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Review Article

EMERGING TECHNOLOGIES IN GUT HEALTH: INTEGRATING MICROBIOME SCIENCE WITH AYURVEDIC PRINCIPLES

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ABSTRACT

The gut microbiome is increasingly recognized as a central regulator of systemic health through its bidirectional interactions with multiple organ systems, collectively termed the Gut–Organ Axes. Dysbiosis has been implicated in the pathogenesis of numerous disorders, including inflammatory bowel disease, metabolic syndrome, cardiovascular diseases, neuropsychiatric disorders, and chronic kidney disease. Recent technological innovations have significantly enhanced the understanding, diagnosis, and management of gut-related disorders while providing new opportunities to scientifically validate traditional Ayurvedic concepts. Relevant literature published between January 2000 and June 2026 was retrieved from PubMed, Google Scholar, and Scopus using keywords related to gut microbiota, dysbiosis, gut–organ axes, *Agni*, *Dosha*, and technological innovations. Classical Ayurvedic references were obtained from the *Brihattrayis,* including Charaka Samhita, Sushruta Samhita, and *Ashtanga Hridaya*. Advances in microbiome sequencing, artificial intelligence, wearable health technologies, biosensors, personalized nutrition platforms, probiotic delivery systems, gut-on-a-chip models, regenerative medicine, and targeted drug delivery have transformed gut health research and clinical practice. These technologies facilitate precise characterization of microbial communities, early disease detection, and individualized therapeutic interventions. Emerging evidence also demonstrates correlations between Ayurvedic concepts and modern microbiome science, including associations between *Prakriti* and gut microbial profiles, the relationship between *Agni* and gut homeostasis, and the application of *Ayurgenomics* in precision medicine. To conclude**,** the integration of technological innovations with Ayurvedic principles offers a promising framework for precision, preventive, and patient-centred healthcare. Such convergence may advance microbiome-based therapeutics and contribute to improved gut and systemic health outcomes.

INTRODUCTION

The human gut, once viewed primarily as a digestive organ, is now recognized as a key regulator of systemic health through extensive Gut–Organ Axes. Central to these interactions is the gut microbiome, whose balance- particularly between *Firmicutes* and *Bacteroidetes*- supports homeostasis.[1] Disruption of this balance, known as dysbiosis, contributes to disease through impaired barrier function, chronic inflammation, immune dysregulation, and metabolic disturbances.[2] Ayurveda similarly regards the gastrointestinal system as the foundation of health through the concepts of *Agni, Dosha,* and *Ama*. This manuscript examines how advances in microbiome science, artificial intelligence, personalized nutrition, and regenerative medicine provide scientific perspectives on these classical principles.

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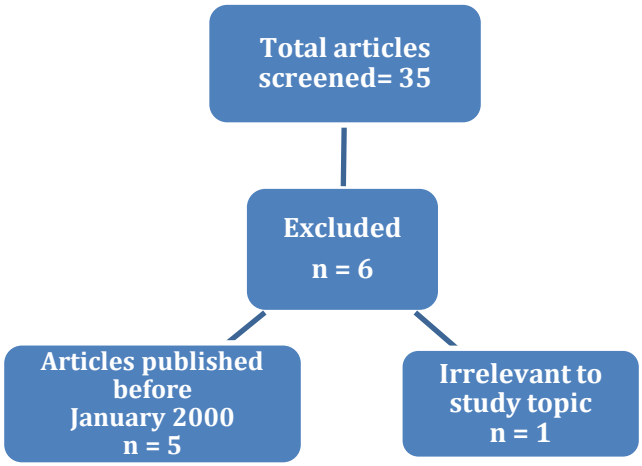
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METHODS

Primary Ayurvedic references were drawn from *Bṛihattrayis, Charaka Samhita, Sushruta Samhita,* and *Ashtanga Hridaya,* with a focus on *Agni*. Interpretations supported by standard commentaries were considered. Scientific literature was retrieved from PubMed, Google Scholar, and Scopus. Only peer-reviewed articles published in English between

January 2000 and June 2026 were considered. Preclinical, in vitro, and clinical studies examining the gut microbiota, dysbiosis, recent technological innovations were also considered. Relevant findings were critically analysed to identify the role of techno innovations in complimenting gut health.

Figure 1: Records identified through database searching



RESULTS

Understanding gut health- a brief overview

The human gut microbiome is a complex and dynamic ecosystem composed of trillions of microorganisms, including bacteria, fungi, viruses, and archaea, that reside primarily in the gastrointestinal tract.[3] A healthy gut microbiota maintains a delicate balance between beneficial microorganisms, such as species of *Lactobacillus* and *Bifidobacterium*, which support digestion, nutrient absorption, immune regulation, and pathogen defence, and potentially harmful microorganisms that can cause disease when they proliferate excessively.

The composition and diversity of the gut microbiota are influenced by numerous factors, including dietary habits, lifestyle choices, antibiotic exposure, psychological stress, and ageing.[4] Diets rich in fiber, fruits, vegetables, and fermented foods promote microbial diversity, whereas processed foods and excessive antibiotic use can disrupt microbial balance, leading to dysbiosis. Such disturbances in gut homeostasis have been associated with the development of several health conditions, including irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), obesity, type 2 diabetes mellitus, and mental health disorders through mechanisms involving inflammation, metabolic dysfunction, and the gut–brain axis.[5]

Gut microbiota and the microbiota–organ axes

The gut microbiota is predominantly composed of *Firmicutes*, *Bacteroidetes*, *Actinobacteria*, and *Proteobacteria*, and contributes to systemic health through the production of numerous bioactive metabolites. Bidirectional communication occurs between the gut and distant organs, including the brain, liver, lungs, heart, kidneys, and skin through neural, endocrine, immune, metabolic, and microbial signalling pathways.[6] Dysbiosis disrupts these pathways, resulting in altered immune responses, metabolic dysfunction, and impaired organ homeostasis.[7]

Need for technological innovations in gut health

The literature reviewed identified several technological innovations that have significantly advanced gut health research. These include microbiome sequencing technologies, artificial intelligence and machine learning, wearable and digital health technologies, biosensors and point-of-care diagnostic devices, personalized nutrition technologies, technological advances in probiotics, prebiotics and synbiotics, gut-on-a-chip and organoid technologies, stem cell and regenerative technologies, and advanced drug delivery systems. These innovations facilitate comprehensive microbial profiling, disease prediction, individualized nutritional interventions, improved therapeutic delivery, disease modelling, regenerative therapies, and precision medicine approaches in gut health

Microbiome Sequencing Technologies

Advances in microbiome sequencing technologies, particularly Next-Generation Sequencing (NGS), have significantly enhanced the understanding of gut health by enabling detailed analysis of microbial communities. Techniques such as 16S rRNA sequencing and whole-genome metagenomics help identify microbial composition, detect dysbiosis, and support personalized therapeutic and nutritional interventions. With their high accuracy and comprehensive microbial profiling capabilities, these technologies are playing a crucial role in advancing precision medicine and microbiome-based healthcare.[8]

Artificial Intelligence (AI) and Machine Learning (ML)

Artificial Intelligence (AI) and Machine Learning (ML) are transforming gut health research by analysing complex microbiome, clinical, and lifestyle data to identify microbial signatures associated with disease. These technologies aid in predicting the risk of conditions such as inflammatory bowel disease (IBD), colorectal cancer, and metabolic disorders while improving diagnostic accuracy. AI-driven microbiome analysis platforms and predictive models also support personalized dietary recommendations and targeted interventions, advancing precision approaches to gut health management.[9]

Wearable and Digital health Technologies

Wearable and digital health technologies are increasingly complementing gut health management by enabling continuous monitoring of factors that influence the gut microbiome. Smart wearables track

physical activity, sleep patterns, and other lifestyle parameters, while mobile health applications facilitate food logging, symptom tracking, and personalized nutrition guidance. By integrating these data, digital health tools help identify lifestyle patterns associated with gastrointestinal health and disease. Their key benefits include real-time monitoring, enhanced patient engagement, improved self-management, and support for personalized interventions aimed at maintaining optimal gut health.[10]

Biosensors and Point-of-Care Devices

Biosensors and point-of-care diagnostic devices are emerging technologies that facilitate rapid and convenient assessment of gut health through the detection of specific biomarkers. These devices can identify inflammatory markers, microbial metabolites, and gastrointestinal pathogens, enabling early detection and monitoring of digestive disorders. Their major advantages include rapid results, non-invasive sample collection, ease of use, and the potential for home-based monitoring, making gut health assessment more accessible and patient-centred.[11]

Personalized Nutrition Technologies

Personalized nutrition technologies leverage advances in microbiome science, artificial intelligence, and nutrigenomics to develop individualized dietary strategies for optimizing gut health. By analysing an individual's microbiome profile, dietary habits, and genetic factors, these technologies can generate tailored nutritional recommendations aimed at promoting beneficial microbial communities and improving overall health. Examples include microbiome testing kits that provide personalized probiotic recommendations and customized dietary plans, supporting a precision nutrition approach to gut health management.[12]

Probiotics, Prebiotics, and Symbiotics: Technological Advances

Technological innovations have enhanced the efficacy of probiotics, prebiotics, and symbiotic through the development of novel formulations such as microencapsulation and targeted delivery systems. These approaches protect beneficial microorganisms from harsh gastrointestinal conditions, improving their survival during transit and promoting effective colonization within the gut. As a result, these advanced formulations enhance the therapeutic potential of microbiome-based interventions for maintaining and restoring gut health.[13]

Gut-on-a-Chip and Organoid Technologies

Gut-on-a-chip and intestinal organoid technologies have emerged as advanced experimental platforms for studying gut physiology and disease. Gut-on-a-chip systems mimic the structure and function of the human intestinal environment, while intestinal organoids are three-dimensional miniature gut models derived from stem cells. These technologies provide valuable tools for drug testing, disease modelling, and the development of personalized therapies, offering more physiologically relevant alternatives to conventional cell culture models.[14]

Stem Cell and Regenerative Technologies

Stem cell and regenerative medicine approaches hold significant promise for the treatment of gastrointestinal disorders by promoting the repair and regeneration of damaged intestinal tissues. Emerging research focuses on the therapeutic potential of intestinal stem cells and organoid-assisted regeneration for conditions such as inflammatory bowel disease and other chronic intestinal injuries. These technologies represent a growing frontier in precision and regenerative gastroenterology.[15]

Drug Delivery Innovations for Gut Health

Advanced drug delivery systems are improving the effectiveness of therapies targeting gastrointestinal diseases. Innovations such as nanotechnology-based drug carriers, targeted colon delivery systems, and controlled-release formulations enable precise delivery of therapeutic agents to specific regions of the gastrointestinal tract. These approaches enhance treatment efficacy, minimize systemic side effects, and improve patient compliance, thereby contributing to more effective management of gut-related disorders.[16]

Ayurvedic Perspective on Technological Innovations in Gut Health

Ayurveda has long recognized the central role of digestion in health and disease through the concepts of *Agni*, *Dosha*, *Dhatu*, and *Mala*. Classical texts describe impaired digestive and metabolic function (*Agni mandya*) as the root cause of numerous disorders, emphasizing that disturbances originating in the gastrointestinal system can affect the entire body.[17] These observations show remarkable parallels with modern concepts of gut dysbiosis and gut–organ communication, providing a foundation for integrating Ayurvedic principles with contemporary technological advances in gut health research.

Advances in microbiome sequencing technologies provide objective insights into gut microbial balance that may correlate with the Ayurvedic concept of *Agni*. Studies have also demonstrated associations between *Prakriti* and gut microbial composition, supporting individualized healthcare approaches. Advances in Ayurgenomics integrate constitutional assessment with genomics, systems biology, and artificial intelligence to facilitate precision medicine. Personalized nutrition technologies complement Ayurvedic dietary principles by integrating microbiome analysis with individualized dietary recommendations.

Agni and Gut Homeostasis

According to Ayurveda, proper digestion, absorption, and metabolism depend on the balanced functioning of *Agni*.[18] When *Agni* is disturbed, incomplete digestion results in the accumulation of *Ama* (metabolic toxins), which contributes to disease development. Modern research has similarly demonstrated that disruption of the gut microbiota, known as dysbiosis, is associated with metabolic disorders, inflammatory diseases, neurodegenerative conditions, and immune dysfunction.

Advanced microbiome sequencing technologies, including 16S rRNA sequencing and metagenomic analysis, enable comprehensive characterization of microbial communities and their metabolic activities.[19] These tools provide objective insights into gut microbial balance and may offer a modern biological perspective on the Ayurvedic concept of *Agni*. A healthy and diverse microbiome may be viewed as a functional correlate of *Samagni*, whereas dysbiosis may reflect states analogous to *Mandagni.*

Prakriti and Gut Microbiota

One of the most significant intersections between Ayurveda and modern biology is the relationship between *Prakriti* and the gut microbiome. *Prakriti*, determined by the relative predominance of *Vata, Pitta,* and *Kapha Doshas*, influences an individual's physiological characteristics, metabolic tendencies, disease susceptibility, and therapeutic responses.

Studies using 16S rRNA gene sequencing have demonstrated that individuals with different *Prakriti* exhibit distinct gut microbial compositions. Chaudhari et al. reported differential abundance of several bacterial genera among *Vata, Pitta*, and *Kapha* constitutions, suggesting that constitutional differences described in Ayurveda may be associated with variations in gut microbiota.[20] Similarly, Chauhan et al. identified *Prakriti*-specific microbial signatures despite an overall predominance of *Bacteroidetes* and *Firmicutes* across all groups, supporting the concept of individualized healthcare in Ayurveda.[21] These findings suggest that constitutional differences described in Ayurveda may be reflected in distinct microbial ecosystems and associated disease risks.

Such evidence supports the Ayurvedic principle of individualized healthcare and highlights the potential of microbiome profiling technologies to facilitate personalized therapeutic approaches based on constitutional characteristics.

Ayurgenomics and Precision Medicine

The emerging field of *Ayurgenomics* integrates Ayurvedic constitutional concepts with modern genomics, systems biology, and bioinformatics. Research has identified associations between *Prakriti* types and specific genetic, metabolic, and immunological signatures, suggesting a biological basis for traditional Ayurvedic classifications.

Advances in genomic sequencing, artificial intelligence, and machine learning have accelerated *Ayurgenomics* research by enabling large-scale analysis of genetic and phenotypic data. These technologies provide opportunities to develop precision medicine models that incorporate both molecular biomarkers and traditional constitutional assessments. Such an approach may improve disease prediction, preventive strategies, and individualized treatment planning while preserving the holistic principles of Ayurveda.

Personalized Nutrition: Ayurveda Meets Artificial Intelligence

Diet plays a central role in Ayurvedic healthcare, with the principles of *Pathya-Apathya Ahara* advocating dietary recommendations based on an individual's constitution, digestive capacity, age, environment, and health status. Modern nutrition similarly recognizes that dietary responses vary among individuals, partly due to differences in gut microbiota composition.

Advances in personalized nutrition use microbiome analysis, artificial intelligence, nutrigenomics, and digital health tools to deliver individualized dietary recommendations that support beneficial microbial communities and metabolic health.[22]

The integration of these technologies with Ayurvedic dietary principles offers a promising approach to precision nutrition, combining *Prakriti* assessment, microbiome profiling, and lifestyle data to provide personalized, evidence-informed dietary guidance.

Technological Validation of Ayurvedic Gut Therapeutics

Recent technological advances, including metabolomics, transcriptomics, microbiome profiling, and organoid technologies, are increasingly being utilized to investigate the mechanisms of Ayurvedic medicines. Several Ayurvedic formulations have been reported to modulate gut microbial composition, intestinal barrier integrity, and microbial metabolite production.[23] *Triphala* has demonstrated prebiotic properties [24], while other Ayurvedic herbs such as *Tinospora cordifolia*, *Terminalia chebula*, *Phyllanthus emblica*, and *Withania somnifera* have shown immunomodulatory, antioxidant, microbiota-modulating, neuroprotective, and gut–brain axis-supporting properties.

Table 1: Selected Ayurvedic Herbs and Formulations with Reported Effects on the Gut Microbiome and Gut–Organ Axes

S.No.	Ayurvedic Herb/Formulation	Scientific Findings Related to Gut Health
1.	*Guduchi* (*Tinospora cordifolia* (Wild) Hook.f & Thomson)	Exhibits immunomodulatory effects and may support intestinal barrier integrity.[25]
2.	*Haritaki* (*Terminalia chebula* Retz.)	Shows antioxidant activity and may help modulate the gut microbiota.[26,27]
3.	*Amalaki* (*Phyllanthus emblica* L.)	Possesses antioxidant and microbiota-modulating properties that may support gut health.[28,29]
4.	*Ashwagandha* (*Withania somnifera* (L.) Dunal)	May influence the gut–brain axis through neuroprotective and stress-modulating mechanisms.[30,31]

Advanced experimental platforms such as gut-on-a-chip systems and intestinal organoids allow researchers to investigate these effects under physiologically relevant conditions, facilitating evidence-based validation of traditional therapies and accelerating the development of microbiome-targeted Ayurvedic interventions.

Gut–Organ Axes Through the Ayurvedic Lens

Modern research has established bidirectional communication between the gut and distant organs through the gut–brain, gut–liver, gut–heart, gut–kidney, gut–lung, and gut–skin axes, mediated by neural, endocrine, immune, metabolic, and microbial signalling pathways. Ayurveda similarly recognizes the gastrointestinal system as the foundation of health, where balanced *Agni* maintains systemic homeostasis and its impairment contribute to disease affecting multiple organ systems. The Ayurvedic concepts of *Agni*, *Pitta*, *Ojas*, and *Vyadhikshamatva* closely parallel modern understanding of gut-mediated metabolism, immunity, and systemic regulation, while advances in metabolomics, microbiome profiling, and systems biology are increasingly providing scientific approaches to investigate these traditional concepts.

DISCUSSION

The present review highlights the rapid advances in gut microbiome research and the role of emerging technologies in improving the understanding of gut physiology while providing scientific support for Ayurvedic concepts. The reviewed literature demonstrates that the gut microbiota is a key regulator of systemic health, with dysbiosis contributing to inflammatory, metabolic, cardiovascular, neurodegenerative, and renal disorders through gut–organ communication.

Technological innovations, including microbiome sequencing, artificial intelligence, wearable technologies, biosensors, personalized nutrition platforms, gut-on-a-chip models, regenerative medicine, and advanced drug delivery systems, have significantly enhanced the diagnosis, monitoring, and management of gut-related disorders, supporting precision medicine approaches.

The review also highlights increasing evidence linking Ayurvedic principles with modern microbiome science. The concepts of *Agni*, *Samagni*, and *Mandagni* closely parallel gut microbial homeostasis and dysbiosis, while studies on *Prakriti* and Ayurgenomics support individualized healthcare and precision medicine. Furthermore, metabolomics, microbiome profiling, and organoid technologies have enabled scientific evaluation of Ayurvedic therapeutics. Evidence on *Triphala*, *Guduchi*, *Haritaki*, *Amalaki*, and *Ashwagandha* suggests that these formulations modulate gut microbiota, enhance intestinal health, and support immune regulation.

CONCLUSION

The expanding understanding of the gut microbiome and gut–organ axes has positioned gut health at the centre of systemic medicine. Emerging technologies- including microbiome sequencing, artificial intelligence, personalized nutrition platforms, organoid models, and targeted therapeutics- are enabling more precise and individualized approaches to gastrointestinal and systemic disorders. Parallel insights from Ayurveda, particularly the concepts of *Agni*, *Prakriti*, and individualized diet and lifestyle, offer a complementary framework for holistic and preventive care. Integrating modern gut microbiome technologies with Ayurvedic principles may help shape future models of precision, patient-centered healthcare.

Future Prospects

The convergence of Ayurveda and modern technology is paving the way for a new era of precision healthcare. Artificial intelligence-assisted *Prakriti* assessment, microbiome-guided therapeutic interventions, wearable health monitoring devices, digital Ayurveda platforms, and multi-omics technologies offer unprecedented opportunities to personalize healthcare while maintaining holistic principles.

Future research integrating genomics, metabolomics, microbiomics, and traditional Ayurvedic knowledge may enable the development of evidence-based precision Ayurveda, where

interventions are tailored according to an individual's constitution, microbial profile, lifestyle, and disease risk. Such an approach has the potential to complement conventional medicine, improve preventive healthcare, and promote long-term gut and systemic health.

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