

The Microbiome Immunity Axis: Friends, Foes, and Future Therapies

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DESCRIPTION

The human body is home to trillions of microorganisms that live on the skin, in the gut, in the lungs, and across many other surfaces. This vast community of bacteria, viruses, fungi, and other microbes is known as the microbiome. Among all these habitats, the gut microbiome has gained the most attention because of its powerful influence on health. The relationship between the microbiome and the immune system forms what is often called the microbiome immunity axis. This axis represents a dynamic and continuous interaction in which microbes and immune cells communicate, cooperate, and sometimes clash. It is a partnership that shapes how the body responds to infection, inflammation, and even chronic disease.

The hidden partnership between microbiome and immunity

From the earliest moments of life, the immune system begins learning from microbial exposure. At birth, a newborn's immune system is still developing. As microbes colonize the body, they help train immune cells to distinguish between harmless substances and dangerous invaders. Beneficial bacteria in the gut stimulate the production of protective immune molecules and support the development of immune tissues. They encourage balance by promoting regulatory immune cells that prevent excessive inflammation. Without this guidance, the immune system may become overreactive or weak. Studies involving germ-free animals, which lack a microbiome, show underdeveloped immune structures and poor immune responses. This demonstrates that microbes are not merely passengers but essential partners in immune education.

The gut lining acts as a crucial interface between the microbiome and the immune system. It forms a barrier that keeps harmful pathogens out while allowing nutrients to pass into the bloodstream. Friendly microbes strengthen this barrier by producing short-chain fatty acids and other metabolites that nourish intestinal cells. These compounds also signal immune cells to maintain tolerance and reduce unnecessary inflammation. When the microbiome is diverse and balanced, the immune system tends to function efficiently and calmly. It

responds strongly to real threats while remaining tolerant of food particles and beneficial bacteria. This delicate equilibrium reflects a state of health where microbes and immune defenses support each other.

However, the relationship can shift when the microbiome becomes imbalanced, a condition often referred to as dysbiosis. Factors such as poor diet, chronic stress, infections, pollution, and excessive antibiotic use can disrupt microbial diversity. When beneficial microbes decrease and harmful species increase, the immune system may react differently. Dysbiosis can weaken the intestinal barrier, allowing microbial fragments to enter the bloodstream. This can trigger chronic low-grade inflammation. Over time, such inflammation has been linked to a range of conditions, including autoimmune diseases, allergies, metabolic disorders, and inflammatory bowel disease. The microbiome immunity axis therefore plays a central role not only in defense against infection but also in long-term immune regulation.

Emerging research also highlights the influence of the microbiome beyond the gut. Signals from gut microbes travel through the bloodstream and interact with distant organs. The gut lung axis and the gut brain axis illustrate how microbial metabolites can shape immune responses in the lungs and even influence mood and cognition. This interconnected network shows that the microbiome immunity axis extends throughout the body. It acts as a communication highway that links local microbial communities with systemic immune responses. Understanding this axis offers insight into why disruptions in one area can affect overall health.

Friends, foes, and future therapies

Within the microbiome, not all microbes play the same role. Some act as loyal allies, supporting immune balance and protecting against pathogens. Others can become opportunistic foes under certain conditions. Beneficial microbes compete with harmful bacteria for nutrients and attachment sites, preventing infections from taking hold. They produce antimicrobial substances and stimulate immune defenses that keep invaders under control. At the same time, the immune system tolerates these friendly microbes, recognizing their value in maintaining

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stability. This mutual respect forms the foundation of microbial friendship within the body.

Pathogenic microbes represent the opposing side of this relationship. When harmful bacteria, viruses, or fungi breach protective barriers, the immune system launches a rapid and targeted response. In a balanced system, beneficial microbes help prevent such breaches. In a disrupted system, pathogens may gain an advantage. For example, after repeated antibiotic use, protective bacterial populations may decline. This can allow resistant organisms to flourish and cause infection. The immune system may then respond with intense inflammation, which can further disturb microbial balance. This cycle demonstrates how closely linked microbial composition and immune activity truly are.

The recognition of the microbiome immunity axis has opened new possibilities for therapy. Instead of focusing solely on suppressing immune responses or killing pathogens, researchers are exploring ways to restore microbial balance. Probiotics, which contain live beneficial bacteria, aim to replenish helpful species. Prebiotics, which are dietary fibers that nourish good microbes, encourage the growth of protective communities. Diet itself has emerged as a powerful tool, as plant-based fibers and fermented foods can enhance microbial diversity and support immune health. These strategies seek to strengthen the friendly side of the axis rather than simply targeting the foe.

More advanced therapies are also under development. Fecal microbiota transplantation involves transferring stool from a healthy donor into a patient with severe microbial imbalance. This approach has shown success in treating recurrent intestinal infections and is being studied for other immune-related

conditions. Scientists are also investigating personalized microbiome medicine, where treatments are tailored to an individual's unique microbial profile. By analyzing specific bacterial strains and their metabolic products, clinicians may one day design targeted interventions that modulate immune responses with precision.

The future of microbiome-based therapies may include engineered bacteria that deliver therapeutic molecules directly within the gut. Such microbes could be programmed to reduce inflammation, enhance immune tolerance, or fight specific pathogens. Advances in sequencing technology and computational biology are making it possible to map complex microbial networks and understand how they interact with immune pathways. This knowledge could transform the management of autoimmune diseases, allergies, cancer, and even vaccine responses. The microbiome immunity axis is becoming a central focus in modern medicine because it offers a new way to view health as a cooperative system rather than a battlefield.

CONCLUSION

The concept of friends and foes within the microbiome immunity axis reflects a deeper truth about human biology. Health depends on balance, diversity, and communication between microbes and immune cells. Disruption can lead to disease, while restoration can promote resilience. As research continues to uncover the intricate dialogue between these two systems, the promise of innovative therapies grows stronger. The microbiome immunity axis represents a frontier where biology, medicine, and ecology converge, offering hope for more holistic and sustainable approaches to human health.