Journal of Nanomedicine and Biotherapeutic Discovery

OPEN ACCESS Freely available online

Perspective

Biomimetic Nanoparticles for Selective Targeting and Disruption of Bacterial Biofilms

Nagendra Kumar*

Department of Biomedical Engineering, Birla Institute of Technology, Ranchi, India

DESCRIPTION

Bacterial biofilms present a formidable challenge in infection management due to their enhanced antibiotic tolerance and immune evasion capabilities. Conventional antimicrobial approaches often fail to penetrate the complex extracellular matrix of biofilms, necessitating novel strategies that can specifically target and disrupt these structured communities. We have developed biomimetic nanoparticles that combine the matrix-degrading capabilities of bacteriophages with targeted antibiotic delivery, creating a dual-action approach for enhanced biofilm eradication. These nanoparticles, approximately 120nm in diameter, feature a core-shell architecture with complementary components designed to sequentially degrade the biofilm matrix and eliminate the resident bacteria.

The nanoparticle design incorporates a polymersome core encapsulating high concentrations of ciprofloxacin, selected for its broad-spectrum activity against both gram-positive and gram-negative pathogens commonly found in biofilm infections. The polymeric shell consists of a biodegradable di-block copolymer functionalized with recombinant de-polymerase enzymes derived from bacteriophages specific to *Pseudomonas aeruginosa* and *Staphylococcus aureus*, two predominant biofilm-forming pathogens. These enzymes specifically degrade exopolysaccharides within the biofilm matrix, creating channels for improved penetration of both the nanoparticles themselves and the subsequently released antibiotics. Additionally, the nanoparticle surface was modified with peptide sequences that bind to bacterial cell surface structures with high affinity, enabling targeted accumulation within the biofilm microenvironment.

In vitro characterization using microfluidic biofilm models demonstrated superior penetration capabilities compared to free antibiotics, with confocal laser scanning microscopy revealing distribution throughout the biofilm depth within 4 hours of application. Quantitative analysis showed approximately 4.3-fold higher antibiotic concentrations achieved within the biofilm core compared to equivalent doses of free ciprofloxacin. The sequential action mechanism was confirmed through time-lapse imaging, which demonstrated initial degradation of matrix components followed by progressive bacterial killing throughout the biofilm structure. Importantly, this approach maintained efficacy against antibiotic-tolerant persister cells typically recalcitrant to conventional treatments, likely due to the high local concentrations achieved and prolonged exposure time.

Evaluation in an *in vivo* murine chronic wound model infected with multidrug-resistant *P. aeruginosa* demonstrated significant reductions in bacterial burden, with approximately 4-log reduction in colony-forming units following three daily topical applications compared to standard antibiotic therapy. Histological analysis revealed extensive degradation of biofilm architecture with minimal host tissue damage, suggesting specificity for bacterial extracellular polymeric substances. Inflammatory marker analysis demonstrated resolution of the hyper-inflammatory state typically associated with chronic biofilm infections, with reduced neutrophil elastase activity and pro-inflammatory cytokine levels in wound fluid. Importantly, wound closure kinetics were significantly accelerated in treated animals, with complete re-epithelialization observed by day 14 compared to persistent, non-healing wounds in control groups.

CONCLUSION

Safety assessment demonstrated no evidence of systemic absorption following topical application, with serum antibiotic levels below detection limits throughout the treatment period. Local tissue compatibility was confirmed through histological and immune-histochemical analysis, with no evidence of delayed wound healing or aberrant inflammatory responses. Resistance development studies using repeated sub-lethal exposures showed no significant shifts in minimum inhibitory concentrations over 15 passages, suggesting a reduced propensity for resistance development compared to conventional antibiotic monotherapy. This biomimetic nanoparticle approach represents a promising strategy for addressing biofilm-associated infections across

Correspondence to: Nagendra Kumar, Department of Biomedical Engineering, Birla Institute of Technology, Ranchi, India, E-mail: nagendrakumar@gmail.com

Received: 03-Jan-2025, Manuscript No. JNBD-25-37291; **Editor assigned:** 06-Jan-2025, Pre QC No. JNBD-25-37291 (PQ); **Reviewed:** 20-Jan-2025, QC No. JNBD-25-37291; **Revised:** 27-Jan-2025, Manuscript No. JNBD-25-37291 (R); **Published:** 03-Feb-2025, DOI: 10.35248/2155-983X -25.15.297

Citation: Kumar N (2025). Biomimetic Nanoparticles for Selective Targeting and Disruption of Bacterial Biofilms. J Nanomedicine Biotherapeutic Discov. 15:297.

multiple clinical scenarios, including chronic wounds, implant-associated infections, and cystic fibrosis-related pulmonary infections, where biofilm formation represents a significant barrier to effective antimicrobial therapy.