**Review Article**

**Exploring the potential impact of probiotics use on pharmacokinetics and pharmacodynamics of drugs: A narrative review**

**Abstract**

Probiotics are live microorganisms that, when administered in adequate amounts, confer health benefits to the host. Their impact on drug bioavailability and efficacy, particularly in gastrointestinal disorders, has gained considerable interest. This paper explores how probiotics can modulate the pharmacokinetics and pharmacodynamics of various medications used in treating gastrointestinal conditions such as irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), and peptic ulcers. Probiotics may influence drug absorption, metabolism, and excretion through mechanisms such as alteration of gut microbiota composition, enhancement of intestinal permeability, and modulation of drug-metabolizing enzymes.The review synthesizes findings from recent studies demonstrating that probiotics can enhance drug efficacy by improving gut health and reducing inflammation. For instance, certain probiotic strains have been shown to increase the bioavailability of drugs by optimizing intestinal flora and reducing gastrointestinal disturbances. Conversely, probiotics may also impact drug metabolism, potentially leading to altered drug levels and effects. The paper discusses both the positive and negative implications of probiotic-drug interactions and highlights the need for individualized therapeutic strategies. It also underscores the importance of clinical trials to establish clear guidelines for integrating probiotics into drug therapy regimens for gastrointestinal disorders. Overall, while probiotics hold promise for improving drug outcomes in gastrointestinal conditions, their effects on drug bioavailability and efficacy require further investigation to ensure safe and effective therapeutic use.

**Keywords:** Probiotics, Drug Bioavailability, Gastrointestinal Disorders, Drug-Drug Interactions, Pharmacokinetics, Intestinal Microbiota

**Introduction**

Oral administration is the most common approach to drug delivery due to its safety, convenience, low cost, a greater degree of flexibility and better patient compliance. Good absorption and high bioavailability are very important for the therapeutic efficacy of oral drugs. The efficiency of this process is subject to drug’s physicochemical properties, like drug solubility and permeability, individual physiological characteristics, like gastrointestinal pH, gastrointestinal transit time, transport systems and other factors like diet. As symbiotic microorganisms in the gut, the gut microbiota has a good chance of contacting with oral drugs especially those absorbed in the lower gastrointestinal tract (Zhang *et al*., 2018).Hence, the influence of the gut microbiota on the pharmacokinetics of oral drugs could not be neglected. Some research has shown that gut microorganisms can affect oral drug’s bioavailability either direct or in indirect ways, such as changing the intestinal properties. Gut microbial enzyme activity can directly influence the bioavailability of oral drugs by affecting their metabolism, first-pass effect or enterohepatic recirculation(Flowers *et al.*, 2020).It may also influence drug pharmacokinetics by participating in the biotransformation of bile acids which can affect the bioavailability of lipophilic drugs. Early research has demonstrated that the gut microbiota can influence the drug transport by substrate competition or regulating the expression of transporters(Bai *et al.*, 2022).

Therefore, it is necessary to investigate the association between the gut microbiota and the bioavailability of oral drugs to ensure a better clinical outcome. Having a deep insight into the relationship between gut microorganisms and oral drugs, bioavailability can help us to have better comprehension of the inter-individual variation in bioavailability, and then providing personalized and precise clinical advice. It may also help us to avoid some potential drug-drug interactions induced by the change in the gut microbiota. Besides, it can also help us to understand the differences of the results obtained from in vitro and in vivo experiments or the possible different outcomes of oral drug’s bioavailability in animal experiments and clinical trials. In addition, it may also offer us many innovative ideas of the drug delivery system design, especially the design of colon-targeted drug delivery systems.

Probiotics are substances containing live microorganisms that are thought to have a beneficial effect on the human body by manipulating microbiome and host properties and in some cases, they can prevent disease. They are immunomodulating bacteria that have very low virulence compared with the more pathogenic gut flora such as Escherichia coli and clostridia(Raheem *et al.*, 2021). Lactobacilli and bifidobacteria are examples of probiotics found in the large intestine. Lactobacillus GG can prevent diarrhoea and atopy in children. In the gut, probiotic bacteria are thought to occupy binding sites on the gut mucosa, preventing pathogenic bacteria from adhering to the mucosa(Van Zyl *et al*., 2020). Lactobacilli also produce proteinaceous compounds—bacteriocins—that act as local antibiotics against more pathogenic organisms(Darbandi *et al.*, 2022; Zacharof *et al*., 2012).

Diarrhoea associated with antibiotics is presumed to result from the antibiotics disrupting the normal flora in the gut of a healthy person. Such disruptions cause dysfunction of the gut's ecosystem, and they may allow pathogenic bacteria to colonize the gut and gain access to the mucosa.

In model systems, probiotics have been shown to modulate the immune system, provide resistance to invasion by pathogens, improve intestinal barrier function, lower the pH of the gut, and modulate intestinal motility and pain perception(Gou *et al*., 2022). The notions of “beneficial” microbes originated more than a century ago in the Pasteur Institute on the heels of the emergence of the germ theory of disease, which linked many of the most common maladies of the time to specific microbial pathogens(Adams, 2020). In 1899, Henry Tissier, a pediatrician working at the Institute, isolated irregular Y-shaped, “bifid,” bacteria from the feces of healthy human infants, now known as Bifidobacterium, and suggested their potential in treatment of diarrhea(Khoruts *et al*., 2020).

Probiotics, defined as live microorganisms that confer health benefits to the host when administered in adequate amounts, have gained significant attention for their role in maintaining and improving gastrointestinal health. They are commonly used to manage and prevent a range of gastrointestinal disorders, such as irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), and peptic ulcers. These disorders often disrupt normal gastrointestinal function, leading to symptoms such as abdominal pain, bloating, and irregular bowel movements. Probiotics, through their beneficial effects on gut microbiota, intestinal permeability, and inflammation, offer a potential adjunctive therapy to traditional treatments. The gut microbiota, the complex community of microorganisms residing in the gastrointestinal tract, plays a crucial role in maintaining gut health and influencing systemic disease outcomes(Guinane *et al.*, 2013). Disruptions in this microbial balance can lead to dysbiosis, which has been associated with various gastrointestinal disorders(Singh et al., 2021). Probiotics are thought to restore microbial balance, thereby alleviating symptoms and improving overall gut health. In addition to their effects on gut microbiota, probiotics can impact drug absorption, metabolism, and efficacy, which is particularly important in the context of managing gastrointestinal disorders where medication is a cornerstone of treatment.

Drug bioavailability refers to the proportion of an administered dose of a drug that reaches the systemic circulation and is available for therapeutic action. It is a critical factor influencing the effectiveness of medications. In the context of gastrointestinal disorders, the bioavailability of oral medications can be significantly affected by the physiological changes and microbial interactions within the gut.

Factors such as altered gut motility, increased intestinal permeability, and changes in gut microbiota composition can affect drug absorption and metabolism(Li *et al*., 2020). Therefore, understanding how probiotics influence drug bioavailability is essential for optimizing treatment regimens and improving patient outcomes. Drug efficacy, on the other hand, refers to the ability of a drug to produce the desired therapeutic effect. The effectiveness of medications used to treat gastrointestinal disorders can be influenced by several factors, including the drug's pharmacokinetics (absorption, distribution, metabolism, and excretion) and pharmacodynamics (the drug's effects on the body). Probiotics may influence these processes by modulating gut microbiota, which can alter the metabolism of drugs and affect their therapeutic outcomes. For instance, probiotics might enhance the efficacy of certain medications by improving gut health, reducing inflammation, or influencing drug-metabolizing enzymes.

**Gastrointestinal Health and Probiotics**

1. **Mechanisms of Action**

Probiotics exert their beneficial effects on gastrointestinal health through several mechanisms. One primary **mechanism is the modulation of gut microbiota**. The gut microbiota, a diverse community of microorganisms residing in the intestines, plays a critical role in maintaining gastrointestinal homeostasis. Probiotics can positively influence this microbial balance by outcompeting pathogenic bacteria for resources, thereby reducing microbial dysbiosis(Khaneghah *et al.*, 2020). This competition helps to restore a healthy microbial ecosystem, which can alleviate symptoms of gastrointestinal disorders such as IBS and IBD. By promoting the growth of beneficial microorganisms, probiotics also contribute to a more stable gut environment, enhancing overall gut health.

Another important **mechanism is the enhancement of intestinal barrier function**. The intestinal barrier, composed of epithelial cells and tight junctions, serves as a critical defense against pathogens and toxins. Probiotics can strengthen this barrier by enhancing the expression of tight junction proteins, which improves gut permeability and prevents leaky gut syndrome(Aleman *et al*., 2023; Rose *et a*l., 2021). This reinforcement reduces systemic inflammation and prevents the translocation of harmful substances into the bloodstream, thereby mitigating symptoms of gastrointestinal disorders. Probiotics also play a role in modulating gut inflammation. They can produce anti-inflammatory compounds and regulate the immune system's response within the gut. By reducing the levels of pro-inflammatory cytokines and promoting anti-inflammatory pathways, probiotics help to alleviate inflammation associated with conditions such as IBD(Cristofori *et al*., 2021). This modulation of inflammation contributes to improved symptom management and overall gastrointestinal health.

**Common Probiotic Strains and Their Effects**

Several probiotic strains have been studied for their effects on gastrointestinal health, each with distinct properties and benefits.

**Lactobacillus species**, such as Lactobacillus rhamnosus and Lactobacillus acidophilus, are well known for their ability to adhere to the intestinal mucosa and outcompete harmful bacteria(Dempsey *et al.*, 2022). These strains have been shown to improve symptoms of IBS by enhancing gut barrier function and reducing inflammation.

**Bifidobacterium species**, including Bifidobacterium bifidum and Bifidobacterium lactis, are also prominent in gastrointestinal health. They help to ferment dietary fibers, producing shortchain fatty acids (SCFAs) that nourish the intestinal lining and modulate immune responses(Markowiak-Kopeć et al., 2020; H. Wang et al., 2022). These strains have demonstrated efficacy in managing IBD by reducing mucosal inflammation and restoring microbial balance.

**Saccharomyces boulardii,** a probiotic yeast, is known for its unique ability to resist antibiotics and maintain its beneficial effects during antibiotic therapy. It has been used effectively in treating and preventing antibiotic-associated diarrhea and maintaining gut health during gastrointestinal disturbances(Ansari *et al.*, 2023).

**Probiotics and Pharmacokinetics (Drug Bioavailability)**

Probiotics as gut-conditioning agents, modify the gut microflora composition and activity which brings about a change of the pharmacokinetics of administered drugs.

**1. Effects on Drug Absorption**

Drug absorption is a critical factor in determining the bioavailability of oral medications, and the gastrointestinal tract's complex ecosystem plays a vital role in this process. One of the primary ways probiotics impact drug absorption is by modifying gut microbiota(Zhang *et al.*, 2018). The gut microbiota, a diverse community of microorganisms, can affect the dissolution and solubility of drugs. Probiotics can alter the composition of this microbiota, potentially enhancing the solubility and dissolution of drugs. For example, probiotics may help break down certain compounds into more absorbable forms, thereby increasing the availability of the drug for systemic absorption(Li *et al.*, 2020).

Additionally, probiotics influence gut motility, which can affect drug absorption. Probiotics have been shown to enhance gut motility in some cases, reducing the time drugs spend in the gastrointestinal tract and potentially decreased absorption. Conversely, probiotics might also slow down gut transit in other instances, which could lead to prolonged drug exposure andincreased absorption. The net effect of probiotics on drug absorption will depend on the specific strain used, the drug in question, and the overall state of the gut environment(Yunes *et al.*, 2022).Probiotics also affect the intestinal permeability or "leaky gut" syndrome. Enhanced intestinal permeability can increase the rate at which drugs pass through the gut lining and enter the bloodstream. By strengthening the intestinal barrier, probiotics can reduce excessive permeability and ensure more consistent drug absorption(Gou *et al.*, 2022). This can be particularly important for drugs with narrow therapeutic windows or those that are highly sensitive to changes in absorption rates.

**2. ProbioticsInteraction with Drug-Metabolizing Enzymes**

Drug metabolism primarily occurs in the liver, but the gut microbiota also plays a role in the metabolism of certain drugs. Probiotics can influence the activity of gut microbiota and, consequently, the activity of drug-metabolizing enzymes. This interaction can affect both the efficacy and safety of medications.

One significant interaction is with enzymes involved in drug conjugation and detoxification, such as UDP-glucuronosyltransferases (UGTs)(Luo *et al.*, 2022; Purdel et al., 2023). Probiotics can modulate the expression and activity of these enzymes, potentially altering the rate at which drugs are metabolized. For instance, certain probiotic strains might enhance the activity of these enzymes, leading to increased drug clearance and potentially reduced efficacy if the drug is metabolized too quickly.

Conversely, probiotics may inhibit the activity of certain enzymes, leading to increased drug levels and potential toxicity(Luo *et al.*, 2022). This effect can be observed with drugs that undergo extensive metabolism in the gut, such as those that are subject to first-pass metabolism. By altering enzyme activity, probiotics can modify the concentration of active drug forms and impact therapeutic outcomes. Additionally, probiotics can influence the gut microbiota's production of metabolites that interact with drug-metabolizing enzymes. For example, short-chain fatty acids (SCFAs) produced by probiotic fermentation can affect enzyme activity and alter drug metabolism(Markowiak-Kopeć *et al.*, 2020).

**Effect of Probiotics on Drug Excretion**

Probiotics can also affect the excretion of drugs from the body, which can influence overall drug efficacy and safety. Drug excretion primarily occurs through the kidneys and liver, but the gut microbiota and probiotics can play a role in this process as well.

One way probiotics influence drug excretion is through their effects on gut motility. By altering gut transit time, probiotics can influence the reabsorption and excretion of drugs. For example, enhanced gut motility can lead to more rapid drug elimination, while slowed transit might result in increased drug reabsorption and prolonged drug action.

Probiotics can also affect the enterohepatic circulation of drugs. Many drugs undergo enterohepatic recycling, where they are reabsorbed from the intestine back into the bloodstream after being metabolized in the liver(Sun *et al.*, 2019). Probiotics can influence this process by modifying gut microbiota and affecting bile acid metabolism. Changes in bile acid composition can influence the reabsorption of drugs, altering their overall pharmacokinetics. Moreover, probiotics can affect the gut microbiota's production of enzymes and metabolites that influence drug excretion. For instance, probiotics might alter the production of compounds that affect drug solubility and excretion rates. These changes can influence how drugs are processed and eliminated from the body, influencing therapeutic outcomes and potential side effects.

**Probiotics and Pharmacodynamics (Drug Efficacy)**

One of the first recognized and mostly studied interactions of intestinal bacteria with drugs is in the case of anticoagulant therapy. Namely, intestinal bacteria have the role in the synthesis of vitamin K. Broad spectrum of antibiotics, by decreasing the population of bacterial flora in the gut, can remove an important source of this vitamin. Vitamin K deficiency may consequently enhance the anticoagulant therapy action causing clinically significant adverse events.

**1. Mechanisms of Action Enhancement**

Probiotics can enhance drug efficacy by modifying various physiological and biochemical mechanisms in the gastrointestinal tract. One primary way probiotics influence drug pharmacodynamics is through the modulation of gut microbiota, which affects drug absorption, metabolism, and the overall drug response(Purdel *et al.*, 2023; Zhao *et al.*, 2023). The gut microbiota interacts with drugs in severalways, including influencing their solubility and stability. By altering the gut microbialcomposition, probiotics can improve drug solubility and enhance the drug's ability to interactwith its target. Probiotics can also affect drug efficacy by modulating the immune response. Many gastrointestinal drugs, particularly those used to treat inflammatory conditions, rely on precise immune system interactions to achieve their therapeutic effects. Probiotics can influence local immune responses by promoting a balanced immune environment, reducing inflammation, and enhancing mucosal immunity. For instance, probiotics can increase the production of anti-inflammatory cytokines and decrease pro-inflammatory cytokines, thus supporting the efficacy of drugs that target inflammation(Aghamohammad *et al*., 2022; Cristofori *et al.*, 2021).

Additionally, probiotics can influence drug efficacy through their effects on gut motility and barrier function. Improved gut motility can lead to more consistent drug absorption, while enhanced intestinal barrier function can reduce drug degradation and loss. By stabilizing these physiological parameters, probiotics help ensure that drugs reach their intended targets and maintain their therapeutic effects.

**2. Influence of Probiotics on Modulation of Drug-Metabolizing Enzymes**

Probiotics can modulate the activity of drug-metabolizing enzymes, which plays a crucial role in determining drug efficacy. The gut microbiota produces various enzymes that can metabolize drugs, and probiotics can alter the expression and activity of these enzymes. For example, probiotics may increase the activity of certain enzymes involved in drug activation or detoxification, enhancing the therapeutic effect of specific medications(Średnicka *et al.*, 2021).

Conversely, probiotics can also inhibit the activity of enzymes responsible for drug metabolism, potentially increasing drug levels and prolonging their effects. This modulation can be particularly relevant for drugs with narrow therapeutic windows or those requiring precise dosing. Understanding how probiotics interact with drug-metabolizing enzymes helps in predicting their impact on drug efficacy and tailoring therapeutic strategies accordingly(Wu *et al.*, 2024).

**Probiotic-positive Interactions**

Probiotic-drug interactions can have beneficial effects on the efficacy and safety of various medications, particularly in gastrointestinal disorders. One of the most significant positive interactions is the enhancement of drug bioavailability. Probiotics can improve the solubility and absorption of certain drugs by altering the gut environment, such as by modulating the gut microbiota or enhancing the integrity of the intestinal barrier. This leads to more consistent and efficient drug absorption, ensuring that the medication reaches its target site effectively. Additionally, probiotics can reduce gastrointestinal side effects commonly associated with certain drugs, such as antibiotics, by restoring the balance of gut microbiota and preventing antibiotic-associated diarrhea(Yang *et al*., 2024). This interaction not only improves patient comfort but also ensures that the therapeutic benefits of the drug are fully realized without compromising thepatient’s gut health.

Another positive interaction is the ability of probiotics to support the immune system, which can enhance the therapeutic effects of immunomodulatory drugs used in treating conditions like inflammatory bowel disease (IBD)(Cristofori *et al.*, 2021; Yousefi *et al*., 2019). By promoting a balanced immune response, probiotics help to reduce inflammation and support the efficacy of the medication.

**Probiotic Negative Interactions**

While probiotics generally have beneficial effects, there are instances where they may negatively interact with certain medications. One potential negative interaction is the alteration of drug metabolism. Probiotics can modulate the activity of drug-metabolizing enzymes in the gut, which may lead to either increased or decreased drug levels in the bloodstream. For example, probiotics could enhance the activity of enzymes that break down a drug too quickly, reducing its therapeutic effect. Conversely, they could inhibit these enzymes, leading to higher-than-expected drug levels and potential toxicity. Such interactions are particularly concerning with drugs that have narrow therapeutic windows, where precise dosing is critical.

Additionally, the use ofprobiotics may interfere with the efficacy of certain immunosuppressive drugs by boosting the immune system, which could counteract the desired suppression of immune activity. This is especially relevant in patients who have undergone organ transplants or are being treated for autoimmune diseases, where maintaining a delicate balance in immune function is crucial. Therefore, careful consideration and monitoring are necessary when probiotics are used alongside medications that are highly dependent on specific metabolic pathways or immune responses(Suez *et al.*, 2019).

**Personalized Therapeutic Strategies**

Given the complex nature of probiotic-drug interactions, personalized therapeutic strategies are essential to maximize the benefits and minimize potential risks. Personalizing treatment involves selecting specific probiotic strains that are known to interact favorably with the patient’s medication regimen. This approach requires a deep understanding of the patient’s health status, the nature of their gastrointestinal disorder, and the specific drugs they are taking. For example, a patient with IBD who is on immunosuppressive therapy might benefit from probiotics that support gut health without significantly altering immune function or drug metabolism(Beaugerie *et al*., 2019). Moreover, individual variations in gut microbiota composition can influence how a patient respond to both probiotics and medications.

Personalized medicine, which includes genomic and microbiome analysis, can help identify the most suitable probiotic strains and dosages for each patient, optimizing their treatment outcomes(Ratiner *et al.*, 2024; Schupack *et al.*, 2022). Regular monitoring of the patient’s response to therapy, including both the efficacy and potential side effects, is crucial to adjusting the treatment plan as needed. This personalized approach not only enhances the therapeutic benefits of bothprobiotics and medications but also reduces the risk of adverse interactions, ensuring safer and more effective care.

**Probiotics - Future Research Directions**

The field of probiotic-drug interactions is still in its early stages, and there is a significant need for further research to fully understand these complex relationships. Future studies should focus on elucidating the specific mechanisms by which probiotics influence drug absorption, metabolism, and excretion. This includes identifying the roles of different probiotic strains in modulating drug-metabolizing enzymes and their impact on pharmacokinetics.

Additionally, research should aim to explore the effects of probiotics on a broader range of medications, particularly those used to treat non-gastrointestinal conditions, to determine whether similar interactions occur. Large-scale clinical trials are needed to validate the safety and efficacy of using probiotics in conjunction with various drug therapies, particularly in populations with specific health conditions like chronic gastrointestinal disorders, cancer, or autoimmune diseases. These studies should also consider the long-term effects of probiotic use on drug efficacy and patient outcomes.

Another important area for future research is the development of guidelines for healthcare providers on the appropriate use of probiotics in clinical practice. These guidelines should be based on evidence from robust clinical trials and include recommendations for specific probiotic strains, dosages, and timing relative to drug administration. Overall, continued research in this area will be critical to harnessing the full potential of probiotics in enhancing drug therapy while minimizing the risks of adverse interactions.

**Probiotics - Clinical Implications**

The integration of probiotics into therapeutic regimens, especially in the management of gastrointestinal disorders, presents both promising opportunities and significant challenges. The clinical implications of probiotic-drug interactions are vast, influencing the efficacy, safety, and overall outcomes of treatment protocols(Das *et al.*, 2025). As the understanding of the gut microbiome's role in health and disease deepens, the potential for probiotics to enhance drug therapy becomes increasingly apparent. However, this also necessitates careful consideration of how probiotics are used in conjunction with conventional medications. One of the most significant clinical implications of using probiotics is their potential to enhance drug efficacy. For patients with gastrointestinal disorders such as irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), and peptic ulcers, probiotics can improve the absorption and bioavailability of drugs, leading to better therapeutic outcomes(Dahiya *et al.*, 2023).

For instance, in cases where drugs are poorly absorbed due to compromised gut function, probiotics may help by stabilizing the gut environment, enhancing the solubility of drugs, and supporting the integrity of the intestinal barrier. This not only ensures that more of the drug is absorbed but also that it reaches the target site in a more effective form. This has been particularly evident in studies where probiotics have been shown to enhance the efficacy of anti-inflammatory drugs in IBD, reducing the severity of symptoms and improving patients' quality of life.

 Moreover, probiotics can mitigate some of the adverse effects associated with drug therapy, particularly those that affect the gastrointestinal tract. Antibiotics, for example, are notorious for disrupting the gut microbiota, leading to side effects such as diarrhea and increased susceptibility to infections like Clostridioides difficile(Khanna *et al.*, 2016; Ramirez *et al.*, 2020). By co-administering probiotics, these negative impacts can be minimized. Probiotics help maintain a healthy balance of gut bacteria, reducing the risk of antibiotic-associated diarrhea and other gastrointestinal disturbances. This protective effect is crucial, as it not only improves patient comfort but also supports adherence to antibiotic therapy, ensuring that infections are effectively treated without the need for dose adjustments or discontinuation due to side effects.

However, the use of probiotics in clinical settings is not without challenges. One of the primary concerns is the variability in patient responses to probiotic therapy. This variability can be attributed to differences in individual gut microbiota composition, the specific strains of probiotics used, and the patient’s overall health status(Suez *et al.*, 2019). For example, while some patients may experience significant improvements in drug efficacy and reduced side effects with probiotic use, others may not benefit to the same extent or may even experience negative interactions.

This highlights the need for personalized medicine approaches, where probiotic therapy is tailored to the individual’s specific microbiome and health needs(Ratiner *et al.*, 2024; Schupack *et al.*, 2022). Advances in microbiome sequencing and analysis are making these increasingly feasible, allowing clinicians to select the most appropriate probiotic strains and dosages based on a patient’s unique gut microbiome profile.

Another critical clinical implication is the potential for probiotics to interact negatively with certain drugs, particularly those that have narrow therapeutic windows or are highly dependent on specific metabolic pathways(Purdel *et al.*, 2023; Zhao *et al.*, 2023). For instance, probiotics may alter the activity of drug metabolizing enzymes, leading to either increased or decreased drug levels. In the case of drugs with a narrow therapeutic index, where the difference between a therapeutic and toxic dose is small, such interactions could be dangerous. This necessitates careful monitoring and, in some cases, the adjustment of drug dosages when probiotics are introduced into the treatment regimen. Clinicians must be aware of these potential interactions and consider them when prescribing probiotics alongside conventional medications. Furthermore, the regulatory landscape surrounding probiotics remains a challenge in clinical practice. Unlike pharmaceuticals, probiotics are often classified as dietary supplements, which means they are subject to less rigorous testing and regulation. This can lead to variability in the quality, potency, and purity of probiotic products available on the market, raising concerns about their consistency and efficacy in clinical use. Clinicians need to be cautious in selecting probiotic products, opting for those that have been clinically validated and are produced by reputable manufacturers. Standardizing the formulation and ensuring the consistency of probiotic products will be crucial as their use in conjunction with drug therapies becomes more widespread.

Finally, the long-term implications of probiotic use in conjunction with drug therapy require further exploration. While short-term benefits are increasingly well-documented, the effects of prolonged probiotic use on drug efficacy, resistance, and overall health are not yet fully understood. For example, continuous use of probiotics could potentially lead to changes in the gut microbiota that might affect how patients respond to drugs over time(Maftei *et al*., 2024; Sanders, 2011). There is also the question of whether the benefits of probiotics persist after discontinuation or if ongoing use is necessary to maintain their positive effects. These are critical areas for future research, as understanding the long-term impact of probiotics will be essential for developing comprehensive guidelines for their use in clinical practice.

**Conclusion**

The integration of probiotics into therapeutic regimens for gastrointestinal disorders presents a promising avenue for enhancing drug bioavailability and efficacy. Probiotics exert their beneficial effects through mechanisms such as modulation of gut microbiota, enhancement of intestinal barrier function, and reduction of gut inflammation(Cristofori *et al.*, 2021; X. Wang *et al*., 2021). These interactions can improve the absorption and metabolism of drugs, leading to better therapeutic outcomes for conditions like irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), and peptic ulcers. Clinical evidence suggests that probiotics can enhance drug efficacy by improving drug absorption rates, reducing adverse effects, and supporting immune function. For instance, probiotics have been shown to increase the bioavailability of anti-inflammatory drugs in IBD, reduce antibiotic associated diarrhea, and enhance the effectiveness of treatments for IBS. However, the potential for negative interactions, such as altered drug metabolism leading to either increased toxicity or reduced efficacy, underscores the need for careful consideration when integrating probiotics with conventional medications. Personalized therapeutic strategies, which consider the patient’s specific gut microbiota and the drugs being used, are essential to maximize the benefits and minimize the risks of probiotic-drug interactions. As probiotics hold significant potential for improving drug therapy in gastrointestinal disorders, their use must be carefully managed to ensure safe and effective treatment outcomes. Further research is necessary to fully understand the long-term implications and optimize the use of probiotics in clinical settings.

**References**

Adams, D. P. (2020). *Foundations of Infectious Disease: A Public Health Perspective: A Public Health Perspective*: Jones & Bartlett Learning.

Aghamohammad, S., Sepehr, A., Miri, S. T., Najafi, S., Pourshafie, M. R., & Rohani, M. (2022). The role of combining probiotics in preventing and controlling inflammation: a focus on the anti‐inflammatory and immunomodulatory effects of probiotics in an in vitro model of IBD. *Canadian Journal of Gastroenterology and Hepatology, 2022*(1), 2045572.

Aleman, R. S., Moncada, M., & Aryana, K. J. (2023). Leaky gut and the ingredients that help treat it: a review. *Molecules, 28*(2), 619.

Ansari, F., Alian Samakkhah, S., Bahadori, A., Jafari, S. M., Ziaee, M., Khodayari, M. T., & Pourjafar, H. (2023). Health-promoting properties of Saccharomyces cerevisiae var. boulardii as a probiotic; characteristics, isolation, and applications in dairy products. *Critical reviews in food science and nutrition, 63*(4), 457-485.

Bai, X., Yang, J., Liu, G., Zhu, J., Wang, Q., Gu, W., . . . Li, X. (2022). Regulation of CYP450 and drug transporter mediated by gut microbiota under high-altitude hypoxia. *Frontiers in pharmacology, 13*, 977370.

Beaugerie, L., & Kirchgesner, J. (2019). Balancing benefit vs risk of immunosuppressive therapy for individual patients with inflammatory bowel diseases. *Clinical Gastroenterology and Hepatology, 17*(3), 370-379.

Cristofori, F., Dargenio, V. N., Dargenio, C., Miniello, V. L., Barone, M., & Francavilla, R. (2021). Anti-inflammatory and immunomodulatory effects of probiotics in gut inflammation: a door to the body. *Frontiers in immunology, 12*, 578386.

Dahiya, D., & Nigam, P. S. (2023). Biotherapy using probiotics as therapeutic agents to restore the gut microbiota to relieve gastrointestinal tract inflammation, IBD, IBS and prevent induction of cancer. *International journal of molecular sciences, 24*(6), 5748.

Darbandi, A., Asadi, A., Mahdizade Ari, M., Ohadi, E., Talebi, M., Halaj Zadeh, M., . . . Kakanj, M. (2022). Bacteriocins: properties and potential use as antimicrobials. *Journal of Clinical Laboratory Analysis, 36*(1), e24093.

Das, U., Mehra, R. K., Mandal, S., Ashique, S., Kumar, S., Farid, A., . . . Taghizadeh-Hesary, F. (2025). Toxicology of Probiotics: Challenges and Future Prospects. *The Role of Probiotics in Cancer Management*, 379-428.

Dempsey, E., & Corr, S. C. (2022). Lactobacillus spp. for gastrointestinal health: current and future perspectives. *Frontiers in immunology, 13*, 840245.

Flowers, S. A., Bhat, S., & Lee, J. C. (2020). Potential implications of gut microbiota in drug pharmacokinetics and bioavailability. *Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy, 40*(7), 704-712.

Gou, H.-Z., Zhang, Y.-L., Ren, L.-F., Li, Z.-J., & Zhang, L. (2022). How do intestinal probiotics restore the intestinal barrier? *Frontiers in microbiology, 13*, 929346.

Guinane, C. M., & Cotter, P. D. (2013). Role of the gut microbiota in health and chronic gastrointestinal disease: understanding a hidden metabolic organ. *Therapeutic advances in gastroenterology, 6*(4), 295-308.

Khaneghah, A. M., Abhari, K., Eş, I., Soares, M. B., Oliveira, R. B., Hosseini, H., . . . Cruz, A. G. (2020). Interactions between probiotics and pathogenic microorganisms in hosts and foods: A review. *Trends in Food Science & Technology, 95*, 205-218.

Khanna, S., & Pardi, D. S. (2016). Clinical implications of antibiotic impact on gastrointestinal microbiota and Clostridium difficile infection. *Expert review of gastroenterology & hepatology, 10*(10), 1145-1152.

Khoruts, A., Hoffmann, D. E., & Britton, R. A. (2020). Probiotics: promise, evidence, and hope. *Gastroenterology, 159*(2), 409-413.

Li, X., Liu, L., Cao, Z., Li, W., Li, H., Lu, C., . . . Liu, Y. (2020). Gut microbiota as an “invisible organ” that modulates the function of drugs. *Biomedicine & Pharmacotherapy, 121*, 109653.

Luo, Y., & Zhou, T. (2022). Connecting the dots: targeting the microbiome in drug toxicity. *Medicinal research reviews, 42*(1), 83-111.

Maftei, N. M., Raileanu, C. R., Balta, A. A., Ambrose, L., Boev, M., Marin, D. B., & Lisa, E. L. (2024). The Potential Impact of Probiotics on Human Health: An Update on Their Health-Promoting Properties. *Microorganisms, 12*(2). doi:10.3390/microorganisms12020234

Markowiak-Kopeć, P., & Śliżewska, K. (2020). The effect of probiotics on the production of short-chain fatty acids by human intestinal microbiome. *Nutrients, 12*(4), 1107.

Purdel, C., Ungurianu, A., Adam-Dima, I., & Margină, D. (2023). Exploring the potential impact of probiotic use on drug metabolism and efficacy. *Biomedicine & Pharmacotherapy, 161*, 114468.

Raheem, A., Liang, L., Zhang, G., & Cui, S. (2021). Modulatory effects of probiotics during pathogenic infections with emphasis on immune regulation. *Frontiers in immunology, 12*, 616713.

Ramirez, J., Guarner, F., Bustos Fernandez, L., Maruy, A., Sdepanian, V. L., & Cohen, H. (2020). Antibiotics as major disruptors of gut microbiota. *Frontiers in cellular and infection microbiology, 10*, 572912.

Ratiner, K., Ciocan, D., Abdeen, S. K., & Elinav, E. (2024). Utilization of the microbiome in personalized medicine. *Nature Reviews Microbiology, 22*(5), 291-308.

Rose, E. C., Odle, J., Blikslager, A. T., & Ziegler, A. L. (2021). Probiotics, prebiotics and epithelial tight junctions: a promising approach to modulate intestinal barrier function. *International journal of molecular sciences, 22*(13), 6729.

Sanders, M. E. (2011). Impact of probiotics on colonizing microbiota of the gut. *Journal of clinical gastroenterology, 45*, S115-S119.

Schupack, D. A., Mars, R. A., Voelker, D. H., Abeykoon, J. P., & Kashyap, P. C. (2022). The promise of the gut microbiome as part of individualized treatment strategies. *Nature reviews Gastroenterology & hepatology, 19*(1), 7-25.

Singh, R., Zogg, H., Wei, L., Bartlett, A., Ghoshal, U. C., Rajender, S., & Ro, S. (2021). Gut microbial dysbiosis in the pathogenesis of gastrointestinal dysmotility and metabolic disorders. *Journal of neurogastroenterology and motility, 27*(1), 19.

Średnicka, P., Juszczuk-Kubiak, E., Wójcicki, M., Akimowicz, M., & Roszko, M. (2021). Probiotics as a biological detoxification tool of food chemical contamination: A review. *Food and chemical toxicology, 153*, 112306.

Suez, J., Zmora, N., Segal, E., & Elinav, E. (2019). The pros, cons, and many unknowns of probiotics. *Nat Med, 25*(5), 716-729.

Sun, C., Chen, L., & Shen, Z. (2019). Mechanisms of gastrointestinal microflora on drug metabolism in clinical practice. *Saudi Pharmaceutical Journal, 27*(8), 1146-1156.

Van Zyl, W. F., Deane, S. M., & Dicks, L. M. (2020). Molecular insights into probiotic mechanisms of action employed against intestinal pathogenic bacteria. *Gut microbes, 12*(1), 1831339.

Wang, H., Huang, X., Tan, H., Chen, X., Chen, C., & Nie, S. (2022). Interaction between dietary fiber and bifidobacteria in promoting intestinal health. *Food chemistry, 393*, 133407.

Wang, X., Zhang, P., & Zhang, X. (2021). Probiotics regulate gut microbiota: an effective method to improve immunity. *Molecules, 26*(19), 6076.

Wu, K., Kwon, S. H., Zhou, X., Fuller, C., Wang, X., Vadgama, J., & Wu, Y. (2024). Overcoming Challenges in Small-Molecule Drug Bioavailability: A Review of Key Factors and Approaches. *International journal of molecular sciences, 25*(23), 13121.

Yang, S., Qiao, J., Zhang, M., Kwok, L.-Y., Matijašić, B. B., Zhang, H., & Zhang, W. (2024). Prevention and treatment of antibiotics-associated adverse effects through the use of probiotics: A review. *Journal of Advanced Research*.

Yousefi, B., Eslami, M., Ghasemian, A., Kokhaei, P., Salek Farrokhi, A., & Darabi, N. (2019). Probiotics importance and their immunomodulatory properties. *Journal of cellular physiology, 234*(6), 8008-8018.

Yunes, R., Poluektova, E., Belkina, T., & Danilenko, V. (2022). Lactobacilli: legal regulation and prospects for new generation drugs. *Applied Biochemistry and Microbiology, 58*(5), 652-664.

Zacharof, M.-P., & Lovitt, R. (2012). Bacteriocins produced by lactic acid bacteria a review article. *Apcbee Procedia, 2*, 50-56.

Zhang, J., Zhang, J., & Wang, R. (2018). Gut microbiota modulates drug pharmacokinetics. *Drug metabolism reviews, 50*(3), 357-368.

Zhao, Q., Chen, Y., Huang, W., Zhou, H., & Zhang, W. (2023). Drug-microbiota interactions: an emerging priority for precision medicine. *Signal transduction and targeted therapy, 8*(1), 1-27.