How Microbes Are Useful in Medicine: From Antibiotics to Living Therapies

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ABSTRACT

Microbes contribute to modern medicine in ways that extend far beyond causing infectious diseases. Beneficial bacteria support gut health and immune function, while bacteria and fungi have provided important antibiotics. Microbial systems are also used to manufacture therapeutic proteins, develop vaccines, and improve diagnostic methods. Microbiome based products have offered new approaches to preventing recurrent *Clostridioides difficile* infection. Scientists are investigating engineered bacteria, defined microbial communities, bacteriophages, and CRISPR-based strategies for more targeted treatments, including approaches for cancer and AMR. Although these living therapies show considerable promise, their safety, stability, effectiveness, and regulation require careful evaluation. This article outlines established medical uses of microbes and emerging technologieswhich may shape future healthcare.

INTRODUCTION:

When we hear the word "microbes," many of us think of germs that cause infections. But the truth is far more surprising: many microbes are our allies. Bacteria, fungi, algae, viruses and other microscopic organisms help train our immune system, protect our gut, make medicines, and fight dangerous diseases. Modern medicine would look very different without them (Williams, 1997; Marcum, 2008).

Microbes as Medicine Factories

Some microbes are used as tiny biological factories. Scientists insert a human gene into bacteria and/or yeast, allowing the microbe to produce useful therapeutic proteins such as antibodies, growth factors, and insulin. As the microbes grow and multiply, they produce the medicine, which is then purified for use in patients. The approach is especially important as it allows large-scale, relatively reasonable production of complex drugs that would be difficult to make chemically. Many modern biopharmaceuticals depend on genetically engineered microbial systems (Williams, 1997).

The Source of Antibiotics

Certain soil bacteria and fungi naturally produce chemicals that kill and/or stop the growth of other microbes. *Penicillium* fungi produce penicillin, while *Streptomyces* species have given us antibiotics such as streptomycin, tetracycline, erythromycin, vancomycin, and rifampicin. The discoveries transformed healthcare by making bacterial infections treatable. Antibiotic resistance is now a major concern, so scientists are searching for new antimicrobial compounds from less explored microbes in soil, oceans, and even the human body (Marcum, 2008).

Probiotics & Gut Health

Beneficial bacteria such as *Lactobacillus* and *Bifidobacterium* are used as probiotics. These live microbes can help maintain a healthy balance of gut bacteria, support digestion, and reduce the chance that harmful pathogens establish themselves in the intestine. The gut microbiome helps produce vitamins and short-chain fatty acids, strengthens the intestinal barrier, and communicates with the immune system. Beneficial microbes contribute not only to digestion but also to overall health.

Training & Supporting Immunity

Our immune system constantly interacts with the trillions of microbes living in and on our bodies. Microbes help "educate" immune cells, helping the body distinguish between harmless substances and real threats. They compete with disease-causing organisms, a protective effect known as colonization resistance (Lucius, 2025). This is why disruptions to the microbiome such as excessive antibiotic use can sometimes increase vulnerability to infections and/or inflammatory conditions. Maintaining microbial balance may support immune health (Marcum, 2008; Lucius, 2025).

Microbes in Vaccines & Diagnostics

Microbes and their components are central to vaccines. Weakened or inactivated microbes, or purified pieces of them, can teach the immune system to recognize a pathogen without causing the disease. Vaccines have saved millions of lives and prevented enormous suffering worldwide (Williams, 1997). Microbes are useful in diagnostics. Specific microbial markers, genetic material, or immune responses can help doctors identify infections & analyse diseases. Microbial technologies are increasingly being combined with molecular tools to create faster and more accurate diagnostic tests (Williams, 1997).

Microbiome Medicines

One of the biggest recent advances is the approval of microbiome-based therapies for recurrent *Clostridioides difficile* infection, a serious diarrheal illness which often returns after antibiotics. In 2022, the U.S. FDA approved Rebyota, the first live microbiome product for preventing recurrent *C. difficile* infection in adults; in 2023, it approved Vowst, the first oral fecal microbiome therapy for the same purpose (Monday *et al.*, 2024). The treatments restore a healthier mixture of

gut bacteria after antibiotics have disrupted it. They mark a major shift: instead of only killing microbes with drugs, doctors can now use carefully prepared microbial communities as medicine (Monday *et al.*, 2024; Yadegar *et al.*, 2024).

Engineered "Smart" Bacteria

Researchers engineer bacteria to sense disease signals, release therapeutic molecules, and sometimes report what is happening inside the body. Such "smart" living medicines are being explored for inflammatory bowel disease, metabolic disorders, and cancer (Luo *et al.*, 2024). A notable example is i-ROBOT, an engineered bacterium designed to combine fluorescent reporting, gene-editing, and drug secretion in one system. In animal studies, it was used to diagnose, record, and treat inflammatory bowel disease. New gene-editing tools are also making it possible to modify bacteria directly within the gut. One approach, called MetaEdit, uses CRISPR associated transposases to insert large DNA sequences into the genomes of gut bacteria in mice, potentially enabling precision microbiome programming in the near future.

Bacteria Against Cancer

Engineered bacteria are being developed to target tumors. Some bacterial platforms can preferentially grow in low oxygen tumor environments and deliver anticancer drugs or immune stimulating molecules directly to the tumor site. Between 2022 & 2024, several engineered bacterial systems moved from lab experiments into early clinical testing, showing that safe colonization and metabolic activity in humans are possible. Researchers are combining bacteria with nanomaterials. In experimental systems, magnetic nanoparticles can help control when engineered bacteria break open and release their therapeutic payload, offering a potential way to make treatment more specific.

Defined Microbial Communities

Scientists are developing defined microbial consortia which are precisely defined mixtures of selected beneficial bacteria. The products could be safer, more consistent, and easier to manufacture than traditional fecal microbiota transplantation (Yadegar *et al.*, 2024). In 2026, researchers at Mount Sinai reported a manufacturing platform for producing targeted mixtures of beneficial gut bacteria, that could make microbiome therapy more scalable & accessible for patients with recurrent *C. difficile* infection.

Phages and CRISPR

Bacteriophages (viruses which infect bacteria) are being revisited as alternatives to antibiotics, especially against drug resistant bacteria. Researchers are engineering microbes to deliver CRISPR-based tools which selectively remove harmful bacteria or silence resistance genes while sparing beneficial sp (Ghazaei, 2026; Rahman *et al.*, 2026). The approaches could be especially valuable as AMR continues to rise. Rather than broad spectrum antibiotics that disturb the entire microbiome, future treatments may precisely target only the disease-causing microbes.

Future Prospects

The future of medicine may involve more than pills, injections, and conventional antibiotics. Researchers are increasingly exploring how living microbes can be designed to perform specific medical tasks inside the human body. Engineered bacteria help deliver medicines directly to diseased tissues, detect early signs of inflammation, and release therapeutic substances when needed. The approaches make treatments more precise and potentially reduce unwanted effects on healthy tissues and beneficial microbes. Another promising area is personalized microbiome therapy. Since every person's gut microbiome is different, future treatments may be tailored to an individual's

microbial composition, medical condition, and response to treatment. Scientists are investigating bacteriophages and CRISPR based technologies that target particular pathogenic bacteria while leaving other members of the microbiome relatively undisturbed. These approaches become valuable tools in the global fight against AMR. Living therapies must be proven safe, effective, stable, and predictable in humans. researchers need to understand how engineered microbes behave inside the body, how long they remain active, and how their effects can be controlled and/or stopped when required. Large clinical trials, strict quality controls, and appropriate regulatory approval will be essential before many experimental treatments become widely available. Progress is encouraging, but several of the technologies are still in the research or early stages of clinical development.

CONCLUSION

Microbes have helped us discover life saving antibiotics, manufacture essential medicines, develop vaccines, protect our digestive system and better understand the human immune system. Advances in Microbiology and synthetic biology are opening a new chapter in which carefully selected or genetically engineered microbes may become medicines themselves. The change represents an important shift in how to think about healthcare. Instead of relying only on treatments that eliminate harmful organisms or suppress disease symptoms, medicine is beginning to explore ways to restore microbial balance, recruit beneficial microbes, and program living organisms to perform useful functions. Some of the smallest biological partners have the potential to make a remarkable difference to human health. The medicine of tomorrow may not simply fight life at the microscopic level may learn to work with it.

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