinfection chamber.

2.1. Installation of the Disinfection Chamber in Hospitals and Reference Healthcare Units Designated for the Treatment of COVID-19

Following the guidelines and recommendations of the national regulatory agency (Anvisa) [29] and the state of Bahia (Brazil) (Divisa BA) [30], the disinfection chambers were installed in hospitals and reference healthcare units that were designated for the treatment of patients suspected of or diagnosed with COVID-19. The configurations of the disinfection chamber were described in our previous study [49]. In general, the disinfection chambers installed in the units were developed in a modular framework constructed of aluminum and carbon steel, with dimensions of 240 × 150 × 250 cm (height × depth × width). The
nebulization system for the biocidal agent (0.25% sodium hypochlorite solution) was composed of six nebulizer nozzles (Senninger, Clermont, FL, USA) that were installed on the inner side and on the top of the chamber. The nebulizer system was automatically triggered by a presence sensor. The chambers were installed in areas near intensive care units (ICUs) or wards, allowing professionals to use the chamber after contact with the patient or after their work routine, as well as before the PPE doffing process. The Planning Secretariat of the State of Bahia (SEPLAN) carried out the definition and distribution of the disinfection chambers as one of the measures to control the COVID-19 pandemic in the state.

2.2. Study Design

This was a cross-sectional descriptive study conducted using a questionnaire to evaluate the perception of professionals regarding a new technology that was proposed for the instantaneous decontamination of PPE before the doffing process during the COVID-19 pandemic. The questionnaire was used in 3 of the hospitals or health units where the disinfection chamber was installed: Hospital Espanhol, Hospital Arena Fonte Nova, and Hospital Ernesto Simões, all located in the city of Salvador (Bahia, Brazil). The study was conducted between April and July 2020. The main outcome of the study was the acceptance of the new technology (chamber) for the instantaneous decontamination of personal protective equipment before the doffing stage.

2.3. Survey Population

Trial participants were selected from each hospital and healthcare unit and included in the study based on the following inclusion criteria: both sexes; professionals related to the hospitals and healthcare units participating in the trial; professionals who agreed to participate in the trial after reading the disinfection chamber use protocol (Figure 2); and professionals who signed the informed consent form. The exclusion criteria used for this trial were as follows: a history of some type of allergy to sodium hypochlorite or to products containing sodium hypochlorite (even at low concentrations); refusing to participate in the trial after following the chamber use protocol and not signing the informed consent form; and not having any connection with the hospitals or healthcare units participating in the study. All eligible participants were informed about the objective of the study; they were advised about the use of the disinfection chamber and instructed to fill out the questionnaire.

Figure 2. Protocol for the use of the disinfection chamber in hospitals and reference health units designated for the treatment of coronavirus disease (COVID-19) in the state of Bahia (Brazil): (a) mandatory use of personal protective equipment (PPE) for use of the chamber—use before the PPE doffing process; (b) guidelines for the use of the chamber.
To obtain a representative sample of the target population, an estimated response of 30%, a confidence interval of 95%, and a margin error of 5% were established using the Raosoft tool for sample size calculation. These parameters were established based on the study by Roupa et al. [57]. The target population was defined from the estimated number of ICU staff in each participating hospital during the study period (established by multiplying the number of ICU beds for COVID-19 in each hospital [58–60] by 4.0), and the minimum number of staff per bed in public hospitals in Brazil [61], totaling 936 individuals. Therefore, the required sample of the study was a minimum of 241 subjects. Participants were selected from the convenience or consecutive sampling technique, where they were selected consecutively in order of suitability according to their convenient accessibility, respecting the eligibility criteria [62]. For this, a trained nursing staff approached the individuals, where, if eligible, they were invited to participate in the study by completing the questionnaire. Sampling ended when the minimum sample size was reached.

2.4. Data Collection (Questionnaire Development and Application)

The study data were obtained through the application of a paper questionnaire with qualitative questions, in addition to acquiring additional information regarding the profession and the hospital or healthcare unit (Table S1). The participants answered the survey questions in pen to respect the security and inviolability of the data. After filling out the document, they were stored according to the ethical recommendations. The questionnaire was divided into two main categories: history of contact with the biocidal agent (sodium hypochlorite), and the perception related to the use of the disinfection chamber. The main objective of the questions was to assess the clinical safety and satisfaction/acceptability of the technology for use during the COVID-19 pandemic, as per the participating professionals. Therefore, the participants were asked the following questions:

1. What is your occupation?
2. Do you use sodium hypochlorite to clean/disinfect surfaces in your home?
3. If the answer to the previous question was yes, do you take any precautions when handling sodium hypochlorite?
4. Have you experienced any type of prior adverse reaction to sodium hypochlorite in previous contact? If yes, please indicate the type(s) of reaction(s).
5. Do you consider that sodium hypochlorite is a good disinfectant?
6. Did you know that sodium hypochlorite (0.1% to 0.5%) is effective for the inactivation of the new coronavirus (SARS-CoV-2), and is recommended by the World Health Organization (WHO) for the disinfection of home and hospital environments?
7. Did you know that a sodium hypochlorite solution is used in the chamber for the instantaneous disinfection of Personal Protective Equipment (PPE)?
8. Did you experience any discomfort when using the disinfection chamber? If yes, please indicate the discomfort(s) you felt and specify the degree of irritation.
9. Did you know that the chamber was developed to reduce the microbial load, including that of SARS-CoV-2, on the surface of PPE?
10. Do you consider the use of the disinfection chamber before the PPE doffing process to be a safe alternative? If you answered NO to the previous question, why do you not find it to be a safe alternative?
11. Did you check that all of the PPE was uniformly humidified after using the chamber?
12. Do you consider the disinfection chamber to be effective as an additional protective barrier for healthcare workers?
13. Do you consider that the use of the disinfection chamber can lead to a false sense of safety? If you answered YES to the previous question, why do you think using the disinfection chamber leads to a false sense of security?
14. Did you know that even with the use of the chamber, all PPE doffing procedures and protocols must be followed strictly?
15. After using the chamber, have you followed all the appropriate procedures for the doffing of the PPE?
Do you have any remarks or comments you want to add about the chamber?

The answer options for questions 2, 4, 6, 7–9 and 14 were binary (Yes or No), while for questions 5, 10–13 and 15 the options were: Yes, No or Don’t Know. The questionnaire was administered to qualified professionals from nurse staff in an area of the hospital or healthcare unit that was specifically designated for this purpose.

2.5. Data Analysis

A descriptive analysis was performed to evaluate the absolute (%) and relative (n) frequencies, using the GraphPad Prism version 9.2 software (San Diego, CA, USA). For each of the questions in the study questionnaire, the percentage of professionals who expressed their opinion related to the use of the disinfection chamber, as well as their history of contact with the biocidal agent, were evaluated. The responses were compared using a nonparametric Friedman test with Dunn’s multiple comparisons test, considering a p < 0.05, which was also performed in GraphPad Prism software.

2.6. Ethics Approval and Consent to Participate

This study was conducted after its approval by the Ethics and Research Committee of SENAIF CIMATEC University Center (No. 4132735), and by following the ethical principles for medical research as per the International Declaration of Helsinki [63] and the Brazilian legislation [64]. All participants voluntarily participated in the study and were informed of all their rights. Written informed consent was obtained from all participants for participation. In addition, the participants were also made aware of possible risks, such as the occurrence of an adverse event during or after the use of the chamber, and the benefits, such as reducing the SARS-CoV-2 spread rate. The personal information of each participant was kept anonymous.

3. Results

Figure 3 shows the results related to the overall profile of the trial participants. In total, 245 professionals participated in the study; Hospital Arena Fonte Nova (Field Hospital for COVID-19) was the health unit with the highest number of participants (n = 98), followed by Hospital Espanhol (n = 74) (Field Hospital for COVID-19), and Hospital Ernesto Simões (n = 73), (Figure 3a). Most participants who answered the questionnaire were women (71% or n = 174), whereas men accounted for 29% (or n = 71) of the total participants (Figure 3b). The percentage between men and women who participated in the study according to the hospital is shown in Table S2. The highest frequency of participation was observed for nursing technicians (36.73% or n = 90), followed by nurses (13.06% or n = 32) (Figure 3c and Table S2). The lowest frequency of participation was observed for receptionists, social workers and biomedical professionals (0.41% or n = 1, 0.41% or n = 1, and 0.82% or n = 2, respectively) (Figure 3c and Table S2). Healthcare professionals represented 72.24% (n = 177) of the population that was investigated in this study. In addition, it is important to note that the selection of participants was not directed to any specific occupation, respecting only the eligibility criteria. The opinion of professionals from different areas can minimize any kind of bias of a specific professional class.

Figure 4 presents the results pertaining to two questions associated with the history of contact (familiarity) of the professionals with the biocidal agent used in the disinfection chamber (sodium hypochlorite at a concentration of 0.25% (2500 ppm)). Of the participating professionals, 92% (n = 225) answered that they used sodium hypochlorite in the cleaning/disinfection processes of surfaces in domestic activities (Figure 4a and Table S2). Of the professionals who answered yes to this question, 49.60% (n = 124) stated that they were concerned about the dilution of the hypochlorite solution; 32.80% (n = 82) answered that they handled the disinfectant agent using gloves; and 16.40% (n = 41) answered that they did not have concerns about handling the sodium hypochlorite solution (Figure 4a). Regarding reactions during previous contact with sodium hypochlorite, 79.59% (n = 195) of the participants answered that they did not experience any type of reaction to the biocidal
agent, and although 20.41% \((n = 50)\) of the participants answered that they experienced some type of reaction (Figure 4b), they did not oppose the use of the chamber or refuse to participate in the study. Among the previous reactions reported, 35.14% \((n = 26)\) referred to skin irritation or itching, 36.49% \((n = 27)\) to eye irritation or itching, and 25.68% \((n = 19)\) to difficulty in breathing (Figure 4b).

![Chart showing the number of participants by hospital or healthcare unit]

![Pie chart showing the sex distribution: 71% female, 29% male]

![Bar chart showing the number of participants by profession]

Figure 3. The profile of professionals participating in the survey: (a) total number of participants according to hospital or healthcare unit; (b) sex; and (c) profession according to hospital or healthcare unit.
Figure 4. Responses of professionals to the following survey questions: (a) Do you use sodium hypochlorite for surface cleaning/disinfection in your home? If the answer to the previous question was YES, do you have any concerns about handling sodium hypochlorite? (b) Have you had any kind of reaction to sodium hypochlorite in previous contact? If YES, please indicate the type(s) of reaction(s). * represents \( p < 0.05 \) by Friedman test with Dunn’s multiple comparisons test.

Responses to the next three questions regarding the history of contact with the biocidal agent are presented in Figure 5. Figure 5a presents the opinion of professionals regarding the efficiency of sodium hypochlorite, where 85.31% \((n = 209)\) of the participants considered it as a good disinfectant, 3.27% \((n = 8)\) did not consider it as a good disinfectant, and 11.43% \((n = 28)\) did not know, with significant difference between responses \((p < 0.05)\). The percentage of professionals who knew that sodium hypochlorite is effective for the inactivation of SARS-CoV-2 and that it is recommended by the WHO for the disinfection of home and hospital environments was 85.71% \((n = 210)\), and that of professionals who were not aware of this information was 14.29% \((n = 35)\), with significant difference between responses \((p < 0.05)\) (Figure 5b). Of the 245 study participants, 90.2% \((n = 221)\) reported that they knew that the biocidal agent used for the decontamination of the surface of PPE in
the disinfection chamber was sodium hypochlorite, whereas 9.8% (n = 24) did not, with significant difference between responses (p < 0.05) (Figure 5c).

Figure 5. Responses of professionals to the following survey questions: (a) Do you consider sodium hypochlorite to be a good disinfectant? (b) Did you know that sodium hypochlorite (0.10% to 0.50%) is effective for the inactivation of the new coronavirus and is recommended by the World Health Organization (WHO) for the disinfection of home and hospital environments? (c) Did you know that the disinfectant solution used in the chamber for the instantaneous disinfection of personal protective equipment (PPE) is sodium hypochlorite solution? * represents p < 0.05 by Friedman test with Dunn’s multiple comparisons test.

The distribution of responses related to discomfort during use of the disinfection chamber is shown in Figure 6. Of the 245 participating professionals, 84.90% (n = 208) did not report any discomfort or adverse event during the use of the disinfection chamber, whereas 15.10% (n = 37) reported some type of discomfort, with significant difference between responses (p < 0.05) (Figure 6a). In general, regarding the type of discomfort, eye irritation was the most frequently reported (25.68% or n = 19) adverse event, followed by throat irritation (18.92% or n = 14) (Figure 6b). It is important to note that the participants who reported some discomfort after the use of the chamber reported similar effects with the previous domestic use of the biocidal agent (Figure 4b and Table S2). In addition, no participant reported discomfort that was characterized as a claustrophobic sensation after using the proposed disinfection chamber. It is important to emphasize that the discomfort
modalities reported were all mild or moderate, and none was of severe intensity (Table S2). Even in these cases, the professional who presented with the adverse event was promptly evaluated and guided by the study team, and no interventions were needed for any of the adverse events.

![Figure 6](image_url)

**Figure 6.** Responses of professionals to the following survey questions: (a) Did you experience any discomfort when using the disinfection chamber? (b) If yes, please indicate the type of discomfort(s) you felt. * represents $p < 0.05$ by Friedman test with Dunn’s multiple comparisons test.

The results that were obtained for the perception of professionals regarding the use of the disinfection chamber are presented in Figure 7. About 96.33% ($n = 236$) of the professionals were aware that the disinfection technology available in hospitals and health units was developed to reduce the microbial load on the surface of PPE, including that of SARS-CoV-2. However, 3.67% ($n = 9$) were unaware of this information, with significant difference between responses ($p < 0.05$) (Figure 7a). The vast majority of professionals (68.57% or $n = 168$) who were interviewed considered the use of the disinfection chamber before the PPE doffing process as a safe option, whereas 7.76% ($n = 19$) of the professionals did not, with significant difference between responses ($p < 0.05$). Of the total study participants, 23.67% ($n = 58$) did not know regarding the safety of the technology available for use (Figure 7b). An important parameter that influences the effectiveness of the instantaneous disinfection process is the ability of the technology to evenly distribute the biocidal agent onto the surfaces of interest (PPE). Therefore, the participants were questioned about the visual perception regarding the uniform distribution of the droplets of the biocidal agent that were produced during spraying. The results showed that 51.43% ($n = 126$) of the professionals noticed that after passing through the chamber (a process that lasted between 10 and 30 s), all the PPE surfaces were uniformly humidified, whereas the percentage of those who did not notice or did not know was 23.27% ($n = 57$) and 25.31 ($n = 62$), respectively, without significant difference between responses ($p > 0.05$) (Figure 7c). Some of the professionals who reported the non-uniformity of the biocidal agent distribution on the PPE (four professionals from Hospital Espanhol and three professionals from Hospital Arena Fonte Nova) suggested that additional nebulizer nozzles could be installed in other locations within the chamber, mainly below the knees, in addition to necessary adjustments in the intensity of the biocidal agent solution spray.
Figure 7. Perception of professionals as evaluated using the following survey questions: (a) Did you know that the chamber was developed to reduce the microbial load, including that of the new coronavirus (severe acute respiratory syndrome coronavirus 2 [SARS-CoV-2]), from the surface of personal protective equipment (PPE)? (b) Do you consider the use of the disinfection chamber before the PPE doffing process to be a safe option? (c) Did you notice if after using the chamber, all surfaces of the personal protective equipment (PPE) were uniformly humidified? * represents \( p < 0.05 \) by Friedman test with Dunn’s multiple comparisons test.

The last four research questions in the questionnaire for data collection are presented in Figure 8. In this study, important results were obtained regarding the perception of the importance of the technology as a safe and effective option for PPE disinfection during the SARS-CoV-2 pandemic. As Figure 8a shows, 75.10% or \( n = 184 \) of the professionals considered the disinfection chamber that was developed for exclusive use in hospitals as an important and effective protective barrier for healthcare professionals when applied before the PPE doffing process. Only 7.35% \( (n = 18) \) of the interviewees did not consider the use of the proposed technology as an effective measure, and 17.55% \( (n = 43) \) did not express an opinion. Among the interviewees, 47.35% \( (n = 116) \) responded that the use of the chamber would not cause a false sense of security for the users (Figure 8b), and 20.41% \( (n = 50) \) did not express an opinion (with significant difference between responses \( p < 0.05 \)), totaling 67.75% \( (n = 166) \). However, 32.24% \( (n = 79) \) of the participants were of the opinion that the technology could lead to a false sense of security for professionals. When questioned about the false sense of safety, professionals from Hospital Espanhol stated that it was related to the area chosen for the installation of the chamber, and suggested a greater proximity to the exit area of the ICU and the wards. In the hospital in question, although the location of the chamber was in accordance with the basic premise of the study, many professionals did not carry out doffing of the PPE before passing through the
chamber, as they preferred to carry out this process within the ICU or the ward. In addition, professionals from Hospital Ernesto Simões (n = 11), Hospital Arena Fonte Nova (n = 12) and Hospital Espanhol (n = 5) reported that the false sense of safety could be related to the lack of uniformity in the coverage of the PPE surface (mainly near the knee) by the biocidal agent, which could lead to inefficient disinfection. It is important to highlight that a great majority of the professionals interviewed (97.55% or n = 239) stated that they were aware that even with the use of the camera for instantaneous disinfection of the PPE, the doffing process should be performed strictly respecting all biosecurity procedures and following all protocols of the hospital of origin. However, 2.45% (n = 6) of the participants responded that they “not” about the need to follow biosafety procedures, with significant difference between responses p < 0.05 (Figure 8c). This result may be related to the high percentage of professionals (86.94%, n = 213) who followed all the appropriate procedures for the doffing process after using the chamber, since only 0.85% (n = 2) reported that they did not follow the doffing procedures, and 12.24% (n = 30) reported that they could not answer the question (Figure 8d). Among the professionals who stated that they were not aware of the need to follow the doffing protocols or that they did not do so, none were healthcare professionals.

**Figure 8.** Perception of professionals as evaluated using the following survey questions: (a) Do you consider the disinfection chamber to be effective as an additional protective barrier for healthcare professionals? (b) Do you consider that the use of the disinfection chamber can lead to a false sense of security? (c) Did you know that even with the use of the camera, all the procedures for doffing must be strictly followed? (d) After using the chamber, have you followed all the appropriate procedures for the doffing process? * represents p < 0.05 by Friedman test with Dunn’s multiple comparisons test.
4. Discussion

Since the “Black Death” in the 14th century (1347–1351), different measures have been taken to contain the spread of the Yersinia pestis bacterium, such as the use of masks by doctors [65], and social isolation (quarantine) of the infected individuals [66]. More recently, in the 20th century, different pandemics have occurred, such as those associated with genetic variants of the influenza type A viruses (Spanish flu and swine flu) [67,68]; Ebola [69]; severe acute respiratory syndrome (SARS) [70]; and middle eastern respiratory syndrome (MERS) [71]. This has fostered the search for new immunization technologies [72], more efficient drug therapy [73], different types of diagnostic methods [74], and new or improved PPEs [75]. The importance of hand hygiene in controlled environments for the control of infection rates is also well understood [76–78].

When the study was conducted, Brazil had the highest mean transmission potential (R₀) for SARS-CoV-2, compared to countries such as Italy, the United Kingdom, France, and Spain [79], which have recorded high infection rates. Several factors contributed to Brazil presenting this high rate of transmission, and, consequently, a periodic weekly increase in the number of cases of COVID-19 [80]. Among these factors, we can highlight the low test rate per inhabitant [79], the lack of essential safety measures for healthcare professionals such as adequate PPE [81], different social and economic behaviors in each region (state) of the country [82], and the lack of articulated public policies to face the pandemic in the national territory [81,83]. However, the state of Bahia, located in the Northeast region of Brazil, adopted immediate measures to confront the COVID-19 pandemic, such as restricting the mobility of citizens, implementing sanitary barriers, rapidly opening field hospitals, increasing the number of hospital beds, and creating a scientific committee to encourage research for innovative measures [84]. Due to these measures, the number of hospital beds deployed by the state of Bahia that were dedicated to COVID-19 patients (n = 2833) was larger than that deployed by other northeastern states [85], such as Pernambuco and Ceará, with 1543 and 2648 beds [86,87], respectively, as well as the states of other regions, such as Amazonas in the northern region (n = 681) [88]. In total, two field hospitals were built and made available exclusively for the treatment of COVID-19; the Hospital Espanhol with 160 beds and the Hospital da Arena Fonte with 180 beds participated in this study [85]. In this context, disinfection chambers were made available for exclusive use in healthcare units in order to minimize the possible risk of the self-contamination of healthcare workers during the doffing of PPEs.

It is important to highlight that devices for disinfecting surfaces, environments, and people (despite the absence of recommendations for this purpose by health organizations and agencies) have become popular in different countries, including Brazil. Thus, although Anvisa (in Brazil) issued an official technical note recommending against the use of cameras or devices for direct application in people, the use of biocidal agent spraying systems for the “disinfection” of individuals in places with a high circulation of people, such as shopping centers and public squares, was observed in some regions of the country [89–91]. It should be emphasized that the use of biocidal agents, mainly disinfecting agents, can cause adverse health effects through direct contact with mucous membranes and other regions of the human body [29]. Thus, even during a pandemic, safety criteria should always be recommended to maintain the well-being of the population.

Thus, the development of new technologies must always be associated with proof of effectiveness [53], safety, and user acceptance. We highlight that, because the disinfection chamber is a new technology [49], no study available in the literature has been carried out with the objective of evaluating its perception among professionals. In this context, the results found in this study showed that, in general, professionals from the different hospitals and healthcare units investigated had a positive perception regarding the safety and efficacy of using the chamber for the instantaneous decontamination of PPE. This demonstrates that the technology could potentially be applied prior to PPE doffing during the COVID-19 pandemic (mainly in reference hospitals designated for the treatment of COVID-19).
Rock et al. [92] evaluated the perception of healthcare workers regarding the use of a new technology for surface disinfection. They investigated the daily impact of disinfection by ultraviolet light (UV)-C for the reduction in infections related to the nosocomial environment. In agreement with the results of the present study, the authors reported a positive perception by healthcare workers, who believed that the daily use of the technology decreased the risk of patients acquiring infections, and a perception of “acceptable” by patients, who reported an improvement in their experience during the time of hospitalization [92]. A similar investigation was also performed by Duun et al. [93] in relation to the perception of healthcare workers, general service providers, and patients, in the use of UV light for the decontamination of environments (hospital rooms). The results of the study showed that the vast majority of patients, healthcare workers, and environmental services staff presented a positive perception for the use of UV-C light technology in the prevention of possible infections in a hospital environment. In addition, different studies have shown that the control of nosocomial infections can result in a reduction in the period of hospitalization of the patient and can result in financial benefits for the institution [94–96].

It is important to highlight that only 15.10% of participants reported moderate or severe adverse events, as well as the absence of the need for any type of medical intervention in mild events. In this context, the most reported episodes were eye and throat irritation, which together accounted for 44.6% of the total number of adverse events. These results indicate that the use of PPE (donning of PPE), such as face masks and goggles, reduces the possibility of contact of the biocidal agent with the mucous membranes or other regions of the human body, and, consequently, the possibility of adverse events. Some studies have reported that depending on the level of exposure, sodium hypochlorite can be toxic when in contact with the mucous membranes or skin and can lead to tissue injury or cause allergic reactions [97,98]. The concentration of sodium hypochlorite is also important when it comes to chronic exposure, since it has been reported that long exposure to this agent can lead to non-allergic symptoms, such as non-allergic asthma [99]. However, in vivo tests showed that exposure for 14 days to an aerosolized form of active chlorine at a concentration of $1.7 \pm 0.13 \text{mg/m}^3$ did not result in significant toxic effects [100].

Thus, our results demonstrate that the practice of using PPE can be extrapolated beyond the nosocomial environment, resulting in protocols for surface disinfection that consider the correct use as a way to mitigate the adverse events that are caused by biocidal agents such as sodium hypochlorite. A study by Carpenter et al. [101] showed that prolonged exposure to chlorine solution at a concentration of 0.5% during continuous decontamination procedures of an Ebola treatment unit caused an episode of respiratory difficulty in only one patient. However, such an episode could also be associated with the patient’s previous clinical status. In another study, cleansing paper towels with 0.05% or 0.25% of active chlorine were used for immediate hand disinfection, and the effectiveness and potential of their use during the COVID-19 pandemic was demonstrated [102].

The complete removal of pathogens such as SARS-CoV-2 from the surface of PPE could also allow the reuse of these PPE [103]. During times of crisis in the public health system, one of the main concerns is the scarcity of PPE, which makes the population, especially healthcare workers, highly vulnerable [104]. In view of this, the WHO, by means of an interim guide, has recommended the rational use of PPE for healthcare workers who are dedicated to COVID-19 management [105]. The guide document recommends that a sodium hypochlorite solution at a concentration of 0.1% (1000 ppm) be used in the process of sanitizing goggles for healthcare workers so that the goggles can be reused [105]. Thus, the reuse of some of the PPE could also be performed after the disinfection process by means of the technology investigated (instantaneous disinfection by spraying), which could directly contribute to the rational use of PPE during the pandemic.

Finally, it is highlighted that the occurrence of emergencies/crises in the healthcare arena favors the search for and implementation of new coping measures. This ensures that emergent diseases are quickly elucidated, and, consequently, that new therapies and control methods are proposed [106–108]. In this context, the COVID-19 pandemic has
led to the development or improvement of different health strategies. Such strategies include the construction of field hospitals with beds dedicated to the treatment of patients with respiratory failure [109]; the development of low-cost portable lung ventilators [110]; research into innovative technologies for monitoring hand hygiene [111]; and the advancement of telemedicine [112,113]. In addition, devices to reduce the spread of the virus in nosocomial environments are also being developed, such as boxes for containing aerosols for application during the intubation of infected patients [114,115], and spraying systems for the rapid decontamination of surfaces [3,116]. Our study has some limitations, since even with a representative sample being included, only three hospitals from the COVID-19 patient care network in Salvador (from at least 14 healthcare facilities) were included in the clinical trial. Furthermore, by using a convenience sampling, comparison of the perception of the new disinfection technology from the study population to all hospital professionals may be limited. The study is also prone to social desirability bias, which could lead to over/underestimation of the results, even though social issues are not the focus of this clinical trial.

Nevertheless, the professionals participating in the study reported a high rate of acceptance of the disinfection technology. Thus, this technology can serve as an effective option to confront and combat COVID-19, especially in countries with a high infection rate. The use of disinfection chambers can contribute to the reduction in the self-contamination rate of professionals during the PPE doffing process. This technology can also aid in the control of the load of microorganisms in nosocomial environments, which is one of the main public health problems worldwide [5,117,118].

5. Conclusions

The results of this study demonstrated a positive perception among professionals from different hospitals and healthcare units who used the decontamination chamber for the instantaneous decontamination of PPE before the doffing process. Based on the results that were obtained regarding the perception of efficacy and safety, the technology can be an effective option to control the load of microorganisms in controlled environments. This equipment can be used in reference hospitals that are designated for the treatment of patients with COVID-19, mainly to avoid self-contamination of the healthcare workers during the doffing of PPE. The PPE doffing process is considered critical due to the high transmission capacity of SARS-CoV-2. It is also important to install disinfection chambers in areas near the ICUs and wards to be used by professionals who have donned PPE, so as to avoid any type of direct contact with the biocidal agent. Additionally, it can be used by professionals after contact with patients or at the end of their work shift. The results found in this study demonstrate the safety and usefulness of disinfection technologies in environments where the microbial load must be controlled, especially during the COVID-19 pandemic.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app12157771/s1, Table S1: Questionnaire of the experimental use of the disinfection chamber; Table S2: Absolute and relative frequency of responses to survey questions evaluated in this study according to the hospital or healthcare unit (values in percentages (%) are presented in brackets).

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of SENAI CIMATEC University Center (No. 413273 and date of approval was 3 July 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors would like to thank the staff of all the hospitals and healthcare units who participated in the study, all the professionals who kindly and voluntarily agreed to participate in the survey, the teams from the SENAI units located in the interior of the state of Bahia who provided support in the application of the questionnaires, and SEPLAN. The authors are also grateful to CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) (BASM is a Technological fellow from CNpq 306041/2021-9).

Conflicts of Interest: The authors declare no conflict of interest.

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