The Egyptian Journal
of Critical Care Medicine

CASE REPORT Open Access

Revolutionizing infection control in ICUs: photocatalytic binder materials with platinum nanoparticles

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Abstract
We present maintenance-free, spray-applied binder materials that photocatalytically form and permanently adhere uniformly distributed platinum nanoparticles on solid and textile surfaces, enabling instantaneous viral inactivation. Authorized third-party evaluations (Japan Textile Products Quality and Technology Center, September 2021 and April 2024) under ISO 18184:2019 demonstrated 99.97% (1–10^-3.6) reduction for Influenza A and 99.9% (1–10^-3.0) for Feline Calicivirus in 15 s; 99.94% (1–10^-3.2) against SARS-CoV-2 was confirmed in 2021. The binder ensures even nanoparticle formation without agglomerates and durable adhesion, outperforming materials requiring frequent replacement. This approach targets contact surfaces, droplets, and aerosols, complementing but surpassing HEPA filters that lack instant inactivation and impose maintenance burdens. The technology promises improved infection control for ICUs and hospitals, with added benefits in sustainability, cost reduction, and straightforward deployment.

Keywords ICU infections, Maintenance-free filters, Virus inactivation, Infection control, ISO 18184:2019

Our initial investigation examined the efficacy of unbonded platinum nanoparticles against various viral pathogens, including SARS-CoV-2 and norovirus. These preliminary tests revealed a critical limitation: without an appropriate binding agent, the nanoparticles exhibited inconsistent surface distribution patterns, significantly compromising their antimicrobial performance. To address this challenge, we engineered novel binding materials that facilitate uniform dispersion of platinum nanoparticles across treated surfaces, as demonstrated in Fig. 1. This optimized distribution creates a more effective antimicrobial barrier with maximized surface coverage and active contact points. The enhanced formulation has demonstrated remarkable efficacy against multiple pathogen classes. Specifically, we achieved consistent and significant inactivation rates when tested against norovirus, Influenza A virus, and three distinct fungal species. Our optimized binding methodology has successfully standardized the antimicrobial performance across these diverse pathogen types, representing a substantial improvement over the unbound nanoparticle application.

This paper presents a novel strategy to reduce Intensive Care Unit (ICU) and hospital-acquired infections by employing maintenance-free materials capable of instantaneously inactivating viruses. Authorized third-party evaluations, which are generally more reliable than in-laboratory tests due to the minimized risk of result alteration, confirmed the efficacy of these materials. Specifically, assessments conducted by the Japan Textile Products Quality and Technology Center in September

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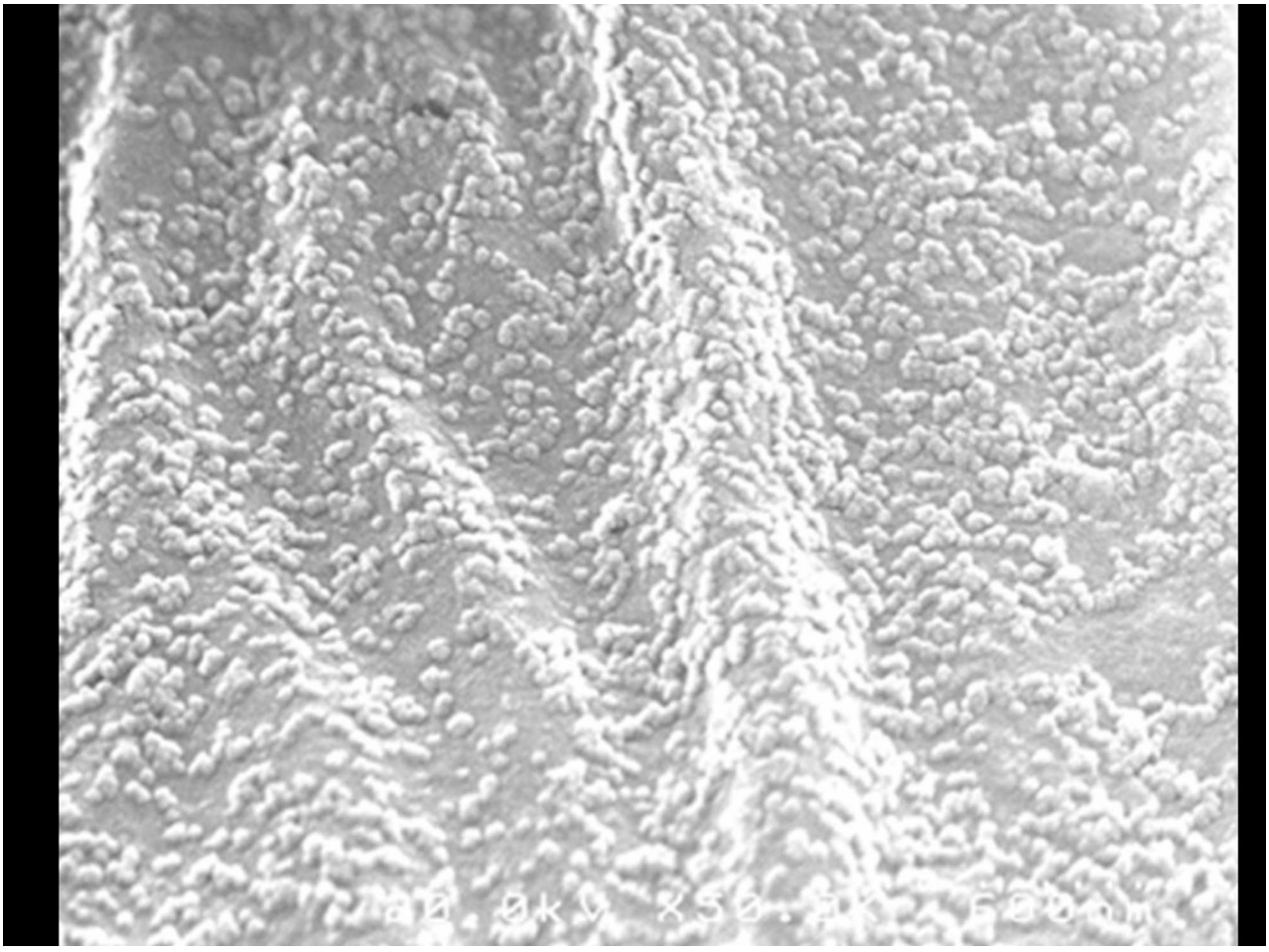

Fig. 1 Polyester fiber: a 20K x close-up

2021 and April 2024 demonstrated robust antiviral performance. The role of binders is crucial for achieving uniform formation of platinum nanoparticles on textile surfaces, as shown in Fig. 1, where the nanoparticles are evenly distributed and free from large agglomerates.

Binder materials, based on silica, perform photocatalysis to form platinum nanoparticles. These nanoparticles are uniformly distributed on solid surfaces and are permanently adhered to the surfaces due to the strong binding forces induced by the photocatalytic process. In other words, binder materials ensure a uniform distribution of platinum nanoparticles on surfaces and provide sustainability, a feat that existing materials have not achieved. When sprayed on any solid surface, binder materials ensure that platinum nanoparticles adhere permanently.

This study achieved a remarkable reduction of (1-10^-3.6)=0.9997, or 99.97%, and (1-10^-3.0)=0.999, or 99.9%, against Influenza A and Feline Calicivirus (surrogate of norovirus), respectively, in just 15 s, significantly surpassing existing research. This could revolutionize our approach to fighting not only these viruses but also bacteria and fungi. Note that 3.6 and 3.0 are given by the official tests attached by three supplements while a reduction of (1-10^-3.2)=0.9994 or 99.94% against SARS-Cov-2 was confirmed in 2021.

In ICUs or hospitals, bacterial and fungal infections are prevalent, affecting up to half of the patients, as reported by Rawson et al. [1]. These infections, often caused by drug-resistant organisms, lead to worse patient outcomes and pose challenges in treatment selection. Conway and Smielewska highlighted the significant role of viral infections, including COVID-19, in the ICU workload [2]. The rise of molecular diagnostics has improved pathogen recognition but also introduced new challenges. They discussed various aspects of viral infections, including diagnosis, management, and prevention strategies [2].

Gaudet et al. emphasized that a significant portion of ICU-acquired infections are linked to multidrug-resistant bacteria (MDR), leading to increased mortality and longer ICU stays [3]. Studies suggest that COVID-19 patients are at similar risk of MDR colonization as non-COVID-19 patients, but have a higher risk of ICU-acquired MDR infections. Factors such as immunomodulatory treatments, longer ICU stays, invasive procedures,

and antimicrobial treatment may contribute to this risk. The surge in COVID-19 cases and associated workload may also play a role. Further research is needed to understand the immune status of COVID-19 patients and develop personalized treatments [3].

ISO 18184:2019 is a universal standard that provides detailed testing procedures to evaluate the antiviral, antibacterial, and antifungal properties of diverse textile products. This includes, but is not limited to, woven and knitted fabrics, fibres, yarns, and braids. A typical ISO 18184:2019 test involves applying the virus to the textile for a certain period, after which the virus is retrieved, and the remaining infectious virus is quantified. In ISO 18184:2019 tests, two samples, including a negative control (Phosphate-Buffered Saline, PBS) and the sample agents (binder materials), are compared using logarithmic computation to assess their antiviral activity. This study achieved a remarkable reduction of (1-10^-3.6)=0.9997, or 99.97%, where 3.6 is calculated from two samples (7.61 and 4.0). Additionally, it achieved (1-10^-3.0)=0.999, or 99.9%, where 3.0 is calculated from two samples (7.27 and 4.25) against Influenza A and Feline Calicivirus, respectively, in just 15 s. This significantly surpasses existing research.

HEPA filters, which require regular maintenance and are frequently used in ICUs and hospitals, have the ability to filter out microorganisms [4]. However, they do not have the capacity to instantaneously inactivate viruses. Despite this, their utilization could substantially mitigate the propagation of viral activity [4]. Obitková et al. recommended replacing the HEPA nanotextile monolayer three times, with a replacement interval of approximately 33 h [5], which imposes a heavy burden. The proposed technology mitigates the need for frequent replacements and enhances sustainability by inactivating viruses.

This paper presents an innovative approach to tackle infections in Intensive Care Units (ICUs) and hospitals. Rather than relying on filters, it suggests a method of spraying a material on any solid surfaces that can instantaneously neutralize viruses or bacteria. This material can be applied permanently to any solid surface. The process involves the use of a binder that enables platinum nanoparticles to form a uniform distribution on surfaces and adhere to the surfaces of solid materials due to the binder material. This ensures a lasting and effective barrier against viral infections. These materials, which include platinum nanoparticles bound with a binder, effectively target contact surfaces, droplets, and airborne particles. This innovative solution not only enhances the safety of ICU and hospital environments but also opens up new strategies for infection control in healthcare settings. Validated by the official center, this could revolutionize our fight against ICU and hospital pathogens. ICU infections, often caused by drug-resistant organisms, lead to severe patient outcomes. A large portion of these are linked to multidrug-resistant bacteria (MDR), resulting in higher mortality and extended ICU stays. Despite their limitations, regularly maintained HEPA filters can significantly reduce viral propagation. The proposed method aims to make ICU and hospital filters maintenance-free, marking a significant advancement in ICU and hospital infection control.

In addition to the aforementioned benefits, the proposed technology also offers economic advantages. By reducing the need for frequent replacements of HEPA filters and other maintenance-intensive materials, hospitals can significantly cut down on operational costs. This cost-effectiveness, combined with the enhanced safety and sustainability, makes the proposed technology an attractive option for healthcare facilities worldwide. Furthermore, the ease of application and the long-lasting effects of the binder materials ensure that the implementation process is straightforward and does not require extensive training or specialized equipment. This accessibility further underscores the potential of this technology to revolutionize infection control practices in healthcare settings.

Moreover, the environmental impact of the proposed technology is minimal. Traditional methods of infection control often involve the use of harsh chemicals and frequent disposal of used materials, contributing to environmental pollution. In contrast, the binder materials used in this technology are designed to be long-lasting and require minimal replacement, thereby reducing waste and environmental footprint. This aligns with global efforts to promote sustainable practices in healthcare and other industries. By adopting this innovative approach, healthcare facilities can not only improve patient outcomes but also contribute to a healthier planet.

It is important to note that formal durability testing was beyond the scope of this study. The ISO 18184:2019 standard, which guided our experimental protocols, does not specifically prescribe durability testing for nanoparticle adhesion permanence. However, the authorized third-party certifications, while not explicitly reporting durability metrics, involved multiple rounds of testing on the same treated materials. It took at least 2 months for the authorized third-party tests. Throughout these repeated assessments, the antiviral efficacy remained consistent, indirectly confirming the stability of our nanoparticle system. Additionally, we have maintained samples under observation for over 3 months with preserved antimicrobial performance, suggesting long-term adhesion stability. Future work could explore more rigorous and standardized durability characteristics of the proposed system under various environmental conditions and extended use scenarios. Nevertheless, our

current observations provide promising preliminary indications of the system's durability potential.

Our platinum nanoparticles serve as potent catalysts in the viral inactivation process through redox-mediated mechanisms. Specifically, they facilitate both oxidation (addition of oxygen) and reduction (removal of oxygen) reactions at viral surface structures, depending on the microenvironment conditions. This catalytic activity generates reactive oxygen species (ROS) that damage critical viral components including envelope proteins, lipid membranes, and potentially nucleic acids. Additionally, platinum nanoparticles can directly interact with viral surface proteins through affinity for thiol (-SH) groups, disrupting protein conformation and viral attachment capabilities.

The platinum nanoparticle system we developed is intended primarily for surface treatments in high-touch environments such as healthcare settings, public transportation, and commercial spaces where pathogen transmission is a concern. Regarding toxicity, the 10 ppm concentration of platinum nanoparticles used in our formulation falls well below established safety thresholds. The European Scientific Committee on Consumer Safety (SCCS) considers platinum compounds generally safe at concentrations up to 50 ppm in leave-on cosmetic products [6]. The food-contact substance (FCS) is intended for use in an oxygen scavenging multi-layered inner liner for closures of polyethylene terephthalate (PET) bottles. Specifically, calcium hydride may be used at up to 27% in the non-food contact (active) layer and the platinum source (platinum oxide or zeolite encapsulated platinum) may be used at up to 200 ppm platinum loading in the food-contact (control) layer [7].

While this study focused primarily on viral pathogens, we recognize that healthcare-associated infections, particularly in ICU settings, often involve multidrug-resistant bacteria and opportunistic fungal pathogens in immunocompromised patients. Although not presented in this manuscript, our preliminary investigations have demonstrated efficacy of the binder-incorporated materials against common fungal pathogens including Aspergillus niger, Penicillium citrinum, Cladosporium sphaerospermum, and Trichophyton mentagrophytes.

The promising results against both enveloped (Influenza A) and non-enveloped (Feline Calicivirus) viruses suggest a broad-spectrum antimicrobial potential. Future studies will expand our evaluation to include clinically relevant bacterial pathogens, especially multidrug-resistant organisms commonly associated with nosocomial infections. This comprehensive antimicrobial profiling will provide valuable insights into the potential of these materials to address the complex microbial challenges faced in healthcare environments.

Our future work will include extending antimicrobial testing to additional high-priority pathogens, including drug-resistant bacterial species (such as MRSA, CRE, and VRE), fungal organisms (particularly Candida and Aspergillus species), and other clinically significant viruses beyond those in our initial testing. We also plan to conduct longitudinal studies to determine the durability and sustained efficacy of these binder materials under actual healthcare environment conditions, including repeated cleaning and disinfection protocols.

Furthermore, we will implement clinical trials to evaluate patient-centered outcomes when these materials are deployed in ICU settings, specifically measuring impacts on healthcare-associated infection rates, length of stay, mortality, and cost-effectiveness. Additionally, we intend to explore potential applications in other high-risk healthcare environments beyond ICUs, such as operating rooms and emergency departments. This comprehensive approach will provide valuable evidence regarding the real-world efficacy of these materials as part of a multifaceted infection control strategy.

Acknowledgements
Not applicable.

Authors' contributions
Yoshiyasu Takefuji completed this research and wrote this article.

Funding
This research has no fund.

Data availability
Two supplements are attached.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The author has no conflict of interest.

Received: 31 October 2024 / Accepted: 16 February 2026
Published online: 07 April 2026

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