ISSN: 3029-0716

Research Article

Journal of Infectious Diseases & Treatments

Insights and Perspectives on the Competence of Nanotechnology: Emerging Standards in the Post-Pandemic Context of COVID-19

Sheeba S[1*], Murugan M[2] and Suman Sankar AS[3]

[1]*Research Scholar, Department of Organon of Medicine, Sarada Krishna Homoeopathic Medical College (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University, Chennai), Kulasekharam, Kanniyakumari District, Tamilnadu, India*

[2]*Department of Organon of Medicine, Sarada Krishna Homoeopathic Medical College (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University, Chennai), Kulasekharam, Kanniyakumari District, Tamilnadu, India*

[3]*Department of Repertory, Sarada Krishna Homoeopathic Medical College (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University, Chennai), Kulasekharam, Kanniyakumari District, Tamilnadu, India*

***Corresponding author**
Sheeba S, Research Scholar, Department of Organon of Medicine, Sarada Krishna Homoeopathic Medical College (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University, Chennai), Kulasekharam, Kanniyakumari District, Tamilnadu, India.

Received: September 16, 2025; **Accepted:** September 23, 2025; **Published:** September 30, 2025

ABSTRACT
The outbreak of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), underscored the urgent need for innovative therapeutic strategies. Despite nearly two decades of recurring coronavirus threats such as SARS-CoV and MERS-CoV, no specific and universally effective antiviral drugs have been approved for this viral family. This gap has highlighted the importance of exploring novel approaches alongside traditional therapies. Nanotechnology, particularly Nano medicine, has emerged as a promising field due to its potential applications in diagnostics, drug delivery, vaccine development, and targeted therapy. Current global research efforts are actively investigating how nanoscale interventions can enhance the prevention, management, and treatment of COVID-19, while also setting new standards for post-pandemic preparedness. This article provides insights and perspectives on the competence of nanotechnology, emphasizing its evolving role and the emerging norms that may shape healthcare innovation in the post-pandemic era.

Keywords: Coronavirus, Nano medicine, Pandemic, Respiratory Syndrome

Introduction

The coronavirus disease 2019 (COVID-19) outbreak, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), marked a global health crisis unprecedented since the 1918 Spanish Flu pandemic. First identified in China in 2019, the rapid transmission of COVID-19 soon escalated into a worldwide emergency, highlighting the critical need for effective diagnostic, therapeutic, and preventive strategies for highly contagious diseases. The persistence of the pandemic and the limitations of existing treatments underscored the urgency of developing innovative approaches to reduce the pathogenicity, morbidity, and mortality associated with SARS-CoV-2 [1]. Amid these challenges, nanotechnology has gained significant attention for its potential role in medical science. As an advancing discipline, Nano medicine offers unique advantages in overcoming barriers faced by conventional therapeutic methods. The ability of nanomaterials to improve drug delivery, enhance vaccine efficacy, and provide targeted interventions presents opportunities for safer and more efficient treatment options [2]. If harnessed appropriately, nanotechnology could contribute to transformative progress in 21st-century medicine, offering not only improved approaches against COVID-19 but also long-term innovations to strengthen global preparedness for future infectious disease outbreaks.

Molecular Architecture of Viruses

Coronaviruses (CoVs) are enveloped, positive-sense, single-stranded RNA viruses, possessing the largest known RNA

Citation: Sheeba S, Murugan M, Suman Sankar AS. Insights and Perspectives on the Competence of Nanotechnology: Emerging Standards in the Post-Pandemic Context of COVID-19. J Infect Dise Treat. 2025. 3(3): 1-4. DOI: doi.org/10.61440/JIDT.2025.v3.44

genomes, ranging from 8.4 to 12 kDa in size. Their genomes consist of two distinct regions: the 5′ and 3′ terminals. The 5′ terminal comprises open reading frames that encode non-structural proteins essential for viral replication, while the 3′ terminal encodes the major structural proteins. Five key structural proteins are encoded in the 3′ terminal: spike (S), membrane (M), nucleo capsid (N), envelope (E), and hemagglutinin-esterase (HE) [3]. The S protein is critical for viral attachment and membrane fusion, mediating entry into host cells and facilitating spread between infected and uninfected cells.

Moreover, it obliges as the primary target for neutralizing antibodies, making it a cornerstone of vaccine development. The N protein plays a pivotal role in viral assembly by forming RNA–protein complexes that regulate transcription and packaging. The M protein, the most abundant structural component, determines the viral envelope's shape and integrity. The E protein, though small and less understood, is abundantly expressed during replication and is essential for viral assembly and release [4]. The HE protein contributes to receptor binding and host specificity, further influencing viral pathogenesis. Understanding this molecular framework provides critical insights for developing nanotechnology-based strategies in vaccine design, antiviral therapies, and diagnostic tools, particularly in the post-pandemic context where innovation and precision medicine are crucial.

Indulgent Transmission Paths

Human-to-human transmission of COVID-19 occurs through multiple pathways, including direct contact, contact with contaminated surfaces, aerosolized particles, and exposure during medical procedures. Common routes of viral entry include coughing, sneezing, inhalation of respiratory droplets, and contact with mucous membranes of the mouth, nose, or eyes. Additionally, viral propagation can occur via shedding from the respiratory tract, saliva, faces, and urine [5]. Patients with severe COVID-19 tend to carry a higher and more prolonged viral load, increasing the risk of transmission. Notably, healthcare workers and airline personnel in close contact with infected individuals have been documented as secondary cases. Frequently observed clinical manifestations include fever, cough, sputum production, dyspnoea, myalgia, lower back pain, diarrhoea, rhinorrhoea, anosmia and headache. Understanding these transmission pathways is essential for the development of nanotechnology-based interventions and emerging preventive standards in the post-pandemic era.

Multisystem Impact of COVID-19: Key Organs Affected

A critical target of SARS-CoV-2 is the angiotensin-converting enzyme II (ACE2), a surface receptor expressed in various human cells, which facilitates viral entry into host cells. The viral spike (S) glycoprotein binds to the peptidase domain of ACE2, marking the initial and essential step of infection; therefore, disrupting this interaction represents a key therapeutic strategy. The respiratory system is primarily affected due to high ACE2 expression in the lungs and airway epithelial cells, allowing efficient viral entry into alveolar cells, leading to pneumonia, acute respiratory distress syndrome (ARDS), and, in severe cases, multi-organ failure. Beyond the lungs, ACE2 is highly expressed in cardiovascular tissues, [6] where viral binding can disrupt blood pressure regulation and myocardial contractility, potentially causing myocardial inflammation and fibrosis.

The central nervous system may also be impacted directly through viral invasion or indirectly via hypoxia, with astrocyte, macrophage, and microglial activation triggering cytokine storms that can compromise the blood–brain barrier (BBB) and result in significant neuronal injury. Hepatic and pancreatic cells, which exhibit elevated ACE2 and TMPRSS2 expression, are susceptible to viral infection, potentially contributing to metabolic dysregulation. The reproductive system, particularly the uterus, placenta, and foetal interface in pregnant women, expresses ACE2 at high levels, making foetal tissues vulnerable and increasing morbidity and mortality risks [6]. Severe COVID-19 is frequently accompanied by a cytokine release syndrome (CRS), characterized by elevated pro-inflammatory cytokines such as tumour necrosis factor (TNF) and interleukins (IL-1, IL-6), which exacerbate multi-organ damage and contribute to fatal outcomes when combined with ARDS. This multisystem involvement underscores the importance of understanding organ-specific vulnerabilities to SARS-CoV-2 in order to develop targeted therapeutic and preventive strategies.

Nano Medicine Interpolations for Disease Super Vision

Despite the availability of numerous treatment options, Nano medicine techniques have demonstrated significant efficacy in precisely targeting and treating a variety of diseases. However, their application as an adjuvant therapy in pulmonary drug delivery remains underexplored [7]. Advances in Nano engineering enables the development of improved strategies for managing lung infections by facilitating the targeted delivery of potential therapeutics. Pulmonary Nano drug delivery systems are particularly well-suited for treating COVID-19 and similar respiratory infections due to their unique physicochemical properties, including enhanced mucosal penetration, ease of ligand functionalization, small particle size for improved permeation, higher local drug concentrations, and strong adjuvant potential for vaccine applications.

Nanoparticle-Based Antiviral Strategies

Nanoparticles have shown considerable promise in enhancing antiviral compound delivery, while also exhibiting direct antiviral activity. Various nanoparticle systems, including silver nanoparticles, functionalized gold nanoparticles, and quantum dots, have demonstrated antiviral properties. Many of these nanoparticles operate by preventing viruses from attaching to or entering host cells. Nano-encapsulation of antiviral drugs offers a safer and more targeted approach for treating COVID-19 and other viral infections, as these particles can disrupt viral transcription, translation, and replication [8]. Drugs can be effectively delivered to infected cells through nanoparticle carriers, improving therapeutic efficacy while reducing associated toxicity compared to conventional formulations. An important feature of these systems is their muco adhesive property, which is particularly advantageous for developing treatments against respiratory infections. To enhance this property, various functionalization techniques have been employed, allowing nanomaterials to achieve higher adhesion and targeted antiviral activity.

Nanomaterial-Enabled COVID-19 Diagnostics

Nanoparticles can be engineered as highly sensitive biosensors for the rapid detection of SARS-CoV-2 biomarkers, including nucleic acids (DNA, RNA), specific antigens (proteins, enzymes), and antibodies [9]. Recent advancements in nanotechnology have enabled the use of graphene coupled with anti-spike antibodies as an effective diagnostic tool for COVID-19. Additional innovative detection strategies include dual-function plasmatic biosensors that leverage DNA–RNA hybridization energetics, as well as graphene oxide nanoparticles functionalized with fluorophore-labelled DNA strands capable of identifying viral helicase. These nanomaterial-based platforms offer rapid, accurate, and reliable detection, enhancing diagnostic efficiency for viral infections.

Nanoparticle-Based Tactics in Vaccine Adjuvant Organizations
Adjuvants are often required to enhance the immunogenicity of recombinant and inactivated protein vaccines. Nanoparticles (NPs) can serve as carriers for molecular adjuvants and, in many cases, exhibit inherent adjuvant properties when combined with antigens. Conventional administration of molecular adjuvants faces limitations that can be addressed through nanoparticle-based delivery systems. Licensed vaccine adjuvants include alum (aluminium salts), MF59 (squalene-based emulsion), AS01 (liposome-based), AS03 (squalene-based emulsion), AF03 (squalene-based emulsion), AS04 (containing TLR4 agonist MPL), and viruses. MF59, as a nanoparticle adjuvant, demonstrates potent humoral and T helper type 1 immune responses, [7] while alum is used in vaccines such as DTaP, Hib, hepatitis A, and hepatitis B. Viruses are incorporated in the hepatitis A vaccine (Epaxal®) and influenza vaccines (Inflexal® V, Invivac®), whereas MF59 and AS03 are licensed for influenza vaccines targeting older adults.

Emerging nanomaterials, including virus-like particles, PLGA NPs, cationic liposomes, Nano emulsions, and cholesterol-bearing Nano gels, are being explored for their adjuvant properties, which enhance antigen presentation and activate innate immune responses. Cyclic dinucleotides (CDNs) have also shown promise as adjuvants; for example, cyclic di-GMP (cdGMP) loaded PEGylated lipid NPs (NP-cdGMP) effectively delivered CDNs to draining lymph nodes and enhanced CD4+ and CD8+ T cell responses. Vaccine adjuvants may be particularly beneficial for immunocompromised individuals and patients with comorbidities, potentially reducing the required COVID-19 antigen dose. Matrix-M, a saponin-based adjuvant, combined with a SARS-CoV-2 recombinant spike protein NP vaccine, is currently under phase I clinical trials to evaluate its immunogenicity and safety [9]. Collectively, the integration of nanotechnology-based vaccines with adjuvants represents a critical strategy for improving immune responses, especially in elderly and immunocompromised populations.

Nanoparticle-Based Prophylactic Interventions

Nano-engineered masks, with their additional nanofiber layers and microscopic pores, effectively block viral entry into the respiratory system, offering superior protection compared to conventional masks. Beyond masks, nanotechnology has enhanced lab coats, surgical aprons, and other protective equipment with features such as hydrophobicity and antibacterial activity, without compromising material integrity or breathability. Nanofibers also reduce pressure and breathing resistance while efficiently filtering ultrafine particles (<50 nm), providing markedly higher protection than traditional surgical masks [10]. Since mucous membranes serve as primary entry points for SARS-CoV-2, strategies that prevent viral access and enable targeted drug delivery across these membranes are critical [9]. Nanotechnology shows significant potential in facilitating the transport of therapeutics through mucosal barriers, highlighting its role in preventive interventions against viral infections.

Barriers and Challenges to Effective Nano Medicine Implementation

A major challenge in Nano medicine is the large-scale production of nanoparticles, especially while keeping treatments cost-effective [11]. Although successful nanomaterials and Nano-vaccines could reduce overall healthcare costs by preventing diseases like COVID-19, the complexity of nanoparticle manufacturing and intellectual property constraints may increase expenses. Nanoparticles also pose potential risks, including unwanted tissue interactions, toxicity, and unintended systemic distribution, such as crossing the blood–brain barrier. Depending on their size and chemical composition, accidental inhalation may lead to pulmonary fibrosis, inflammation, and epithelial damage [12]. Additionally, nanoparticles can disrupt biological processes, including oxidative stress regulation, inflammation, mitochondrial function, macrophage phagocytosis, and platelet activity. They may also induce reactive oxygen species (ROS) production, cell membrane binding, DNA damage, altered cell cycle control, and protein denaturation, with both acute and long-term effects. A critical concern remains the limited understanding of the long-term impacts of nanoparticles on human health and the environment.

Conclusion

Nanotechnology has emerged as a transformative platform in the post-pandemic era, particularly for the prevention, diagnosis, and treatment of COVID-19. Nano medicines, including nanoparticles (NPs), lipid nanoparticles (LNPs), and virus-like particles (VLPs), have shown significant potential due to their ability to improve antigen stability, enhance antigen processing, and boost immunogenicity [11]. These platforms also enable sustained and targeted delivery of therapeutics and vaccines, minimizing systemic side effects while maximizing efficacy. Nanoparticle-based antiviral strategies can directly inhibit viral entry, replication, and transcription, offering a complementary approach to conventional therapies. In diagnostics, nanomaterials have been employed as biosensors to rapidly and accurately detect viral nucleic acids, antigens, and antibodies, enhancing early identification and containment measures.

Nanotechnology has further revolutionized vaccine development, serving as an effective adjuvant delivery system that enhances immune responses, particularly in elderly and immunocompromised populations. Pulmonary Nano drug delivery systems and Nano engineered masks provide preventive interventions by efficiently blocking viral entry and ensuring localized therapeutic action. Despite these advantages, challenges remain in scaling up production, ensuring reproducibility, and controlling long-term toxicity. Regulatory frameworks and emerging standards are now being developed to ensure safe, consistent, and effective applications of Nano medicine [13]. The integration of nanotechnology with conventional antiviral strategies presents an opportunity for personalized and precision medicine approaches in infectious disease management. Looking ahead, nanotechnology is expected to play a pivotal role in repurposing existing antiviral drugs and optimizing vaccine formulations for future pandemics. Collectively, the competence of nanotechnology in the post-COVID era underscores its potential to redefine therapeutic, diagnostic, and preventive standards globally.

Reference

1. Sharma A, Kontodimas K, Bosmann M. Nano medicine: a diagnostic and therapeutic approach to COVID-19. Frontiers in Medicine. 2021. 8: 648005.
2. Sheeba S, Murugan M, Sankar AS. Consequences of COVID-19: A wide-ranging on efficacious action of homoeopathic medicines with stratagems tool aids: Literature research. International Journal of Homoeopathic Sciences. 2023. 7: 460–462.
3. Upadhyay, Rajendran, Nayak, Chaturbhuja. Homeopathy emerging as Nano medicine. International Journal of High Dilution Research. 2011. 10.
4. Rajendran ES. An evaluation of Avogadro's number in the light of HRTEM and EDS study of high dilutions of Ferrum metallicum6, 30, 200, 1M, 10M and 50Mc. Int. J High Dilution Res. 2015. 14: 3-9.
5. Sheeba S, Murugan M, Sankar A S. Applications and challenges of Nano medicine for COVID-19 outbreak: The potential relevance of therapeutic and diagnostic approaches for treatment. Nano Medicine & Nanotechnology. 2025. 10: 000343.
6. Malik, Nancy. Recent Advances in Nanoparticle Research in Homeopathy. Homeopathy 4 Everyone. 2015, 12.
7. Sheeba S, Gipuzkoa ST, Ramya S. Sanju S, Reghu R. Exploring the Nexus of Nanoparticles and Homoeopathic Potentized Medicine: A Narrative Review. Nano medicine & Nanotechnology Open Access. 2024. 9: 000309.
8. Sheeba S, Murugan M, Sankar AS, Gopukumar ST, Reshma R. COVID-19 and homeopathy: Systematic review and meta-analysis of clinical outcomes. Journal of Natural & Ayurvedic Medicine. 2024. 8: 000453.
9. Uma kanthan S, Sahu P, Ranade AV, Bukelo MM, Rao JS. Origin, transmission, diagnosis and management of coronavirus disease 2019 (COVID-19). Postgraduate medical journal. 2020. 96: 753-758.
10. Sheeba S, Murugan M, Sankar AS, Gopukumar ST, Reshma R. COVID-19 and homeopathy: Systematic review and meta-analysis of clinical outcomes. Journal of Natural & Ayurvedic Medicine. 2024. 8: 000453.
11. Wilson B, Geetha KM. Nano medicine to deliver biological macromolecules for treating COVID-19. Vaccine. 2022. 40: 3931-3941.
12. Vahedifard F, Chakravarthy K. Nano medicine for COVID-19: the role of nanotechnology in the treatment and diagnosis of COVID-19. Emergent materials. 2021 4: 75-99.
13. Mainardes RM, Diedrich C. The potential role of Nano medicine on COVID-19 therapeutics. Therapeutic Delivery. 2020. 11: 411-414.
14. Sheeba S. Innovative advances in homeopathy: Based on nano particles exploration. Nano medicine & Nanotechnology Open Access. 2024. 9: 1-5.