

Review

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Posted Date: 27 December 2024

doi: 10.20944/preprints202412.2369.v1

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Review

Enhancing Gut Microbiome Using Innovative Supplements

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Abstract: Metabolic syndrome is a complex, multifactorial disorder, with emerging research emphasizing the significant role of gut health in its prevention and management. Recent studies suggest that dietary strategies promoting a healthy gut microbiome, including the incorporation of fibre, fermented foods, and healthy fats, are crucial for regulating metabolism. Additionally, the use of postbiotics and supplements such as probiotics, omega-3 fatty acids, and polyphenols provides promising avenues for enhancing metabolic health. This holistic approach to managing metabolic syndrome not only supports gut health but also offers the potential for improving long-term health outcomes. In this chapter, we try to understand the gut microbiome's influence on metabolism deepens; these innovative interventions will play an increasingly vital role in combating metabolic syndrome.

Keywords: metabolic syndrome; healthy gut microbiome; probiotics; omega-3 fatty

Introduction

Metabolic syndrome, a cluster of risk factors for cardiovascular diseases, diabetes, and obesity, has become one of the leading global health challenges of the 21st century. Defined by a combination of abdominal obesity, hypertension, dyslipidemia, and insulin resistance, this condition affects millions worldwide and has a profound impact on healthcare systems and individuals' well-being. As a multifactorial disorder, the treatment and management of metabolic syndrome require a comprehensive, integrated approach that goes beyond traditional pharmaceutical interventions (Andersen and Fernandez, 2013; Castro-Barquero et al., 2020; Croci et al., 2021).

Recent research has highlighted the critical role of the gut microbiome in influencing metabolic health. The gut microbiome, consisting of trillions of microorganisms residing in the digestive tract, is involved in the digestion of food, regulation of metabolism, immune function, and even mental health. A growing body of evidence suggests that the composition of the gut microbiome plays a pivotal role in the development and progression of metabolic syndrome. Consequently, dietary strategies that promote a healthy gut microbiome, using postbiotics, and incorporating innovative supplements are emerging as key interventions for managing and potentially reversing metabolic syndrome (Ambroselli et al., 2023; Marrone et al., 2021; Mohamed et al., 2023).

The Role of the Gut Microbiome in Metabolic Syndrome

The gut microbiome is essential for digesting complex carbohydrates, producing short-chain fatty acids (SCFAs), and regulating metabolic pathways. Studies have shown that individuals with metabolic syndrome tend to have an altered gut microbiome characterized by lower microbial diversity and an overabundance of harmful bacteria. This dysbiosis contributes to systemic inflammation,

insulin resistance, and lipid metabolism disturbances—key metabolic syndrome features (Dabke et al., 2019; Mazidi et al., 2016).

SCFAs, such as butyrate, acetate, and propionate, are produced by gut bacteria during the fermentation of dietary fibres. These SCFAs have numerous beneficial effects on metabolic health, including enhancing insulin sensitivity, reducing inflammation, and improving lipid profiles—furthermore, SCFAs act as signalling molecules, influencing gene expression in the gut and other organs (Festi et al., 2014; Hur and Lee, 2015; Wang et al., 2020). A healthy gut microbiome, rich in fiber-fermenting bacteria, helps maintain optimal SCFA production, supporting metabolic processes crucial for preventing and managing metabolic syndrome with different modes of action, as given in Table 1.

Table 1. Role of gut microbiome and their mode of action against various metabolic syndromes.

Aspect of Metabolic Syndrome	Role of the Gut Microbiome	Mechanisms of Action
Obesity	Gut microbiota composition is linked to obesity risk	Dysbiosis (imbalance of gut microbiota) may lead to increased energy extraction from food and altered fat storage. Certain bacteria (e.g., <i>Firmicutes</i>) are associated with higher energy harvest from food, contributing to weight gain.
Insulin Resistance	Gut microbiota affects insulin sensitivity	Altered gut microbiome can influence insulin resistance by increasing inflammation, producing metabolites like short-chain fatty acids (SCFAs) that improve insulin function, or modifying bile acid metabolism.
High Blood Pressure	Gut microbiota may influence blood pressure regulation	Imbalance in gut microbiota can lead to increased production of endotoxins that promote inflammation and

Dyslipidemia	Microbiota affects lipid metabolism	<p>hypertension. Gut-produced SCFAs can help regulate blood pressure by affecting vascular tone and sodium balance.</p> <p>Gut bacteria can influence lipid metabolism, bile acid synthesis, and fat absorption. Dysbiosis can result in elevated LDL cholesterol, triglycerides, and low HDL cholesterol. Beneficial bacteria like <i>Lactobacillus</i> and <i>Bifidobacterium</i> may help improve lipid profiles.</p>
Inflammation	Dysbiosis promotes chronic low-grade inflammation	<p>An imbalance in gut microbiota increases gut permeability ("leaky gut"), allowing endotoxins to enter the bloodstream, triggering systemic inflammation. This inflammation contributes to metabolic dysfunction and metabolic syndrome.</p>
Fatty Liver Disease (NAFLD)	Gut microbiota plays a role in liver health	<p>The gut microbiome can influence liver fat accumulation and inflammation. Dysbiosis may promote the development of fatty liver disease by enhancing intestinal permeability and causing an</p>

		inflammatory response in the liver.
		Imbalanced gut microbiota, especially with an overgrowth of gram-negative bacteria, can
Endotoxemia	Gut microbiota contributes to endotoxin production	lead to the production of lipopolysaccharides (LPS), which are pro-inflammatory and contribute to metabolic syndrome.
		Gut microbiota affects the release of appetite-regulating
Gut-Brain Axis	Gut microbiome influences appetite and metabolism through the gut-brain axis	hormones such as ghrelin and leptin, influencing hunger and satiety signals. Altered microbiota can disrupt these signals, contributing to overeating and obesity.
		SCFAs (e.g., acetate, propionate, butyrate) help
Short-Chain Fatty Acids (SCFAs)	SCFAs produced by gut microbiota are beneficial for metabolic health	regulate glucose metabolism, reduce inflammation, and improve insulin sensitivity. SCFAs are produced by the fermentation of dietary fibers by beneficial gut bacteria.
		Gut bacteria modify bile acids, influencing fat digestion and
Bile Acid Metabolism	Gut microbiome regulates bile acid metabolism	absorption. Altered bile acid

Microbial Diversity	Greater microbial diversity is associated with better metabolic health	metabolism can affect lipid metabolism, insulin sensitivity, and the development of metabolic diseases. Higher microbial diversity is linked to a healthier metabolic profile, better immune function, and reduced inflammation. Low diversity is often associated with obesity, insulin resistance, and dyslipidemia.
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Dietary Strategies to Enhance Gut Microbiome Health

A diet that supports gut health is essential for preventing and managing metabolic syndrome. Table 2 provides several dietary strategies that can enhance the gut microbiome, improve metabolic markers, and help mitigate the risk factors associated with metabolic syndrome.

Table 2. Outlines dietary strategies to improve gut health and metabolism.

Dietary Strategy	Food Sources	Mechanisms of Action	Impact on Metabolic Syndrome
Increase Fiber Intake	Whole grains (e.g., oats, quinoa), legumes (e.g., beans, lentils), fruits (e.g., apples, berries), vegetables (e.g., broccoli, spinach), nuts, seeds	Fibre serves as a prebiotic, feeding beneficial gut bacteria and promoting the production of short-chain fatty acids (SCFAs).	It improves insulin sensitivity, supports weight management, and helps reduce inflammation, all key factors in managing metabolic syndrome.
Incorporate Prebiotics	Garlic, onions, leeks, asparagus, bananas, chicory, artichokes	Prebiotics stimulate the growth of beneficial gut bacteria, supporting	Enhances gut health, lowers inflammation, and supports better metabolic control.

		microbial diversity and SCFA production.	
Consume Fermented Foods	Yogurt, kefir, sauerkraut, kimchi, miso, kombucha, pickles	Fermented foods contain probiotics that introduce beneficial bacteria to the gut, improving microbial balance and digestion.	Enhances gut microbiota, boosts immunity, and may help lower cholesterol and blood pressure.
Add Polyphenol-Rich Foods	Berries, apples, dark chocolate, green tea, olive oil, red wine, nuts (e.g., almonds, walnuts)	Polyphenols support the growth of beneficial bacteria and help reduce harmful bacterial growth, promoting anti-inflammatory effects.	Reduces oxidative stress, supports heart health, and improves lipid profiles, reducing metabolic syndrome risks.
Consume Omega-3 Fatty Acids	Fatty fish (e.g., salmon, mackerel), chia seeds, flaxseeds, walnuts	Omega-3s promote the growth of anti-inflammatory gut bacteria and help regulate gut function.	Reduces systemic inflammation, supports better lipid metabolism, and improves insulin sensitivity.
Limit Processed Foods & Added Sugars	Refined sugars, sugary drinks, processed snacks, fast food	High consumption of processed foods and added sugars disrupts gut microbiota and promotes harmful bacteria, leading to inflammation and metabolic disturbances.	Reduces the risk of obesity, insulin resistance, and dyslipidemia associated with metabolic syndrome.

		Excessive animal protein and fat intake	Helps prevent weight gain, insulin resistance, and dyslipidemia by supporting a balanced gut microbiome.
Moderate Animal Protein & Fat	Red meat, processed meats, fatty cuts of meat	can lead to an imbalance in gut microbiota, promoting inflammation and metabolic dysfunction.	
Increase Plant-Based Foods	Vegetables, fruits, whole grains, legumes, nuts, seeds	Plant-based foods are rich in fiber, antioxidants, and polyphenols that nurture a diverse microbiome and enhance overall gut health.	Supports weight management, improves insulin sensitivity, and reduces inflammation, all key to preventing metabolic syndrome.
Include Resistant Starch	Cooked and cooled potatoes, pasta, rice, green bananas, legumes	Resistant starch feeds beneficial gut bacteria, enhancing SCFA production and gut health.	Improves insulin sensitivity, supports healthy blood sugar levels, and aids in weight management.
Hydrate Well	Water, herbal teas, soups	Proper hydration supports digestion and gut motility, maintaining gut microbiota balance.	Promotes healthy digestion, enhances nutrient absorption, and helps regulate metabolic processes.
Avoid Excessive Alcohol	N/A (Moderation or avoidance of alcohol)	Excessive alcohol disrupts gut microbiota and increases gut permeability, leading	Reduces risk of liver disease, insulin resistance, and inflammation

		to inflammation and associated with metabolic disturbances.	
Diverse Diet	A variety of fruits, vegetables, whole grains, legumes, nuts, seeds, and lean proteins	A diverse diet promotes the growth of a diverse microbiome, which is linked to better overall health and metabolic function.	Enhances metabolic flexibility, reduces inflammation, and supports weight management, all crucial for managing metabolic syndrome.
Use Bone Broth	Bone broth, collagen-rich foods	Bone broth supports gut barrier integrity and reduces gut permeability, helping maintain a healthy microbiome.	Supports gut health and immune function, improving overall metabolic markers.

1. Increase Fiber Intake

Dietary fibre, particularly prebiotics, serves as food for beneficial gut bacteria. The microbiota ferments Prebiotic fibres in fruits, vegetables, whole grains, legumes, and certain tubers to produce SCFAs. High-fiber diets promote a healthy microbiome composition and have been shown to improve insulin sensitivity, reduce inflammation, and lower blood cholesterol levels. Foods rich in soluble fibre, such as oats, barley, and legumes, are particularly effective in modulating blood sugar and cholesterol levels, key components of metabolic syndrome (Alexandre and Miguel, 2008; Deehan et al., 2024).

2. Incorporate Fermented Foods

Fermented foods, such as yogurt, kefir, kimchi, sauerkraut, and miso, are rich in probiotics—live microorganisms that confer health benefits when consumed in adequate amounts. Probiotics have been shown to improve gut microbiome diversity and modulate the immune system, which can help alleviate the systemic inflammation associated with metabolic syndrome. Regular consumption of fermented foods may help restore a healthy gut microbiome, enhance SCFA production, and improve insulin sensitivity, which is crucial for preventing and managing metabolic syndrome (Chan et al., 2023; Csanlier et al., 2019; Kim et al., 2021).

3. Reduce Intake of Processed Foods and Sugars

Processed foods, mainly those high in refined sugars and unhealthy fats, contribute to gut dysbiosis and inflammation. High-sugar diets promote the growth of pathogenic bacteria and fungi in the gut, leading to an imbalance that exacerbates insulin resistance and metabolic dysfunction. Reducing the intake of processed foods, sugary beverages, and trans fats can help restore gut health and improve metabolic parameters. Instead, a diet rich in whole, unprocessed foods—especially plant-based—supports a more diverse and beneficial microbiome (Shu et al., 2023; Steele et al., 2019).

4. Increase Healthy Fats

Monounsaturated and polyunsaturated fats in foods such as olive oil, avocados, fatty fish, and nuts have anti-inflammatory properties that can improve metabolic health. These healthy fats help modulate the gut microbiome, supporting beneficial bacteria growth while reducing harmful bacteria's proliferation. Omega-3 fatty acids, in particular, have been shown to improve insulin sensitivity and reduce inflammation, which are key factors in managing metabolic syndrome (Ristic-Medic and Vucic, 2013).

Postbiotics and Their Role in Metabolic Health

While probiotics are live microorganisms that confer health benefits, postbiotics are the bioactive compounds produced by probiotics during fermentation. These include short-chain fatty acids, peptides, enzymes, and other metabolites that positively impact health. Postbiotics are gaining attention for their potential therapeutic applications in managing metabolic syndrome.

Research has shown that postbiotics derived from fermented foods and probiotics can enhance insulin sensitivity, reduce inflammation, and support the gut barrier function. Butyrate, one of the most studied postbiotics, has been shown to have potent anti-inflammatory and insulin-sensitizing effects. Butyrate, produced by the fermentation of fibre, helps regulate the expression of genes involved in glucose metabolism and fatty acid oxidation. By increasing butyrate production, individuals with metabolic syndrome can potentially experience improvements in their metabolic health (Cani and Van Hul, 2015; Tenorio-Jiménez et al., 2020).

In addition to butyrate, other postbiotics such as lactate, propionate, and acetate also play crucial roles in regulating metabolism. These metabolites help regulate the immune response, improve gut barrier integrity, and modulate lipid metabolism, all essential for managing metabolic syndrome (He and Shi, 2017).

Innovative Supplements for Metabolic Syndrome

Alongside dietary changes and postbiotics, innovative supplements are gaining popularity as adjuncts to managing metabolic syndrome. These supplements target specific aspects of metabolism, gut health, and inflammation, as shown in Table 3.

Table 3. Innovative supplements complement dietary changes to manage metabolic syndrome effectively.

Supplement	Key Ingredients	Potential Benefits	Mechanisms of Action
Probiotics	<i>Lactobacillus</i> , <i>Bifidobacterium</i> , <i>Saccharomyces</i>	Improves gut microbiome health, enhances insulin sensitivity, reduces inflammation, aids weight management	Probiotics restore gut microbiota balance, enhance SCFA production, and reduce systemic inflammation, which improves metabolic markers like blood sugar and lipid profiles.

Berberine	Berberine extract (from <i>Berberis</i> species)	Improves insulin sensitivity, reduces blood sugar and lipids, supports weight loss	Berberine activates AMP-activated protein kinase (AMPK), improving insulin sensitivity, glucose metabolism, and lipid regulation.
Curcumin	Curcumin (from turmeric)	Reduces inflammation, improves insulin sensitivity, supports liver health	Curcumin has potent anti-inflammatory effects, reduces oxidative stress, and modulates metabolic pathways linked to insulin resistance and fat metabolism.
Omega-3 Fatty Acids	Fish oil (EPA, DHA), Algal oil	Reduces inflammation, improves blood lipids, supports cardiovascular health	Omega-3 fatty acids reduce systemic inflammation, lower triglycerides, improve HDL cholesterol, and enhance insulin sensitivity.
Alpha-Lipoic Acid (ALA)	Alpha-lipoic acid	Improves insulin sensitivity, reduces oxidative stress, supports weight management	ALA acts as an antioxidant, reduces oxidative damage, enhances glucose uptake, and improves lipid metabolism, helping to reduce risk

			factors of metabolic syndrome.
			Cinnamon increases insulin receptor sensitivity and enhances glucose uptake in cells, contributing to better blood sugar control.
Cinnamon Extract	Cinnamon polyphenols (Cinnamomum cassia)	Lowers blood sugar, improves insulin sensitivity, reduces inflammation	
			Chromium plays a role in enhancing insulin action, improving glucose uptake, and stabilizing blood sugar levels.
Chromium Picolinate	Chromium (elemental form)	Improves blood glucose regulation, enhances insulin sensitivity	
			Magnesium helps regulate glucose metabolism, supports endothelial function, and improves insulin sensitivity, which is crucial for metabolic syndrome management.
Magnesium	Magnesium citrate, magnesium glycinate	Improves insulin sensitivity, supports blood pressure regulation, aids sleep	
			CoQ10 boosts cellular energy production, reduces inflammation, and protects against
Coenzyme Q10 (CoQ10)	CoQ10 (ubiquinone)	Supports mitochondrial function, reduces	

			oxidative stress, oxidative damage, improves heart health improving overall metabolic function and cardiovascular health.
			Vitamin D plays a role in calcium metabolism, insulin sensitivity, and immune function, while deficiencies are linked to metabolic dysfunction and increased risk of diabetes.
Vitamin D	Vitamin D3 (cholecalciferol)	Improves insulin sensitivity, supports immune function, regulates blood pressure	
			L-Carnitine transports fatty acids into mitochondria for energy production, aiding fat oxidation and helping with weight management.
L-Carnitine	L-Carnitine (from animal or plant sources)	Supports fat metabolism, improves exercise performance, aids in weight loss	
			Fiber supplements improve gut motility, help regulate blood sugar levels, and promote satiety, which aids in weight loss and reduces risk
Fiber Supplements	Psyllium husk, inulin, glucomannan	Reduces blood sugar, improves gut health, supports weight loss	

			factors for metabolic syndrome.
			EGCG in green tea increases thermogenesis, fat
		Increases fat oxidation, and	
Green Tea Extract	Epigallocatechin gallate (EGCG)	oxidation, improves insulin sensitivity, supports weight loss	enhances insulin sensitivity, which helps in reducing body fat and improving metabolic health.
			Resveratrol acts as an antioxidant and anti-inflammatory, improving endothelial function, reducing oxidative stress, and enhancing insulin sensitivity.
Resveratrol	Resveratrol (from grapes, red wine)	Reduces inflammation, improves insulin sensitivity, supports cardiovascular health	
			Garlic extract has anti-inflammatory
		Reduces blood pressure, improves cholesterol levels, supports weight loss	properties, reduces blood pressure, and improves lipid profiles, contributing to improved metabolic health.
Garlic Extract	Allicin, sulfur compounds		

Ashwagandha	Withanolides (from <i>Withania somnifera</i>)	Reduces stress, improves insulin sensitivity, supports weight management	Ashwagandha modulates cortisol levels, reducing stress-related fat accumulation and inflammation while improving glucose metabolism and insulin sensitivity.
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1. Probiotic and Prebiotic Supplements

Supplements can be a valuable tool for individuals who cannot get sufficient probiotics and prebiotics from food. Probiotic supplements containing specific strains of beneficial bacteria have been shown to improve gut microbiome diversity, reduce inflammation, and enhance insulin sensitivity. Prebiotic supplements containing fibres like inulin and fructooligosaccharides can help promote the growth of beneficial bacteria and support the production of SCFAs. When combined, probiotics and prebiotics—often called synbiotics—offer synergistic benefits for metabolic health (He and Shi, 2017; Yoo and Kim, 2016).

2. Omega-3 Fatty Acids

Omega-3 supplements, derived from fish oil or algae, have been extensively studied for their anti-inflammatory and metabolic benefits. Omega-3 fatty acids have been shown to improve insulin sensitivity, lower triglyceride levels, and reduce inflammation—key factors in managing metabolic syndrome. Regular supplementation with omega-3s can help restore balance to the gut microbiome and support overall metabolic health (Jang and Park, 2020).

3. Polyphenols and Antioxidants

Polyphenols, found in foods like berries, green tea, and dark chocolate, are potent antioxidants that can reduce oxidative stress and inflammation. Recent studies suggest that polyphenols may also have prebiotic-like effects, promoting the growth of beneficial gut bacteria. Supplements containing polyphenol-rich extracts, such as resveratrol and curcumin, may help improve insulin sensitivity and reduce the risk of developing metabolic syndrome (Chiva-Blanch and Badimon, 2017).

4. Berberine

Berberine, a plant-derived compound, has gained attention for improving insulin sensitivity, regulating blood sugar, and reducing cholesterol levels. Several studies have demonstrated its potential to combat metabolic syndrome by modulating gut microbiome composition and improving systemic inflammation. As a supplement, berberine has shown promise as a natural adjunct to conventional treatments for metabolic syndrome (Och et al., 2022; Tabeshpour et al., 2017).

Conclusion

Metabolic syndrome is a complex and multifactorial disorder, but emerging research highlights the critical role of gut health in its prevention and management. Dietary strategies that promote a healthy gut microbiome, postbiotics, and innovative supplements offer promising avenues for enhancing metabolic health. By adopting a diet rich in fibre, fermented foods, and healthy fats, individuals can support a diverse and beneficial gut microbiome that is pivotal in regulating metabolism. Coupled with the use of postbiotics and supplements such as probiotics, omega-3 fatty acids, and

polyphenols, these dietary strategies provide a holistic approach to managing metabolic syndrome and improving long-term health outcomes. As we continue to uncover the intricate connections between the gut microbiome and metabolic health, these innovative interventions will become increasingly important in the fight against metabolic syndrome.

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