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Potential use of 3-(trimethoxysilyl)propyldimethyl octadecyl ammonium chloride as an antimicrobial and antiviral agent for the disinfection of personal protective equipment

Yujin Kim[1], Hana Youn[2], Junbeom Kim[2], Daye Lee[2], Seonghye Go[2], Ji-eun Park[2], Sunhak Lee[1], Jinyong Noh[2], Sang-Soep Nahm[1]

[1]College of Veterinary Medicine, Konkuk University, Seoul; [2]Konkuk Ctc Bio Animal Vaccine Co. Ltd., Seoul, Korea

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Corresponding author: Sang-Soep Nahm, DVM, PhD
College of Veterinary Medicine, Konkuk University, 120 Neungdong-ro, Gwangjin-gu, Seoul 05029, Korea
Tel: +82-2-450-3706
Fax: +82-2-450-3037
E-mail: ssnahm@konkuk.ac.kr

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Currently, no vaccine or established therapeutic agents are available for coronavirus disease 2019. The sharp increase in demand for personal protective equipment (PPE) necessitates an improvement in the protective efficacy of PPE. We evaluated the potential antimicrobial and antiviral effects of a surface-coating disinfectant (3-(trimethoxysilyl)propyldimethyl octadecyl ammonium chloride, Si-QAC) when applied onto PPE. Si-QAC-pre-coated PPE was artificially contaminated with either influenza virus or *Salmonella*. The results showed significantly reduced influenza and *Salmonella* titers in Si-QAC-coated PPE; these antimicrobial effects lasted 7 days. This suggests that this surface-coating disinfectant effectively reduces pathogen contamination of PPE, enabling their safe and long-term use.

Keywords: Coating disinfectant, Si-QAC, Antimicrobial, Antiviral, Long-lasting

The new coronavirus disease 2019 (COVID-19) is posing a dire health threat to the world. It has spread to more than 202 countries, and over 470,000 cases have been confirmed globally [1]. Approximately 9,241 cases have been confirmed in Korea as of March 26, 2020 [2], and the increasing numbers of patients are causing a significant medical burden. The virus is not a conventional coronavirus that infects the human body, but is an animal-originated virus adapted to the human body as a highly contagious pathogen [3].

The frontline protection primarily used in pandemic situations is vaccination. In addition, therapeutic agents for the disease should be available [4]. However, as of now, no vaccine has been developed for COVID-19, and it is expected that a vaccine will take a relatively long time to become available for public use. Recently, considerable efforts have been made to find an effective treatment for COVID-19 by repurposing or combining existing drugs [5].

Under this emergency situation, it is especially important for high-risk individuals to thoroughly prevent COVID-19 infection by maintaining personal hygiene and using protective equipment such as masks [6]. Personal protective equipment (PPE) plays a very important role in controlling the spread of diseases through direct or indirect contact exposure. Viruses that can cause respiratory symptoms such as coronavirus,

influenza virus, or rhinovirus are transmitted through contact with respiratory epithelial cells in the form of droplets or aerosols [7]. Recently, the increasing demand for PPE in this pandemic situation has resulted in a shortage of masks and protective clothing in several essential environments such as hospitals. Thus, it is necessary to develop effective ways to either use PPE for longer periods of time or improve their protective efficacy.

There have been many attempts to develop safer and more effective disinfectants, for example, a long-lasting physical disinfectant, using carbon-nanostructures [8] or salt crystals [9]. Surface-coating disinfectants are different from conventional disinfectants in terms of their mechanism of action and the duration of their effects. Organosilicon (3-(trimethoxysilyl) propyldimethyl octadecyl ammonium chloride, Si-QAC), which was used in this experiment, is a surface-coating disinfectant that forms spike-like structures on various surfaces and puts pressure on cell membranes using its protruding structure; therefore, it is expected to exert physical antimicrobial effects (Fig. 1). In this article, we examined the potential use of Si-QAC as an antimicrobial to disinfect PPE.

To conduct the disinfection efficacy test, we used three types of commercially available healthcare masks (HDmedis, Bucheon, Korea; Hyundai Chemical, Seoul, Koea; and Welkeeps, Seoul, Korea) and four types of protective clothing (Mtech STS, Daejeon, Korea; Yuhan-kimberly, Seoul, Korea; 3M, St. Paul, MN, USA; and DuPont, Wilmington, DE, USA).

In the control group, the materials were artificially contaminated with either influenza virus (A/NWS/33(H1N1), 10^7 tissue culture infectious dose [TCID]/mL; H9N2, 10^8 TCID/mL) or *Salmonella typhimurium* (10^8 CFUs/mL) as pathogens by spraying 100 μL of the sample of each pathogen on the test materials from a distance of 25 cm. In the experimental group, the test materials were coated with Si-QAC (SDpro; SDLab Korea, Seoul, Korea) by spraying 4 mL/m^2 of the disinfectant before contamination with the same amount of *Salmonella* or influenza samples. Antimicrobial or antiviral effects were measured by culturing the pathogens from the PPE in either nutrient agar or Madin-Darby Canine Kidney cell culture.

We also examined the efficacy of microbial contamination inhibition under field conditions by wearing disinfectant-

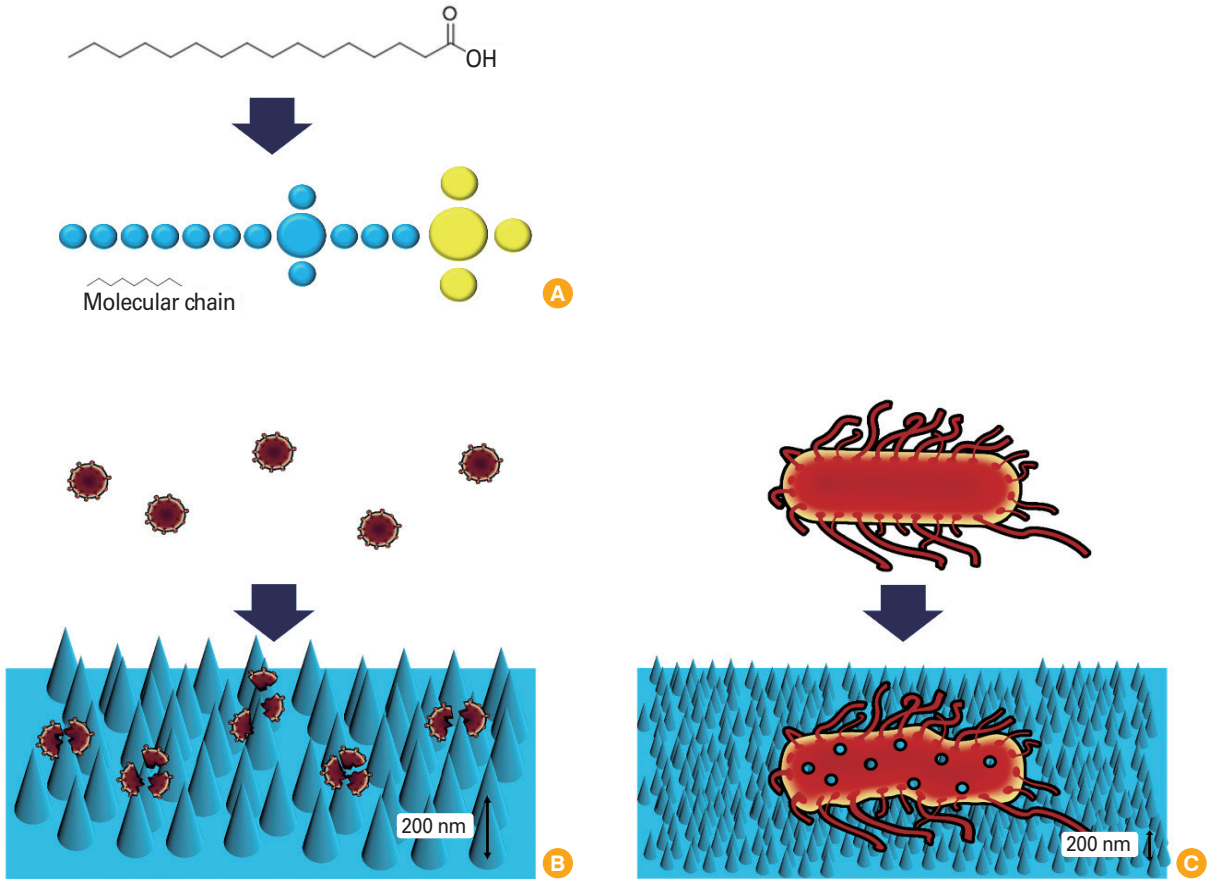

Fig. 1. Schematic diagram of the disinfectant used in the test (A), and the mechanism of action on a virus (B) and bacteria (C).

coated or non-coated protective clothing during the processes of transporting, packing, and cleaning in a food-processing factory. The used protective clothing were individually packaged and transported to the lab. After using the protective clothing for 8 hours, the number of bacteria was measured by swabbing the clothes in the middle of the neck, left sleeve, and hem of the clothing and dissolving the swabs in PBS for subsequent microbial culture.

The average reduction in influenza virus in the protective clothing was $10^{2.7}$ and $10^{4.1}$ $TCID_{50}$/mL for samples from which the virus was retrieved immediately and after 15 minutes, respectively, compared to the controls (Fig. 2A). For mask samples, after 30 minutes of reaction, the average reduction was $10^{2.5}$ $TCID_{50}$/mL in viral tests; a 115-fold reduction was observed in the bacterial tests (Fig. 3A, B). The antimicrobial effects lasted at least 7 days (Fig. 3C). In the field test, results varied slightly depending on the type of activity and the location of the measurement; however, on average,

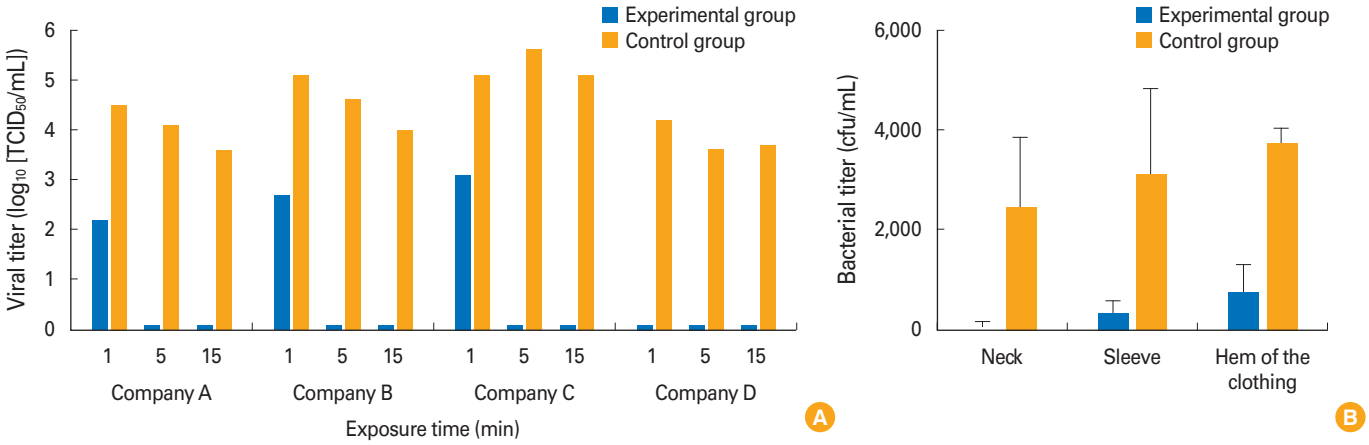

Fig. 2. Antiviral (A) and antimicrobial (B) effects of 3-(trimethoxysilyl)propyldimethyl octadecyl ammonium chloride when applied on protective clothing. $TCID_{50}$, 50% tissue culture infectious dose.

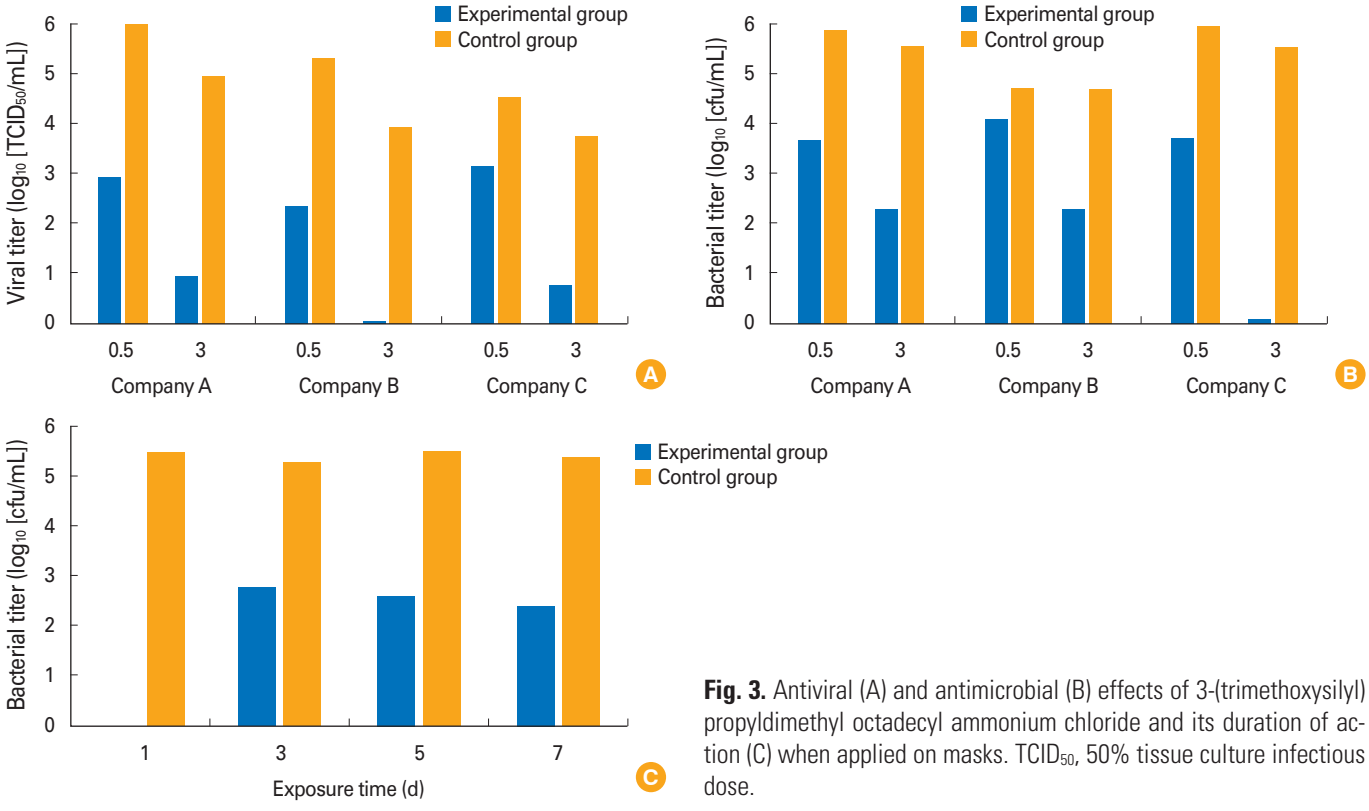

Fig. 3. Antiviral (A) and antimicrobial (B) effects of 3-(trimethoxysilyl) propyldimethyl octadecyl ammonium chloride and its duration of action (C) when applied on masks. $TCID_{50}$, 50% tissue culture infectious dose.

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the number of bacteria measured was about 30 times lower in the experimental group than in the controls (Fig. 2B).

In this study, we examined the effectiveness of applying surface-coating disinfectant onto PPE such as masks and protective clothing. It was observed that applying the disinfectant significantly decreased the bacterial and viral contamination on the surface. Tamimi et al. [10] and Orti-Lucas and Munoz-Miguel [11] also indicated that microbial contamination can be reduced via the surface coating of equipment with various substances, which is in agreement with our results.

There is an increasing demand for PPE to prevent COVID-19 infection, resulting in shortages of masks and other items. This often results in the need to use PPE for longer periods of time or even reuse them, which may reduce the demand for PPE. Based on the results of our study, it is expected that PPE coated with Si-QAC would provide a higher degree of antibacterial and antiviral protective effects. According to Tomas et al. [12], medical personnel can be contaminated while removing their soiled gloves and gowns. Thus, it is expected that the use of surface-coating disinfectants may reduce the risk of spreading pathogens upon disposal of used PPE.

The surface-coating disinfectant used in this test inactivates the pathogen by damaging the envelope of the pathogen and exerting its physical structure-based mechanism of action [13]. Damage to cell membranes leads to the antimicrobial effect. The longer the duration of interaction between the nanostructure and bacterial cell, the greater the extent of damage, which results in the bactericidal activity; our results are consistent with this theory. In contrast, a virus is relatively small in size; therefore, the disinfectant exerts less pressure on the surface of the virus compared to fungi and bacteria. Thus, the reduction in viral titer is considered to be the result of not only simple damage to the viral envelope but also the trapping phenomenon caused by the electrical force exerted by nanostructures. Recently, Quan et al. [9] reported a similar concept of disinfection using salt crystals. They coated a mask filter with salt to cause the virus to quickly lose its infectivity. The mechanism of action of the surface-coating disinfectant used in this experiment is quite different from that of the salt crystals because this agent adheres to the surface of the PPE via covalent bonding. Thus, the application of this disinfectant to surfaces with high probability of pathogen contamination, such as ambulances or medical facilities, is likely to have a significant disinfection effect. This would be helpful to people who are at a high risk of exposure to pathogens, such as patients and hospital/health workers.

ORCID

Yujin Kim *https://orcid.org/0000-0002-0073-8705*
Hana Youn *https://orcid.org/0000-0001-5105-3987*
Junbeom Kim *https://orcid.org/0000-0001-9770-1185*
Daye Lee *https://orcid.org/0000-0002-9261-6704*
Seonghye Go *https://orcid.org/0000-0002-9589-5147*
Ji-eun Park *https://orcid.org/0000-0002-4633-3500*
Sunhak Lee *https://orcid.org/0000-0002-0960-0550*
Jinyong Noh *https://orcid.org/0000-0003-4824-2335*
Sang-Soep Nahm *https://orcid.org/0000-0002-0519-580X*

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