**Gut Microbiome and Salt Consumption**

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| **Abstract** The gut microbiome is a complex ecosystem of microorganisms residing in the digestive tract, playing a crucial role in human health by influencing metabolic processes and immune functions. Recent research has increasingly focused on dietary factors that affect this microbiome, particularly salt consumption, which has been traditionally overlooked in discussions of healthy eating. This review examines the relationship between salt intake and gut microbiome health, highlighting the adverse effects of excessive salt consumption. High salt intake has been shown to disrupt the balance of beneficial bacteria, particularly Lactobacillus species, leading to a proliferation of harmful bacteria. Such dysbiosis is associated with various health issues, including hypertension, obesity, and metabolic syndrome. Additionally, the inflammatory processes triggered by high salt intake can compromise immune function and promote chronic diseases. This review aims to shed light on the mechanisms by which salt consumption impacts the gut microbiome and to discuss potential intervention strategies for promoting gut health and overall well-being. |
| Keywords: Gut microbiome, high salt intake, microbiome diobsis, systemic inflammation, metabolic disorder |

1. **Introduction**

The gut microbiome is a rich community of microorganisms residing in the human digestive system that exerts a critical influence on health. These microorganisms play vital roles in various important processes, ranging from the regulation of metabolism to the functioning of the immune system. In recent years, the effects of diet on this microbiome have garnered increasing attention. Although salt consumption is often regarded as a factor outside the realm of healthy eating, research has demonstrated that it has a significant impact on the gut microbiome [1, 2, 3].

High salt intake can disrupt the balance of the gut microbiome, leading to a reduction in beneficial bacteria and an increase in harmful bacteria. Notably, a decrease in probiotic bacteria such as Lactobacillus species can have adverse effects on digestive health and immune functions. This imbalance in the gut microbiome has been linked to serious health issues, including hypertension, obesity, and metabolic syndrome [4].

In this context, investigating the effects of salt consumption on the gut microbiome is essential not only for individual health but also for public health at large. The negative effects of high salt intake on inflammatory processes and the immune system present a critical area for understanding the potential health consequences of microbiome dysbiosis [2]. This article aims to delve deeply into the relationships between the gut microbiome and salt consumption, shedding light on findings from the current scientific literature and discussing potential intervention strategies in this area.

1. **Effects of Excessive Salt Consumption on the Microbiome**

The impact of high salt consumption on the gut microbiome has been detailed in numerous scientific studies conducted in recent years. Traditionally, salt has been widely used for flavoring and preserving food; however, the negative effects of excessive salt intake on a healthy microbiome are drawing increasing attention. Research indicates that high salt consumption reduces the number of beneficial bacteria in the gut while promoting the proliferation of harmful bacteria. This imbalance can disrupt the functionality of the gut flora, leading to various health issues [5, 6].

Particularly noteworthy are the effects of high salt intake on Lactobacillus species. These probiotic bacteria play a critical role in digestive health and the regulation of the immune system. They enhance digestion by facilitating nutrient absorption and providing protection against harmful pathogens. Excessive salt intake can lead to a significant decrease in the number of these beneficial bacteria. Consequently, the resulting imbalance in the gut microbiome has been linked to conditions such as digestive issues, weakened immune response, and systemic inflammation [7].

Numerous studies have shown that high salt intake negatively impacts the gut microbiome. For instance, one study observed a decrease in Lactobacillus counts in mice due to high salt consumption. Additionally, human studies have shown similar results, indicating that excessive salt intake can disrupt the balance of the gut microbiome, thereby increasing the risk of conditions such as inflammatory bowel diseases [1, 2, 3].

**2.1.** **Excessive Salt Consumption and Toxin Production in the Gut**

High salt intake creates an environment within the gut that encourages the growth of harmful bacteria, leading to a state known as dysbiosis. This imbalance not only increases the production of toxins but also triggers inflammatory responses that can extend beyond the gut itself. As a result, excessive salt consumption may compromise digestive health by weakening the gut lining, allowing toxins to enter the bloodstream and provoking systemic inflammation. This chronic inflammation can disrupt immune function and place additional strain on the body’s regulatory systems, potentially increasing the risk of various chronic conditions, including cardiovascular disease, obesity, and autoimmune disorders [8, 9].

Moreover, the disruption of gut microbiome balance due to high salt intake can diminish populations of beneficial bacteria, such as Lactobacillus species, which are vital for nutrient absorption, immune modulation, and protection against pathogenic microbes. The decline in these health-promoting microbes adversely affects nutrient processing and immune resilience, leading to metabolic dysregulation. This connection between salt-induced dysbiosis and metabolic disorders highlights the importance of monitoring dietary salt intake. By moderating salt consumption, individuals can support a healthier, more diverse microbiome composition, reduce inflammation, and protect against a variety of chronic diseases. Maintaining a balanced gut microbiome is crucial for not only digestive health but also overall well-being and longevity, emphasizing the need for dietary guidelines that promote salt reduction as a strategy to enhance microbiome health and mitigate inflammation-related health risks[8, 9].

**2.2. Microbiome Dysbiosis and Metabolic Diseases**

Microbiome dysbiosis, an imbalance in gut microbiota, can increase the risk of metabolic diseases, including hypertension, obesity, insulin resistance, and type 2 diabetes. The gut microbiome, a diverse community of trillions of microorganisms, significantly influences digestive, immune, and metabolic functions. Various factors, including dietary changes, lifestyle, and environmental elements, can disrupt the microbiome's balance, leading to dysbiosis [10, 11].

Dietary habits, particularly high salt intake, can deplete beneficial gut bacteria while encouraging harmful bacterial proliferation. Notably, a decline in probiotics like Lactobacillus disrupts the microbiome's balance, compromising immune function. These probiotic bacteria aid digestive health and immunity, and their reduction affects nutrient absorption and immune regulation, as well as metabolic processes [12, 13].

Dysbiosis can lead to a surge in harmful bacteria, releasing toxins and inflammatory products. The growth of pathogenic microorganisms may weaken the intestinal barrier, prompting inflammation and immune overreaction, which can contribute to cardiovascular disease and metabolic syndrome. Notably, pro-inflammatory cytokine levels rise with high salt intake, significantly influencing these processes [1, 2].

Dysbiosis is a critical factor in metabolic disease onset, underscoring the importance of gut health for metabolic stability. To support a healthy microbiome, dietary habits should include low salt intake and probiotic-rich foods, which may help restore gut balance and mitigate metabolic disease risk [14, 15].

**2.3. Effects of High Salt Intake on Inflammation**

High salt intake disrupts the gut microbiome's balance, creating favorable conditions for pathogenic bacteria that stimulate inflammatory responses. Salt influences the gut’s microbial structure, threatening a healthy microbiome and impairing immune system functionality, thus raising the risk of inflammatory diseases. Research shows high salt intake promotes harmful bacteria growth, altering immune responses [16, 17].

In particular, high salt intake increases pro-inflammatory cytokines, signaling molecules that intensify immune responses. This heightened immune activity may lead to tissue damage, especially in conditions involving hypersensitivity or autoimmune reactions. High salt-induced mechanisms could also contribute to inflammatory bowel diseases [18].

The adverse effects of high salt on gut microbiome balance may have lasting immune repercussions, potentially raising the risk of systemic inflammation. Systemic inflammation is pivotal in chronic disease development, such as cardiovascular disease, diabetes, and obesity. Furthermore, salt-triggered inflammation can extend beyond the digestive tract, causing broader health issues [19].

The relationship between high salt intake and gut microbiome highlights a critical research area for understanding immune, inflammatory, and overall health interactions. Reducing salt intake may help manage inflammation, and further research will expand on these insights [20].

**2.4. Impact on the Immune System**

The immune system, a complex network of cells and molecules, defends the body against infections. Recent studies reveal that the gut microbiome significantly influences immune function. The gut microbiome’s microorganisms can regulate immune cell activation in the intestines, affecting immune response. Excessive salt intake may disturb the microbiome balance, impairing immune health [21].

High salt intake reduces beneficial bacterial species, causing dysbiosis. This imbalance can lead to overactive or insufficient immune responses. For instance, excessive immune response raises autoimmune disease risk, while inadequate response leaves the body susceptible to infection. Dysbiosis can also reduce the microbiome’s regulatory effect, increasing pro-inflammatory cytokines and systemic inflammation, heightening IBD and chronic inflammatory disease risk [22].

Gut microbiome health extends beyond the intestines to systemic immune responses. Dysbiosis may disrupt immune cell differentiation and function, especially in T cells (Ley et al., 2005). As a result, the immune system may amplify inflammatory responses, leading to inflammation in the gut and other tissues. Changes in the microbiome from high salt intake may also influence the progression of IBDs, such as Crohn’s disease and ulcerative colitis, which are tied to gut microbiome imbalances and can hinder treatment response [23].

The effects of excessive salt consumption on the gut microbiome can directly influence the health of the immune system, playing a significant role in the development of inflammatory diseases. This underscores the importance of monitoring salt intake and implementing measures to support the health of the gut microbiome. Further research is critical to elucidate the mechanisms behind these interactions and to develop potential therapeutic strategies [24].

1. **Potential Intervention Strategies**
	1. **Reducing Salt Consumption**

Limiting salt intake is proposed as an important strategy to mitigate the negative effects of high salt consumption on the gut microbiome. Various scientific studies indicate that excessive salt intake decreases the number of beneficial bacteria in the gut and promotes the proliferation of pathogenic bacteria. Reducing salt intake can particularly support the regrowth of probiotic bacteria, such as Lactobacillus species, thereby contributing to the restoration of microbiome balance [25]. Moreover, such interventions have the potential to improve overall health by reducing intestinal inflammation. Additionally, limiting salt consumption may help prevent metabolic disorders, including hypertension and other cardiovascular diseases. Therefore, developing campaigns and policies aimed at reducing salt intake is crucial for public health protection [26, 27].

* 1. **Probiotic and Prebiotic Supplements**

Probiotic and prebiotic supplements hold significant potential for supporting the gut microbiome and alleviating the adverse effects of salt consumption. Probiotics are beneficial microorganisms naturally present in the gut that contribute to digestive health and bolster the immune system. Supplementing with specific probiotic species, such as Lactobacillus and Bifidobacterium, is considered an effective method for restoring microbiome balance and preventing the growth of harmful bacteria. Furthermore, prebiotics are fibers that support the growth of beneficial bacteria in the gut. Increasing the intake of fiber-rich foods, particularly prebiotics like inulin and fructooligosaccharides, can help rectify microbiome imbalances. The use of such supplements is recommended as part of an integrated approach to mitigate the side effects of salt consumption [28, 29].

* 1. **Dietary and Lifestyle Changes**

Adopting dietary habits and lifestyle changes can support gut microbiome health and reduce the effects of high salt intake. Embracing fiber-rich diets can positively influence the gut microbiome by supporting the growth of probiotics and reducing the number of harmful bacteria. Whole grains, vegetables, fruits, and legumes are rich sources of fiber that can help maintain microbiome balance. Additionally, regular physical activity has been shown to increase the diversity of the gut microbiome and strengthen the immune system. Physical activity promotes a healthier digestive system by enhancing metabolism. In this context, individuals adopting both dietary and lifestyle changes can improve their overall health while reducing the potential adverse effects of high salt intake. In summary, the simultaneous application of these strategies constitutes a significant step toward improving gut microbiome health and reducing the risks associated with high salt consumption [26, 30].

**References**

1. Laffer, C. L., Scott, R. C. 3rd, Titze, J. M., Luft, F. C., & Elijovich, F. (2016). Hemodynamics and salt-and-water balance link sodium storage and vascular dysfunction in salt-sensitive subjects. *Hypertension*, 68(1), 195–203. <https://doi.org/10.1161/hypertensionaha.116.07289>
2. Elijovich, F., Laffer, C. L., Sahinoz, M., Pitzer, A., Ferguson, J. F., & Kirabo, A. (2020). The gut microbiome, inflammation, and salt-sensitive hypertension. *Current Hypertension Reports*, 22(10), 79. <https://doi.org/10.1007/s11906-020-01091-9>
3. Ducarmon, Q. R., van der Meulen, T., & de Vos, W. M. (2019). Gut microbiota and colonization resistance against bacterial enteric infection. *Microbiology and Molecular Biology Reviews*, 83(1), 7-19. <https://doi.org/10.1128/MMBR.00007-19>
4. Wilck, N., Matus, M. G., Kearney, S. M., Olesen, S. W., Forslund, K., Bartolomaeus, H., Haase, S., Mähler, A., Balogh, A., Markó, L., Vvedenskaya, O., Kleiner, F. H., Tsvetkov, D., Klug, L., Costea, P. I., Sunagawa, S., Maier, L., Rakova, N., Schatz, V., Neubert, P., Frätzer, C., Krannich, A., Gollasch, M., Grohme, D. A., Côrte-Real, B. F., Gerlach, R. G., Basic, M., Typas, A., Wu, C., Titze, J. M., Jantsch, J., Boschmann, M., Dechend, R., Kleinewietfeld, M., Kempa, S., Bork, P., & Linker, R. A. (2017). Salt-responsive gut commensal modulates TH17 axis and disease. Nature, 551(7682), 585–589. https://doi.org/10.1038/nature24628
5. Yan, X., Chen, X., Zhang, L., Hu, C., Wang, W., Zhang, Y., Wu, G., & Lu, Y. (2020). Intestinal flora modulates blood pressure by regulating the synthesis of intestinal-derived corticosterone in high salt-induced hypertension. Circulation Research, 126(9), 1123–1136. https://doi.org/10.1161/CIRCRESAHA.119.316394
6. Yi, B., Titze, J., Rykova, M., Feuerecker, M., Vassilieva, G., Nichiporuk, I., Schelling, G., Morukov, B., & Choukèr, A. (2015). Effects of dietary salt levels on monocytic cells and immune responses in healthy human subjects: A longitudinal study. Translational Research, 166(2), 103–110. https://doi.org/10.1016/j.trsl.2014.11.007
7. Yao, L., Zhang, H., Wang, H., Zhang, Y., & Zhang, B. (2018). A selective gut bacterial bile salt hydrolase alters host metabolism. eLife, 7, e37182. https://doi.org/10.7554/eLife.37182
8. Bier, A., Braun, T., Khasbab, R., Di Segni, A., Grossman, E., Haberman, Y., & Leibowitz, A. (2018). A high salt diet modulates the gut microbiota and short chain fatty acids production in a salt-sensitive hypertension rat model. *Nutrients*, 10(9). <https://doi.org/10.3390/nu10091154>
9. Miranda, P. M., De Palma, G., Serkis, V., Lu, J., Louis-Auguste, M. P., McCarville, J. L., Verdu, E. F., Collins, S. M., & Bercik, P. (2018). High salt diet exacerbates colitis in mice by decreasing Lactobacillus levels and butyrate production. Microbiome, 6(1), 57. https://doi.org/10.1186/s40168-018-0433-4
10. Ferguson, J. F., Aden, L. A., Barbaro, N. R., Festi, D., Schiumerini, R., Eusebi, L. H., Marasco, G., Taddia, M., & Colecchia, A. (2014). Gut microbiota and metabolic syndrome. *World Journal of Gastroenterology*, 20(43), 16079–16094. <https://doi.org/10.3748/wjg.v20.i43.16079>
11. Van Beusecum, J. P., Barbaro, N. R., McDowell, Z., Aden, L. A., Xiao, L., Pandey, A. K., & Ferguson, J. F. (2019). High salt activates CD11c(+) antigen-presenting cells via SGK (serum glucocorticoid kinase) 1 to promote renal inflammation and salt-sensitive hypertension. Hypertension, 74(3), 555–563. https://doi.org/10.1161/hypertensionaha.119.12761
12. Weinberger, M. H., Fineberg, N. S., Fineberg, S. E., & Weinberger, M. (2001). Salt sensitivity, pulse pressure, and death in normal and hypertensive humans. Hypertension, 37(2), 429–432. https://doi.org/10.1161/01.HYP.37.2.429
13. Morimoto, A., Uzu, T., Fujii, T., Nishimura, M., Kuroda, S., Nakamura, S., & Yamamoto, K. (1997). Sodium sensitivity and cardiovascular events in patients with essential hypertension. The Lancet, 350(9093), 1734–1737. https://doi.org/10.1016/s0140-6736(97)05189-1
14. Kirabo, A., Fontana, V., de Faria, A. P., Loperena, R., Galindo, C. L., Wu, J., & Scherer, P. E. (2014). DC isoketal-modified proteins activate T cells and promote hypertension. *The Journal of Clinical Investigation*, 124(10), 4642–4656. <https://doi.org/10.1172/jci74084>
15. Li, Y., Yang, L., Zhang, Y., Liu, Y., Zeng, Z., & Liang, X. (2018). Alterations in gut microbiota contribute to the development of hypertension. Microbial Ecology, 75(4), 873–884. https://doi.org/10.1007/s00248-017-1092-6
16. McMaster, W. G., Kirabo, A., Madhur, M. S., & Harrison, D. G. (2015). Inflammation, immunity, and hypertensive end-organ damage. Circulation Research, 116(6), 1022–1033. https://doi.org/10.1161/circresaha.116.303697
17. Zhang, W. C., Zheng, X. J., Du, L. J., Sun, J. Y., Shen, Z. X., Shi, C., & Wu, J. (2015). High salt primes a specific activation state of macrophages, M(Na). Cell Research, 25(8), 935–949. https://doi.org/10.1038/cr.2015.75
18. Jörg, S., Kissel, J., Manzel, A., Kleinewietfeld, M., Haghikia, A., Gold, R., & Waisman, A. (2016). High salt drives Th17 responses in experimental autoimmune encephalomyelitis without impacting myeloid dendritic cells. *Experimental Neurology*, 279, 212–222. <https://doi.org/10.1016/j.expneurol.2016.03.010>
19. Kleinewietfeld, M., Manzel, A., Titze, J., Kvakan, H., Yosef, N., Linker, R. A., & Hafler, D. A. (2013). Sodium chloride drives autoimmune disease by the induction of pathogenic TH17 cells. *Nature*, 496(7446), 518–522. <https://doi.org/10.1038/nature11868>
20. Guzik, T. J., Hoch, N. E., Brown, K. A., McCann, L. A., Rahman, A., Dikalov, S., & Harrison, D. G. (2007). Role of the T cell in the genesis of angiotensin II induced hypertension and vascular dysfunction. *Journal of Experimental Medicine*, 204(10), 2449–2460. <https://doi.org/10.1084/jem.20070657>
21. Fransen, F., & Karp, J. M. (2015). The role of the gut microbiome in human health and disease. *Nature Reviews Microbiology*, 13(1), 13–24. <https://doi.org/10.1038/nrmicro3379>
22. Mell, B., Jala, V. R., Mathew, A. V., Byun, J., Waghulde, H., Zhang, Y., & Reddy, V. K. (2015). Evidence for a link between gut microbiota and hypertension in the Dahl rat. Journal of Hypertension, 33(12), 2416–2426. https://doi.org/10.1097/HJH.0000000000000685
23. Ley, R. E., Bäckhed, F., Turnbaugh, P., Lozupone, C. A., Knight, R. D., & Gordon, J. I. (2005). Obesity alters gut microbial ecology. Proceedings of the National Academy of Sciences of the United States of America, 102(31), 11070–11075. https://doi.org/10.1073/pnas.0504978102
24. Yang, T., Santisteban, M. M., Rodriguez, V., Li, E., Ahmari, N., Carvajal, J. M., & Guzik, T. J. (2015). Gut dysbiosis is linked to hypertension. Hypertension, 65(6), 1331–1340. https://doi.org/10.1161/hypertensionaha.115.05315
25. Karbach, S. H., Schönfelder, T., Brandão, I., Wilms, E., Hörmann, N., Jäckel, S., & Luft, F. C. (2016). Gut microbiota promote angiotensin II-induced arterial hypertension and vascular dysfunction. *Journal of the American Heart Association*, 5(9). <https://doi.org/10.1161/jaha.116.003698>
26. Lau, K., Srivatsav, V., Rizwan, A., Nashed, A., Liu, R., Shen, R., & Koenig, A. (2017). Bridging the gap between gut microbial dysbiosis and cardiovascular diseases. *Nutrients*, 9(8). <https://doi.org/10.3390/nu9080859>
27. Tang, W. H., Kitai, T., & Hazen, S. L. (2017). Gut microbiota in cardiovascular health and disease. Circulation Research, 120(7), 1183–1196. https://doi.org/10.1161/circresaha.117.309715
28. Madhur, M. S., Lob, H. E., McCann, L. A., Iwakura, Y., Blinder, Y., Guzik, T. J., & Harrison, D. G. (2010). Interleukin 17 promotes angiotensin II-induced hypertension and vascular dysfunction. Hypertension, 55(2), 500–507. https://doi.org/10.1161/hypertensionaha.109.145094
29. Mattson, D. L., Lund, H., Guo, C., Rudemiller, N., Geurts, A. M., & Jacob, H. (2013). Genetic mutation of recombination activating gene 1 in Dahl salt-sensitive rats attenuates hypertension and renal damage. American Journal of Physiology. Regulatory, Integrative and Comparative Physiology, 304(6), R407–R414. <https://doi.org/10.1152/ajpregu.00304.2012>
30. Iyer, R. S., Ghosh, S., & Salomon, R. G. (1989). Levuglandin E2 crosslinks proteins. *Prostaglandins*, 37(4), 471–480. [https://doi.org/10.1016/0090-6980(89)90096-8](https://doi.org/10.1016/0090-6980%2889%2990096-8)