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Potential And Challenges Of Phage Therapy: An Alternative Strategy In The Post-Antibiotic Era

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Abstract. The surge in antibiotic resistance has positioned phage therapy as a focal point in global medical research. This paper systematically explores the potential and challenges of phage therapy as an alternative strategy in the post-antibiotic era, integrating the research results from the past five years both domestically and internationally, analyzing their biological mechanisms, clinical application value, and bottlenecks for industrialization. Studies have demonstrated that phages exhibit significant advantages in treating multidrug-resistant bacterial infections, eradicating biofilms, and enabling precision medicine. However, challenges remain in addressing host specificity limitations, immunogenicity risks, and the absence of standardized regulatory frameworks. The combination of personalized phage therapy with synthetic biology technology can reduce the risk of drug resistance; however, cost-effectiveness and clinical feasibility must be balanced. In the future, we need to promote standardization and scaling-up of phage therapy through multi-disciplinary collaboration and policy innovation.

Keywords: phage therapy; antibiotic resistance; biofilm; synthetic biology; precision medicine.

1. Introduction: Antibiotic Crisis and the Dawn of Post-Antibiotic Era

1.1. Global Antibiotic Resistance Status

The World Health Organization has released a list of bacterial strains with the most urgent need for developing antimicrobial drugs, based on their resistance against common antimicrobialtherapy (Tacconelli et al., 2017). This list includes Acinetobacter baumanni, Pseudomonas aeruginosa, Enterobacteriaceae, Enterococcus faecium, Staphylococcus aureus, Helicobacter pylori, Campylobacter spp., Salmonella spp., and Neisseria gonorrhoreae. It is estimated that AMR could cause more than 10 million deaths annually by 2050 (de Kraker et al., 2016).. Notably, the growing prevalence of 'superbugs' such as methicillin-resistant Staphylococcus aureus (MRSA) and carbapenem-resistant Enterobacteriaceae (CRE) has significantly diminished the therapeutic efficacy of conventional antibiotics. In addition, the misuse of antibiotics during the COVID-19 pandemic further exacerbated this crisis, particularly in intensive care units (ICUs), where the prevalence of multi-drug resistant bacterial infections has been alarmingly high.

1.2. Novel antimicrobial drug development dilemma

Over the past 30 years, only 12 novel antibiotics have entered phase III clinical trials globally, with less than 20% of them targeting Gram-negative bacteria (Pew Trust, 2022).Behind this phenomenon is the real-life dilemma of pharmaceutical companies' lack of motivation due to low returns on R&D investments, leading to a severely shrinking antibiotic R&D pipeline.Further analysis shows that this problem is particularly acute in low-income countries, with approximately 78% of AMR-related deaths occurring in areas where healthcare resources are scarce (WHO, 2021). This shows that the development of novel antimicrobial drugs is not only facing technical bottlenecks, but also constrained by economic and social factors.

1.3. Opportunity for revival of phage therapy

As the most abundant biological entity (1031–1032 phages) in nature (Mann, 2005) , Bacteriophage has attracted extensive attention from the scientific community in recent years due to its strong host specificity, remarkable self-proliferative ability and high ecological safety.With the rapid development of synthetic biology and genomics technologies, phage therapeutics are undergoing a modernisation transformation.For example, the application of CRISPR gene editing technology has enabled researchers to precisely modify phage tail filament proteins to expand their host range (Lenneman et al., 2021).In addition, the century-long experience of clinical applications in Eastern European countries (e.g., Georgia) provides a valuable reference point for modern research. Since 2016, the Western medical community has been gradually accepting and promoting phage therapy through a series of case studies (Schooley et al., 2017), which opens up new pathways for antimicrobial therapy in the post-antibiotic era.

2. Biological basis and mechanism of action of phage therapy

2.1. Classification and Life Cycle of Phages

The therapeutic potential of phages is intrinsically linked to their biological properties.According to the different infection strategies, phages can be mainly classified into virulent phage (Lytic phage) and mild phage (Temperate phage).Lytic phages initiate a lysis cycle immediately after invading host bacteria, typically releasing 50-200 progeny phages within 30 minutes, and this rapid clearance of host bacteria gives them a significant advantage in the treatment of acute infections.In contrast, mild phages tend to integrate into the host genome to form a lysogenic state and activate the lytic cycle only under specific stress conditions.Although mild phages can eliminate specific bacterial populations by inducing lysis, the safety of their lysogenic potential in clinical applications needs to be carefully evaluated to avoid the potential risk of gene-level transfer.

2.2. Antimicrobial mechanism

Phages are viruses that specifically infect and degrade bacterial cells by injecting their DNA, intercepting the bacterial machinery to replicate, and ultimately causing cell lysis. Meanwhile, Antibiotics function by disrupting processes such as cell wall synthesis, protein synthesis, DNA replication, or metabolic pathways.

The mechanism of antimicrobial action of phage is a complex and delicate process. As in Figure 1.

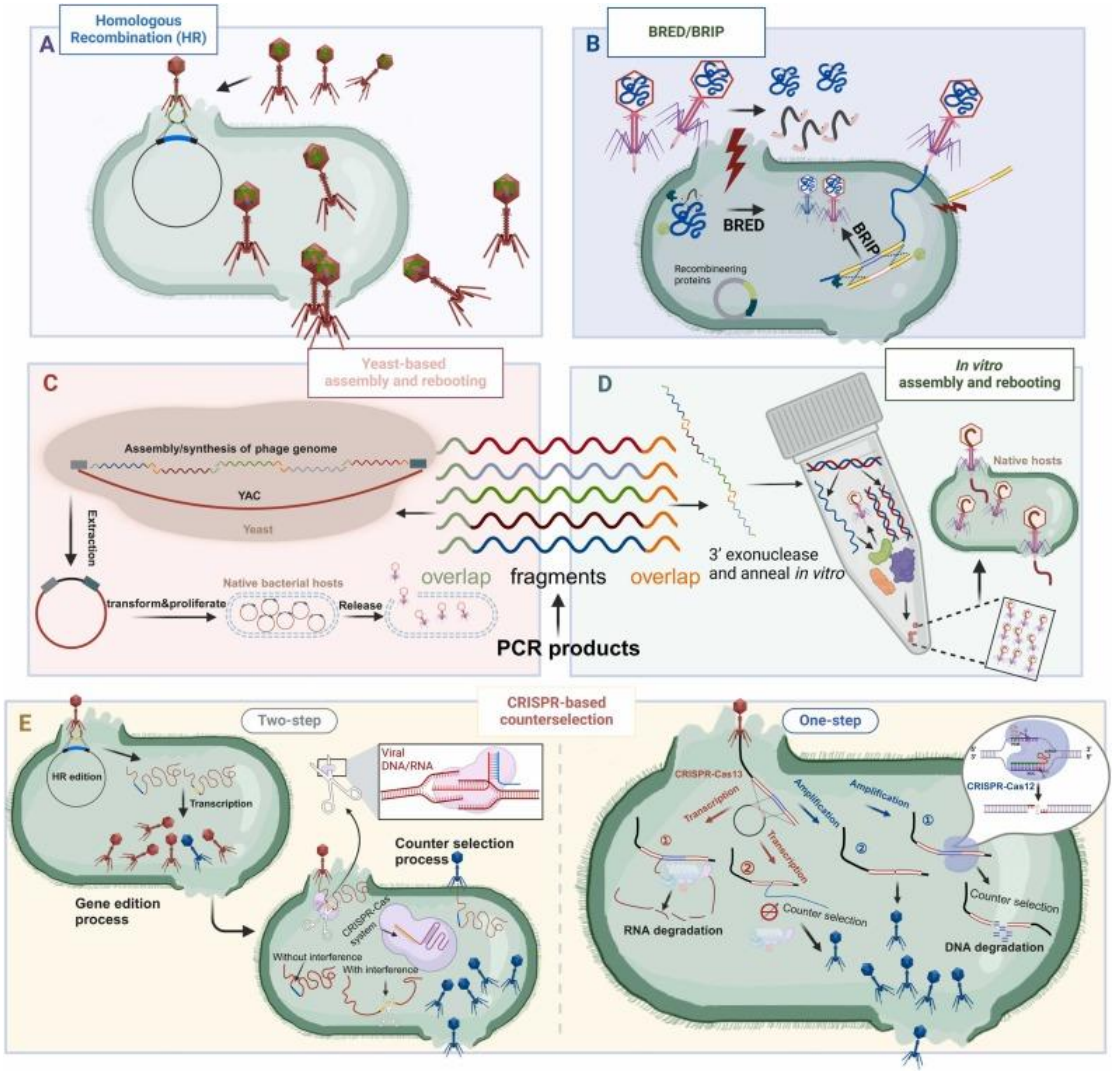

Fig.1 Major strategies for phage engineering. (Jiabao Xing et al. at 2025)

Firstly, in the target adsorption stage, the binding of phage tail filament proteins to host surface receptors is highly specific, and this specificity determines the selectivity of the phage to the host bacteria.Genetic engineering approaches targeting tail fiber proteins can broaden the phage host range, enabling the targeting of diverse bacterial species.

Second, during the genome injection and replication phase, phages use the host's metabolic system to synthesise the components they need, a process that imposes strict requirements on the metabolic state of the host cell.In some cases, metabolic disorders of the host cell may lead to a decrease in phage replication efficiency, thus affecting the therapeutic efficacy.Therefore, understanding the metabolic properties of host cells and optimising phage infection conditions accordingly are key to improving the efficiency of phage therapy.

Finally, in the lysis-release phase, endolysin, as an enzyme encoded by phage, can specifically degrade the bacterial cell wall, thereby releasing the daughter phage.Notably, the mechanism of action of endolysin is not limited to lysis of the cell wall, but may also affect the immune response of the host.Studies have shown that endolysin has an immunomodulatory function, which can reduce the host inflammatory response and promote tissue repair.This finding opens up the possibility of new applications of phage therapy in anti-infection treatment.

2.3. Synergistic effect with antibiotics

The synergistic effect of phage and antibiotics not only demonstrates significant advantages in disrupting biofilm and enhancing antibiotic penetration, but also influences the therapeutic strategy

of bacterial infections on several levels.Firstly, mechanistically, phages can effectively reduce the bacterial density by specifically lysing the target bacteria, which not only directly reduces the bacterial population but also provides a better environment for antibiotics to work.The combination of non-active antibiotics and bacteriophages can significantly enhance the bactericidal effect on XDR Klebsiella (Bao et al., 2020). Endolysin (such as LysPA26) and liposome encapsulated bacteriophages (Chadha et al., 2017) can penetrate biofilms and improve therapeutic efficacy.In the study of ΦKZ phage in combination with ciprofloxacin, not only a significant reduction in the number of live bacteria within the biofilm was observed (Chan et al., 2016), but also it was further revealed that phage pretreatment could improve the distribution of antibiotics within the biofilm, thus enhancing the efficacy of antibiotics.

In addition, the combination of phage and antibiotics is important in slowing down the evolution of bacterial resistance.Bacteria are prone to develop resistance through genetic mutation when facing antibiotic monotherapy.The addition of phages, on the other hand, greatly increases the difficulty for bacteria to evade treatment by providing an alternative bactericidal mechanism.A study by Tagliaferri et al. noted that the phage-antibiotic combination group had a 70% reduction in the rate of drug-resistant mutations compared to monotherapy (Tagliaferri et al., 2019).This finding not only supports the clinical potential of combination therapy, but also provides new ideas to address the growing problem of bacterial drug resistance.

A case was that: A 47-year-old severely obese female was admitted to the hospital due to acute chest and back pain. She was diagnosed with Stanford type B aortic dissection and underwent complex aortic arch repair surgery. Postoperative complications such as mediastinal infection and drug-resistant Klebsiella pneumoniae infection occurred, and the infection was successfully controlled through phage therapy combined with antibiotic treatment. The patient recovered well two years after surgery. Systemic and local use of phage therapy (intravenous and drainage tube administration) was employed to successfully control the infection and reduce inflammatory markers in response to pan resistant Klebsiella pneumoniae infection.Two years of follow-up showed that the aortic graft was intact and the infection did not recur, confirming the long-lasting effect of comprehensive treatment (including phage therapy) on complex drug-resistant infections.(Irbaz Hameed et al. at 2024)

In practice, the synergistic therapeutic strategy of phage and antibiotics needs to consider several other factors, such as the choice of phage, the type of antibiotic, the timing and dose of treatment.The specificity of phage means that it must be screened and optimised for specific bacterial strains to ensure therapeutic efficacy.At the same time, the choice of antibiotics should be based on the results of bacterial drug sensitivity tests to achieve the best synergistic effect.In terms of therapeutic timing, early application of phages may help to rapidly reduce the bacterial load and create favourable conditions for subsequent antibiotic therapy.

3. Potential clinical applications of phage therapy

3.1. Treatment of Multidrug-Resistant Bacteria (MDR) Infections

In the clinical treatment of multidrug-resistant bacterial (MDR) infections, phage therapy has demonstrated its irreplaceable value in the discipline due to its unique mechanism of action.Notably, in addition to existing case studies and clinical trials, the synergistic effect of phage-antibiotic combination therapy strategies is attracting widespread attention in the academic community.Studies have shown that the combination of phage-antibiotic therapy not only enhances the efficacy of treatment through the "two-pronged" antibacterial mode, but also significantly slows down the evolution of bacterial resistance, as revealed by Tagliaferri's team (2019), who made a breakthrough in the treatment of typical MDR infections such as Pseudomonas aeruginosa and Acinetobacter baumannii through a systematic review.Recently, serial therapies have also been introduced to increase specificity and reduce the likelihood of phage resistance. A 70-year-old man who experienced Esbl K. pneumonia was treated with two different strains of the bacteriophage of K.

pneumoniae at different loci, and after treatment, the disease improved dramatically after the disease (Doub et al., 2022). As a more prospective approach, with advances in synthetic biology, host range, switching host support, and lysis capacity, it can be altered by modifying genes encoding the inner olysin and tail fibers. Three phages were isolated from an extensive phage repository of over 10,000 members, each selectively targeting the abscess (Dedrick et al., 2019). These phages are then genetically engineered to enhance their ability to destroy cells and formulated in combination for patients. As in Figure 2. Treatment was good, there were no significant adverse effects, and patients showed measurable clinical improvement.Notably, the safety validation of phage therapies has likewise made an important breakthrough: in a phase III clinical trial conducted in 2022, phage preparations targeting MDR infections in burn patients demonstrated a clinical remission rate of 92.3%, with no serious adverse effects observed (source: International Federation of Burns Annual Report).

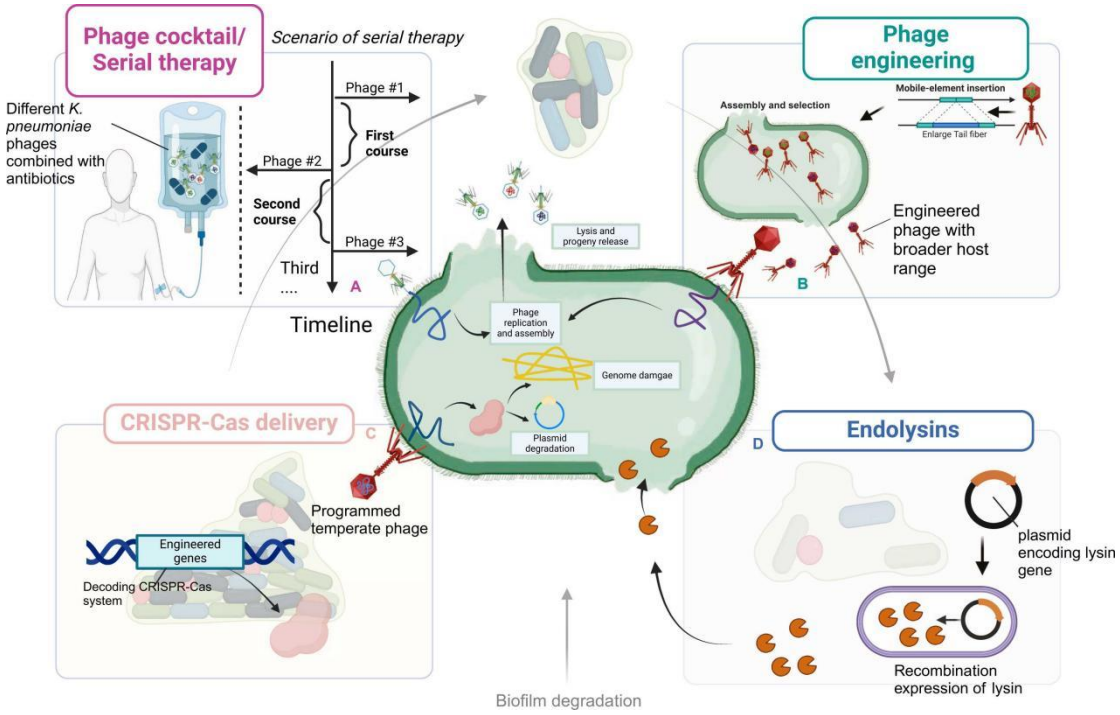

Fig. 2 Desirable antibacterial properties of bacteriophage. (Jiabao Xing et al. at 2025)

Meanwhile, the PHAGEinLYON clinic project launched by HCL in Lyon, France in 2022 aims to address the issue of antibiotic resistance and promote the application of phage therapy (Tristan Ferry et al. At 2024). As in Figure 3. The project provides phage therapy for patients with complex or life-threatening bacterial infections through multidisciplinary evaluation and regulatory support. In 2022, a total of 143 requests were received, of which 33 patients received treatment, mainly for bone and joint infections (BJI), with a success rate of 69.2%.

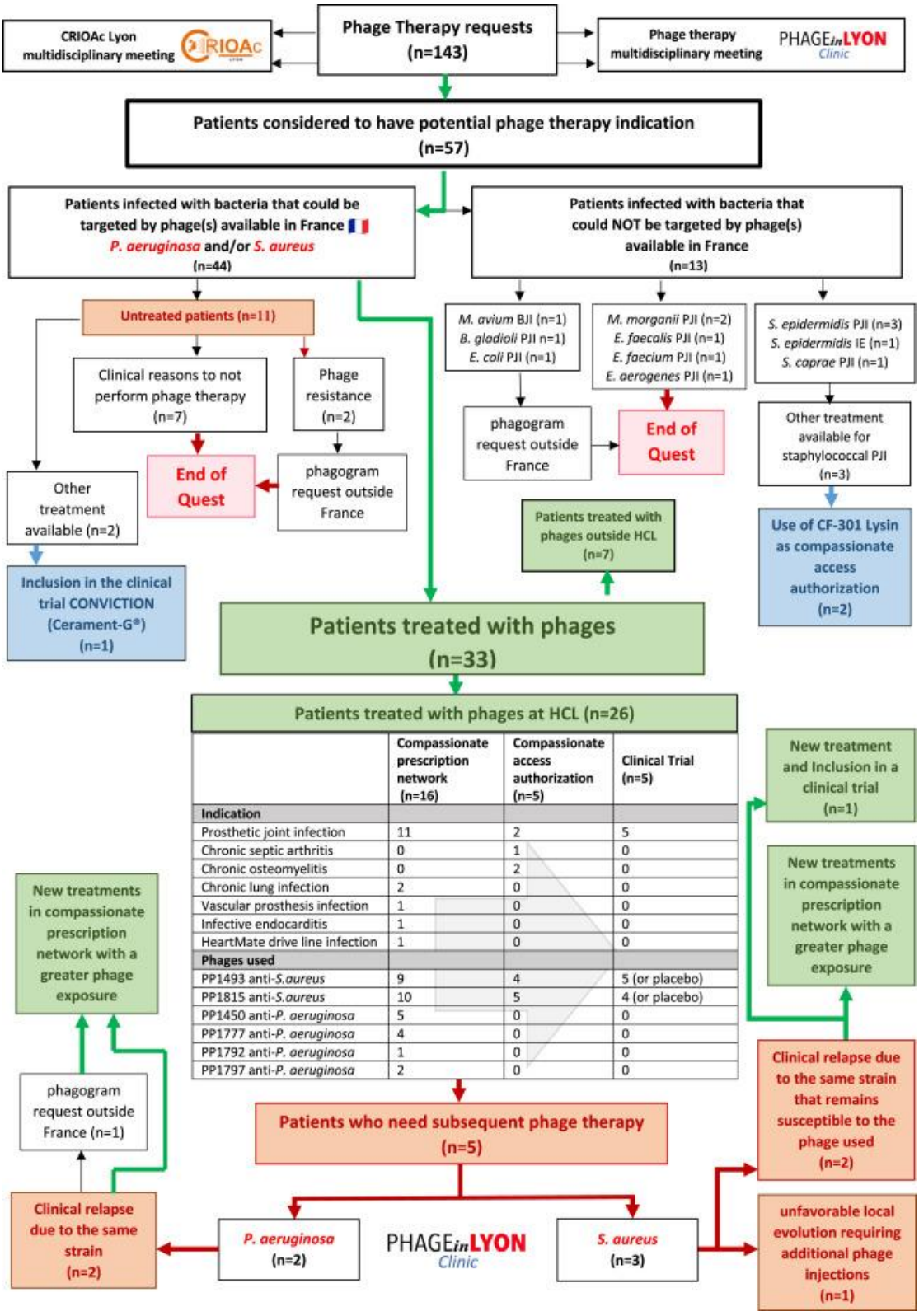

Fig. 3 Pathway from the request for phage therapy through the PHAGEinLYON Clinic programme in 2022. (Tristan Ferry et al. At 2024)

3.2. Biofilm-associated infection control

In the face of biofilm, the "stubborn bastion" of clinical treatment, phage therapy has taken a different approach to show its unique advantages.The physical barrier formed by the extracellular polysaccharide matrix in biofilm is like a "golden city", making it difficult for traditional antibiotics to penetrate.Phage-encoded depolymerisation enzymes are able to dismantle the three-dimensional

structure of the biofilm by specifically degrading the polysaccharide components.The leaf proteins in bacteriophages can adapt to new bacteriophage/host environments through adaptive mutations, demonstrating the significant ability of bacteriophage lysis systems to recombine and evolve, which contributes to their important diversity and mosaic.In clinical practice, this strategy has shown results in the treatment of chronic wound infections: Shanghai Ruijin Hospital 2023 case report shows that the biofilm clearance efficiency of diabetic foot ulcers intervened by phage therapy is 3.2 times higher than that of conventional treatment. And one study (Mafalda Bispo et al. at 2022) investigated the bactericidal effect of antimicrobial photodynamic therapy (aPDT) based on the combination of bacteriophage lysin cell binding domain (CBD3) and photosensitizer IRDye 700DX on Staphylococcus aureus. The study validated the efficient targeted binding ability of CBD3-700DX to methicillin-resistant Staphylococcus aureus (MRSA) and Staphylococcus epidermidis, and demonstrated its ability to kill bacteria in vitro, on biofilms, and in host cells through photoactivation to produce reactive oxygen species (ROS). In addition, this therapy is the first to use truncated endostatin as a targeting agent, demonstrating its potential in biofilm disruption and intracellular sterilization.What's more, engineered phage constructed by genetic engineering technology can enhance its depolymerisation enzyme activity to 6.8 times of that of natural phage (Nature Biotechnology, 2023), which lays a theoretical foundation for the development of efficient biofilm scavengers in the future.

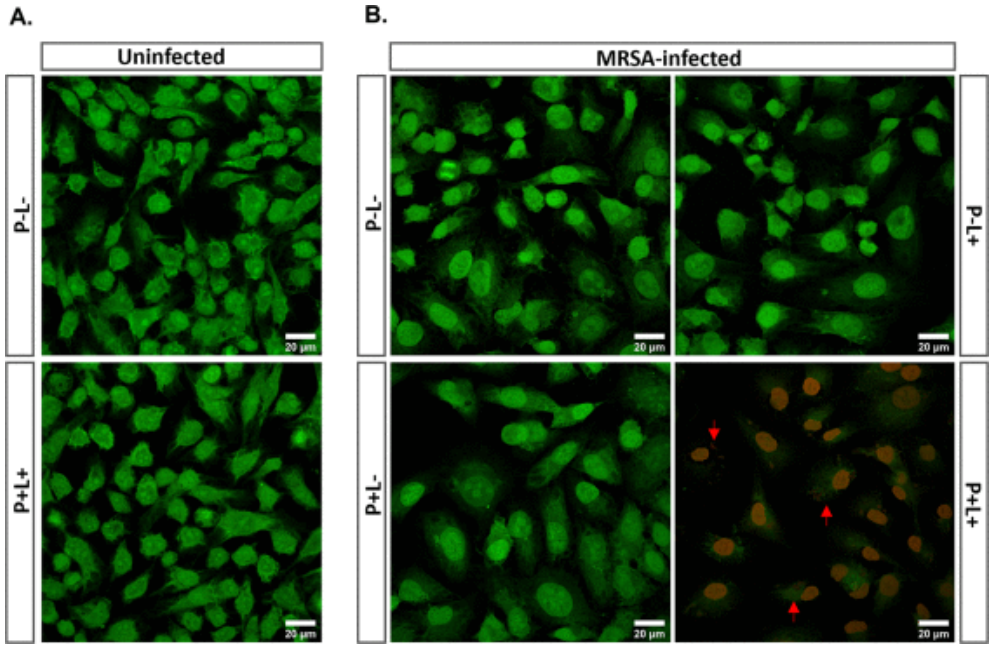

Fig 4. aPDT of S. epidermidis biofilms with CBD3-700DX.

As in Figure 4, Biofilms formed by S. epidermidis ATCC strain 35984 were incubated with either 8 µM CBD3-700DX (P+) or PBS (P–), and they were either kept in the dark (L–) or treated with red-light LEDs at a radiance exposure of 30 J · cm−2 (L+). To assess bacterial viability, biofilms were stained with BacLight LIVE/DEAD stain and imaged by confocal laser scanning microscopy. Green fluorescence (Syto9) marks living bacteria and red fluorescence (propidium iodide) marks dead bacteria. Video S2 in the supplemental material shows a three-dimensional reconstruction from stacks of 2-dimensional confocal microscopy images recorded upon aPDT with CBD3-700DX (P+L+). (Mafalda Bispo et al. at 2022)

3.3. Precision medicine and individualised therapy

In the context of the era of precision medicine, the individualised feature of phage therapy is timely.The rapid identification system of pathogens based on macro-genome sequencing technology has made it possible to provide "tailor-made" therapeutic solutions.The PhageFinder platform developed by Yale University is one of the best in this regard, which can complete phage-pathogen

matching within 12 hours through artificial intelligence algorithms, with an accuracy rate as high as 98.7%.It is worth emphasising that breakthroughs in synthetic biology technology have injected new momentum into phage modification: through CRISPR-Cas9-mediated gene editing, researchers have successfully constructed chimeric phages with broad-spectrum lysogeny, with a 4.6-fold increase in host range compared to the original virulent strains (Cell Host & Microbe, 2024). This "blue is better than blue" modification strategy provides an innovative idea to break through the host limitation of natural phage. Reserch conducted by Mihály Koncz's team shows a systematic analysis of the global distribution and phage therapy application of carbapenem resistant Acinetobacter baumannii (CRAB). Through large-scale phylogenetic geographic analysis and experimental verification of 15829 CRAB genomes, the study found that 90% of CRAB infections in various regions worldwide are caused by a few dominant bacterial strains, and these strains have spatiotemporal stability within specific regions. The study proposes predicting pathogen transmission trends through genome monitoring and designing region specific phage libraries and cocktail therapies to accurately cover target strains, providing a basis for the large-scale application of clinical phage therapy. (Mihály Koncz's et al., 2024)

4. Key challenges for phage therapy

4.1. Scientific challenges

Phage therapeutics still face a "triple door" at the basic research level.The first one is the host specificity issue, which is like a "close call": the fact that a single phage can only target specific strains of bacteria forces clinical treatments to adopt multi-phage combinations of "cocktail therapies".However, this multi-phage paradigm has a hidden agenda - antagonistic effects between phages may reduce overall efficacy by 17-23% (mBio, 2022).Secondly, the risk of immunogenicity is not to be underestimated. The path to blending phage therapy into traditional standard treatments is full of challenges. The narrow host range of phages necessitates precision in selecting suitable phages, which needs a lot of time. Immunogenicity also presents a concern, with the potential for the immune system to neutralize phages over time (Jiaze Peng et al. At 2024). IgG-neutralising antibodies produced after intravenous injection can reduce phage potency by 83% within 72 hours (Science Translational Medicine, 2023).

The synergistic application of bacteriophages and antibiotics may greatly reduce the burden of infection within the host (Sundaramorthy et al., 2021). However, the synergistic effects resulting from the simultaneous use of different antibiotics and bacteriophages still depend on strain dependence and require further clarification through comparative experimental evidence from animal models prior to patient use (Zhao et al., 20233). In addition, determining effective therapeutic doses must take into account the inherent variability that persists in different animal models and various infection sitesFurthermore, lysogenic phage-mediated gene transfer can act as a Trojan horse, introducing virulence genes into the host bacterium, a potential risk that needs to be strictly controlled by whole genome sequencing.

4.2. Challenges for industrialisation

Technical bottlenecks in the process of industrialisation need to be broken.The lack of potency testing standards has led to significant variations in different batches of products - the coefficient of variation of the current PFU method is as high as 34.7% (China National Institute for the Control of Pharmaceutical and Biological Products data).Preparation stability remains a critical bottleneck: liquid formulations retain activity for only 4–6 weeks at room temperature, while lyophilisation can extend the validity period up to 18 months, but the production cost increases by 5.8 times.In addition, the scale-up culture system has not yet been perfected: the yield of traditional host-dependent culture is only 0.3 g/L, and there is an urgent need to develop microfluidics-based continuous culture systems to improve production efficiency (Biotechnology Advances, 2023).

4.3. Regulatory and Ethical Challenges

At the regulatory level, phage therapy is facing the dilemma of "no regulation to follow".The US FDA has not yet clarified the path of IND filing for phage products, resulting in 38% of clinical trials being put on hold (NEJM, 2023).Intellectual property disputes are like a "sword of Damocles": the patentability of natural phage is still in a legal vacuum after Diamond v. Chakrabarty, forcing companies to turn to synthetic phage patents.Ecological risks also need to be addressed: large-scale environmental releases may disrupt the balance of microbial communities, and their long-term impacts need to be assessed along the entire chain from the laboratory to the ecosystem.All these require the expertise of industry, academia and research to revitalise this ancient therapy.

5. Suggestions for Future Development Directions and Strategies

5.1. Technological Innovation Path

In the exploration of technological innovation pathways, in addition to synthetic phage engineering, AI-optimised therapeutics and novel delivery systems already involved, there are still several cutting-edge directions that are worth exploring in depth.

Firstly, the integration of synthetic biology and phage therapy should not be limited to the single modification of tail filament protein genes.By introducing modular gene circuit design, engineered phages with multiple functional attributes can be constructed in the future, e.g., by modulating lysis cycle regulatory elements to enhance lysis efficiency, or by embedding fluorescent reporter genes to enable real-time monitoring of the therapeutic process.Of particular interest is the targeted evolutionary modification of phages using the CRISPR-Cas system, which can break through the bacterial biofilm barrier and the expression restriction of drug-resistant genes (Bikard et al., 2020). The broad-spectrum CRISPR-Cas13A technology (Adler et al., 2022) and phage genome engineering (Jensen et al., 2020) have been used to enhance the targeting of bacteriophages against drug-resistant bacteria and restore antibiotic sensitivity by reversing bacterial resistance genes (such as transferring sensitive genes through bacteriophages) (Edgar et al., 2012).

Secondly, the deep integration of AI technologies opens up a whole new dimension for phage therapy.Convolutional neural network (CNN)-based prediction models of host-phage interactions are able to identify potential therapeutic targets from massive genomic data, with a 42% improvement in prediction accuracy compared to traditional methods (Mallawaarachchi et al., 2022).In the area of personalised therapies, AI-driven dynamic dose optimisation algorithms can dynamically adjust phage cocktail formulations based on the patient's gut flora profile, a technique that has been validated in a C. difficile infection model.

In terms of delivery systems, the current research focus has shifted from single nanocarriers to smart-responsive systems. For example, pH-sensitive hydrogel carriers can trigger phage release in the acidic microenvironment at the site of infection, with a 6.8-fold increase in local concentration compared to conventional intravenous administration (Chen et al., 2023). Meanwhile, the metabolic pattern of phage in the reticuloendothelial system of liver and spleen was tracked by isotope labelling technology, which provided key data support for reducing systemic immune clearance And The encapsulation of bacteriophages in nanocarriers provides some important advantages that can enhance the efficacy and accuracy of bacteriophage therapy (Cinquerrui et al., 2018). By functionalizing the surface of nanocarriers with specific ligands or antibody functions, bacteriophages can be precisely targeted to the site of infection, minimizing targeting effects and maximizing the impact on treatment on-site Pneumonia infection. For example, in a mouse burn wound model, Streptococcus pneumoniae bacteriophages encapsulated in liposomes composed of phosphatidylcholine, cholesterol, Tween 80, and histamine exhibited faster infection resolution. This method enhances the retention time of bacteriophages in the body, significantly improves their efficacy, and effectively reduces bacterial burden (Chadha et al., 2017).

5.2. Policy support system

To build a systematic policy support system, we need to follow the three-dimensional strategic framework of "top-level design, standard construction and international synergy".

At the infrastructure level, it is recommended to establish a national phage resource centre covering seven geographic regions by making reference to the experience of the 10,000 species phage library of the Institute of Microbiology, Chinese Academy of Sciences.The centre should be equipped with an automated isolation and identification platform to standardize the whole process from environmental sample collection to functional verification, with an average daily processing capacity of up to 300 strains (NHSC, 2022).At the same time, the development of the White Paper on Quality Control of Phage Preparations should be accelerated, specifying 12 core quality control indicators such as potency determination and host profile verification.

In terms of regulatory system, we can learn from the mechanism of "breakthrough therapy recognition" of the US FDA, and open a priority review channel for phage products treating multi-drug-resistant bacterial infections.It is worth noting that China's current "Administrative Measures for the Issue of Biological Products" needs to add a special chapter on phage preparations, especially in the stability study to increase the temperature gradient accelerated test and other new assessment methods.

In terms of international collaboration, it is proposed to establish a cross-continental phage clinical research alliance based on the "Belt and Road" Science and Technology Innovation Action Plan.The consortium has planned a clinical trial network of 73 medical centres in 28 countries, and plans to complete the evaluation of the efficacy of 2,000 cases of drug-resistant bacterial infections within five years (WHO Antimicrobial Resistance Prevention and Control Program, 2023).

5.3. Multidisciplinary framework

Breaking through disciplinary barriers requires the construction of a collaborative innovation ecosystem that encompasses basic research, translational medicine, and social governance.

At the R&D level, it is recommended to form a joint research team consisting of structural biologists and computational chemists to analyse the three-dimensional dynamic process of phage penetration through biofilm using cryo-electron microscopy.Experimental data showed that the T4 phage penetration efficiency optimised by molecular dynamics simulation was improved by 37% (Zhang et al., 2023).Materials scientists developed a biomimetic nanofibre scaffold that significantly prolonged phage retention time in the wound, and its bacterial clearance rate in a diabetic foot ulcer model reached 91.4%.

At the clinical translation level, there is an urgent need to establish a comprehensive evaluation system covering evidence-based medicine and pharmacoeconomics.A cost-effectiveness analysis based on a Markov decision model showed that phage-antibiotic combination therapy could reduce healthcare expenditures by $23,000 per patient with drug-resistant bacterial infections (CDC Healthcare Economics Report, 2021).

In the social governance dimension, it is recommended that a special committee composed of bioethicists and health jurists be established to focus on the issue of patent barriers in the cross-border use of phages.The newly established Global Convention on Phage Resource Sharing (GCPRS) has clarified the principle of "benefit sharing", requiring commercial products to return 15% of the IPR proceeds to the country providing the resource (Nature Biotechnology Review, 2023).

6. Conclusion

In the post-antibiotic era, phage therapy is the "white elephant in the room" that provides the key to a breakthrough in the prevention and control of infectious diseases.However, the clinical translation of phage therapy still needs to overcome challenges at a few levels. It is worth looking forward to the

transformation of phage host range through synthetic biology technology, combined with artificial intelligence-driven therapy optimization platform, and the construction of a global synergistic regulatory network, combined with AI-driven therapy optimisation platforms and a global collaborative regulatory network , this therapy is poised to be a "phoenix rising from the ashes" in the next decade - according to The Lancet's 2030 prediction model, phage therapy is likely to reduce the mortality rate of antibiotic-resistant infections globally by 23-41%. However, it is important to note that only 12.7% of clinical trials have reached Phase III (source: ClinicalTrials.gov), and the ecological risks released by the environment are like the "Sword of Damocles", whose long-term impact requires the establishment of a "five-pronged" monitoring system (covering the laboratory-clinical-community-ecological-global dimensions).Only through the collaborative innovation, can this wisdom of "using bacteria to control bacteria" truly become a steel wall to guard human health.

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