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REVIEW PAPER

FECAL MICROBIOTA TRANSPLANTATION: A REVOLUTIONARY THERAPY FOR METABOLIC DISORDERS

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Summary

Recent interest in the role of gut microbiota in metabolism has led to exploration of fecal microbiota transplantation (FMT) as a therapy for metabolic disorders, including obesity. However, its effectiveness remains unclear. This review analyzed studies published between 2019 and 2025 from PubMed and Google Scholar using the keywords "obesity" and "FMT". Findings indicate that FMT can reduce insulin resistance, as evidenced by decreased HOMA-IR levels. In several trials, improved glucose tolerance and lipid profiles were also observed, suggesting broader metabolic benefits. Donor selection and recipient compatibility emerged as important factors influencing outcomes, highlighting the need for standardized protocols. Most studies reported significant gut microbiota shifts post-FMT, including increased Bacteroides/Firmicutes ratios and higher Bifidobacterium and Lactobacillus abundance. Only one study found no significant metabolic improvements. FMT appears promising for metabolic disorder treatment, particularly alongside diet, lifestyle changes, or bariatric surgery. Given these findings, FMT may serve as a valuable adjunct in obesity management, though not a standalone cure. Further large-scale studies are needed to confirm its therapeutic potential.

Keywords: HOMA-IR index, FMT, BMI, metabolic disorders, obesity

Introduction

Fecal microbiota transplantation (FMT) is a therapeutic procedure involving the administration of minimally processed stool from a healthy donor into the intestine of a diseased recipient. While the first experiments with gut microbiota date back to the 4th century AD in China, the widespread research in this aspect and its common application in daily medicine can be traced back to the year 2008, coinciding with the emergence of the *Clostridioides difficile* epidemic. This event served as a turning point, as since then, the procedure has garnered interest for its potential impact on other aspects of human metabolism. The mechanism of transplantation involves restoring microbial diversity and the dominance of organisms that protect the intestinal environment, as it existed before its depletion, often caused by prolonged antibiotic therapy. FMT has also found wide application in combating infections caused by *C. difficile*, achieved through competition for nutritional resources by the healthy flora, production of bacteriostatic and bactericidal substances, as well as direct involvement in the metabolism of bile acids, inhibiting spore germination in the intestines and ultimately achieving homeostasis with the host, thereby stimulating their immune system. Previously, such procedures were performed by directly administering freshly suspended stool via endoscopic procedures of the upper or lower gastrointestinal tract, making multiple administrations impractical due to their invasiveness. However, the latest methods involve orally administering frozen capsules, yielding equally effective results as endoscopic methods [1].

There is growing interest in the potential impact of FMT on the course of obesity, insulin resistance, and other common metabolic disorders. Due to the ongoing lack of progress and the limitations, costs, and side effects of pharmacotherapy in combating these conditions, which are inundating the civilized world, scientists are increasingly exploring new ways to

address the epidemic of modern times [2]. Despite the limited number of studies conducted in this area, it is well known that gut microbiota dysbiosis commonly accompanies obesity and serious metabolic diseases. Additionally, pre-existing disturbances in gut microbiota composition, caused for instance by antibiotic therapy, may predispose to obesity later in life, even if it occurred during childhood. Studies have shown that adults with type 2 diabetes and obesity have a markedly different gut microbiome composition compared to lean individuals, and larger cohort studies have identified correlations between microbiome and body mass, metabolism, and body composition [3]. Many studies also report on the potential use of FMT as one of the therapies for metabolic disorders in the course of obesity, enabling weight reduction and normalization of metabolic pathways [4-8].

Aim of the work

This review aims to assess the potential of FMT as a therapeutic approach for metabolic disorders, with a particular focus on obesity and insulin resistance. In this review, we reviewed recent reports describing the effects of FMT on the composition of the gut microbiota and focused on the impact of these changes on insulin resistance and overall metabolic health. Understanding these effects may provide insight into its clinical application and the need for further research.

Methods

A review of articles published between January 2019 and March 2025 was conducted using PubMed and Google Scholar databases. The review was conducted using a systematic method by two independent reviewers, and the results were compared. Articles were searched

using the keywords "obesity" and "FMT". The results of research related to each of these phenomena were analyzed, compared, and common conclusions were drawn based on this analysis. Inclusion criteria were: publication year between 2019 and 2025, topics related to the role of FMT in obesity therapy, availability of a full-text original research article, randomized study design, and publication in English or Polish. The exclusion criteria included: inappropriate type of publication (e.g., abstract, editorial, letter to the editor, review), lack of randomization, and publication outside the 2019-2025 date range. Initially, 129 publications were retrieved. After applying the time frame, 17 papers were excluded, leaving 112. Next, 23 duplicate papers were removed, reducing the pool to 89. The titles and abstracts of these papers were screened for relevance. 80 studies were excluded for not meeting substantive criteria such as inappropriate publication type (e.g., editorial, letter, abstract, or poster), lack of randomization, irrelevance to obesity, or lack of significant results. Ultimately, 9 publications were included in the final review.

Literature review results

The findings of studies on this topic show certain similarities, although they are not entirely conclusive. Despite minor differences, the overall picture remains consistent. Detailed information on each of the analyzed articles is presented in Table 1.

Table 1. Analysis of studies on the effectiveness of FMT in the treatment of metabolic diseases [3,9-16]

Authors (year)	Study design	Participants	Number of participants	Intervention	Control	Primary outcome	Clinically significant parameters reported	Follow up primary outcomes
Yu et al. (2020) [3]	RCT	Age: 25-60 Obese (BMI ≥ 30) and insulin-resistant individuals, aged 25 to 60 years	n=24: Placebo n=12 FMT n=12	FMT from leans donors (BMI 19.5-21.8) by oral capsules once a week for 6 weeks	Placebo oral capsules in the same scheme as the study group	No statistically significant differences between placebo and FMT groups	HOMA -IR, HbA1c, fasting glucose, cholesterols/triglycerides, weigh	12 weeks
Leong et al. (2020) [9]	RCT	Age: 14-18 Obese (BMI ≥ 30), without chronic diseases	n=87 Placebo n=45 FMT n=42	FMT from leans and health donors by oral capsules; each participant received 7 capsules	Placebo oral capsules in the same scheme as the study group	Reductions in android-to-gynoid-fat ratio and reduction in the severity of metabolic syndrome in the FMT vs placebo group; no effect of FMT on BMI, no observed effects on insulin sensitivity, liver function, lipid profile, inflammatory markers, blood pressure, total body fat percentage, gut health, and health-related quality of life	Total body fat percentage and android-to-gynoid-fat (A/G) ratio, blood pressure, HOMA-IR, metabolic markers	6 weeks
Allegretti et al. (2019) [10]	RCT	Obese BMI ≥ 35, without chronic diseases	n=22 FMT n=11 Placebo n=11	FMT from a single lean donor (BMI, 17.5 kg/m^2); induction dose of 30 capsules at week 4 and maintenance dose of 12 capsules at week 8	Placebo capsules in the same scheme as a study group	No significant differences in BMI, AUC of GLP1; FMT group had a sustained decrease in stool levels of taurocholic acid; patients' obese gut microbiome profile similar to the donors' lean microbiome profile	AUC of GLP1, BMI, taurocholic acid in stool	12 weeks
Xue et al. (2022) [11]	RCT	NAFLD patients with obese (BMI ≥ 25) and leans patient with BMI < 25	n=75 FMT n=47 Placebo n = 28	FMT from healthy donors, 200 ml of fresh bacteria solution per day, for 3 days in total (colonoscopy)	Placebo oral capsules with probiotics per day, for 3 days	No statistical differences were found in the blood lipid and liver function results; *Bacteroides* decreased, the proportions of *Bacteroidetes* and the *Bacteroidetes-to-Firmicutes* (B/F) increased after FMT	Fasting blood glucose and insulin, HOMA IR, BMI, changes in the gut microbiota	4 weeks

Mocanu et. al. (2021) [12]	RCT	Obese (BMI > 30) and metabolic syndrome	n=70 FMT (HF-FMT, LF-FMT) n=34 Placebo (HF, LF) n=36	FMT from four healthy and lean donors; 20 FMT capsules (weighing 50 g in total) orally	20 placebo oral capsules orally in the same scheme as a study group	Only patients in the FMT-LF group had significant improvements in HOMA2-IR	HOMA2-IR, changes in the gut microbiota, oral glucose tolerance test	6 weeks
Lahtinen et al. (2022) [13]	RCT	Obese (BMI ≥ 40) and obese (BMI ≥ 35) with other metabolic disorders	n=41 FMT n=21 Placebo n=20	FMT from 2 lean donors (BMI < 20 and BMI < 25) by gastroscopy into the duodenum, 6 months later – bariatric surgery	Placebo administration by gastroscopy in the same scheme as a study group	Bariatric surgery 6 months after FMT or placebo administration reduced weight equally in both groups during the 1-year follow-up	BMI, body composition measured with BIA, blood chemistry, and QoL	1 year
Ng et al. (2021) [14]	RCT	Age 18–70 (BMI ≥ 28) and a diagnosis of T2DM	n=61 FMT n=41 (FMT+LSI, FMT alone) Placebo (LSI) n=20	FMT from lean donors (BMI < 23) 50g stool into the distal duodenum every 4 weeks for up to week 12 (4 times)	Placebo (saline infusion) into the distal duodenum in the same scheme as a study group + LSI	Proportions of subjects acquiring ≥ 20% of lean-associated microbiota at week 24 were 100%, 88.2% and 22% in the FMT plus LSI, FMT alone, and sham plus LSI groups; LSI and FMT led to increase in *Bifidobacterium* and *Lactobacillus* and reduced total and low-density lipoprotein cholesterol and liver stiffness	Proportion of subjects acquiring ≥ 20% of microbiota from lean donors at week 24, LDL and liver stiffness	24 weeks
Su et al. (2022) [15]	RCT	T2DM without serious organic illnesses	n=13 FMT + diet n=5 Placebo (diet) n=8	FMT from healthy donors without T2DM; 30 oral capsules (1g) three times every 7 days; orally prebiotics every day (first 20 days)	Orally prebiotics and whole grains 3 times a day (20 days)	Increased *Bifidobacterium* faster in FMT group, negatively correlated with blood glucose levels, blood pressure, blood lipids, and BMI; number of sulfate-reducing bacteria (SRB), *Bilophila*, and *Desulfovibrio* decreased; earlier effect of weight loss was demonstrated in the DF group	Glucose, C-peptide, triglyceride, HDL, LDL, HbA1c	
Wu et al. (2023) [16]	RCT	T2DM without serious organic illnesses	n=29 FMT plus metformine n=8 FMT n=9	FMT (50g) from healthy donors injected via the nasointestinal	Only metformine orally	FMT with or without metformin significantly improve insulin resistance and BMI; *Bacteroidetes* decreased, *Firmicutes*	HOMA-IR, BMI, fasting blood glucose, postprandial blood glucose, HbA1c	4 weeks

			Placebo (metformine) n=12	tube plus metformine orally		increased after intervention in both FMT alone and FMT plus metformin groups		

Notes: HOMA2-IR – Homeostatic Model Assessment of Insulin Resistance; HbA1c – glycated hemoglobin; BMI – body mass index; AUC of GLP-1 – Area Under the Curve of Glucagon-Like Peptide 1; NAFLD – Nonalcoholic Fatty Liver Disease; (HF-FMT – high-fermentable fiber supplements and FMT group, LF-FMT – low-fermentable (LF) fiber supplements and FMT group; LF – low-fermentable fiber supplements group; HF – high-fermentable fiber supplements group; BIA – Bioimpedance Analysis; QoL – Quality of Life; T2DM – Type 2 Diabetes Mellitus; LSI – lifestyle intervention group; FMT+LSI – FMT and lifestyle intervention group; DF – FMT and diet group; D – diet group.

Yu et al. [3], in a study involving 24 patients, did not observe an effect of FMT on the therapy process of obese patients. They noted that the transplant resulted in a qualitative change in gut microbiota; however, there was no statistically significant improvement in insulin sensitivity (mean difference 9%; 95% CI =-5%-28%; *p*=0.16), homeostatic model assessment of insulin resistance (HOMA-IR) (mean difference 0.2; 95% CI=-0.9-0.9; *p*=0.96), as well as fat (mean difference 1.2 kg; 95% CI=-0.6-3.0 kg; *p*=0.18) and lean body mass (mean difference -0.1 kg; 95% CI=-1.9-1.6 kg; *p*=0.87). The authors pointed out that factors such as the small study group, relatively mild insulin resistance in patients, and the lack of simultaneous dietary intervention may have influenced the study outcome [3].

Leong et al. conducted a study involving 87 adolescents with obesity aged 14-18 years. Similarly, they observed changes in gut microbiota (decreased counts of *Escherichia coli* and increased counts of *Faecalibacterium prausnitzii, Bacteroides ovatus, Bacteroidales bacterium, Alistipes onderdonkii, Alistipes finegoldii*, and *Alistipes shahii*). However, they did not observe a significant effect of FMT on body mass index (BMI) (adjusted mean difference [aMD] -0.026; 95% CI=-0.074-0.022; *p*=0.291). Initially, they observed improvements in HOMA-IR by 34%, fasting insulin by 29%, and fasting glucose by 7%, but these results were

only temporary and did not persist at the end of the study. Importantly, the authors noted a decrease in the android-to-gynoid-fat ratio (-0.029; 95% CI -0.049, -0.008; p=0.0069) and resolution of metabolic syndrome in 78% of participants (adjusted odds ratio [aOR] = 0.06; 95% CI=0.01-0.45; p=0.0074) [9,17]. This change represented a reduction in visceral fat tissue by 2-3% and was primarily associated with the anti-inflammatory and gut barrier-sealing effects of *F. prausnitzii* and *Alistipes spp* [9,18].

Allegretti et al. [10] observed that taking FMT capsules for 12 weeks did not affect BMI change in patients. They observed a significant increase in gut microbiota diversity in obese individuals, making its composition more similar to that of transplant donors (p<0.001), with some of the significant changes involving *Faecalibacterium*, which produces butyrate and hydrolyzes bile. This corresponded to a decrease in the concentration of taurocholic acid in the stool of obese individuals to levels found in healthy donors (p<0.05) [10].

Similar observations were made by Xue et al. [11]. In a study involving 75 patients with nonalcoholic fatty liver disease (NAFLD), they observed enrichment of gut microbiota after FMT (p<0.05) and an increase in the *Bacteroides*/Firmicutes ratio from 0.7 before treatment to 0.93 after treatment (it was 1.54 in healthy individuals). This was particularly noticeable in the group of lean patients with NAFLD, although the changes, while noticeable, were not as pronounced in obese individuals. Furthermore, in lean NAFLD patients after FMT, average fat attenuation significantly decreased to values characteristic of healthy individuals compared to the obese group (p=0.029). This suggests that FMT, besides its beneficial effect on gut microbiota composition (reduced *Bacteroides*/Firmicutes ratio leading to decreased energy expenditure and disrupted lipid deposition), also influences the course of NAFLD, especially in lean individuals [11,19].

Mocanu et al. [12] not only investigated the effectiveness of FMT but also its correlation with the administration of fiber. After 6 weeks in the group receiving FMT and

supplementation with low-fermentable fiber, they observed a significant increase in the abundance of *Phascolarcobacterium*, Christensenellaceae, *Bacteroides*, and *Akkermansia muciniphila*, along with a decrease in Dialister and Ruminococcus torques. This group also showed an improvement in the HOMA2-IR index (3.77 vs. 3.16; p=0.02). Moreover, significant improvement was observed in the Glucagon-Like Peptide 1 (GLP –1) secretion rhythm and a decrease in peak insulinemia in the oral glucose tolerance test (OGTT) (p<0.05). This result would suggest an improvement in insulin sensitivity in obese patients with metabolic syndrome due to the combination of both therapeutic methods [12].

One of the methods for treating obesity is bariatric surgery. Researchers are investigating whether combining the procedure with FMT can lead to better clinical outcomes for both. Lahtinen et al. [13] did not observe such a correlation in a study involving 41 patients. The decrease in body weight was similar in the FMT and placebo groups (4.8% and 4.6%, respectively) and did not show a statistically significant difference. Additionally, the values of glycated hemoglobin (HbA1c), triglycerides, and uric acid in the FMT and placebo groups reached similar final values [13].

Ng et al. [14] made interesting observations regarding the correlation of therapeutic methods. They observed that when FMT was used in combination with lifestyle change intervention, a significantly higher percentage of patients showed significant changes in gut microbiota structure compared to FMT alone or lifestyle change alone (100%, 88.2%, and 22%, respectively; p<0.0001). The use of FMT, regardless of the introduction of lifestyle changes, resulted in an increase in the abundance of bacteria producing butyrate, and the combination of both methods resulted in a significant increase in the abundance of *Bifidobacterium* and *Lactobacillus* compared to FMT alone (p<0.05). In the case of combining both methods, a significant decrease in cholesterol and low-density lipoprotein (LDL) concentrations was also observed at the endpoint (p<0.05) [14].

Su et al. [15] also compared the effectiveness of diet and FMT. The researchers pointed out that in the group using only the diet, there was a significant increase in the abundance of *Acidaminococcus, Bifidobacterium, Blautia,* and *Pseudomonas,* while the abundance of *Bilophila, Oscillospira, Roseburia,* and *Ruminococcus* was significantly reduced. In the group where diet and FMT were combined, the population of *Bifidobacterium, Collinsella, Lactobacillus,* and *Prevotella* significantly increased, while *Bacteroides, Bilophila, Lachnospira, Odoribacter, Phascolarctobacterium,* and *Sutterella* decreased. After this treatment in patients with diabetes, *Prevotella* became the dominant bacterium, as in healthy individuals. In the studied groups, a decrease in BMI (23.4 vs. 24.8 m/kg^2 in the diet group and 23 vs. 25.2 m/kg^2 in the diet and FMT group; $p<0.05$), fasting glucose level (6.7 vs. 9.6 mmol/l in the diet group, $p<0.05$), HbA1c level (6.6 vs. 8.3% in the diet group and 6.2 vs. 6.9% in the diet and FMT group; $p<0.001$, $p<0.01$, respectively), and mean systolic blood pressure (118 vs. 135 mmHg in the diet group and 109 vs. 133 mmHg in the diet and FMT group; $p<0.05$, $p<0.01$, respectively) were observed. These changes were most strongly negatively correlated with the abundance of *Bifidobacterium* and less so with *Lactobacillus* [15]. Interestingly, *Bifidobacterium* is frequently indicated as having a protective effect against the development of type 2 diabetes through its inhibitory effect on the growth of pathogenic bacteria and improvement of gut barrier integrity [15,20]. *Lactobacillus*, on the other hand, by producing lactate, acidifies the gut environment, inhibiting the growth of pathogenic bacteria and positively influencing the course of treatment for type 2 diabetes and obesity [21,22].

Wu et al. [16] made similar observations. In a study involving 31 patients with type 2 diabetes treated with metformin, they observed that patients treated with FMT and metformin achieved a significant improvement in glucose level (6.78 vs. 9.24; $p<0.01$), HbA1c (8.76 vs. 9.1%; $p<0.01$), BMI (26.46 vs. 27.27; $p<0.01$), and HOMA-IR (3.61 vs. 5.51; $p<0.01$). Importantly, patients treated only pharmacologically did not improve in terms of BMI and

HOMA-IR during the 4-week study period. This suggests a therapeutic effect potentiated by FMT. The observed effect was mainly associated with an increase in the abundance of *Prevotella* and *Bifidobacterium* bacteria [16]. Changes in the composition of the gut microbiota after FMT and their impact on the metabolism of obese patients are shown in Figure 1.

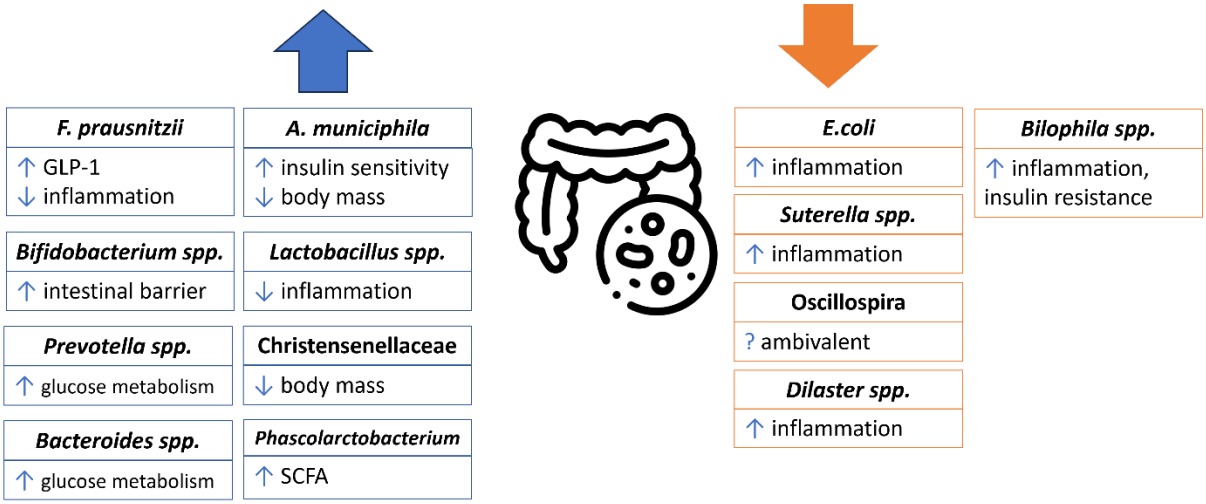

Figure 1. Changes in the composition of the gut microbiota after FMT and their impact on the metabolism of obese patients [3,9-16]

Discussion

Intestinal dysbiosis is a component of the specific etiological triad of obesity, which also includes genetic factors and dietary irregularities. The influence of gut microbiota in this disease primarily relies on generating systemic inflammation, immune response, energy metabolism, and intestinal barrier function [23].

Human microbiota mainly consists of bacteria belonging to the *Bacteroidetes*, Firmicutes, Proteobacteria, Actinobacteria, and *Verrucomicrobia*, with the first two comprising up to 90% of the total population [24,25]. Approximately half of the microbiota composition, known as the core, is identical in all individuals. However, the second half constitutes a variable

feature among individuals [24,26]. Interestingly, the composition of gut microbiota can change depending on the diet, forming so-called enterotypes. A higher proportion of *Prevotella* is associated with a high-carbohydrate diet, while *Bacteroides* predominates in high-fat and animal protein-rich diets [27,28].

In obese individuals, the most significant pathogenetic change in gut microbiome is a decrease in *Bacteroides*, with a proportional increase in Firmicutes bacteria [28]. Additionally, a decreased level of Christensenellaceae bacteria and *Akkermansia* and an increased level of *Lactobacillus* are indicated. Introduction of a low-calorie diet and weight loss contribute to restoring the correct quantitative ratio between these bacteria. Excess Firmicutes bacteria leads to an increased presence of enzymes involved in the digestion and fermentation of complex carbohydrates, as well as changes in gene promoter methylation responsible for promoting obesity and cardiovascular diseases [29-31]. Conversely, a reduced presence of *Akkermansia* affects increased serum triglyceride levels, increased adipose tissue, and insulin resistance [32]. Increased levels of Firmicutes bacteria contribute to heightened production of short-chain fatty acids (SCFAs), which serve as stored energy, thus increasing the positive energy balance in obesity pathogenesis [28]. Furthermore, SCFAs stimulate fat accumulation in adipocytes by insulin synthesis stimulation, activating G protein-coupled receptors GPR43 and GPR41 [28,33]. Additionally, gut bacteria contribute to the hydrolysis of bile acid salts, which regulate lipid and cholesterol metabolism, leading to adipose tissue and weight gain through activation of PPARγ, ANGPLT4, ABCG5/G8 [33,34].

A high-fat diet, as one of the pathogenic factors of obesity, contributes to decreased synthesis of occludin and zonula occludens-1, thereby loosening epithelial cell junctions in the intestines, leading to intestinal barrier damage and penetration of bacterial toxins, including lipopolysaccharide (LPS), into the bloodstream. LPS endotoxemia activates Toll-like receptor TLR-4, exacerbating insulin resistance and weight gain by stimulating excessive

cholecystokinin secretion in a MyD88-dependent mechanism and protein kinase C [28,35,36]. These induced inflammatory changes were not acute but over time induced obesity and its complications.

Another pathomechanical pathway in the development of microbiota-dependent obesity involves its influence on the liver. Intestinal dysbiosis is one of the factors in the development of non-alcoholic fatty liver disease (NAFLD) and exacerbation of liver fibrosis. These processes are dependent on the abundance of *Bacteroides* and *Ruminococcus* [37,38]. The aforementioned inflammatory state induced by LPS presence in the blood induces NF-κB and TLR-4 and TLR-9, increasing interleukin 18 and 22 levels, which condition the recruitment of inflammatory cells, including macrophages secreting fibrosis-stimulating cytokines in the liver [28,38]. Additionally, a deficiency of fasting-induced adipose factor (Fiaf) caused by dysbiosis contributes to lipoprotein lipase activation, carbohydrate response element-binding protein (ChREBP), and sterol regulatory element-binding protein 1 (SREBP-1), resulting in liver triglyceride accumulation [28]. Moreover, ethanol, a product of certain bacterial metabolisms (Proteobacteria), exacerbates liver damage [38].

The third pathway of microbiota interaction with metabolic pathways involves a central influence on the brain, both through stimulation of the vagus nerve and immunological mechanisms [27,29,39]. Bacterial metabolites such as lactate and acetate affect postprandial satiety, and bacterial effects on intestinal hormone levels (cholecystokinin, peptide YY, glucagon-like peptide 1) increase vagus nerve tension and regulate appetite. Inflammation-stimulating LPS enhances cytokine secretion, which may affect autonomic nervous system activation [28,40]. Changes in the composition of the gut microbiota in obesity are shown in Figure 2.

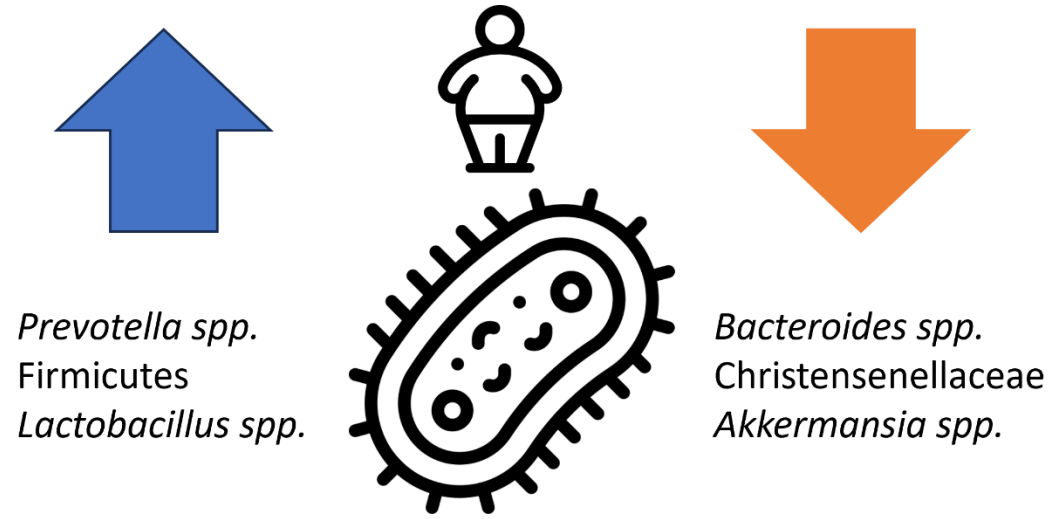

Figure 2. Changes in the composition of the gut microbiota in obesity [28-40]

The impact of gut microbiota on organism metabolism is presented in Figure 3. The above observations indicate that gut microbiota significantly influences the development and control of obesity, insulin resistance, diabetes, and their metabolic complications.

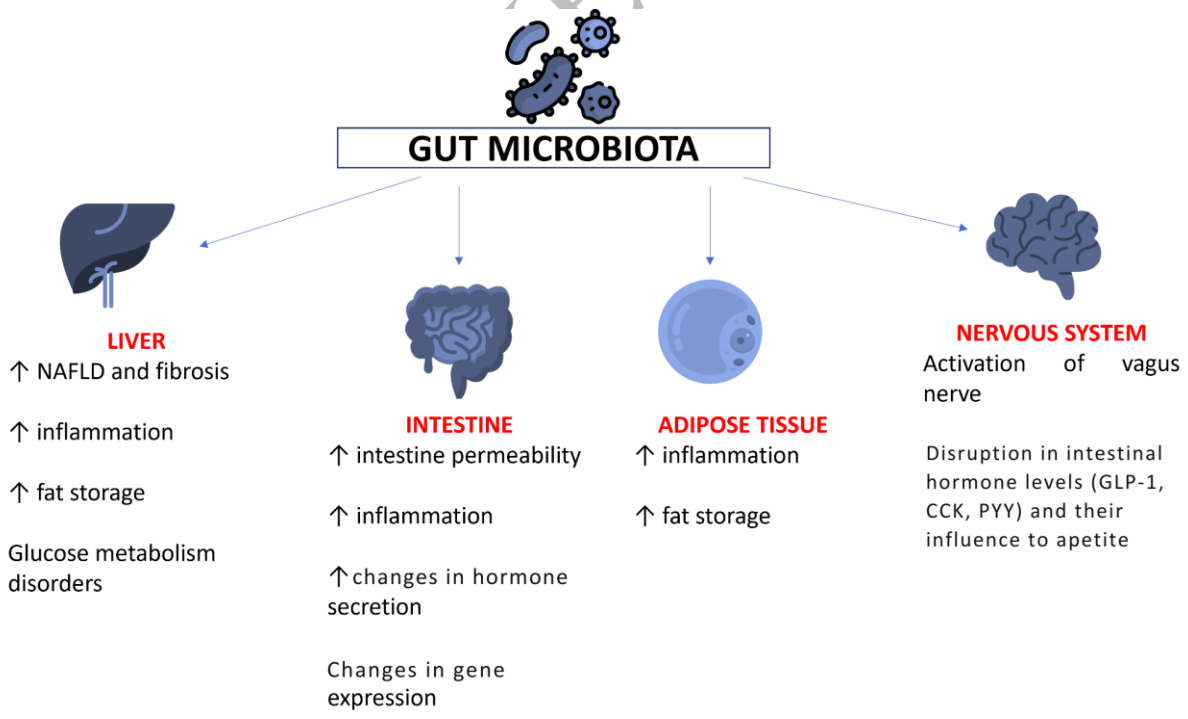

Figure 3. The impact of gut microbiota on the body's metabolism and the functioning of various organs: liver, intestines, brain, and adipose tissue [28-40]

Conclusions

FMT can be effectively used in the therapy of metabolic disorders, especially as a complementary element to classical therapeutic methods. Although research results regarding weight loss are not conclusive, FMT improves metabolic control of diseases and is one of the factors supporting positive therapeutic effects. Further research is necessary to assess the relationship between FMT and beneficial metabolic changes, as it seems to be a promising form of treatment for obesity and metabolic syndrome in the future.

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Artificial intelligence (AI) was not used in the creation of the manuscript.

References:

1. Cheng YW, Fischer M. Fecal microbiota transplantation. Clin Colon Rectal Surg. 2023; 36(2): 151-156. https://doi.org/10.1055/s-0043-1760865
2. Zecheng L, Donghai L, Runchuan G, Yuan Q, Qi J, Yijia Z, et al. Fecal microbiota transplantation in obesity metabolism: a meta analysis and systematic review. Diabetes Res Clin Pract. 2023; 202: 110803.https://doi.org/10.1016/j.diabres.2023.110803

3. Yu EW, Gao L, Stastka P, Cheney MC, Mahabamunuge J, Torres Soto M, et al. Fecal microbiota transplantation for the improvement of metabolism in obesity: the FMT-TRIM double-blind placebo-controlled pilot trial. PLoS Med. 2020; 17(3): e1003051. https://doi.org/10.1371/journal.pmed.1003051
4. Zikou E, Koliaki C, Makrilakis K. The role of fecal microbiota transplantation (FMT) in the management of metabolic diseases in humans: a narrative review. Biomedicines. 2024; 12(8): 1871. https://doi.org/10.3390/biomedicines12081871
5. Karimi M, Shirsalimi N, Hashempour Z, Omran HS, Sedighi E, Beigi F. Safety and efficacy of fecal microbiota transplantation (FMT) as a modern adjuvant therapy in various diseases and disorders: a comprehensive literature review. Front Immunol. 2024; 15: 1439176. https://doi.org/10.3389/fimmu.2024.1439176
6. Zhou X, Zhang X, Yu J. Gut mycobiome in metabolic diseases: mechanisms and clinical implication. Biomed J. 2024; 47(3): 100625. https://doi.org/10.1016/j.bj.2023.100625
7. Horvath A, Zukauskaite K, Hazia O, Balazs I, Stadlbauer V. Human gut microbiome: therapeutic opportunities for metabolic syndrome-hype or hope?. Endocrinol Diabetes Metab. 2024; 7(1): e436. https://doi.org/10.1002/edm2.436
8. Yuan L, Li Y, Chen M, Xue L, Wang J, Ding Y, et al. Therapeutic applications of gut microbes in cardiometabolic diseases: current state and perspectives. Appl Microbiol Biotechnol. 2024; 108(1): 156. https://doi.org/10.1007/s00253-024-13007-7
9. Leong KSW, Jayasinghe TN, Wilson BC, Derraik JGB, Albert BB, Chiavaroli V, et al. Effects of fecal microbiome transfer in adolescents with obesity: the gut bugs randomized controlled trial. JAMA Netw Open. 2020; 3(12): e2030415. https://doi.org/10.1001/jamanetworkopen.2020.30415

10. Allegretti JR, Kassam Z, Mullish BH, Chiang A, Carrellas M, Hurtado J, et al. Effects of fecal microbiota transplantation with oral capsules in obese patients. Clin Gastroenterol Hepatol. 2020; 18(4): 855-863. https://doi.org/:10.1016/j.cgh.2019.07.006
11. Xue L, Deng Z, Luo W, He X, Chen Y. Effect of fecal microbiota transplantation on non-alcoholic fatty liver disease: a randomized clinical trial. Front Cell Infect Microbiol. 2022; 12: 759306. https://doi.org/10.3389/fcimb.2022.759306
12. Mocanu V, Zhang Z, Deehan EC, Kao DH, Hotte N, Karmali S, et al. Fecal microbial transplantation and fiber supplementation in patients with severe obesity and metabolic syndrome: a randomized double-blind, placebo-controlled phase 2 trial. Nat Med. 2021; 27(7): 1272-1279. https://doi.org/10.1038/s41591-021-01399-2
13. Lahtinen P, Juuti A, Luostarinen M, Niskanen L, Liukkonen T, Tillonen J, et al. Effectiveness of fecal microbiota transplantation for weight loss in patients with obesity undergoing bariatric surgery: a randomized clinical trial. JAMA Netw Open. 2022; 5(12): e2247226. https://doi.org/10.1001/jamanetworkopen.2022.47226
14. Ng SC, Xu Z, Mak JWY, Yang K, Liu Q, Zuo T, et al. Microbiota engraftment after faecal microbiota transplantation in obese subjects with type 2 diabetes: a 24-week, double-blind, randomised controlled trial. Gut. 2022; 71(4): 716-723. https://doi.org/10.1136/gutjnl-2020-323617
15. Su L, Hong Z, Zhou T, Jian Y, Xu M, Zhang X, et al. Health improvements of type 2 diabetic patients through diet and diet plus fecal microbiota transplantation. Sci Rep. 2022; 12(1): 1152. https://doi.org/10.1038/s41598-022-05127-9
16. Wu Z, Zhang B, Chen F, Xia R, Zhu D, Chen B, al. Fecal microbiota transplantation reverses insulin resistance in type 2 diabetes: a randomized, controlled, prospective

study. Front Cell Infect Microbiol. 2023; 12: 1089991. https://doi.org/10.3389/fcimb.2022.1089991

17. Xu TC, Liu Y, Yu Z, Xu B. Gut-targeted therapies for type 2 diabetes mellitus: a review. World J Clin Cases. 2024; 12(1): 1-8. https://doi.org/10.12998/wjcc.v12.i1.1
18. Ghorbani Y, Schwenger KJP, Sharma D, Jung H, Yadav J, Xu W, et al. Effect of faecal microbial transplant via colonoscopy in patients with severe obesity and insulin resistance: a randomized double-blind, placebo-controlled Phase 2 trial. Diabetes Obes Metab. 2023; 25(2): 479-490. https://doi.org/10.1111/dom.14891
19. Zhu M, Dagah OMA, Silaa BB, Lu J. Thioredoxin/Glutaredoxin systems and gut microbiota in nafld: interplay, mechanism, and therapeutical potential. Antioxidants (Basel). 2023; 12(9): 1680. https://doi.org/10.3390/antiox12091680
20. Riveros NFH, García-Corredor L, Martínez-Solarte MA, González-Clavijo A. Effect of bifidobacterium intake on body weight and body fat in overweight and obese adult subjects: a systematic review and meta-analysis. J Am Nutr Assoc. 2024; 43(6): 519-531. https://doi.org/10.1080/27697061.2024.2320192
21. Li CP, Chen CC, Hsiao Y, Kao CH, Chen CC, Yang HJ, et al. The role of lactobacillus plantarum in reducing obesity and inflammation: a meta-analysis. Int. J. Mol. Sci. 2024; 25(14): 7608. https://doi.org/10.3390/ijms25147608
22. Qiu B, Liang JX, Li C. Effects of fecal microbiota transplantation in metabolic syndrome: a meta-analysis of randomized controlled trials. PLoS One. 2023; 18(7): e0288718. https://doi.org/10.1371/journal.pone.0288718
23. Hemachandra S, Rathnayake SN, Jayamaha AA, Francis BS, Welmillage D, Kaur DN, et al. Fecal microbiota transplantation as an alternative method in the treatment of obesity. Cureus. 2025; 17(1): e76858. https://doi.org/10.7759/cureus.76858

24. Puljiz Z, Kumric M, Vrdoljak J, Martinovic D, Ticinovic Kurir T, Ozren Krnic M, et al. Obesity, gut microbiota, and metabolome: from pathophysiology to nutritional interventions. Nutrients. 2023; 15(10): 2236. https://doi.org/10.3390/nu15102236
25. Yarahmadi A, Afkhami H, Javadi A, Kashfi M. Understanding the complex function of gut microbiota: its impact on the pathogenesis of obesity and beyond: a comprehensive review. Diabetol Metab Syndr. 2024; 16(1): 308. https://doi.org/10.1186/s13098-024-01561-z
26. Mansour S, Alkhaaldi SMI, Sammanasunathan AF, Ibrahim S, Farhat J, Al-Omari B. Precision nutrition unveiled: gene-nutrient interactions, microbiota dynamics, and lifestyle factors in obesity management. Nutrients. 2024; 16(5): 581. https://doi.org/10.3390/nu16050581
27. Zhang L, Wang P, Huang J, Xing Y, Wong FS, Suo J, et al. Gut microbiota and therapy for obesity and type 2 diabetes. Front Endocrinol (Lausanne). 2024; 15: 1333778. https://doi.org/10.3389/fendo.2024.1333778
28. Perler BK, Friedman ES, Wu GD. The role of the gut microbiota in the relationship between diet and human health. Annu Rev Physiol. 2023; 85: 449-468. https://doi.org/10.1146/annurev-physiol-031522-092054
29. Luqman A, Hassan A, Ullah M, Naseem S, Ullah M, Zhang L, et al. Role of the intestinal microbiome and its therapeutic intervention in cardiovascular disorder. Front Immunol. 2024; 15: 1321395. https://doi.org/10.3389/fimmu.2024.1321395
30. Gómez-Pérez AM, Muñoz-Garach A, Lasserrot-Cuadrado A, Moreno-Indias I, Tinahones FJ. Microbiota Transplantation in individuals with type 2 diabetes and a high degree of insulin resistance. Nutrients. 2024; 16(20): 3491. https://doi.org/10.3390/nu16203491

31. Tavassol ZH, Ejtahed HS, Atlasi R, Saghafian F, Khalagi K, Hasani-Ranjbar S, et al. Alteration in gut microbiota composition of older adults is associated with obesity and its indices: a systematic review. J Nutr Health Aging. 2023; 27(10): 817-823. https://doi.org/10.1007/s12603-023-1988-8
32. Crudele L, Gadaleta RM, Cariello M, Moschetta A. Gut microbiota in the pathogenesis and therapeutic approaches of diabetes. eBioMedicine. 2023; 97: 104821. https://doi.org/10.1016/j.ebiom.2023.104821
33. Colangeli L, Marcillo DIE, Simonelli V, Iorio E, Rinaldi T, Sbraccia P, et al. The crosstalk between gut microbiota and white adipose tissue mitochondria in obesity. Nutrients. 2023; 15(7): 1723. https://doi.org/10.3390/nu15071723
34. Li X, Huang J, Yun J, Zhang G, Zhang Y, Zhao M, et al. d-Arabitol ameliorates obesity and metabolic disorders via the gut microbiota-SCFAs-WAT browning axis. J. Agric. Food Chem. 2023; 71: 522-534. https://doi.org/10.1021/acs.jafc.2c06674
35. Sochacka K, Kotowska A, Lachowicz-Wiśniewska S. The role of gut microbiota, nutrition, and physical activity in depression and obesity—interdependent mechanisms/co-occurrence. Nutrients. 2024; 16(7): 1039.https://doi.org/10.3390/nu16071039
36. Pillai SS, Gagnon CA, Foster C, Ashraf AP. Exploring the gut microbiota: key insights into its role in obesity, metabolic syndrome, and type 2 diabetes. J Clin Endocrinol Metab. 2024; 109(11): 2709-2719. https://doi.org/10.1210/clinem/dgae499
37. Huang Y, Cao J, Zhu M, Wang Z, Jin Z, Xiong Z. Bacteroides fragilis aggravates high-fat diet-induced non-alcoholic fatty liver disease by regulating lipid metabolism and remodeling gut microbiota. Microbiol Spectr. 2024; 12(4): e0339323. https://doi.org/10.1128/spectrum.03393-23

38. Zhang XL, Chen L, Yang J, Zhao SS, Jin S, Ao N, et al. Vitamin D alleviates non-alcoholic fatty liver disease via restoring gut microbiota and metabolism. Front Microbiol. 2023; 14: 1117644. https://doi.org/10.3389/fmicb.2023.1117644

39. Micic D, Polovina S, Micic D, Macut D. OBESITY AND GUT-BRAIN AXIS. Acta Endocrinol (Buchar). 2023 Apr-Jun;19(2):234-240. https://doi.org/10.4183/aeb.2023.234

40. Barton JR, Londregan AK, Alexander TD, Entezari AA, Covarrubias M, Waldman SA. Enteroendocrine cell regulation of the gut-brain axis. Front Neurosci. 2023; 17: 1272955. https://doi.org/10.3389/fnins.2023.1272955