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Control of Healthcare-Associated Infections using Silver Nanoparticles in Radiology

Gyunheung Ahn, Sungchul Kim¹

Department of Radiology, Chung-Ang University Hospital, Heukseok-ro, Dongjak-gu, Seoul, ¹Department of Radiological Science, Gachon University Medical Campus, Hambangmoe-ro, Incheon, Republic of Korea

Abstract

Aims: The control of healthcare-associated infections (HCAIs) is a significant concern in the field of radiology due to multiple contact-transmitted pathogens on imaging devices. The antimicrobial effects of silver nanoparticles (AgNPs) in preventing HCAIs and their effects on imaging quality were evaluated. **Methods:** The antimicrobial effects of AgNPs were tested on prevalent contact-transmitted pathogens present in radiology examination rooms, including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant Enterococci (VRE), *Pseudomonas aeruginosa*, and *Acinetobacter baumannii*. Furthermore, we investigated the effects of AgNPs on X-ray image quality using humanoid head and hand phantom. **Results:** AgNPs did not affect the quality of X-ray images. They had antimicrobial effects against Gram-positive *Bacillus*, including MRSA, VRE, and Gram-negative *Bacillus*, including *P. aeruginosa* and *A. baumannii*. **Conclusion:** AgNPs are considered effective in controlling HCAIs in radiology through sterilization by coating shooting devices and accessories where physical contact between patients and healthcare professionals is frequent.

Keywords: Contrast-to-noise ratio, healthcare-associated infections, radiology, signal-to-noise ratio, silver nanoparticles

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INTRODUCTION

Healthcare-associated infections (HCAIs) occur during medical procedures or treatments in medical institutions. HCAIs have emerged as a critical issue since the number of invasive procedures and tests has increased along with antibiotic-resistant pathogens.^[1] Sources of HCAIs are classified as endogenous and exogenous. Prevention of endogenous infection is relatively difficult since the microorganisms that the patient possesses are the sources of infection. Exogenous sources of HCAIs are other patients, hospital staff members, visitors, medical equipment, and other items in the hospital setting.^[2] HCAIs cause sickness, increase medical costs, and lead to the creation of new resistant pathogens.^[3]

Over the past 30 years, the risk of HCAIs in the radiology department has increased due to an increased number of patients visiting and increased number of X-ray examinations.^[4]

Methicillin-resistant *Staphylococcus aureus* (MRSA) nearly accounts for half of all the deaths caused by antibiotic-resistant organisms,^[5] and vancomycin-resistant *Enterococci* (VRE), another concerning HCAI pathogen, can be transmitted

to healthcare professionals or patients by contaminated surroundings, nonsymptomatic staff, and patients, or medical devices.^[6] Immunocompromised patients who contract *Pseudomonas aeruginosa*, a super bacterium, and progress to sepsis have a mortality rate of more than 60% because it is hard to cure.^[7] *Acinetobacter baumannii*, a Gram-negative, nonglucose fermented, and opportunistic pathogen, also causes community-acquired infections.^[8]

Silver nanoparticles (AgNPs) are nontoxic, have antimicrobial and sterilization effects, can be mass produced, and applied almost anywhere. AgNPs cause DNA damage and decrease the function of proteins in microorganisms, essentially inactivating them, especially in the form of dissolved ions. These traits allow AgNPs to be applied as an antimicrobial agent in many situations.^[9]

Address for correspondence: Prof. Sungchul Kim,

Department of Radiological Science, Gachon University Medical Campus,
21936, 191 Hambangmoe-ro, Incheon, Republic of Korea.

E-mail: ksc@gachon.ac.kr

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This study aimed to understand the infection risks of contact-transmitted HCAs from diagnostic X-ray devices in radiology, evaluate changes in X-ray results after AgNPs application, and provide basic data on the use and safety of AgNPs in radiology.

METHODS

In radiology, HCAs occur in places where patients and workers come in contact, such as IP cassette, patient table, and stand bucky,^[10-12] leading to infections in both patients and workers. Since AgNPs are harmless to the human body and possess excellent sterilization ability, this study was conducted based on the hypothesis that diluting silver nanoparticles of less than 100 nm in physiological saline will provide a sterilization effect without adversely affecting the image quality of diagnostic X-ray scans.

Antimicrobial effects of silver nanoparticles

The antimicrobial effects of AgNPs were tested^[13] on prevalent contact-transmitted pathogens present in radiology examination rooms, including MRSA, VRE, *P. aeruginosa* (ATCC 27853 strain), and *A. baumannii* (H 10887 strain).^[14,15]

The control group samples of four pathogens were prepared using 0.5 McFarland standard turbidity ($OD_{600} = 0.08 - 0.13$; 1.5×10^8 CFU/ml) with a digital turbidity meter (DensiCHEK Plus, Biorad, USA). The test group standards were established using a 20 ppm AgNP solution where *Salmonella* was unable to proliferate in the pilot test. A platinum loop was dipped into each solution of four pathogens, and 20 ppm of AgNPs was added to 0.001 ml of each pathogen solution [Figure 1]. After evenly mixing the solution using an automatic



Figure 1: Samples of control groups (a-d) and test groups (e-h) for each MRSA, VRE, *Pseudomonas aeruginosa*, and *Acinetobacter baumannii*. MRSA: Methicillin-resistant *Staphylococcus aureus*, VRE: Vancomycin-resistant *Enterococci*

blender, the cells were cultured for 24 h in an incubator (Forma Series II, Thermo Electron Corporation, USA). We collected 0.001 ml of each sample under an ambient air environment ($35^\circ\text{C} \pm 2^\circ\text{C}$), spread them evenly on Mueller–Hinton agar, and incubated for an additional 24 h. The plates were checked for colonies after total 48 h of incubation.

Effects of silver nanoparticles on X-ray image quality

To investigate the effects of AgNPs (SilverGEN, Nano Chemical Co. Ltd.) on X-ray image quality, 24 cc of normal saline and 24 cc of AgNP substance (20 ppm) were prepared on two 9 cm Petri dishes. Each Petri dish was located between the humanoid head and hand phantom (Model: PUB-50, Kyoto Kagaku Co., Ltd.) image detector; skull AP (74 kVp, 200 mA, 100 ms) and hand AP (50 kVp, 100 mA, 50 ms) were taken using a digital radiographic device (GC85A, SAMSUNG, Korea) under adult sizing conditions in a hospital with 10 repetitions per position.

The same size region of interest (ROI) was set in the Marotech Maro View Program (Infinit, Republic of Korea) using the images. Background areas of the skull AP image were defined using the glabella area as the center of the image and the left marginal area. The hand AP image was defined using the third distal metacarpus as the center of the image and the left marginal area. Then, the signal-to-noise ratio (SNR) (Equation 1)^[16] and contrast-to-noise ratio (CNR) (Equation 2)^[16] were measured to evaluate the image quality of the X-ray [Figures 2 and 3].

$$SNR = \frac{Background SI_{Avg} - ROI SI_{Avg}}{ROI SD} \quad (1)$$

$$CNR = \frac{Background SI_{Avg} - ROI SI_{Avg}}{\frac{1}{2} \sqrt{(Background SD^2 - ROI SD^2)}} \quad (2)$$

where Background SI_{Avg} : The average intensity of the background signal; ROI SI_{Avg} : The average intensity of the ROI signal; ROI SD_{Avg} : Standard deviation of the intensity of the ROI signal; Background SD: Standard deviation of the intensity of the background signal.

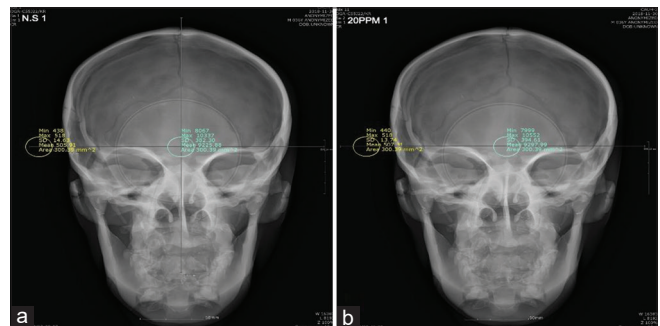


Figure 2: SNR and CNR of normal saline (a) and silver nanoparticle substance (b) during the X-ray test with the head humanoid phantom. SNR: Signal-to-noise ratio, CNR: Contrast-to-noise ratio

Statistical validation

The mean values of SNR and CNR were compared between two groups of images containing normal saline and 20 ppm of AgNPs. Since the number of samples in each group was 10 and a normal distribution could not be assumed, a nonparametric Mann–Whitney test was performed, using SPSS Version 23.0 (IBM Corporation, Chicago, NY, USA). The P value significance threshold was set to 0.05.

RESULTS

Antimicrobial effects of silver nanoparticles

The control groups showed pathogen proliferation [Figure 4]. In contrast, no proliferation was found for all four pathogens with 20 ppm of AgNPs after 48 h in culture [Figure 5].

Effects of silver nanoparticles on X-ray image quality

The SNR of normal saline and 20 ppm of AgNP using the head humanoid phantom was -22.88 ± 0.12 and -22.81 ± 0.22 , respectively, and the CNR was -45.03 ± 0.07 and -44.9 ± 0.15 , respectively. With respect to the comparison of the mean values of SNR and CNR using head phantom by the Mann–Whitney test, the significance levels of SNR and CNR was $P = 0.280$ and $P = 0.143$, respectively, which was greater than 0.05, demonstrating no difference in image quality between the two groups [Table 1].

The SNR of normal saline and 20 ppm AgNPs solution using the hand humanoid phantom was -18.7 ± 0.57 and -18.7 ± 0.28 , respectively, and the CNR was -37.1 ± 1.10 and -37.0 ± 0.55 , respectively. With respect to the comparison of the mean values of SNR and CNR using hand phantom by the Mann–Whitney test, significance levels of SNR and CNR were $P = 0.315$ and $P = 0.315$, respectively, which were greater than 0.05, demonstrating no difference in image quality between the two groups [Table 2].

DISCUSSION

Radiology examination rooms are full of patients and staff handling equipment and coming into contact with each other.^[17] Infection management such as radiology infection control training, regular disinfection of equipment, and hand

hygiene are necessary to prevent the spread of HCAs. Since patients are coming from all hospital areas 24 h a day, this area has a higher risk of HCAs than other departments. For this reason, in 2010, the Ministry of Health and Welfare suggested systemic and intensive control by preparing a document called “the disinfection guideline for the tools and equipment in the medical institutions.”^[18]

According to previous studies on the contamination of X-ray devices and accessories in radiology, multiple pathogens including MRSA, VRE, *A. baumannii*, and *P. aeruginosa* generate contact-transmitted infections and cross-infection.

Table 1: Signal-to-noise ratio and contrast-to-noise ratio tests of images using the head humanoid phantom analyzed by the Mann-Whitney U test

	SNR	CNR
Mann-Whitney U	35.000	30.000
Wilcoxon W	90.000	85.000
Z	-1.134	-1.512
Approximate significance probability (two sides)	0.257	0.131
Significance probability (2 X [one-sided significance probability])	0.280	0.143

SNR: Signal-to-noise ratio, CNR: Contrast-to-noise ratio

Table 2: Signal-to-noise ratio and contrast-to-noise ratio tests of images using the hand humanoid phantom analyzed by the Mann-Whitney U test

	SNR	CNR
Mann-Whitney U	36.000	36.000
Wilcoxon W	91.000	91.000
Z	-1.058	-1.058
Approximate significance probability (two sides)	0.290	0.290
Significance probability (2 X [one-sided significance probability])	0.315	0.315

SNR: Signal-to-noise ratio, CNR: Contrast-to-noise ratio

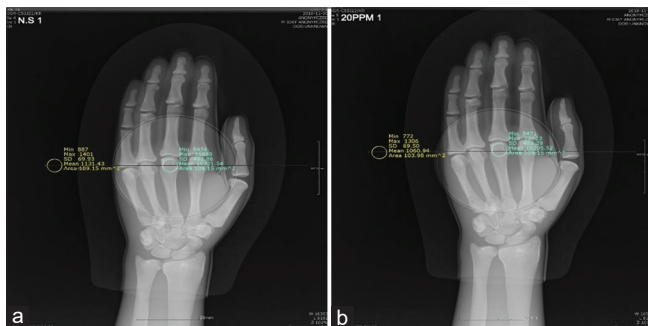


Figure 3: SNR and CNR of normal saline (a) and silver nanoparticle substance (b) during the X-ray test with the hand humanoid phantom. SNR: Signal-to-noise ratio, CNR: Contrast-to-noise ratio

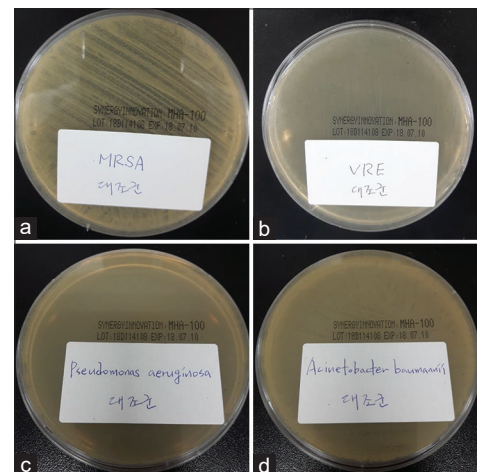


Figure 4: Control group (MRSA (a), VRE (b), *Pseudomonas aeruginosa* (c), and *Acinetobacter baumannii* (d)) proliferation assay after 48 h in culture. MRSA: Methicillin-resistant *Staphylococcus aureus*, VRE: Vancomycin-resistant Enterococci

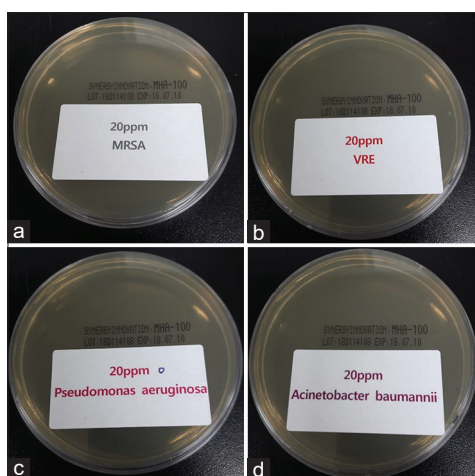


Figure 5: (a-d) HAI pathogen group (MRSA (a), VRE (b), *Pseudomonas aeruginosa* (c), and *Acinetobacter baumannii* (d)) proliferation assay after 48 h in culture with 20 ppm silver nanoparticles. MRSA: Methicillin-resistant *Staphylococcus aureus*, VRE: Vancomycin-resistant Enterococci

Infections can be transmitted by diagnostic X-ray devices, mobile X-ray devices, IP Cassettes, CR developer, surrounding environment of examination rooms, and so on.^[10-12]

Previous results show that radiographers have low levels of personal sanitation control, cleaning, and environment control, demonstrating their lack of awareness of hospital infection control.^[19] This proved that alternative sanitation control needs to be considered.

Stevens *et al.* reported that the COVID-19 pandemic would affect HCAI monitoring and prevention efforts, although its influence on typical HCAI has yet to be determined.^[20]

To reduce infections in radiology, studies have assessed the use of disinfectant tissue containing alcohol and disinfectant^[10] and disinfection by diluting lacquer in water,^[11] but it was found that the sterilization effect of AgNPs was excellent. In addition, the method of diluting AgNPs with a size of 100 nm or less in saline was recognized for its excellent antibacterial effect without affecting image quality (Korean Patent No. 20-0492213).

To lower the impact of HCAI in radiology, use of AgNPs coating as an assisted tool may be an alternative to supplement primary sanitation and environment controls.

There were some limitations to this study, the proliferation of only four pathogens was measured for 48 h, and the image quality was evaluated by SNR and CNR methods. Further studies are required with an increased number of pathogens and longer-term antimicrobial effects. Additional testing is also necessary to apply the clinical practices using a coated shooting table.

CONCLUSION

The 20 ppm AgNPs solution showed excellent antimicrobial and sterilization effects against Gram-positive *Bacillus*,

including MRSA and VRE, and Gram-negative *Bacillus*, including *P. aeruginosa* and *A. baumannii*, without influencing the quality of X-ray images. AgNPs are considered effective in controlling HCAI in radiology through sterilization by coating the shooting devices and accessories where physical contact between patients and healthcare professionals is frequent.

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Conflicts of interest

There are no conflicts of interest.

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