Sarcouncil Journal of Applied Sciences

ISSN(Online): 2945-3437

Volume- 06| Issue- 03| 2026

Review Article **Received:** 05-02-2026 | **Accepted:** 03-03-2026 | **Published:** 19-03-2026

Prospects and Challenges Reprogramming the Human Microbiome Using Phage Therapy

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Abstract: Human microbiome is essential in the process of maintaining physiological homeostasis, immune control and metabolic balance. Dysbiosis, also referred to as structural and functional disturbance of microbial communities, has been suggested in a wide range of diseases, including metabolic abnormalities, inflammatory diseases, as well as antimicrobial-resistant infections. Bacteriophage (phage) therapy has resurfaced as one of the potential approaches to precision based selection of pathogenic bacteria and preservation of beneficial commensals. In contrast to the general antibiotics, phages are highly specific to the host and have self-amplifying properties among the target bacterial groups. This review critically evaluates a conceptual framework of microbiome reprogramming with phage therapy and discusses the principles of mechanistic, ecological, translational, and regulation issues. We discuss the progress in synthetic biology, phage engineering, delivery systems, and clinical trial design, and discuss the challenges of developing resistance, immunogenicity, and ecological unpredictability. The interactions between phages and microbiomes and their hosts have to be thoroughly studied in order to utilize phage therapy as a new generation microbiome-modulating intervention.

Keywords: Human microbiome; Bacteriophage therapy; Dysbiosis; Antimicrobial resistance; Microbial ecology.

INTRODUCTION

Human microbiome forms an ecological community of bacteria, viruses, fungi and archea which interrelates in a complex way to regulate the host physiology. These micro communities regulate nutrient metabolism, immune development, epithelial stability and neuroendocrine feedback. The alteration in the composition of microbiome can lead to dysbiosis, which is normally due to antibiotics, diet, and environmental stress predisposing people to infection, inflammatory disease, and metabolic dysfunction [Ma, Z. *et al*., 2024].

Standard antimicrobial treatment is not specific and often disruptions of the useful microbial biomes intensify ecological destabilization. The antimicrobial resistance (AMR) increased globally has made the targeted therapeutic alternatives more essential [Puri, B. *et al*., 2025]. Viruses which infect bacteria such as bacteriophages provide a biologically-specific means of selectively targeting bacterial populations. [Federici, S. *et al*., 2021].

The scientific interest in phage therapy has a long history, beginning at the beginning of the twentieth century, although nowadays it is undergoing a new wave of interest due to the birth of genomics, bioinformatics and synthetic biology [Serwer, P. 2025]. Rather than simply eliminating the pathogens, the contemporary approach proposes using phages to recode microbial ecosystems - to restore the ecological balance and preserve the commensal diversity, however. Such a change in paradigm leads to the emergence of phage therapy being seen as a microbiome engineering solution rather than an antibacterial one [Singh, H. *et al*., 2025].

THE HUMAN MICROBIOME AS A THERAPEUTIC TARGET

Structural and Functional Complexity

Human microbiome is highly varied and redundant. Although taxonomically diverse, core metabolic processes, including the synthesis of short chain fatty acids, bile acid metabolism and vitamin synthesis are preserved between healthy individuals [Joos, R. *et al*., 2025].

Microbial communities are organised biofilms, quorum sensing interactions and dynamically respond regarding interaction with host epithelial and immune system. It is the interactions that create a regulatory network in both directions, which is a precondition of systemic homeostasis [Deo, R. *et al*., 2025].

Dysbiosis and Disease

In addition to being associated with gastrointestinal diseases (e.g., inflammatory bowel disease), metabolic syndromes, autoimmune diseases, and neuropsychiatric diseases, the microbiome disruption is also associated with conditions characterized by immune system malfunctions. Pathobionts - usually harmless microbes that become pathogenic in an unbalanced state may proliferate in the case of dysbiosis [Heidari, H., & Lawrence, D. A. 2024].

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DOI- https://doi.org/10.5281/zenodo.19118157

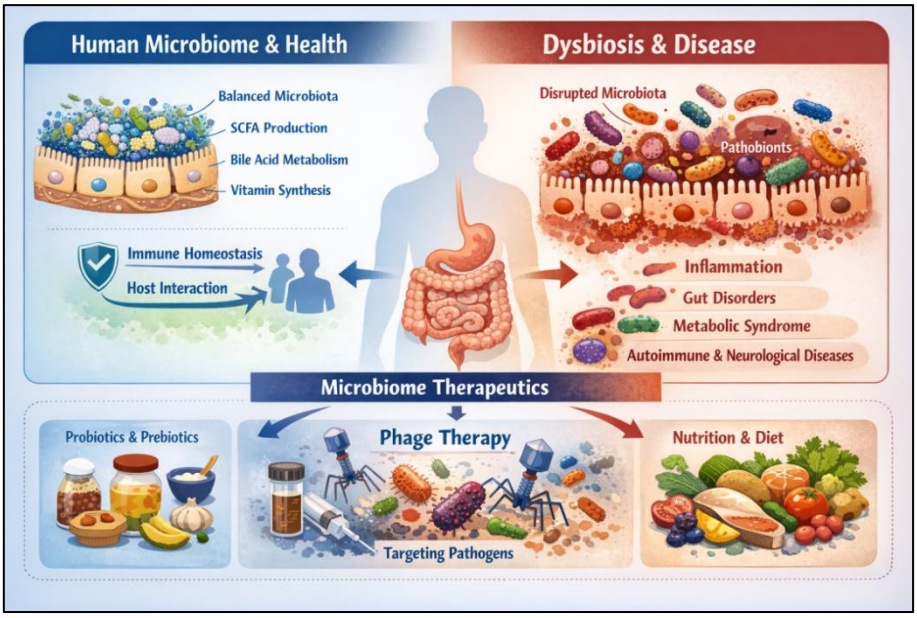

Figure 1 : The Human Microbiome as a Therapeutic Target

Among microbiome restoration therapeutic measures, there are probiotics, prebiotics, fecal microbiota transplantation (FMT), and nutrition. These methods are however usually imprecise and reproducible [Mengoli, M. 2025].

Phage therapy proposes a specific ecological correction mechanism, which has a selective ability to reduce pathogenic strains and restore the populations of good people [Abedon, S. T. 2023].

MECHANISMS OF PHAGE-MEDIATED MICROBIOME REPROGRAMMING

Lytic Activity and Selective Bacterial Elimination

Lytic phages possess a highly precise mechanism of action, beginning with the affinity of bacterial surfaces receptors which can be strain or species-specific. In binding, phages interfere with bacterial functions to introduce their genetic materials into the host cell that is replicated and progeny virions are generated [Shuwen, H., & Kefeng, D. 2022]. This cytogenetic amplification ultimately causes the lysis of bacterial cell that can release the novel formed phages that can infect the surrounding pathogenic cells. The high specificity of lytic phages is used to ensure that collateral damage is avoided to the beneficial microorganisms that are not the target without affecting the overall structure and functionality of the microbiome [Shuwen, H., & Kefeng, D. 2022]. Selectively, the lytic phages can influence the interspecies competitive interactions, which allows the commensal species to rise and restore the ecological balance [Chevallereau, A. *et al*., 2022]. Specific ablation of this kind can also reduce the inflammatory impact of pathogens and improve the work of the barrier and restoration of metabolic balance. In addition, lytic phages can also be self-amplifying and hence can be employed to sustain a constant bacterial population, even when low initial concentrations are used, which is advantageous to therapeutic interventions as well [Bhale, B. *et al*., 2026].

Lysogenic Conversion and Genetic Modulation

Temperate phages live a different life cycle in which the genome of the phage becomes part of the bacterial chromosome as a prophage that is referred to as lysogeny. Integration can result in lysogenic conversion where the host bacterium acquires new genetic features that can either change its metabolism, virulence or antibiotic resistance [Jiang, A. *et al*., 2024]. This under certain conditions could exacerbate pathogenicity but with current phage engineering studies, it is now possible to make temperate phages selectively transfer desirable genetic factors. To take the example of a phage that is CRISPR-Cas, these phages can be designed to be utilized to cut out antibiotic resistance genes and therefore sweep out the resistome in complex microbial communities [Amen, R. A. *et al*., 2025]. These phages may also be induced to regulate the expression of genes to support symbiosis-adaptive traits or inhibit virulence. The lysogenic approach can be more subtle in microbiome re-programming as it operates at the genetic level, as opposed to simply lysing them. Also, engineered temperate phages

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will provide a platform on which microbial ecosystems could be functionally restored through the accurate manipulation in the long term [Atkins, H. 2025].

Biofilm Disruption

Organized communities of microbes are known as biofilms and are enclosed with extra cellular polymeric materials that provide resistance to environmental stress and antibiotics. Phages invade such complicated matrices through production of depolymerase enzymes, which degrade the elements of biofilm, to approaching entrap bacterial cells [Husain, F. M. *et al*., 2025]. In addition to increasing the lytic effect of phages, such destabilization renders bacteria more susceptible to immunity against host defense and adjunctive antimicrobial therapy. The phages can reduce the biofilm architecture and, as a result, bacterial persistence, pathogenicity and horizontal gene transfer in high-density microbial communities [Kovacs, C. J. *et al*., 2024]. Particularly useful have been biofilm-targeting phages to chronic infections on which the bacteria have developed biofilm-associated lifestyles resistant to the usual mode of treatment. Biofilm degradation also through phages can modify the microbial composition allowing colonization of niches by beneficial commensal species and the restoration of ecological balance [Odoom, A., & Dzuvor, C. K. 2026]. Phages are the best instrument to be used in the preciseness reprogramming of microbiomes, especially in environments where structural microbial resistance obstructs therapeutic accessibility by breaking down biofilms with the assistance of targeted bacterial killing. [Saxena, D. *et al*., 2024].

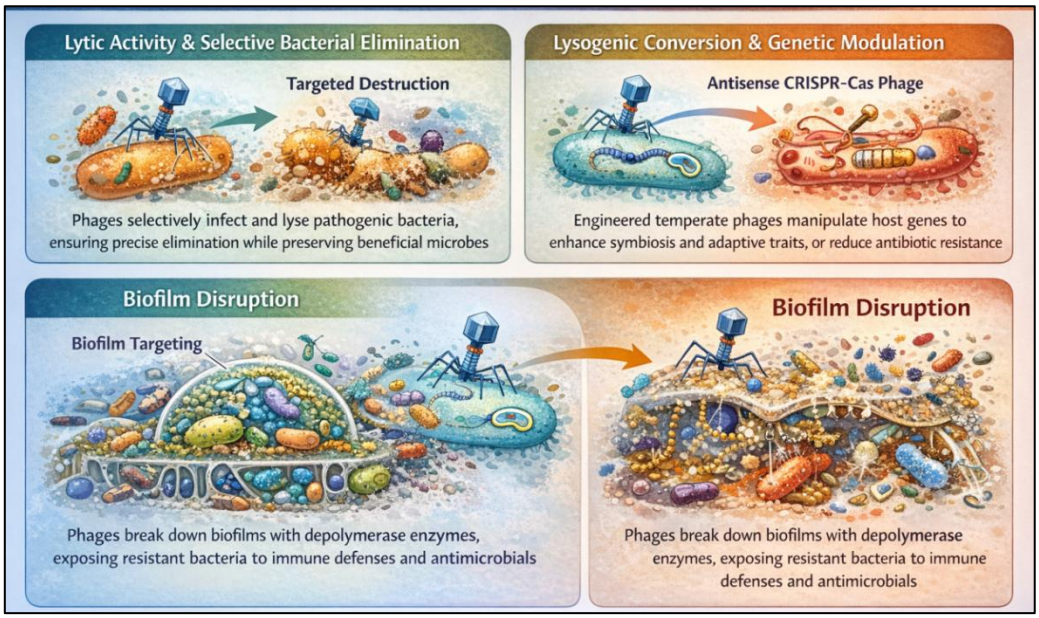

Figure 2: Mechanisms of Phage-Mediated Microbiome Reprogramming

TECHNOLOGICAL ADVANCES IN PHAGE ENGINEERING

Genome Editing and Synthetic Biology.

In the recent molecular technology, rational design of phage genomes has been feasible in order to increase host range specificity, stability and safety. Genetic engineering has the potential to eliminate genes relevant to the virulence and maximize the lytic efficiency [Yoon, B. *et al*., 2026].

Phage Cocktails and Individualized Therapy

The use of several phages as cocktails increases the coverage of antibacterial effects and minimizes the occurrence of resistance. Individual phage therapy, which is a type of phage therapy that is guided by patient-specific bacterial isolates, improves the precision of therapy. [Kim, M. K. *et al*., 2025].

Delivery Systems

The routes of delivery are being explored as oral, topical, inhalational and intravenous. The phages are also encapsulated to protect the phages against gastrointestinal acid and immune clearance to increase the efficacy of treatment [Yue, Y. *et al*., 2025].

To enhance targeted delivery in complicated microbial environments, it is also being investigated in nanocarrier systems and biomaterial scaffolds to enhance increased targeted delivery [Sisodiya, D. *et al*., 2024].

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CLINICAL APPLICATIONS AND EMERGING EVIDENCE

Gastrointestinal Disorders

The phage therapy has a great potential in the treatment of pathogenic strains of *Escherichia coli* and *Clostridioides difficile* that are linked to gut dysbiosis. In particular, phages decrease the state of inflammation by lysing these pathogens without interfering with commensal microbiota at large scale [Ding, B. *et al*., 2025]. The specified modulation may contribute to the recovery of the microbial diversity and the metabolical equilibrium of the ecosystem of the intestines. This means that the degree of epithelial integrity/barrier activity could be restored to lower the incidence rate and enhance gastrointestinal tract homeostasis [Kong, C. *et al*., 2024].

Multidrug-Resistant Infections

Individual phage preparations have been reported to be used successfully in compassionate use and case-report studies in the successful treatment of multidrug-resistant bacteria. These types of interventions are usually performed using patient specific phage cocktails, using susceptibility testing of identified bacterial isolates [Bhale, B. *et al*., 2026]. A few examples of clinical improvement in refractory infections hint to the leeway of phage therapy. Such findings make phage treatment a promising adjunct or replacement of conventional antibiotics in the time of the rise in antimicrobial resistance [Rahman, M. U. *et al*., 2025].

Dermatological and Respiratory Applications

Topical phage preparations are currently being considered in the scenario of acne vulgaris, as well as chronic wound infections by the resistant bacterial strains. This is because of their localized use, which enables them to be highly specific and minimize systemic effects and perturbations of microbiomes. Respiratory medicineinhaled phage therapy Inhaled phage therapy has potential in the treatment of chronic pulmonary infection particularly in cystic fibrosis patients. Selectivity of Airway biofilm bacteria can promote better lung performance and reduce the number of exacerbations [Chan, B. K. *et al*., 2025].

CHALLENGES AND LIMITATIONS

Phage Resistance

The mechanism that the bacteria adapt against infection of bacteria originating through phage is either by receptor modification, utilization of the immune system called crcr-cas, and restriction modification systems. This resistance can decrease the efficacy of phages and restrict the therapeutic potential in case of non-proactive treatment [Oromí-Bosch, A. *et al*., 2023]. It is thus highly essential to monitor the bacteria population and select the adaptive phages continuously. Phage cocktail and sequential administration are a few of the strategies that can be used to overcome this emergence of resistance. The behavior of evolution in a microbial community is of importance to long term success [Bhale, B. *et al*., 2026].

Host Immune Responses

The innate and adaptive mechanisms have a potential to neutralise therapeutic phages by the human immune system. Viral capsid composition is the factor that dictates immunogenicity of phages, route of administration and dosing frequency [Obaida, M. H., & Yasir, S. J. 2025]. Antibody neutralization can be used to reduce repeated therapy, by preventing the persistence of phages [Bernabéu-Gimeno, M. *et al*., 2024]. Capsulation, chemical modification, or localized delivery technologies are currently being considered to improve bioavailability. Immunological profiling will be cautiously performed to strike the balance between efficacy and safety [Chen, A. *et al*., 2025].

Ecological Unpredictability

Human microbiome is an active and a complicated ecosystem with multifaceted interactions among species as well as metabolic relationships. Certain destruction of pathogenic bacteria may inadvertently disrupt the state of the microflora and the proliferation of opportunistic species may take place [Ravichandran, S. *et al*., 2025]. The achievement of the environmental outcomes is predicted with adherence to the complete systems-level modeling and metagenomic surveillance. Phage interventions should, therefore, be environmental friendly in the consideration of the unidentified consequences. Experiments and computational simulations can be employed to make sure that the predictions are less predictable and unsafe. [Panda, A. *et al*., 2025].

Regulatory and Standardization Barriers

Huge regulatory demands by the biological variability, compounded preparations and developing manufacturing technologies characterise the Phage therapy [Niazi, S. K. 2025]. There are no universal global standards that complicate the processes of approving processes. Phage specificity, patient heterogeneity, adaptive responses of the microbiome should be done to design clinical trials. The regulations are to be

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changed in order to treat phages as living therapeutics and offer safety and reproducibility [Gallina, A. *et al*., 2026].

ETHICAL AND SAFETY CONSIDERATIONS

The biosafety and ecological concerns are also raised in genetic engineering and phage modification particularly in the case of horizontal gene transfer [Attar, R. 2025] Comprehensive genomic sequencing, containment measures and controlled preclinical testing should help mitigate the risks. The question of patient consent and the release of the environment and the ecological monitoring over the long-term also fall under ethical issues. The products must be used sustainably via the responsible development and implementation [Joshi, M., & Patel, B. M. 2025].

FUTURE DIRECTIONS

Recent advances in multi-omics technologies, including metagenomics, metabolomics, and transcriptomics will allow learning more about the interactions between phage and microbiome, and scale-level outcomes [Moguel, B. *et al*., 2026]. Combined with artificial intelligence and computational modeling, predictive, personalized microbiome reprogramming mechanisms can be viable. Phage therapy might also be a special instrument that will be introduced along with antibiotics, probiotics, and dietary interventions [Zhang, J. *et al*., 2026]. Prophylactic microbiome modulation and chronic disease management on a long-term basis can be examples of such uses. Interdisciplinary research will be useful in translating it in full scale [Gilbert, J. A. *et al*., 2025].

CONCLUSION

The phage therapy is a groundbreaking practice of precision medicine involving the reprogramming of human microbiome. It will also be possible to selectively and intentionally control microbial ecosystems with the assistance of the natural specificity and plasticity of bacteriophages. However, to be successful in clinical translation, the issue of resistance development, immune interactions, ecological complexity, and regulatory problem should be solved. Interdisciplinary research that will bring microbiology, immunology, systems biology and bioengineering close will be key in the future of microbiology as a therapeutic option in that we can achieve the entire therapeutic scope of phage-mediated microbiome reprogramming.

REFERENCES

1. Ma, Z., Zuo, T., Frey, N., & Rangrez, A. Y. "A systematic framework for understanding the microbiome in human health and disease: from basic principles to clinical translation." *Signal Transduction and Targeted Therapy* 9.1 (2024): 237.
2. Puri, B., Vaishya, R., & Vaish, A. "Antimicrobial resistance: Current challenges and future directions." *Medical Journal Armed Forces India* 81.3 (2025): 247-258.
3. Federici, S., Nobs, S. P., & Elinav, E. "Phages and their potential to modulate the microbiome and immunity." *Cellular & molecular immunology* 18.4 (2021): 889-904.
4. Serwer, P. "Role of phages in past molecular biology and potentially in future biomedicine." *Encyclopedia* 5.2 (2025): 58.
5. Singh, H., Balusamy, S. R., Sukweenadhi, J., Saravanan, M., Aruchamy, M., Mijakovic, I., & Singh, P. "Smart hybrid nanomaterials for chronic infections: microbiome-responsive and sustainable therapeutic platforms." *Journal of Nanobiotechnology* 23.1 (2025): 698.
6. Joos, R., Boucher, K., Lavelle, A., Arumugam, M., Blaser, M. J., Claesson, M. J., & Ross, R. P. "Examining the healthy human microbiome concept." *Nature Reviews Microbiology* 23.3 (2025): 192-205.
7. Deo, R., Lakra, U., Ojha, M., Nigam, V. K., & Sharma, S. R. "Exopolysaccharides in microbial interactions: signalling, quorum sensing, and community dynamics." *Natural Product Research* 39.11 (2025): 3224-3239.
8. Heidari, H., & Lawrence, D. A. "An integrative exploration of environmental stressors on the microbiome-gut-brain axis and immune mechanisms promoting neurological disorders." *Journal of Toxicology and Environmental Health, Part B* 27.7 (2024): 233-263.
9. Mengoli, M. "Drug and probiotics-based intervention strategies for the restoration of gut microbiome dysbiosis." (2025).
10. Abedon, S. T. "Ecology and evolutionary biology of hindering phage therapy: the phage tolerance vs. phage resistance of bacterial biofilms." *Antibiotics* 12.2 (2023): 245.
11. Shuwen, H., & Kefeng, D. "Intestinal phages interact with bacteria and are involved in human diseases." *Gut microbes* 14.1 (2022): 2113717.
12. Shuwen, H., & Kefeng, D. "Intestinal phages interact with bacteria and are involved in

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human diseases." *Gut microbes* 14.1 (2022): 2113717.
13. Chevallereau, A., Pons, B. J., van Houte, S., & Westra, E. R. "Interactions between bacterial and phage communities in natural environments." *Nature Reviews Microbiology* 20.1 (2022): 49-62.
14. Bhale, B., Shirodkar, S., Sawarkar, S., & Omri, A. (2026). Phage therapy: innovations, challenges, and future directions in combating superbugs and antibiotic resistance. *Expert Review of Anti-infective Therapy*, (just-accepted).
15. Jiang, A., Liu, Z., Lv, X., Zhou, C., Ran, T., & Tan, Z. "Prospects and challenges of bacteriophage substitution for antibiotics in livestock and poultry production." *Biology* 13.1 (2024): 28.
16. Amen, R. A., Hassan, Y. M., Essmat, R. A., Ahmed, R. H., Azab, M. M., Shehata, N. R., & El-Sayed, W. M. "Harnessing the microbiome: CRISPR-based gene editing and antimicrobial peptides in combating antibiotic resistance and cancer." *Probiotics and Antimicrobial Proteins* 17.4 (2025): 1938-1968.
17. Atkins, H. "Selecting for Lysis in a Temperate Phage Population." *MS thesis. Loyola University Chicago*, (2025).
18. Husain, F. M., Zahra, A., Ali, A., Kamthan, M., Al-Shabib, N. A., Farooqui, Z., & Munawar, N. "Bacteriophages and Their Enzymes: Allies Against Microbial Biofilms." *Pharmaceuticals* 18.12 (2025): 1771.
19. Kovacs, C. J., Rapp, E. M., McKenzie, S. M., Mazur, M. Z., Mchale, R. P., Brasko, B., & Barnhill, J. C. "Disruption of biofilm by bacteriophages in clinically relevant settings." *Military Medicine* 189.5-6 (2024): e1294-e1302.
20. Odoom, A., & Dzuvor, C. K. "Pseudomonas aeruginosa: Pathogenesis-Immunity Arm Race, Vaccine and Therapeutics Development Panoramas." *Advanced Therapeutics* 9.1 (2026): e00248.
21. Saxena, D., Maitra, R., Dasgupta, A., & Chopra, S. "Alternative Approaches to Counter Multidrug-Resistant Bacterial Pathogens." *Emerging Paradigms for Antibiotic-Resistant Infections: Beyond the Pill* (2024): 69-121.
22. Yoon, B., Kim, J. A., & Kang, Y. K. "CRISPR–Cas-Mediated Reprogramming Strategies to Overcome Antimicrobial Resistance." *Pharmaceutics* 18.1 (2026): 95.
23. Kim, M. K., Suh, G. A., Cullen, G. D., Rodriguez, S. P., Dharmaraj, T., Chang, T. H. W., & Sacher, J. C. "Bacteriophage therapy for multidrug-resistant infections: current technologies and therapeutic approaches." *The Journal of Clinical Investigation* 135.5 (2025).
24. Yue, Y., Xu, Z., Soteyome, T., Premarathna, M., Yin, X., & Liu, J. "Phage Encapsulation and Delivery Technology: A Strategy for Treating Drug-Resistant Pathogenic Microorganisms." *Pharmaceuticals* 18.11 (2025): 1688.
25. Sisodiya, D., Madhavilatha, B., Bandigari, P., Katual, K. M., Gupta, N., Krosuri, P., & Negi, S. S. "Bacterial Nanocarriers for Site-Specific Drug Delivery: Harnessing Microorganisms for Precision Medicine." *African Journal of Biological Sciences* 6.9 (2024): 2400-2420.
26. Ding, B., Fan, M., Shi, Y. P., Chen, X., & Duan, Y. "Mechanistic roles and therapeutic potential of bacteriophages in inflammatory gastrointestinal diseases." *Microbiome Research Reports* 4.4 (2025): 40.
27. Kong, C., Yang, M., Yue, N., Zhang, Y., Tian, C., Wei, D., & Li, D. "Restore intestinal barrier integrity: an approach for inflammatory bowel disease therapy." *Journal of inflammation research* (2024): 5389-5413.
28. Bhale, B., Shirodkar, S., Sawarkar, S., & Omri, A. "Phage therapy: innovations, challenges, and future directions in combating superbugs and antibiotic resistance." *Expert Review of Anti-infective Therapy* just-accepted (2026).
29. Rahman, M. U., Shah, J. A., Khan, M. N., Bilal, H., Zhu, D., Du, Z., & Mu, D. S. "Innovative approaches to combat antimicrobial resistance: a review of emerging therapies and technologies." *Probiotics and Antimicrobial Proteins* (2025): 1-18.
30. Chan, B. K., Stanley, G. L., Kortright, K. E., Vill, A. C., Modak, M., Ott, I. M., & Koff, J. L. "Personalized inhaled bacteriophage therapy for treatment of multidrug-resistant Pseudomonas aeruginosa in cystic fibrosis." *Nature medicine* 31.5 (2025): 1494-1501.
31. Oromí-Bosch, A., Antani, J. D., & Turner, P. E. "Developing phage therapy that overcomes the evolution of bacterial resistance." *Annual review of virology* 10.1 (2023): 503-524.
32. Bhale, B., Shirodkar, S., Sawarkar, S., & Omri, A. "Phage therapy: innovations, challenges, and future directions in combating superbugs and antibiotic resistance." *Expert*

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Review of Anti-infective Therapy just-accepted (2026).
33. Obaida, M. H., & Yasir, S. J. "Bacteriophages: Molecular and Virologic Review Study." *Journal of Progressive Medical Sciences Vol* 1.2 (2025).
34. Bernabéu-Gimeno, M., Pardo-Freire, M., Chan, B. K., Turner, P. E., Gil-Brusola, A., Pérez-Tarazona, S., & Domingo-Calap, P. "Neutralizing antibodies after nebulized phage therapy in cystic fibrosis patients." *Med* 5.9 (2024): 1096-1111.
35. Chen, A., Gong, Y., Wu, S., Du, Y., Liu, Z., Jiang, Y., & Miao, Y. B. "Navigating a challenging path: precision disease treatment with tailored oral nano-armor-probiotics." *Journal of nanobiotechnology* 23.1 (2025): 72.
36. Ravichandran, S., Thangarasu, D., Ravichandran, A., Dorai, S., Ayyadurai, N., Sivapackiam, J., & Periasamy, S. "Coral Microbiomes and Biofilms: Ecological Features, Response to Microbial Infections, and Conservation Strategies." *Marine Ecology* 46.4 (2025): e70036.
37. Panda, A., Rout, S. S., Dey, S., Parida, C. K., Jena, R., Dhar, S., & Singh, A. K. "Metagenomics and Its Application in Environmental Monitoring." *Advances in Omics Technologies: Exploring Genomics, Proteomics, and Metabolomics*. Singapore: Springer Nature Singapore, (2025). 1-37.
38. Niazi, S. K. "Bacteriophage therapy: discovery, development, and FDA approval pathways." *Pharmaceuticals* 18.8 (2025): 1115.
39. Gallina, A., Gallina, M., Cona, A., Vitulo, P., Mularoni, A., & Provenzani, A. "Phage Therapy at the Crossroads Between Clinical Promise and Regulatory Challenge." *Pharmaceuticals* 19.1 (2026): 162.
40. Attar, R. "Phages Beyond Pathogens: Unexplored Horizons in Genetics, Biotechnology, Space Exploration, and Synthetic Life." *Journal of Pure & Applied Microbiology* 19.4 (2025).
41. Joshi, M., & Patel, B. M. "Pre-clinical and Clinical Studies, Pharmacovigilance, Pharmacogenomics, and Commercialization of Pharmaceutical Products." *Advances in Pharmaceutical Product Development*. Singapore: Springer Nature Singapore, 2025. 423-443.
42. Moguel, B., Olivas, L. C., Guerrero-Osornio, M. G., & Herrera Paredes, S. "Recent microbial evolutionary insights from metagenomics." *Genome Biology and Evolution* (2026): evag029.
43. Zhang, J., Liu, J., & Bayani, A. "Phage therapy and the microbiome in hematologic malignancies: opportunities, mechanisms, and early evidence." *Journal of Cancer Research and Clinical Oncology* 152.1 (2026): 8.
44. Gilbert, J. A., Azad, M. B., Bäckhed, F., Blaser, M. J., Byndloss, M., Chiu, C. Y., & Knight, R. "Clinical translation of microbiome research." *Nature medicine* 31.4 (2025): 1099-1113

Source of support: Nil; **Conflict of interest:** Nil.

Cite this article as:
Abbas, H. F. "Prospects and Challenges Reprogramming the Human Microbiome Using Phage Therapy." *Sarcouncil Journal of Applied Sciences* 6.3 (2026): pp 39-45.

Publisher: SARC Publisher