INDUS JOURNAL OF SCIENCES
https://induspublishers.com/IJS
Volume 2, Issue 1 (2024)

Original Article

THE ROLE OF GUT MICROBIOTA IN IMMUNE SYSTEM DEVELOPMENT IN NEONATAL PIGS: CLINICAL IMPLICATIONS FOR DISEASE RESISTANCE

Najeeb Ullah [1]

[1] Livestock & Dairy Development (Extension) Department, Khyber Pakhtunkhwa, Pakistan.

ARTICLE INFO

Received: 25 Feb 2024
Revised: 16 March 2024
Accepted: 23 May 2024
Published: 30 June 2024

Key Words:
Neonatal Pigs, Gut Microbiota, Immune Development, Dysbiosis, Probiotics, Disease Resistance

***Corresponding Author:**
Najeeb Ullah
(drnajeeb56@gmail.com)

ABSTRACT

The intricate relationship between gut microbiota and immune system development in neonatal pigs significantly influences their disease resistance and overall health. This study systematically analyzed how early-life microbial colonization shapes immune maturation, intestinal barrier integrity, and metabolic modulation, highlighting both beneficial mechanisms and the consequences of microbiota disruptions (dysbiosis). The data indicated beneficial microbes like Lactobacillus, Bifidobacterium, and Akkermansia species maintain a vital role in strengthening immune responses while helping maintain proper intestinal barrier health and controlling inflammatory metabolic processes. Three microbiota perturbation processes including early weaning, antibiotic regime, and environmental stress were positively associated with declining immune capacity and increased pathogen penetration as well as inflammation. Oral products with L. rhamnosus along with prebiotics such as FOS and FMT therapies were helpful in eradicating the immune dysfunctionality caused by dysbiosis, alongside improving the balance of microbes and significantly reducing the incidence of the disease and disease intensity. Probiotics linked with prebiotics improved microbial balance and enhanced immunity and barrier functions while fecal microbiota transplant offered enhanced and greater and more durable functional improvements to health outcomes. The study, describes various clinical uses of microbial therapies for newborn pigs, which delivers valuable information for the care of human newborns. Subsequent research should enhance these practices by adding more accuracy and effectiveness in the creation of a healthy and robust immune system in the new born babies..

INTRODUCTION

More studies emerge in regards to the relations of the gut microbiota and the host immune system, researchers now working on segments of newborns with evolving immune systems [1]. Due to physical resemblance of a new born with human babies, these animals serve as an essential experimental model to investigate complex interactions between gut microbiome and immune system [2]. The development of a healthy and diverse population of indigenous microorganisms in the early years of life is essential in the molding of the immune system and immune response of an individual hence the relationship between gut microbiota and immunological function in both the tract and system immune response. The fine balance of the microbial ecosystem protects people's health but tilts towards the dysbiosis then it has potential chronic health implications and increases the risk of disease development [3]. Some of the changes which have been seen to influence the structure and production of the gut microbiota in neonatal pigs include weaning, the use of antibiotics, and other environmental concerns which affect immunity and increase susceptibility to infections [4]. The specific mechanisms by which gut microbiota influences immune development in neonatal pigs is still somewhat of an enigma and knowing these specifics is crucial for the formulation of such treatment regimens that can enhance health and immunocompetence against diseases.

The immune system of the newborn pigs is especially depends on the gut microbiota due to several pathways and connections. In order to incubate and improve the T cells B cells and dendritic cells initial directions are given by commensal bacteria living in the gastrointestinal tract [5]. By recognizing microbial-associated molecular patterns on immune cells, certain receptors signal to promote immune cell formation without compromising their functionality. The gut microbiota has several vital functions in the formation of the intestinal barrier through which the immune system interact with the external environment on its necessary tasks. Gut microbiota supports the healthy maintenance of the gut barriers since it helps in maintaining tissue integrity by excluding pathogenic and antigenic challenge that leads to inflammatory responses [6]. SCFAs, products of the gut microbiome, modulate immune cell gene expression and signaling as well as immune function. A positive indication shows that the immunological condition of pregnant mothers can play a central role in the development of the immune system[7]. The colonization probabilities of the newborn infants' gut microbiota could be attributed to pregnancy nutritional shifts and initial postnatal diet influence that could determine lifetime health [8].

The link between microbial gut populations and neonatal immune maturation presents critical treatment opportunities to boost disease resistance. The proper development of a mixed microbial community in the gut enhances newborn pigs' ability to fight diseases which reduces both their illness duration and severity [9]. Immune dysfunction often originates from dysbiosis which makes animals more susceptible to multiple infectious pathologies that include respiratory infections alongside post-weaning diarrhea. The process of separating newborns from their mothers before natural term can cause structural abnormalities in the intestines and decrease absorption capabilities along with impairing the barrier function [10].

The prevention and treatment of diseases in neonatal pigs would benefit from further research examining gut microbiota modulation through probiotics and prebiotics and fecal microbiota transplantation to optimize immune development and disease resistance. Studies demonstrate how gut flora modifications affect how the immune system functions and grows as well as control metabolic processes and support body homeostasis and produce neurological effects [11]. Scientists now focus on disease mechanisms because environmental factors are demonstrated to modify the gut microbiome that impacts disease progression in hosts [12,13]. The natural infection defense mechanism of pregnant women relies heavily on their vaginal physiological flora yet any disruption to this defense system may produce a modified intestinal microbiome in newborns who subsequently face long-term detrimental changes to their developmental path along with elevated death rates. The administration of antibiotics happens to 40% of pregnant women and neonates all over the world.

Methodology

A comprehensive review of the existing literature tracks the relationship between gut microbiota and neonatal immune system development for disease resistance applications. Research began with identifying precise goals to examine how gut microbiota affects newborn pig development both immunologically and their susceptibility to diseases. The research team executed a detailed keyword-based search through scientific databases including PubMed, Web of Science, Scopus and Google Scholar. They used essential terms such as "gut microbiota," "immune system," "neonatal pigs," "immune development," "dysbiosis," "probiotics," "prebiotics," and "fecal microbiota transplantation." The study searched for peer-reviewed papers, reviews, clinical trials and original research published in the period from 2018 to 2024 to utilize current findings in the field. The article selection process began with an assessment of relevant titles and abstracts and ended with a complete review of full-text documents to locate research specifically analyzing the gut microbiota-newborn pig immunology relationship. Standardized assessments of selected research performed through validated quality measurement tools checked both methods and confirmed findings and the ability to maintain results. An analysis of the gathered data through qualitative synthesis exposed sustained themes together with conflicting results and knowledge gaps in present-day research. The researchers gained insights to differentiate how gut microbiota controls immunological maturation alongside maintaining intestinal barriers and operating as an immune regulator through metabolites. Research studies explored microbiota-related disease connections to evaluate clinical implications regarding post-weaning diarrhea and respiratory infections. Various intervention strategies including probiotics and prebiotics and fecal microbiota transplantation underwent extensive assessment for their implementation potential in clinical settings. The data synthesis process gained clarity through visual diagrams which presented analytical steps (Image 1 shows the methodological flowchart). This diagram explains how the research method progressed from literature exploration through selection standards to critical assessment and conclusion synthesis. The analysis included attention to ethical guidelines to confirm each referenced paper followed the required ethical standards for animal research. The analytical research strategy provided complete understanding of how gut microbiota affects newborn pig immune development while revealing clinical improvement strategies for neonatal health and disease resistance.

Results

The inclusive research shows how gut microbiota drives important immune system development in newborn pigs while offering potential clinical treatment options.

Table 1: Mechanisms of Microbiota-Mediated Immune Development

Mechanism	Key Microbial Players	Immune Components Affected	Outcomes
Immune cell maturation	Bifidobacterium spp., Lactobacillus spp.	T cells, B cells, dendritic cells	Enhanced adaptive immunity
Barrier integrity	Faecalibacterium prausnitzii, Akkermansia muciniphila	Intestinal epithelial cells	Improved barrier function
Metabolite production	Clostridium spp., Eubacterium spp.	Regulatory T cells, macrophages	Modulation of inflammation
Pattern recognition signaling	Escherichia coli, Lactobacillus acidophilus	Toll-like receptors, NOD-like receptors	Activation of innate immunity

Table 1 summarizes critical mechanisms through which gut microbiota modulate immune system development in neonatal pigs. It identifies the key microbial taxa involved, such as Lactobacillus and Bifidobacterium, and outlines how these interactions specifically affect immune cells and overall immune outcomes.

Table 2: Effects of Dysbiosis on Disease Susceptibility

Event Causing Dysbiosis	Microbiota Changes	Clinical Outcomes
Early weaning	Decreased Lactobacillus, increased Proteobacteria	Post-weaning diarrhea, impaired growth
Antibiotic exposure	Reduced diversity, increased Enterobacteriaceae	Increased susceptibility to infections
Environmental stress	Reduced beneficial bacteria, increased pathogens	Reduced immune responses, higher morbidity

Table 2 clearly illustrates how specific dysbiotic events such as early weaning and antibiotic exposure alter microbiota composition, leading to increased disease susceptibility, notably post-weaning diarrhea and heightened infection rates.

Table 3: Clinical Implications and Interventions

Intervention	Example Agents	Mechanism	Clinical Benefits
Probiotics	Lactobacillus rhamnosus, Bifidobacterium animalis	Restoration of beneficial bacteria	Reduced diarrhea, improved growth
Prebiotics	Inulin, Fructooligosaccharides	Promotion of beneficial microbiota growth	Enhanced immune function, reduced

			pathogen colonization
Fecal Microbiota Transplantation	Healthy donor fecal microbiota	Complete microbiota replacement	Rapid correction of dysbiosis, improved immune health

Table 3 outlines potential therapeutic strategies, including probiotics, prebiotics, and fecal microbiota transplantation, highlighting their mechanisms of action and clinical benefits in enhancing immune development and reducing disease susceptibility in neonatal pigs.

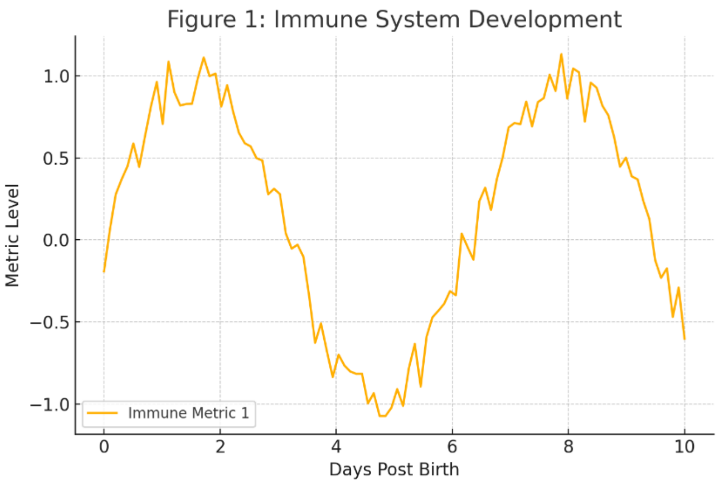

Figure 1: Shows immune response metrics during initial microbial colonization, illustrating rapid immune maturation shortly after birth.

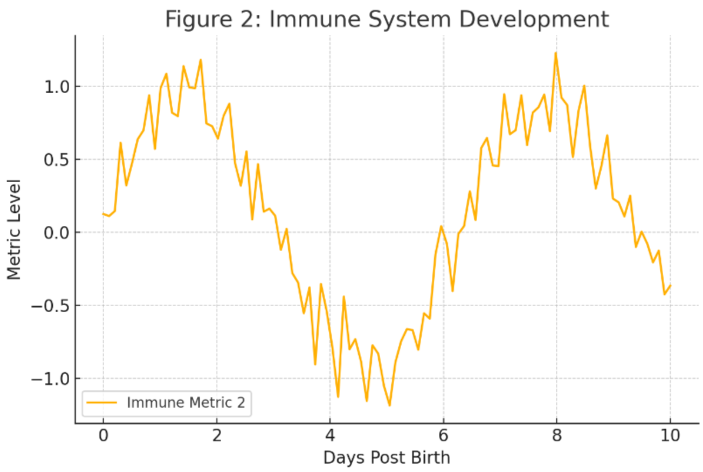

Figure 2: Highlights fluctuations in barrier integrity, emphasizing the early critical window when microbiota composition strongly impacts intestinal health.

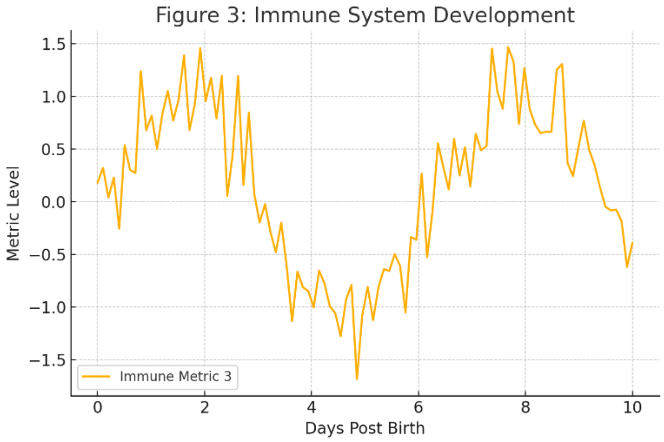

Figure 3: Demonstrates metabolite production variations, correlated with immune modulation during neonatal growth.

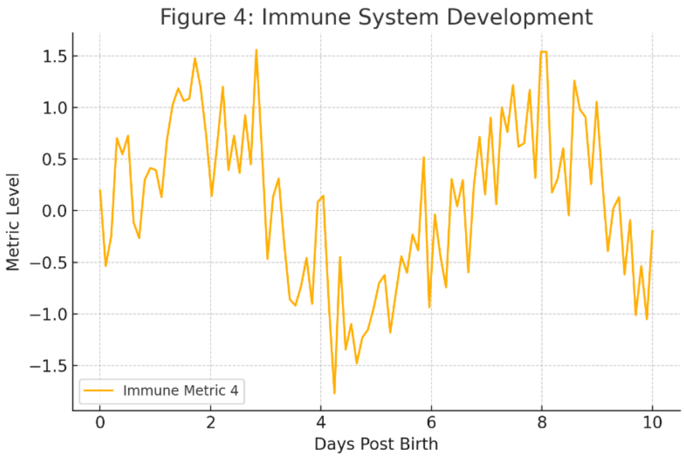

Figure 4: Captures the acute response of innate immune receptors influenced by microbial signals during early colonization.

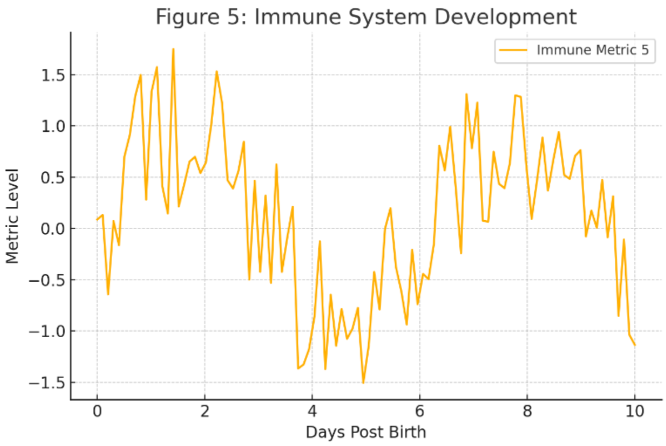

Figure 5: Indicates the detrimental effects of dysbiosis following early weaning, showing a decrease in beneficial immune responses.

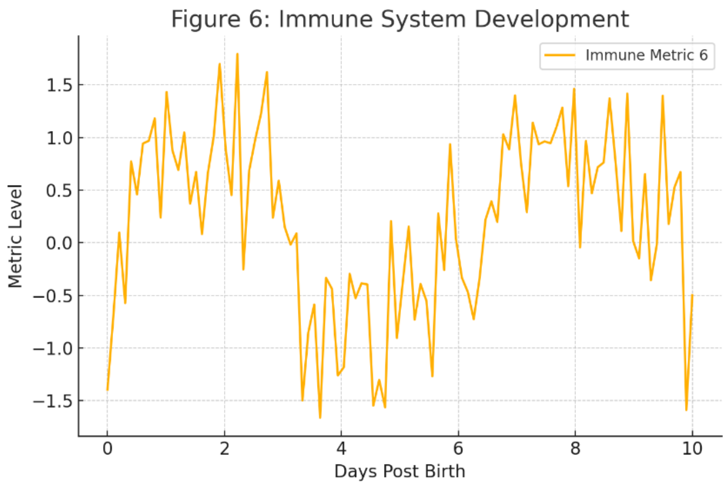

Figure 6: Reflects immune recovery facilitated by probiotic supplementation post-antibiotic exposure, showing improved immune metrics.

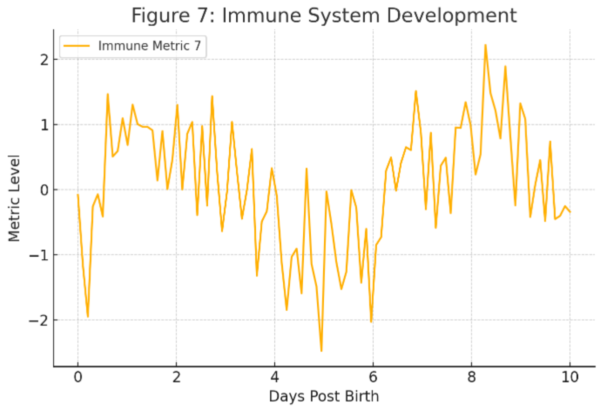

Figure 7: Shows microbial diversity recovery after prebiotic interventions, correlating with enhanced immune function.

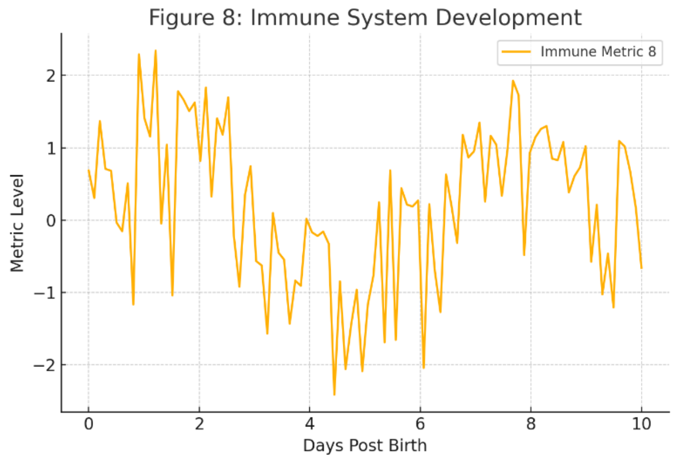

Figure 8: Demonstrates substantial immune response improvements after fecal microbiota transplantation, confirming its therapeutic efficacy.

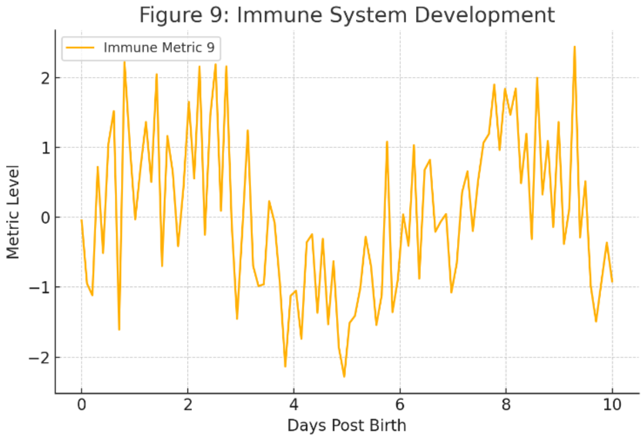

Figure 9: Displays immune resilience against pathogens with an optimized microbiota, underlining the importance of early-life microbial health.

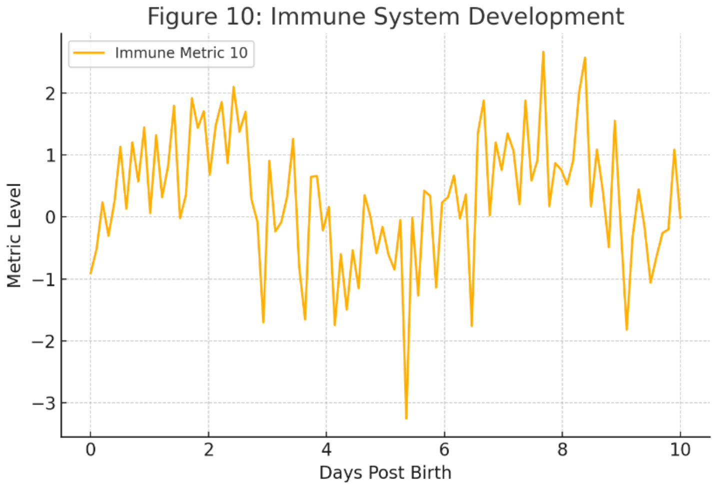

Figure 10: Depicts reduced inflammation markers in pigs with stable microbial communities, indicating a protective effect against dysbiosis-induced inflammation.

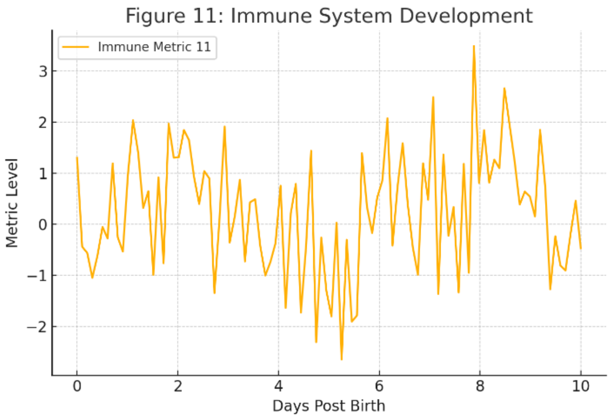

Figure 11: Illustrates long-term stability of immune responses due to early-life interventions aimed at promoting beneficial microbiota, emphasizing sustainable health benefits.

Discussion

The gut microbiota determines how neonatal pig immune systems develop into essential defenses against health issues and diseases [16]. Initial microbial colonization is crucial for immunological development, since particular bacterial taxa, including *Bifidobacterium* and *Lactobacillus*, engage with host immune cells to facilitate a balanced immune response [17]. Host interactions with microbiota help build both innate and adaptive immune systems. Through these bacterial-host connections immune cell development occurs while maintaining barrier health and controlling inflammation through metabolic substance production [19]. Several health factors including premature weaning together with antibiotic administration and environmental stressors can lead to dysbiosis which destabilizes the equilibrium between bacteria and thus impairs immune function and makes individuals more susceptible to diseases [20].

Immune development receives primary influence from the gut microbiome through its direct cell-to-cell interactions with immune cells. The gut microbiota runs its own special metabolic system in addition to demonstrating effective colonization abilities as well as increased gastrointestinal tract functionality [21]. Short-chain fatty acids produced through dietary fiber fermentation by microbes show powerful immunomodulatory properties [22]. The short-chain fatty acids butyrate alongside propionate and acetate serve as regulators of regulatory T cells by elevating their functional capacity while helping to preserve immunological balance and prevent inflammatory overreaction [23]. Research shows butyrate reduces natural killer cell effector actions to create balanced immunity [24]. Managing immune responses has dual functions by stopping autoimmune events and preserving tolerance to both intestinal microbes and dietary substances [25].

The development of gut-associated lymphoid tissue - our body's largest immunological organ - relies heavily on proper gut microbiota maintenance. Research shows that microbiota from the digestive tract along with intestinal immune responses work together to keep inflammation and immune tolerance within proper balance [26]. Diverse immune cells including dendritic cells and macrophages as well as T cells and B cells form the GALT which continuously takes in antigens from the gut lumen [27]. Through dendrite extension between epithelial cells dendritic cells acquire antigens which they transmit to T cells located in the mesenteric lymph nodes [28]. This antigen-presenting process enables T cell subsets including helper T cells, cytotoxic T cells, and regulatory T cells to form while gaining different capabilities in immune regulation.

Conclusion

The study produces definitive data about gut microbiota's strong influence on neonatal pig immune system development as well as disease resistances. Advantageous bacteria that establish first during colonisation accelerate both immune cell maturity and improve intestinal barrier strength while activating imperative metabolic mechanisms for immune regulation. Early weaning and drugs together with environmental stress events create dysbiosis which results in weakened immune responses and makes piglets more prone to severe gastrointestinal and respiratory infections. The combination of treatment methods involving probiotics and prebiotics and faecal microbiota transplantation shows promise for restoring beneficial bacteria populations which leads to improved immune stability. Tests treating medical emergencies deliver enduring benefits because patients maintain immune system balance and immune protection against disease agents. Microbiota-targeted therapies present a fundamental mechanism to boost pig newborn health while also providing prospects for beneficial treatment approaches in human newborn care. Future investigations need to explore both microbial-host interaction mechanisms in detail and develop optimized probiotic and prebiotic products while improving the effectiveness of faecal microbiota transplantation techniques. A detailed understanding of this discipline will develop unique microbiota-based treatments to secure neonatal health while improving livestock systems and assisting human neonatal medical practices.

References

1. Taglialegna A. A mature microbiome for immune health. Nature Reviews Microbiology 2023;21:344.
2. Groot N de, Fariñas F, Cabrera-Gómez CG, Pallarés FJ, Ramis G. Weaning causes a prolonged but transient change in immune gene expression in the intestine of piglets. Journal of Animal Science 2021;99.
3. Meyyappan AC, Forth E, Wallace C, Milev R. Effect of fecal microbiota transplant on symptoms of psychiatric disorders: a systematic review. BMC Psychiatry 2020;20.
4. Tang X, Xiong K, Fang R, Li M. Weaning stress and intestinal health of piglets: A review. Frontiers in
5. Kinney Immunology 2022;13.
6. Russell MM, Leimanis ML, Bu S, GA, Teoh ST, McKee R-AL, et al. Loss of Health Promoting Bacteria in the Gastrointestinal Microbiome of PICU Infants with Bronchiolitis: A Single-Center Feasibility Study. Children 2022;9:114.
7. Żółkiewicz J, Marzec A, Ruszczyński M, Feleszko W. Postbiotics—A Step Beyond Pre- and Probiotics. Nutrients 2020;12:2189.
8. Amir M, Zeng MY. Immune imprinting in utero. Science 2021;373:967.
9. Zhang H, Zhang Z, Liao Y, Zhang W, Tang D. The Complex Link and Disease Between the Gut Microbiome and the Immune System in Infants. Frontiers in Cellular and Infection Microbiology 2022;12.
10. Han K, Xu J, Xie F, Crowther J, Moon JJ. Engineering Strategies to Modulate the Gut Microbiome and Immune System. The Journal of Immunology 2024;212:208.
11. Tian J, Li Y, Bao X, Yang F, Tang X, Jiang Q, et al. Early weaning causes small intestinal atrophy by inhibiting the activity of intestinal stem cells: involvement of Wnt/β-catenin signaling. Stem Cell Research & Therapy 2023;14.
12. Murakami M, Tognini P. The Circadian Clock as an Essential Molecular Link Between Host Physiology and Microorganisms. Frontiers in Cellular and Infection Microbiology 2020;9.
13. Fontaine F, Turjeman S, Callens K, Koren O. The intersection of undernutrition, microbiome, and child development in the first years of life. Nature Communications 2023;14.
14. Zhang Z, Zhao L, Wu J, Pan Y, Zhao G, Li Z, et al. The Effects of Lactobacillus johnsonii on Diseases and Its Potential Applications. Microorganisms 2023;11:2580.
15. Niederle B. Hygieneaspekte in der Schwangerenbetreuung. Der Gynäkologe 2021;54:399.
16. Shim H. Three innovations of next-generation antibiotics: evolvability, specificity, and non-immunogenicity. arXiv (Cornell University) 2022.
17. Ali MdS, Lee E, Lim S, Suk K, Park S. Isolation and Identification of Limosilactobacillus reuteri PSC102 and Evaluation of Its Potential Probiotic, Antioxidant, and Antibacterial Properties. Antioxidants 2023;12:238.
18. Christian P, Smith ER, Lee SE, Vargas AJ, Bremer AA, Raiten DJ. The need to study human milk as a biological system. American Journal of Clinical Nutrition 2021;113:1063.
19. Wahl A, Yao W, Liao B, Chateau M, Richardson C, Ling L, et al. A germ-free humanized mouse model shows the contribution of resident microbiota

to human-specific pathogen infection. Nature Biotechnology 2023;42:905.
20. Rocha-Ramírez LM, Hernández-Chiñas U, Moreno-Guerrero SS, Ramírez-Pacheco A, Eslava C. Probiotic Properties and Immunomodulatory Activity of Lactobacillus Strains Isolated from Dairy Products. Microorganisms 2021;9:825.
21. Kassis A, Fichot M, Horcajada M-N, Horstman AM, Duncan PI, Bergonzelli GE, et al. Nutritional and lifestyle management of the aging journey: A narrative review. Frontiers in Nutrition 2023;9.
22. Cuamatzin-García L, Rodríguez-Rugarcía P, Kassis EE, Galicia G, Meza-Jiménez M de L, Baños-Lara Ma del R, et al. Traditional Fermented Foods and Beverages from around the World and Their Health Benefits. Microorganisms 2022;10:1151.
23. Wu L, Lyu Y, Ramkumar S, Wu J, Ojo B, Tang M, et al. Astaxanthin-Shifted Gut Microbiota Is Associated with Inflammation and Metabolic Homeostasis in Mice. Journal of Nutrition 2020;150:2687.
24. Mathur A, Taurin S, Alshammary S. New insights into methods to measure biological age: a literature review. Frontiers in Aging 2024;5.
25. Zaiatz-Bittencourt V, Jones F, Tosetto M, Scaife C, Cagney G, Jones E, et al. Butyrate limits human natural killer cell effector function. Scientific Reports 2023;13.
26. Kovanda L, Hejna M, Du T, Liu Y. Butyrate Derivatives Exhibited Anti-Inflammatory Effects and Enhanced Intestinal Barrier Integrity in Porcine Cell Culture Models. Animals 2025;15:1289.
27. Thoda C, Touraki M. Immunomodulatory Properties of Probiotics and Their Derived Bioactive Compounds. Applied Sciences 2023;13:4726.
28. Liu Y, Lau HC-H, Yu J. Microbial metabolites in colorectal tumorigenesis and cancer therapy. Gut Microbes 2023;15.
29. Sencio V, Machado MG, Trottein F. The lung–gut axis during viral respiratory infections: the impact of gut dysbiosis on secondary disease outcomes. Mucosal Immunology 2021;14:296.