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Short Communication

Dynamic Interactions Between Cells and Microbiomes in Health and Tissue Maintenance

Sun Qian*

Department of Regenerative Biology, Guangzhou Institute of Health Sciences, Guangzhou, China

DESCRIPTION

Cells interact constantly with diverse microbial populations that reside throughout the tissues. These microorganisms, collectively known as the microbiome, include bacteria, viruses, fungi and other microscopic organisms. Rather than existing as passive residents, these microbial communities form dynamic partnerships with host cells, affecting tissue behavior, metabolic balance and immune activity. Cells respond to microbial signals and in turn, create environments that influence microbial composition and activity. Understanding these interactions provides essential insight into the mechanisms that sustain health and regulate biological functions. Microbial communities are found throughout the body, occupying the skin, gastrointestinal tract, oral cavity, respiratory system and urogenital regions. Each location presents a distinct environment, shaping the microbial populations that thrive there and the nature of their interactions with host cells. For example, epithelial cells lining the gastrointestinal tract form barriers that separate microbial populations from underlying tissues. These cells simultaneously receive molecular signals from microbes, including metabolites and structural components, which guide cellular behavior. This two-way communication ensures the maintenance of tissue integrity and functional balance, while disruptions may lead to cellular stress, inflammation, or tissue injury. Metabolic interplay between microbes and host cells represents another dimension of interaction. Microbes metabolize dietary and host-derived compounds, producing molecules that are absorbed by cells and integrated into cellular pathways. Butyrate, acetate and propionate are examples of microbial metabolites that modulate energy use, transcriptional activity, and differentiation in host cells. Butyrate, in particular, serves as an energy source for intestinal epithelial cells while also regulating gene expression through epigenetic modifications. These metabolic connections illustrate that cells and microbes exist in a network of mutual dependence, with cellular physiology shaped in part by microbial activity.

Stem and progenitor cells also interact with microbial communities. Signals from microbial populations can influence the renewal and differentiation of stem cells, particularly in tissues with high turnover such as the gut lining. Microbial molecules regulate stem cell activity, supporting tissue maintenance and repair. In other tissues, microbial metabolites may modulate stem cell niches, affecting tissue regeneration and resilience. These interactions highlight the significant role of microorganisms in maintaining tissue functionality and cellular renewal, extending beyond immediate immune or metabolic effects. Inflammatory processes are another domain shaped by cell-microbiome interactions. Certain microbial populations produce molecules that limit excessive immune responses, preventing tissue damage from chronic activation. Shifts in microbial composition can provoke immune responses that alter cellular activity and contribute to inflammation. This interplay is especially relevant in conditions where tissue dysfunction is associated with microbial imbalance, demonstrating the importance of microbial communities in maintaining cellular homeostasis. Interactions between microbial communities and neuronal cells also affect physiological processes. Microbial metabolites can influence neuronal activity directly or indirectly through immune modulation. Signals from microbes affect gut motility, neurochemical signaling, and behavioral responses, with neuronal cells integrating these microbial inputs to adjust tissue function. This demonstrates that microbial-cell interactions extend beyond metabolic and immune effects, influencing complex regulatory networks throughout the body.

Imbalances in microbial populations can have profound effects on cellular behavior. Dysbiosis, a state of microbial imbalance, can compromise epithelial barrier function, activate inflammatory pathways and disrupt cellular metabolism. Cells may exhibit altered proliferation, signaling dysfunction, or reduced repair capacity in response to these changes. Laboratory studies reveal the nuanced ways in which microbes shape cellular responses. Specific bacterial species can regulate gene expression in epithelial cells, influence stem cell proliferation, and modulate immune activity. Viruses and fungi within microbial communities also contribute to cellular signaling, although their roles are less well characterized. Cell microbiome interactions are also relevant for tissue engineering and regenerative approaches. Microbial metabolites can influence cultured cell behavior,

Correspondence to: Sun Qian, Department of Regenerative Biology, Guangzhou Institute of Health Sciences, Guangzhou, China, E-mail: qiansu@gmail.com

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promoting differentiation, maturation, and functional integration. By incorporating microbial signals into engineered tissue environments, it is possible to improve tissue development and stability. These interactions highlight the potential for using microbial cues to guide cellular behavior in applied settings, supporting more effective outcomes in tissue construction and repair.

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