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Gut Microbiota–Nanotechnology Interface: A New Frontier in Managing Obesity and Diabetes

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ABSTRACT

The gut microbiota plays a crucial role in maintaining metabolic homeostasis and influencing the development of obesity and type 2 diabetes (T2D). Dysbiosis, an imbalance in gut microbial composition, has been linked to insulin resistance, inflammation, and disrupted glucose metabolism. Recent advances in nanotechnology offer promising solutions to modulate the gut microbiota and its associated metabolic functions. Nanoparticles (NPs) can deliver therapeutic agents, regulate microbial composition, and enhance gut barrier function, all of which contribute to managing obesity and diabetes. This review explores the interface between gut microbiota and nanotechnology, highlighting the mechanisms through which nanoparticles influence microbial diversity, the therapeutic potential of nanomaterials in metabolic disease management, and the challenges and future directions for clinical application.

Keywords: gut microbiota, nanotechnology, obesity, diabetes, metabolic disease

INTRODUCTION

The gut microbiota, consisting of trillions of microbes including bacteria, fungi, viruses, and archaea, plays a pivotal role in regulating various physiological processes, such as digestion, immune function, and metabolism[1–4]. In recent years, the importance of the gut microbiota in the development of metabolic diseases, particularly obesity and type 2 diabetes (T2D), has become increasingly evident. The gut microbiota influences metabolic processes, including nutrient absorption, fat storage, and insulin sensitivity, through complex interactions with host tissues[5].

Obesity, a growing global health issue, is associated with altered gut microbiota composition, often referred to as dysbiosis[6]. Dysbiosis is characterized by a reduction in microbial diversity, an overgrowth of pathogenic bacteria, and a decrease in beneficial species such as Bacteroidetes[7–9]. This imbalance has been implicated in increased gut permeability, low-grade inflammation, and impaired glucose metabolism—all of which contribute to the development of insulin resistance and T2D. Therefore, targeting the gut microbiota offers a potential therapeutic strategy for managing obesity and T2D by restoring microbial balance and improving metabolic functions[10].

Traditionally, interventions aimed at correcting dysbiosis have focused on the use of probiotics, prebiotics, and dietary changes to modify the gut microbiota. However, these approaches often yield limited or inconsistent results. The integration of nanotechnology into gut microbiota research presents new opportunities to enhance therapeutic interventions. Nanoparticles (NPs) possess unique properties, such as high surface area, biocompatibility, stability, and targeted delivery capabilities, which make them suitable for modulating microbial activity and improving metabolic health[11, 12].

Nanotechnology has shown promise in several areas relevant to obesity and T2D management, including the targeted delivery of anti-inflammatory agents, probiotics, prebiotics, and antioxidants to the gut, as well as the regulation of gut microbiota composition. NPs can be engineered to interact with the gut microbiota, modulate the gut immune system, and restore gut barrier integrity, leading to improved metabolic outcomes[13, 14]. Additionally, NPs can be designed to target specific microbial species, reduce gut inflammation, and enhance the absorption of beneficial nutrients, thus addressing the root causes of obesity and diabetes.[15–18]. This review aims to explore the growing field of gut microbiota-nanotechnology interface, focusing on how nanomaterials can modulate the microbiota to improve metabolic health. The review will discuss the mechanisms by which

NPs influence gut microbiota composition, their therapeutic applications in obesity and diabetes management, and the challenges and future prospects for clinical implementation.

2. Mechanisms of Nanotechnology in Modulating Gut Microbiota

Nanotechnology offers several unique mechanisms through which nanoparticles (NPs) can modulate the gut microbiota and influence host metabolism. These mechanisms involve direct interactions with gut bacteria, enhancement of gut barrier integrity, and regulation of immune responses[19–22]. The application of nanomaterials for gut microbiota modulation has opened up new therapeutic avenues for managing obesity and diabetes.

Direct Interactions with Gut Microbial Composition

Nanoparticles, depending on their size, surface charge, and functionalization, can interact directly with gut microbes[23, 24]. NPs can be designed to selectively target specific bacteria, promoting the growth of beneficial species while inhibiting pathogenic microorganisms associated with obesity and diabetes. For example, polysaccharide-based nanoparticles have been used to deliver prebiotics that selectively enhance the growth of beneficial microbes such as Bifidobacteria and Lactobacillus[25]. By promoting the growth of these beneficial bacteria, NPs can help restore microbial balance, improve gut health, and regulate inflammation.

Furthermore, polymeric nanoparticles have been employed to deliver antimicrobial agents that target pathogenic bacteria associated with insulin resistance and obesity. These agents can reduce the overgrowth of Firmicutes and other harmful microbial species that contribute to metabolic dysregulation, thereby mitigating their negative effects on metabolic health.

Modulation of Gut Immune System

The gut-associated lymphoid tissue (GALT) plays a critical role in regulating immune responses in the gut. Dysbiosis, a hallmark of obesity and T2D, leads to chronic low-grade inflammation in the gut and systemic immune activation. Nanoparticles can modulate the immune response by interacting with gut immune cells, such as macrophages and dendritic cells, to reduce inflammation[26, 27].

For instance, liposomal nanoparticles loaded with anti-inflammatory drugs or probiotics have been shown to downregulate the secretion of pro-inflammatory cytokines like TNF-α, IL-6, and IL-1β in the gut. By modulating immune function, NPs help reduce the inflammatory burden in the gut, which plays a critical role in the development of obesity and diabetes. Additionally, nanoformulations of antioxidant compounds such as curcumin and resveratrol can further reduce oxidative stress in the gut and improve overall metabolic health[28, 29].

Restoration of Gut Barrier Integrity

The integrity of the intestinal barrier is crucial for maintaining metabolic homeostasis. In obesity and diabetes, increased intestinal permeability (also known as leaky gut) allows the translocation of endotoxins like lipopolysaccharides (LPS) from the gut into the bloodstream, triggering systemic inflammation and insulin resistance[30]. Nanoparticles can help restore gut barrier integrity by tightening junctions between epithelial cells and promoting the production of mucins that protect the gut lining[30].

For example, chitosan-based nanoparticles have been shown to enhance tight junction protein expression in the intestinal epithelium, thereby reducing gut permeability and preventing the entry of harmful substances[30]. By strengthening the gut barrier, NPs help to reduce inflammation, improve glucose homeostasis, and protect against the development of obesity-related metabolic disorders.

3. Nanoparticle-Based Therapeutic Applications in Obesity and Diabetes

Nanotechnology has numerous therapeutic applications in the management of obesity and diabetes through modulation of the gut microbiota. These applications involve the targeted delivery of anti-inflammatory agents, probiotics, prebiotics, and insulin-sensitizing agents, all of which can help restore metabolic balance and improve insulin sensitivity[31].

Targeted Delivery of Anti-inflammatory Agents

Obesity and diabetes are characterized by chronic inflammation, particularly in adipose tissue and the gut. Nanoparticles can be engineered to deliver anti-inflammatory agents directly to inflamed tissues, including the gut, where they can reduce inflammation and improve insulin sensitivity[32–34]. For example, curcumin-loaded nanoparticles have been shown to reduce gut-derived inflammation and improve insulin sensitivity in animal models of obesity and diabetes[35]. These NPs target macrophages and dendritic cells in the gut to modulate the immune response and attenuate inflammation, leading to improved metabolic health.

Probiotic and Prebiotic Delivery

Probiotics, live beneficial bacteria, and prebiotics, nondigestible food ingredients that promote the growth of beneficial microbes, have been extensively studied for their ability to improve gut microbiota composition and metabolic health[11, 12, 28]. Nanoparticles can serve as carriers for delivering probiotics to the gut, protecting them from degradation in the stomach and enhancing their survival in the intestinal tract. For instance, lipid-based nanoparticles have been used to deliver Lactobacillus and Bifidobacteria to the gut, leading to improved gut health and reduced insulin resistance in obese animal models[36].

Similarly, prebiotic nanoparticles can be designed to promote the growth of beneficial gut bacteria, such as Bacteroidetes, which are associated with improved metabolic outcomes. By delivering short-chain fatty acids

(SCFAs), fructooligosaccharides (FOS), or galactooligosaccharides (GOS), these nanoparticles enhance gut microbial diversity and reduce inflammation, ultimately improving insulin sensitivity[37, 38].

Nanoparticles for Insulin Sensitization

Insulin resistance is a hallmark of obesity and diabetes, and restoring insulin sensitivity is a key therapeutic goal. Nanoparticles can be used to deliver insulin-sensitizing agents such as metformin and berberine directly to the gut or systemic circulation[39–42]. Polymeric nanoparticles designed for controlled release of these agents can improve insulin sensitivity and reduce blood glucose levels in diabetic patients. Moreover, these NPs can also modulate the gut microbiota to promote the growth of microbes that enhance insulin receptor signaling and glucose uptake in peripheral tissues.

4. Challenges and Future Directions

Despite the promising potential of nanotechnology in managing obesity and diabetes through microbiota modulation, several challenges must be addressed before these approaches can be widely implemented in clinical practice.

Biocompatibility and Safety

The biocompatibility of nanoparticles is a critical factor in their clinical application. The interaction between nanoparticles and gut epithelial cells, as well as their potential for systemic toxicity or immune responses, must be thoroughly evaluated. Additionally, the long-term effects of nanoparticle accumulation in tissues and organs need to be assessed to ensure that they do not cause adverse effects.

Scalability and Manufacturing

The scalability and reproducibility of nanoparticle production remain significant challenges. Nanoparticles must be manufactured in large quantities with consistent quality control to meet clinical requirements. Additionally, the functionalization of nanoparticles with specific ligands or bioactive agents for targeting particular microbial species requires precision and efficiency in manufacturing processes.

Clinical Translation

The translation of nanoparticle-based therapies from preclinical models to human clinical applications is complex. Clinical trials must be conducted to establish the efficacy, safety, and optimal dosing regimens for nanoparticle-based therapies targeting the gut microbiota. Regulatory approval pathways for such therapies also need to be established, particularly for the use of nanomaterials in food supplements or pharmaceuticals.

Future Directions

Future research should focus on developing multi-functional nanoparticles that can simultaneously target the gut microbiota, modulate immune responses, and deliver therapeutic agents for obesity and diabetes management. The integration of smart nanocarriers that respond to specific metabolic signals, such as glucose or insulin, could offer more precise and personalized treatment options. Additionally, the combination of nanotechnology with other therapeutic modalities, such as gene therapy or stem cell therapy, may hold promise for more effective and long-lasting treatment strategies.

CONCLUSION

The gut microbiota plays a central role in regulating metabolism, and dysbiosis is a key contributor to the development of obesity and diabetes. Nanotechnology offers a novel approach to modulating the gut microbiota and improving metabolic health. By using nanoparticles to deliver anti-inflammatory agents, probiotics, prebiotics, and insulin-sensitizing drugs, researchers are uncovering new therapeutic avenues for managing obesity and type 2 diabetes. Although challenges related to biocompatibility, scalability, and clinical translation remain, the potential of nanotechnology in addressing obesity-related metabolic disorders is immense. As research continues, the development of targeted, personalized nanoparticle therapies holds the promise of revolutionizing how we manage and treat obesity, insulin resistance, and related diseases. The gut microbiota-nanotechnology interface represents an exciting frontier in metabolic disease management, offering new hope for improving patient outcomes and quality of life.

REFERENCES

1. Cao, C., Yue, S., Lu, A., Liang, C.: Host-Gut Microbiota Metabolic Interactions and Their Role in Precision Diagnosis and Treatment of Gastrointestinal Cancers. Pharmacol. Res. 207, 107321 (2024). https://doi.org/10.1016/j.phrs.2024.107321
2. Fusco, W., Lorenzo, M.B., Cintoni, M., Porcari, S., Rinninella, E., Kaitsas, F., Lener, E., Mele, M.C., Gasbarrini, A., Collado, M.C., Cammarota, G., Ianiro, G.: Short-Chain Fatty-Acid-Producing Bacteria: Key Components of the Human Gut Microbiota. Nutrients. 15, 2211 (2023). https://doi.org/10.3390/nu15092211
3. He, Y., Shaoyong, W., Chen, Y., Li, M., Gan, Y., Sun, L., Liu, Y., Wang, Y., Jin, M.: The functions of gut microbiota-mediated bile acid metabolism in intestinal immunity. J. Adv. Res. (2025). https://doi.org/10.1016/j.jare.2025.05.015
4. Jiang, Z., Mei, L., Li, Y., Guo, Y., Yang, B., Huang, Z., Li, Y.: Enzymatic Regulation of the Gut Microbiota: Mechanisms and Implications for Host Health. Biomolecules. 14, 1638 (2024). https://doi.org/10.3390/biom14121638
5. Ugwu, O.P.-C., Okon, M.B., Alum, E.U., Ugwu, C.N., Anyanwu, E.G., Mariam, B., Ogenyi, F.C., Eze, V.H.U., Anyanwu, C.N., Ezeonwumelu, J.O.C., Egba, S.I., Uti, D.E., Onohuean, H., Aja, P.M., Ugwu, M.N.:

Unveiling the therapeutic potential of the gut microbiota-brain axis: Novel insights and clinical applications in neurological disorders. Medicine (Baltimore). 104, e43542 (2025). https://doi.org/10.1097/MD.0000000000043542
6. Alum, E.U.: Circadian nutrition and obesity: timing as a nutritional strategy. J. Health Popul. Nutr. 44, 367 (2025). https://doi.org/10.1186/s41043-025-01102-y
7. Cuevas-Sierra, A., Ramos-Lopez, O., Riezu-Boj, J.I., Milagro, F.I., Martinez, J.A.: Diet, Gut Microbiota, and Obesity: Links with Host Genetics and Epigenetics and Potential Applications. Adv. Nutr. 10, S17–S30 (2019). https://doi.org/10.1093/advances/nmy078
8. Acevedo-Román, A., Pagán-Zayas, N., Velázquez-Rivera, L.I., Torres-Ventura, A.C., Godoy-Vitorino, F.: Insights into Gut Dysbiosis: Inflammatory Diseases, Obesity, and Restoration Approaches. Int. J. Mol. Sci. 25, 9715 (2024). https://doi.org/10.3390/ijms25179715
9. Vamanu, E., Rai, S.N.: The Link between Obesity, Microbiota Dysbiosis, and Neurodegenerative Pathogenesis. Diseases. 9, 45 (2021). https://doi.org/10.3390/diseases9030045
10. Scheithauer, T.P.M., Rampanelli, E., Nieuwdorp, M., Vallance, B.A., Verchere, C.B., van Raalte, D.H., Herrema, H.: Gut Microbiota as a Trigger for Metabolic Inflammation in Obesity and Type 2 Diabetes. Front. Immunol. 11, 571731 (2020). https://doi.org/10.3389/fimmu.2020.571731
11. Tüsüz Önata, E., Özdemir, Ö.: Microbiome, dysbiosis and use of probiotics in various diseases. World J. Virol. 14, 99574 (2025). https://doi.org/10.5501/wjv.v14.i2.99574
12. Appanna, V.D.: Dysbiosis, Probiotics, and Prebiotics: In Diseases and Health. Hum. Microbes - Power Within. 81 (2018). https://doi.org/10.1007/978-981-10-7684-8_3
13. Wei, Z., Gao, G., He, Q., Kwok, L.-Y., Sun, Z.: The gut-tumor connection: the role of microbiota in cancer progression and treatment strategies. J. Adv. Res. (2025). https://doi.org/10.1016/j.jare.2025.08.038
14. Alagiakrishnan, K., Morgadinho, J., Halverson, T.: Approach to the diagnosis and management of dysbiosis. Front. Nutr. 11, (2024). https://doi.org/10.3389/fnut.2024.1330903
15. Anjum, S., Ishaque, S., Fatima, H., Farooq, W., Hano, C., Abbasi, B.H., Anjum, I.: Emerging Applications of Nanotechnology in Healthcare Systems: Grand Challenges and Perspectives. Pharmaceuticals. 14, 707 (2021). https://doi.org/10.3390/ph14080707
16. Azmi, N.A.N., Elgharbawy, A.A.M.: Advances in Medical Applications: The Quest of Green Nanomaterials. In: Shanker, U., Hussain, C.M., and Rani, M. (eds.) Handbook of Green and Sustainable Nanotechnology: Fundamentals, Developments and Applications. pp. 1889–1909. Springer International Publishing, Cham (2023)
17. Bhange, M., Telange, D.: Convergence of nanotechnology and artificial intelligence in the fight against liver cancer: a comprehensive review. Discov. Oncol. 16, 77 (2025). https://doi.org/10.1007/s12672-025-01821-y
18. Deshmukh, S.S., Yadav, K.S.: Next-gen cancer therapy: The convergence of artificial intelligence, nanotechnology, and digital twin. Nanotechnol. 8, 100286 (2025). https://doi.org/10.1016/j.nxnano.2025.100286
19. Ma, X., Tian, Y., Yang, R., Wang, H., Allahou, L.W., Chang, J., Williams, G., Knowles, J.C., Poma, A.: Nanotechnology in healthcare, and its safety and environmental risks. J. Nanobiotechnology. 22, 715 (2024). https://doi.org/10.1186/s12951-024-02901-x
20. Sharma, D., Arora, S., Banerjee, A., Singh, J.: Improved insulin sensitivity in obese-diabetic mice via chitosan Nanomicelles mediated silencing of pro-inflammatory Adipocytokines. Nanomedicine Nanotechnol. Biol. Med. 33, 102357 (2021). https://doi.org/10.1016/j.nano.2020.102357
21. Uti, D.E., Atangwho, I.J., Alum, E.U., Ntaobeten, E., Obeten, U.N., Bawa, I., Agada, S.A., Ukam, C.I.-O., Egbung, G.E.: Antioxidants in cancer therapy mitigating lipid peroxidation without compromising treatment through nanotechnology. Discov. Nano. 20, 70 (2025). https://doi.org/10.1186/s11671-025-04248-0
22. Sinitsyna, V.V., Vetcher, A.A.: Nucleic Acid Aptamers in Nanotechnology. Biomedicines. 10, 1079 (2022). https://doi.org/10.3390/biomedicines10051079
23. Vitulo, M., Gnodi, E., Meneveri, R., Barisani, D.: Interactions between Nanoparticles and Intestine. Int. J. Mol. Sci. 23, 4339 (2022). https://doi.org/10.3390/ijms23084339
24. Nguyen, D.H.H., El-Ramady, H., Törős, G., Muthu, A., Elsakhawy, T., Abdalla, N., Alibrahem, W., Kharrat Helu, N., Prokisch, J.: Food-Derived Carbon Dots: Formation, Detection, and Impact on Gut Microbiota. Foods. 14, 2980 (2025). https://doi.org/10.3390/foods14172980
25. Cheng, J., Li, X., Ke, T., Gong, J., Jiang, T., Chen, L.: Advances in polysaccharide-based probiotic delivery systems: A review. Carbohydr. Polym. Technol. Appl. 10, 100804 (2025). https://doi.org/10.1016/j.carpta.2025.100804
26. Bemark, M., Pitcher, M.J., Dionisi, C., Spencer, J.: Gut-associated lymphoid tissue: a microbiota-driven hub of B cell immunity. Trends Immunol. 45, 211–223 (2024). https://doi.org/10.1016/j.it.2024.01.006
27. Lamas, B., Evariste, L., Houdeau, E.: Dysregulation along the gut microbiota-immune system axis after oral exposure to titanium dioxide nanoparticles: A possible environmental factor promoting obesity-

related metabolic disorders. Environ. Pollut. 330, 121795 (2023). https://doi.org/10.1016/j.envpol.2023.121795
28. Umekar, M., Chaudhary, A.A., Manghani, M., Shidhaye, S., Khajone, P., Mahore, J., Rudayni, H.A., Trivedi, R.: Probiotics in Nanotechnology-Driven Wound Healing: From Mechanistic Insight to Clinical Promise. Pharmaceutics. 17, 805 (2025). https://doi.org/10.3390/pharmaceutics17070805
29. Cristofori, F., Dargenio, V.N., Dargenio, C., Miniello, V.L., Barone, M., Francavilla, R.: Anti-Inflammatory and Immunomodulatory Effects of Probiotics in Gut Inflammation: A Door to the Body. Front. Immunol. 12, 578386 (2021). https://doi.org/10.3389/fimmu.2021.578386
30. Di Vincenzo, F., Del Gaudio, A., Petito, V., Lopetuso, L.R., Scaldaferri, F.: Gut microbiota, intestinal permeability, and systemic inflammation: a narrative review. Intern. Emerg. Med. 19, 275–293 (2024). https://doi.org/10.1007/s11739-023-03374-w
31. Han, Q., Li, J., Li, Z., Aishajiang, R., Yu, D.: Novel therapeutic strategies and recent advances in gut microbiota synergy with nanotechnology for colorectal cancer treatment. Mater. Today Bio. 31, 101601 (2025). https://doi.org/10.1016/j.mtbio.2025.101601
32. Anand, S., Patel, T.N.: Integrating the metabolic and molecular circuits in diabetes, obesity and cancer: a comprehensive review. Discov. Oncol. 15, 779 (2024). https://doi.org/10.1007/s12672-024-01662-1
33. Alum, E.U., Nwuruku, O.A., Ugwu, O.P.-C., Uti, D.E., Alum, B.N., Edwin, N.: Harnessing nature: plant-derived nanocarriers for targeted drug delivery in cancer therapy. Phytomedicine Plus. 5, 100828 (2025). https://doi.org/10.1016/j.phyplu.2025.100828
34. Ugwu, O.P.-C., Alum, E.U., Okon, M.B., Obeagu, E.I.: Mechanisms of microbiota modulation: Implications for health, disease, and therapeutic interventions. Medicine (Baltimore). 103, e38088 (2024). https://doi.org/10.1097/MD.0000000000038088
35. Yavarpour-Bali, H., Ghasemi-Kasman, M., Pirzadeh, M.: Curcumin-loaded nanoparticles: a novel therapeutic strategy in treatment of central nervous system disorders. Int. J. Nanomedicine. 14, 4449–4460 (2019). https://doi.org/10.2147/IJN.S208332
36. Wang, X., Yu, M., Ye, J., Liu, T., Jian, L., Zheng, X., Wang, Y., Song, W., Luo, Y., Yue, T.: Research advances on encapsulation of probiotics with nanomaterials and their repair mechanisms on intestinal barriers. Food Sci. Hum. Wellness. 13, 3095–3109 (2024). https://doi.org/10.26599/FSHW.2022.9250246
37. Davani-Davari, D., Negahdaripour, M., Karimzadeh, I., Seifan, M., Mohkam, M., Masoumi, S.J., Berenjian, A., Ghasemi, Y.: Prebiotics: Definition, Types, Sources, Mechanisms, and Clinical Applications. Foods. 8, 92 (2019). https://doi.org/10.3390/foods8030092
38. Sankarganesh, P., Bhunia, A., Ganesh Kumar, A., Babu, A.S., Gopukumar, S.T., Lokesh, E.: Short-chain fatty acids (SCFAs) in gut health: Implications for drug metabolism and therapeutics. Med. Microecol. 25, 100139 (2025). https://doi.org/10.1016/j.medmic.2025.100139
39. Bansal, S.K., Bansal, M.B.: Pathogenesis of MASLD and MASH – role of insulin resistance and lipotoxicity. Aliment. Pharmacol. Ther. 59, S10–S22 (2024). https://doi.org/10.1111/apt.17930
40. Bensussen, A., Torres-Magallanes, J.A., Roces De Álvarez-Buylla, E.: Molecular tracking of insulin resistance and inflammation development on visceral adipose tissue. Front. Immunol. 14, 1014778 (2023). https://doi.org/10.3389/fimmu.2023.1014778
41. Ghosh, A., Sarkar, S., Mandal, D., Orasugh, J.T., Ray, S.S., Chattopadhyay, D.: Potential application of nanotechnology in Type-3 diabetes: Bridging insulin resistance and neurodegeneration. Nano Trends. 11, 100144 (2025). https://doi.org/10.1016/j.nwnano.2025.100144
42. Kang, H.S., Liao, G., DeGraff, L.M., Gerrish, K., Bortner, C.D., Garantziotis, S., Jetten, A.M.: CD44 Plays a Critical Role in Regulating Diet-Induced Adipose Inflammation, Hepatic Steatosis, and Insulin Resistance. PLOS ONE. 8, e58417 (2013). https://doi.org/10.1371/journal.pone.0058417

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