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Tea Catechins and Gastrointestinal health, Modulators of Gut Microbiota

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ABSTRACT

Catechins are polyphenol chemicals found in many plants that function as a key component of tea leaves and act as powerful antioxidants. Catechins have been shown to have beneficial anti-microbial, antiviral, anti-inflammatory, anti-allergenic, and anti-cancer properties.(Bae et al., 2020) Tea, derived from the Camellia sinensis (L.) Kuntze plant, is grown in over 50 countries, making it the most consumed beverage globally.(Baldi et al., 2020) Tea has been used for thousands of years and has remained popular because of its many health advantages, flavor, and cultural significance. Over the ages, tea has spread from China to the rest of Asia, along with Europe, America, and Africa.(Pérez-Burillo et al., 2021) Over 300 different types of tea are made using various manufacturing techniques.(Abudureheman et al., 2022) Green tea, oolong tea, black tea, white and yellow teas, and dark tea (also known as pu-erh tea) are the five categories of tea beverages. All varieties are manufactured from C. sinensis leaves, compared to what many people think.

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Keywords: Tea Catechins, Gastrointestinal health, Gut Microbiota

Introduction:

Catechins are polyphenol chemicals found in many plants that function as a key component of tea leaves and act as powerful antioxidants. Catechins have been shown to have beneficial anti-microbial, antiviral, anti-inflammatory, anti-allergenic, and anti-cancer properties.(Bae et al., 2020) Tea, derived from the Camellia sinensis (L.) Kuntze plant, is grown in over 50 countries, making it the most consumed beverage globally.(Baldi et al., 2020) Tea has been used for thousands of years and has remained popular because of its many health advantages, flavor, and cultural significance. Over the ages, tea has spread from China to the rest of Asia, along with Europe, America, and Africa.(Pérez-Burillo et al., 2021) Over 300 different types of tea are made using various manufacturing techniques.(Abudureheman et al., 2022) Green tea, oolong tea, black tea, white and yellow teas, and dark tea (also known as pu-erh tea) are the five categories of tea beverages. All varieties are manufactured from C. sinensis leaves, compared to what many people think.

Actually, the only basis for this classification is the various production methods: partially fermented (oolong tea), fully fermented (black tea), postfermented (dark tea), non-fermented (green tea), and lightly fermented (white and yellow teas).(Baldi et al., 2020). Black tea makes up around 78% of the world's tea production, while green tea, which is mostly consumed in China and Japan, makes up 20%. Oolong tea makes up around 2% of the total tea production and is partially fermented. Tea's main constituents have been determined to be catechins, theaflavins, and thearubigins(Abudureheman et al., 2022). Tea catechins, found in the young leaves and buds of tea plants, belong to the flavonoid family and subclass of flavan-3-ols. Epicatechin (EC), Epicatechin-3-gallate (ECG), Epigallocatechin (EGC), and Epigallocatechin gallate (EGCG) are the primary ingredients in tea. Additionally, (+)-catechin (C), (+)-gallocatechin (GC), (-)-gallocatechin-3-gallate (GCG), and (+)-catechin-3-gallate (CG) are all found in tea(Baldi et al., 2020).

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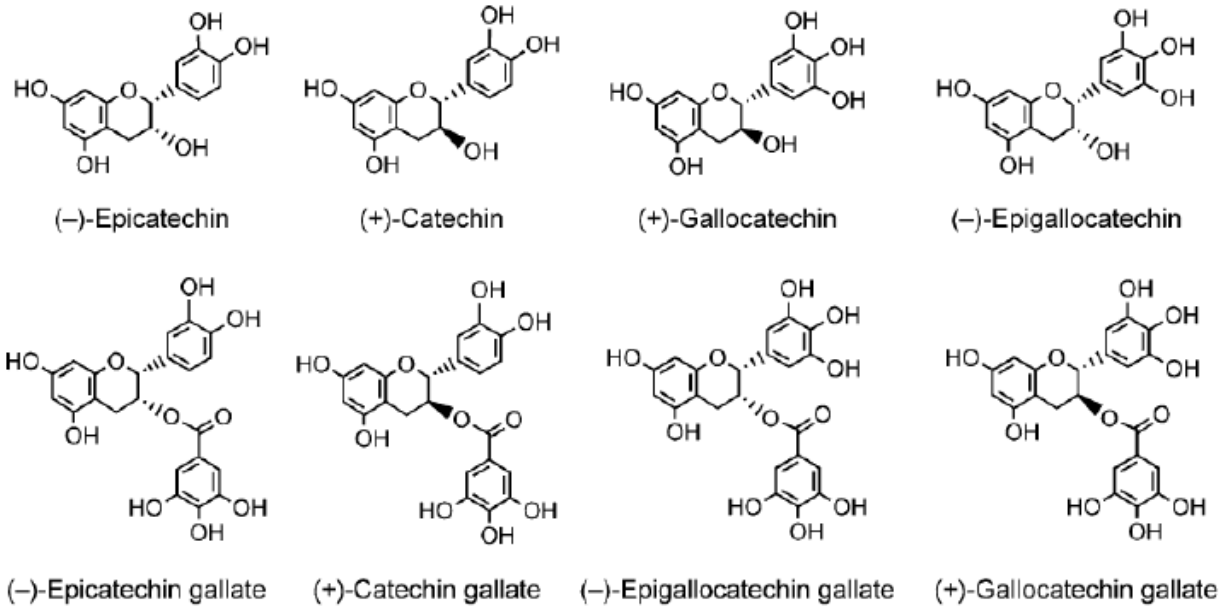


Figure:1(Eight catechins and their structural formulas.Hydroxyl groups (-OH) are one of the many chemical structural characteristics of catechins that make them easy to interact with other substances.C ((-)-catechin), EC ((-)-epicatechin), ECG ((-)-epicatechingallate), EGC ((-)-epigallocatechin), EGCG ((-)-epigallocatechin gallate), GC ((-)-gallocatechin), CG ((-)-catechingallate), and GCG ((-)-gallocatechingallate) are the eight catechins. The primary types are EGCG, EGC, ECG, C, and EC.)

EGCG is the major catechin in tea and, makes up 50-80% of its total catechin content. It shows the highest anti-inflammatory and anticancer potential(Abudureheman et al., 2022). Epicatechin (EC) is a flavanol found in various foods, including tea, cocoa, vegetables, fruits, and cereals. EC is made up of two aromatic rings and an oxygen-containing heterocyclic ring. EC is well-known for its powerful antioxidant properties(Qu et al., 2021). Green tea contains key flavonoids such as catechin, EC, and EGCG(Samanta, 2022). Catechins are naturally present in various foods and beverages, such as black tea, coffee, berries, grapes, and wine.(Farhan, 2022)

Antioxidants, antitumor, anti-inflammatory, antimicrobial, antiviral, anti-diabetic, anti-obesity, and hypotensive actions are some of the biological properties of catechins(Oh et al., 2023). Among green tea bioactive compounds, catechins stand out as the most powerful antioxidants contributing to these health-promoting properties.(Farhan, 2022) For example, it has been demonstrated that catechins control the growth and nutrition of cells and induce tumor cells to undergo programmed cell death.(Oh et al., 2023) Recent research indicate that EC has several health benefits, including anti-oxidant and anti-inflammatory properties, improved muscle performance, reduced symptoms of cardiovascular and cerebrovascular disorders, diabetes prevention, and nervous system protection.(Qu et al., 2021) Tea catechins also have been related to several health benefits, including anti-inflammatory, antiviral, antibacterial, antifungal, anti-osteoporosis, anti-allergenic, anti-estrogenic, and photoprotective properties.

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Catechins and their metabolites can be absorbed by bacteria in the large intestine, resulting in small phenolic acids and valerolactones.(Baldi et al., 2020) GTCs are mainly digested by intestinal bacteria into smaller molecules. The gut microbiota plays a significant role in the biotransformation of catechins.(Su et al., 2024)
Tea catechins can promote the growth of good bacteria while inhibiting harmful micro bes. Polyphenols were therefore added to the list of compounds that may have prebiotic properties. Tea-microbiota interactions may provide health benefits by either direct microbial polyphenol metabolites or indirect activation of beneficial gut microorganisms. The gut microbiota has an important role in chronic diseases such obesity, diabetes, inflammatory bowel disease, and neurological disorders. Studies is focused on understanding the gut microbiota's role in food. Tea, a popular beverage worldwide, has been related to gut microorganisms due to its polyphenol content, leading many studies on the topic.(Pérez-Burillo et al., 2021)

Tea Catechins and Their Bioactivity

Absorption and Metabolism

Following oral ingestion, catechins undergoes limited systemic absorption due to limited bioavailability and extensive presystemic metabolism. Empirical evidence indicated (Kan et al., 2022) approximately 14% of epigallocatechin (EGC), 32% of epicatechin (EC), and 0.1% of epigallocatechin gallate (EGCG) ultimately becomes available for systemic action.

Liver and Colonic Metabolism

Once absorbed, catechins are delivered to liver through hepatic portal vein for metabolism, where they further undergo extensive biotransformation by phase II metabolic enzymes, and get converted into methylated, glucuronidated, sulfated derivatives.(Wang et al., 2020)
Unabsorbed catechins that reach the colon undergoes microbial catabolism, which results in the generation of low-molecular-weight phenolic metabolites, such as Hydroxyvaleric acid and Valerolactone, these get absorbed through the epithelium into the systemic circulation, where they contribute to their therapeutic effects.

Factors Affecting Bioavailability

Extraction method of catechins influences their bioavailability and highlight's the role of formulation in enhancing their absorption. In the study (Oh et al., 2021), using in vitro digestion model with Caco-2 cells, four formulations comparatively were investigated—loose-leaf tea, powdered tea, green tea extract (GTE; 35% catechins), and composite formulation (CATEPLUS™). When evaluated GTE (22.05%) and CATEPLUS™ (18.72%) showed higher epicatechin bio accessibility than powdered (2.30%) and loose-leaf tea (1.27%) CATEPLUS™ showed the highest cellular absorption of epicatechin (171.39 ± 5.39 ng/mg protein), surpassing GTE (57.38 ± 9.31), powdered (3.60 ± 0.67), and loose-leaf tea (2.94 ± 1.03).
Combining tea with targeted herbal infusions had been shown to significantly enhance bioavailability. Study demonstrated that (Ortiz-Islas et al., 2024) , white tea infused with linden flower exhibited up to a threefold increase in antioxidant activity compared to white tea alone because of this synergistic interaction of phenolic

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compounds, which improve catechin stability and absorption.
Strategic formulations of tea extracts and synergistic tea-herbal infusions present as a promising approach to optimize the therapeutic potential of tea catechins

Antioxidant property

Catechins are strong antioxidants that play key role in cellular redox homeostasis. They surpass other well-known antioxidants like glutathione, vitamin C, and other flavonoids in their ability to scavenge free radicals. This ability helps to prevent damage from reactive oxygen species. Furthermore, they had been shown (Kochman et al., 2020), to upregulate the activity of essential detoxifying enzymes, including glutathione peroxidase, catalase, and glutathione reductase. This dual approach of enzymatic upregulation and direct radical neutralization shields cellular structures from oxidative damage.

Anticancer property

EGCG demonstrated anticancer activity through variety of interconnected mechanisms (Tsouh Fokou et al., 2025) it slows down the progression of carcinogenesis and promotes apoptosis by upregulating TP53, Bax, and caspases (-3, -8, -9), while suppressing anti-apoptotic proteins such as Bcl-2 and C-Myc. EGCG also regulates cyclin-dependent kinases and their inhibitors (p21, p27). inducing cell cycle arrest at G1/S and G2/M phases. Moreover, it prevents tumor development and recurrence by inhibiting cancer stem cells regenerative potential and by exerting anti-angiogenic effects.
According to studies (Mazur et al., 2025) epigenetic modifications inhibit DNA methyltransferases, both directly by binding to the DNMT catalytic domain and indirectly by producing S-adenosyl-L-homocysteine that play role in leukemogenesis. EGCG functions as an epigenetic modulator by reversing CpG island hypermethylation. EGCG restores normal gene expression by modulating folate metabolism, downregulating the expression of histone deacetylase (HDAC) and by suppressing DNA/RNA synthesis. These multi-targeted actions highlight the EGCG's therapeutic potential in epigenetic cancer treatment.

Cardiovascular Protective property

Studies on the cardiovascular protective nature of catechins had demonstrated that they improve plasma lipid homeostasis by lowering levels of cholesterol, LDL, and triglycerides through various mechanisms, including inhibition of fatty acid synthesis, enhanced fecal cholesterol excretion, and reduced lipid absorption by altering lipase activity, which potentially leading to weight loss. Additionally, they seem to promote bile acid synthesis by inhibiting intestinal bile acid reabsorption and modulating genes involved in cholesterol metabolism, collectively contributing to the prevention of diet-induced obesity and preservation of endothelial function for blood pressure regulation. These multi-targeted actions reduce the risk of heart diseases. (Abiri et al., 2023)

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Glucose Metabolism property

Catechins contribute to glucose metabolism by reducing glucose absorption and blunting postprandial hyperglycemia by blocking intestinal sugar transporters. According to this study (Ni et al., 2020), EGCG is a strong inhibitor of intestinal cells' absorption of glucose. It does this by modulating the activity of important transporters like the sodium-dependent glucose transporter (SGLT1) and GLUTs (GLUT1, GLUT2, and GLUT5), which are responsible for transporting sugars from the gut into the bloodstream. Findings suggested that catechins could serve as dietary supplements to prevent Type 2 diabetes mellitus by controlling blood glucose levels after meals.

Covid preventive property

Inhibiting SARS-CoV-2 3CL protease, crucial enzyme required for viral replication, is the main way that catechins, and more especially epigallocatechin-3-gallate (EGCG), help reduce COVID-19 (Storozhuk et al., 2023). This inhibitory action is effective against the omicron variant's protease, despite a mutation in its sequence. They also act as zinc ionophores and enhance adaptive immunity, which contributes to their therapeutic potential against covid.

Non-Alcoholic Fatty Liver Disease Management property

Intake of catechins is promising in treatment of NAFLD. High doses of catechin intake had been shown in clinical studies (James et al., 2023) to significantly reduce hepatic fat accumulation, serum alanine aminotransferase (ALT) levels, and oxidative stress markers like urinary 8-isoprostane, which indicates enhanced liver function. Catechins help to reduce hepatic inflammation through their ability to inhibit the nuclear factor protein NF-κB, which causes liver damage. Catechins also decrease endotoxin translocation to the liver, a mechanism linked to the pathophysiology of non-alcoholic steatohepatitis (NASH). Furthermore, catechins suppress excessive lipogenesis and promote lipid oxidation by activating adenosine monophosphate-activated protein kinase (AMPK). These multitargeted activities emphasizes on the therapeutic potential of catechins as important agent in the prevention and treatment of NAFLD.

Bone Metabolism property

Catechins, particularly “epigallocatechin gallate” benefit bone metabolism by modulating both bone formation and resorption. Simultaneously catechins stimulates osteoblastic cells (bone formation) and inhibit osteoclastogenesis (bone resorption). By boosting the synthesis of bone-forming indicators such osteocalcin, alkaline phosphatase (ALP), and osterix, EGCG stimulates osteoblastic activity. By suppressing bone resorption mediators such as nuclear factor of activated T-cells cytoplasmic 1 (NF-ATc1) and tartrate-resistant acid phosphatase (TRAP), it prevents osteoclastogenesis. It also increases bone mineral density and works by suppressing pathways like RANKL/RANK, which are central to the regulation of osteoclast formation. Furthermore, catechins antioxidant and anti-inflammatory properties help to protect bone cells from oxidative stress-induced apoptosis and impaired mineralization. Apart from in vitro research (German et al., 2024), which indicates

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that EGCG can boost bone mineral density, especially in postmenopausal women and lowers the incidence of fractures

Neuroprotective property

Neural tissue is extremely sensitive to oxidative damage due to its elevated metabolic rate, lipid-rich composition, and limited antioxidant capacity. Study showed that EGCG prevents lipid peroxidation and iron-induced DNA damage. EGCG interacts with misfolded proteins like amyloid-β and α-synuclein in neurodegenerative illnesses like Alzheimer's, Parkinson's and Huntington's preventing the production of toxic aggregates and promoting the formation of non-toxic oligomers. Lewy body buildups and amyloid plaques are lessened as a result of this action. Because of its strong antioxidant properties, EGCG reduces oxidative stress, which in turn prevents protein misfolding and instability. Furthermore, by inhibiting microglial activation and cytokine release, EGCG reduces neuroinflammation and prevents the production of neurotoxic nitric oxide derivatives. These neuroprotective benefits demonstrate how EGCG may be used to treat neurodegenerative diseases. (Capasso et al., 2025)

Anti-inflammatory property

The inflammatory response is a complex process involving the activation of immune and inflammatory cells, the release of pro-inflammatory cytokines. These events are driven by the activation of transcription factors like NF-κB, which translocates to the nucleus and upregulate genes involved in inflammation. EGCG has been widely recognized for its anti-inflammatory effects, primarily through its regulation of key signaling pathways. In numerous studies (Musial et al., 2020) EGCG had been shown to suppress NF-κB activation, inhibit its nuclear translocation which leads to the downregulation of pro-inflammatory enzymes like iNOS and COX-2. Furthermore, EGCG's anti-inflammatory effects may also be attributed to its ability to modulate other signaling pathways, including the MAPK (mitogen-activated protein kinase) and PI3K/Akt (phosphatidylinositol 3-kinase/protein kinase B) pathways, which play important roles in the regulation of inflammation.

EFFECTS OF EGCG	DESCRIPTION	MECHANISMS	REFERENCES
LDL CHOLESTEROL REDUCTION	Lowers LDL levels, preventing atherosclerotic plaques	Inhibits LDL oxidation, reduces intestinal cholesterol absorption, suppresses cholesterol synthesis	(Abiri et al., 2023)

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ENDOTHELIAL FUNCTION IMPROVEMENT	Promotes arterial dilation and improves blood flow regulation	Neutralizes ROS, reduces oxidative stress, lowers inflammatory markers like TNF-α, inhibits myeloperoxidase	(Abiri et al., 2023)
OXIDATIVE STRESS REDUCTION	Increases serum antioxidant capacity and reduces oxidative damage	Neutralizes ROS and enhances antioxidant defense.	(Kochman et al.,2020)
BLOOD PRESSURE REDUCTION	Lowers systolic and diastolic blood pressure, improving cardiovascular control	Mitigates hypertension through antioxidant and anti-inflammatory effects	(Abiri et al., 2023)
INFLAMMATION REDUCTION	Decreases inflammatory markers (e.g., TNF-α) and suppresses inflammatory pathways	Regulates NF-κB pathways, reducing cytokine and adhesion molecule production.	(Musial et al., 2020)
EPIGENETIC EFFECTS	Modulates gene expression and inflammatory responses through epigenetic modifications	Influences DNMT, HAT, activates AMPK and mTOR pathways, regulates DNA methylation and histone acetylation	(James et al., 2023)
AUTOPHAGY PROMOTION	Enhances cellular turnover and protects endothelial cells from chronic stress	Activates signaling pathways such as AMPK and mTOR.	(Mazur et al., 2025)

Effect of Tea Catechins on Human Gut Microbiota:

By inhibiting harmful bacteria and promoting beneficial species like Bacteroides galacturonicus, Lactobacillus sp., Enterococcus caccae, Bifidobacterium catenulatum, Ruminococcus gauvreauii, and Escherichia coli, polyphenols like flavanols, including catechins, play a significant role in regulating the composition of the gut microbial community(Khairudin, Mhd Jalil et al. 2021). Studies on human fecal bacteria using batch-culture fermentation show that tea catechins inhibit the growth of pathogens such as C. difficile, C. perfringens, S. pyogenes, and S. pneumoniae. They also inhibit some commensal anaerobes, such as C. sporogenes, but they have no effect on the beneficial Bifidobacterium and Lactobacillus genera. More precisely, substances like (−)-epicatechin gallate, (+)-epicatechin gallate, and (−)-epicatechin inhibit detrimental C. histolyticum and Bacteroides-Clostridium groups while promoting the growth of Bifidobacterium and Lactobacillus/Enterococcus groups. By increasing the activity of

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fiber-fermenting bacteria, catechins promote the synthesis of short-chain fatty acids (SCFAs) like butyric, propionic, acetic, and formic acids, supporting gut health .(Zhao, Chen et al. 2024)A part from these effects, it has been demonstrated that tea catechins and related polyphenols make methicillin-resistant Staphylococcus aureus more sensitive to antibiotics. Catechin gallates may intercalate into bacterial phospholipid bilayers, according to Taylor et al. [115], interfering with cytoplasmic membrane functions essential for virulence and antibiotic resistance [20,115]. (Makarewicz, Drożdż et al. 2021)Studies on gut microbial diversity also shed light on the connection between health status and microbiota. For instance, it has been discovered that obese people have substantially lower Chao1 richness than lean people, and that the trend for Shannon diversity is similar but not statistically significant.(Sasaki, Vodovotz et al. 2022) Tea catechins' abundant presence in Camellia sinensis, where they make up the majority of the flavonoid class and include epicatechin, epigallocatechin, epicatechin-3-gallate, and epigallocatechin-3-gallate, as well as flavanols like myricetin, kaempferol, and quercetin, supports their beneficial effects [100]. Despite being less abundant than extractable polyphenols (EPPs), non-extractable polyphenols (NEPPs) still have α-glucosidase inhibitory qualities and a higher antioxidant activity than vitamin C. Gallocatechin, epigallocatechin, catechin, epicatechin, and caffeine are particularly abundant in green tea [119], and its phenolic compounds lower the number of Clostridium perfringens and other Clostridium species [100]. These results are supported by human intervention studies. For example, one study found that the percentage of Bifidobacteria rose while drinking green tea and fell after stopping, suggesting that tea may have prebiotic-like effects. These results are supported by human intervention studies. For example, one study found that the percentage of Bifidobacteria rose while drinking green tea and fell after stopping, suggesting that tea may have prebiotic-like effects by enhancing beneficial microbial populations without changing the species composition.(Nemzer, Al-Taher et al. 2025) The structural variety and metabolism of polyphenols are important factors contributing to these effects. In the large intestine, the majority of green tea catechins (GTCs) undergo extensive microbial biotransformation after evading absorption in the upper gut. The gut microbiota transforms them into bioactive metabolites like phenolic acids, butyrate, acetate, and phenyl-γ-valerolactones, increasing the biological activities of GTC-derived compounds and their bioavailability.(Liu, Gan et al. 2024)

Maintaining a balance between pathogenic and beneficial species depends on this two-way interaction, in which gut microbes metabolize catechins while catechins reshape microbial communities. The health benefits of tea catechins ultimately depend on individual differences in gut microbiota composition and metabolic capacity.

Catechins and Microbial Composition

Research has concentrated on the uses of tea polyphenols (TPs) in food systems, and their health benefits are well known. Studies have examined the forms of TPs and their mechanisms of interaction with important food components, including proteins and polysaccharides, in order to better utilize them in food. Furthermore, liposomes, nanoemulsions, and nanoparticles are examples of bio-based delivery systems that

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have been investigated to maximize their uses, boost bioactivity, and improve stability. TPs are potent active ingredients that hold great promise for use in functional foods to improve human health.(Niu, Shang et al. 2024) The control of gut microbiota (GM) is one of the most significant ways that TPs function. Studies conducted in vivo and in vitro have demonstrated that TPs enrich beneficial bacteria like Bacteroidetes and Prevotella and affect the composition of GM. According to Chen et al. (2018a), TPs significantly decreased the ratio of Firmicutes to Bacteroidetes in the gut of mice given a high-fat diet. Similarly, FBTPS-3, a purified fraction of crude FBTPS, was shown by Wang et al. (2019) to enrich the metabolic pathways of starch and sucrose while stimulating beneficial microbiota such as Bacteroides, Megasphaera, and Prevotella. Additionally, by improving GM dysbiosis, boosting bacterial diversity, and decreasing the abundance of detrimental families like Erysipelotrichaceae, Coriobacteriaceae, and Streptococcaceae, Chen et al. (2018b) verified that TPs could mitigate metabolic syndrome. These results imply that by altering the balance of gut microbes, indigestible portions of TPs that make it to the large intestine may have a significant impact on host metabolism. (Wu, Gu et al. 2023)The metabolic profiles of (+)-catechin have also been found to differ significantly between individuals, with 5-(3′,4′-dihydroxyphenyl)-γ-valerolactone being one of the main metabolites. Despite significant intrinsic variability in fecal microbiota, participants were stratified into fast, medium, and slow converters based on the microbial metabolic rate of catechins. ASVs with the ability to cleave the C-ring (ASV233_Eggerthella and ASV402_Eubacterium), dihydroxylate the B-ring (ASV402_Eubacterium), and produce short-chain fatty acids (SCFAs) were more abundant in fast converters, according to correlations between these groups and microbiota characteristics. This stratification demonstrates how interindividual variability in the health benefits of catechins is influenced by variations in microbial composit.(Li, Van Herreweghen et al. 2022) The majority of catechins are metabolized by the gut microbiota in the colon because intestinal absorption is comparatively low. The positive cardio metabolic effects linked to catechin consumption are thought to be partially caused by metabolites derived from the microbiota. However, microbial metabolite profiles also differ greatly between individuals and between colon regions due to variations in gut microbial composition and load. According to one study, donor microbiota was divided into two categories: fast-converting and slow-converting. These metabolic distinctions remained after inoculation into the dynamic gut model SHIME, thereby highlighting the significance of microbial efficiency in catechin metabolism.(Li, Van Herreweghen et al. 2021)

Studies on green tea have shown additional evidence of microbiota modulation in addition to catechin metabolism. Green tea and catechins have generally been demonstrated to decrease the abundance of pathogenic bacteria, such as Clostridium spp. (Sakanaka et al., 2000; Cui et al., 2012), while increasing beneficial genera, such as Bifidobacterium and Lactobacillus (Tzounis et al., 2008; Zhang et al., 2013; Sun et al., 2018). According to more recent research, consumption of green tea influences microbiota at the species level as opposed to at higher taxonomic levels. For example, green tea administration increased the amount of F. plautii, a key flavonoid degrader in the human gut that can convert quercetin to butyrate (Mikami et al., 2021; Similarly, the high amino acid content of green tea may help P. excrementihominis, which

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depends on amino acids for its metabolic processes (Ju et al., 2019) (Zhou et al., 2022). All of these findings point to the possibility that regular consumption of green tea, as opposed to isolated catechins or EGCG alone, may influence particular microbial species. Current studies use measures of circulating endotoxins as primary outcomes in order to better understand these mechanisms. Secondary outcomes include intestinal permeability, microbial diversity and composition, inflammatory responses, biomarkers of endotoxin exposure, catechins, and their microbiota-derived metabolites.(Hodges, Zhu et al. 2020) Lastly, it should be mentioned that the degree of oxidation and processing affect the chemical makeup of tea and, in turn, its flavor Green tea and other less oxidized teas have higher levels of catechins like epigallocatechin gallate (EGCG), while black tea and other more oxidized teas have higher levels of polymerization products like arubigins and flavonoids. This distinction not only affects the flavor—green tea has a lighter flavor, whereas black tea has a richer, more robust flavor—but it also establishes the bioactive potential. The final tea composition is determined by a number of factors, including brewing, processing, terroir, production methods, and variety. Therefore, to guarantee consistency and dependability in scientific findings, plant extracts used in research must be thoroughly characterized for their chemical content.(Cerbin-Koczorowska, Waszyk-Nowaczyk et al. 2021)

Mechanism of Interaction

Evidence from science Interaction Mechanism The gut microbiota's enzymatic hydrolysis of unabsorbed polyphenols produces monomers or dimers, which are then further broken down into small-molecule bioactives like benzoic acid, hydroxyphenylacetic acid, and other derivatives. These metabolites aid in the body's absorption, support host health, and take part in important metabolic pathways (Corrêa et al., 2019; Stevens & Maier, 2016; Marhuenda-Muñoz et al., 2019; Sáyago-Ayerdi et al., 2021)(Zhou, Cheng et al. 2025). For smaller catechins, the systemic bioavailability is relatively high; for galloyl catechins, it is lower; and for oligomers and polymers derived from black tea, it is very low or nonexistent. The in vivo effects of large molecular weight TPP may not always be reflected in the biological activities seen in vitro because of its inability to enter systemic circulation efficiently.(Yang, Zhang et al. 2025) Evidence from science The gut microbiota biotransforms the majority of ingested green tea catechins (GTCs) into low-molecular-weight metabolites like phenyl-γ-valerolactones, phenolic acids, butyrate, and acetate in the large intestinal lumen. This microbial metabolism enhances the biological activity of metabolites derived from catechins while also increasing their overall bioavailability.(Liu, Gan et al. 2024) Crucially, polyphenols and the bacterial byproducts they produce have a reciprocal effect on the composition and activity of the gut microbiota. While suppressing pathogenic strains such as Helicobacter pylori, Escherichia coli O157:H7, Prevotella, Clostridium difficile, and Clostridium perfringens, they promote the growth of beneficial bacteria like Bifidobacteriaceae and Lactobacillaceae Thus, a diet high in polyphenols promotes a healthier microbial balance by decreasing Enterococcus, Enterobacteriaceae, and the Firmicutes/Bacteroidetes ratio and increasing Lactobacillus, Bifidobacterium, Roseburia, Akkermansia, Faecalibacterium, and Prevotella (Zhao, Chen et al.

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2024).Recent research also emphasizes how the gut microbiota improves the absorption of herbal products and converts their active ingredients—like quercetin, ginsenosides, and catechins—into bioactive metabolites that have positive health effects(Santangelo, Silvestrini et al. 2019) These conclusions are further supported by experimental data. For instance, it was demonstrated that green tea catechins (GTCs) underwent significant microbial catabolism, producing 35 different metabolites that were identified by UHPLC-Orbitrap-MS/MS analysis. The most prevalent catechin, EGCG, was broken down quickly in 12 hours, but during fermentation, EGC, ECG, and EC first rose and then fell. According to these findings, EGCG undergoes hydrolysis, oxidation, C-ring opening, and additional modifications during metabolism, resulting in a variety of bioactive compounds that support the health advantages of polyphenol consumption(Su, Hu et al. 2024).

Scientific Evidence

Evidence from science The primary bioactive components found in green tea polyphenols are catechins, also known as flavan-3-ols. (−)-epicatechin, (−)-epigallocatechin, (−)-epicatechin-3-gallate, and (−)-epigallocatechin-3-gallate are the four primary catechins found in green tea. Although catechins are not necessary for human nutrition, they do play a significant role in enhancing human health by preventing a number of diseases. Antioxidant, antimicrobial, antiobesity, antioxidative, anti-inflammatory, antiviral, and anticancer properties are just a few of the many biological roles that catechins are known for.(Li, Van Herreweghen et al. 2022) The evidence supporting the use of dietary polyphenols in the treatment of intestinal diseases in children, the impact of children's physiological traits on the effectiveness of polyphenols, and a final look at the new dosage form of polyphenols in pediatrics.(Jiang, Liu et al. 2024)

Evidence from science Together with a wealth of experimental and theoretical data, the observation points to a common binding mode for catechins, which is defined by the creation of hydrophobic interactions and hydrogen bonds with their target (Renzetti, Betts et al. 2020)The preclinical evidence is supported by the findings of recent clinical investigations. There has been a discussion of the difficulties and drawbacks of the current understanding of catechin bioactivities, as well as helpful suggestions for future interventions that will maximize the translational benefits of green tea.(Sidhu, Vasundhara et al. 2024)

Influence of Tea Catechins on Health via Gut Microbiota

Tea is the second most consumed beverage in the world. Tea alleviated the gut microbiota imbalance caused by high-fat diet-induced obesity, diabetes, and ultraviolet-induced damage. A number of diseases are linked to dysbiosis, or an imbalance in the gut microbiota. These illnesses include cancer, multiple sclerosis, diabetes, obesity, liver and cardiovascular disorders, and neurological diseases. Therefore, it has been suggested that the gut microbiota is a possible treatment target for many illnesses.(Khairudin et al., 2021) The anti-cancer, anti-obesity, anti-diabetic, anti-cardiovascular, anti-infectious, or hepatoprotective properties of (-)-epigallocatechin-3-gallate (EGCG) and (-)-epicatechin-3-gallate (ECG) have prompted numerous investigations in recent years. The application of catechins to

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neurodegenerative diseases, such as Parkinson's and Alzheimer's, has been the subject of certain studies. The potential use of these antioxidants as therapeutic agents in less common neurological conditions, neurodegenerative diseases, and age-related cognitive decline.(Sebastiani et al., 2021)The primary substance thought to be in charge of tea's antioxidant properties is catechins, which are the most prevalent antioxidants in green tea.The amount and location of hydroxyl groups or their substituents, as well as the structure of molecules, greatly influence the antioxidant qualities of catechins. By modifying a number of intracellular signaling cascades, ECGC also has strong anti-inflammatory, anti-fibrotic, pro-apoptotic, anti-tumorous, and metabolic effects. Given this information, EGCG may be useful in treating respiratory conditions whose pathophysiology involves acute or chronic oxidative, fibrotic, and inflammatory processes.(Mokra et al., 2022)

Catechin and gut microbiota role in Colorectal Cancer (Catechins' role in cancer prevention and their interaction with gut microbiota)

Colorectal cancer (CRC) is a major global health concern that has a big financial impact on patients, communities, and healthcare systems. These effects include direct medical expenses, lost productivity, and intangibles like stress and a lower standard of living.(Thulasinathan et al., 2025)CRC and rebalance dysbiosis: By reorienting the microbiome away from pathobionts linked to carcinogenesis and toward more advantageous taxa, tea polyphenols can contribute to the restoration of a more robust ecosystem.(X. Wang et al., 2022) Active metabolites resulting from microbial biotransformation: Catechins are broken down by gut bacteria into smaller, more bioavailable phenolics (like γ-valerolactones) that have anti-inflammatory and antiproliferative properties in the colon (Pérez-Burillo et al., 2021) Direct anti-inflammatory effects that are triggered by microbes and hosts: Catechins hydrate colon and immune cells' NF-κB-driven cytokines and adhesion molecules; they also reduce inflammation brought on by bacteria linked to colorectal cancer.(Wang et al., 2020)Focusing on microorganisms that promote tumor growth, such as Fusobacterium nucleatum, While catechins (EGCG, theaflavins) inhibit its growth and virulence and lessen microbe-induced inflammatory signaling and biofilms, F. nucleatum promotes the progression and metastasis of colorectal cancer.(Zhang et al., 2022)Tumor burden reduction in animal models: In APC^Min/+ mice APC = Adenomatous Polyposis Coli (a tumor suppressor gene). Min = Multiple Intestinal Neoplasia (the specific mutation carried by the mouse).EGCG reduces the number of intestinal tumors and modifies gut microbes during chemoprevention.(Wang et al., 2017)

Cardiovascular Health (Impact on cholesterol metabolism, blood pressure, and heart disease prevention)

Catechin, also known as EPI, protects heart cells (NMCMs) from cell death after 12 hours without oxygen by increasing the Bcl-2 to Bax ratio, lowering cleaved caspase-3, and activating the PTEN/PI3K/Akt pathway. It also shields NRCMs from damage and cell death after 16 hours of low oxygen. (Ferenczyová et al., 2021)Catechins, flavanol derivatives from the Chinese herbal medicine Acacia Catechu, have anti-inflammatory, antioxidant, and nutrient-balancing properties, showing therapeutic potential in cardiovascular diseases such as atherosclerosis, hypertension, heart failure,

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and cardiomyopathy.(Chen et al., 2025)Mechanisms in cardiovascular: By activating SIRT1 and enhancing calcium handling, catechins in diabetic models support mitochondrial function and cardiomyocyte contractility. Through SIRT6/AMPK/SREBP1/FAS signaling, EGCG may alter hepatic lipid pathways, lowering triglycerides and increasing phospholipid synthesis in rats lacking the leptin receptor.(Wu et al., 2023)Meta-analysis of Endothelial Function: Research indicates that supplementing with catechins enhances flow-mediated dilatation (FMD), decreases pulse wave velocity (PWV), and lowers augmentation index (AI), all of which are indicators of vascular health.(Shafabakhsh et al., 2020)

Mechanism	**Actions**	
Antioxidant	Scavenges ROS; boosts antioxidant enzymes	(Guo et al., 2023)
Lipid Modulation	Lowers total & LDL cholesterol; inhibits lipid absorption	(Guo et al., 2023)
Vascular Function	Enhances NO-mediated vasodilation	Guo et al., 2023)
Anti-Inflammatory	Inhibits NF-κB, cytokines, and adhesion molecules	Guo et al., 2023)
Anti-Atherosclerotic	Blocks angiogenesis, leukocyte adhesion, and VSMC growth	Guo et al., 2023)
Antithrombotic	Inhibits platelet aggregation and clot formation	Guo et al., 2023)
Metabolic/Cardiac Effects	Activates SIRT1/SIRT6, improves mitochondrial & lipid metabolism (Guo et al., 2023)	Guo et al., 2023)

Green tea significantly reduced total cholesterol (TC) by approximately 4.66 mg/dL and LDL by approximately 4.55 mg/dL compared to control, according to a meta-analysis (2020) based on 31 trials (~3,321 subjects). HDL and triglycerides were not significantly affected. (Xu et al., 2020) Women who are overweight or obese (2024): A meta-analysis involving 1,818 participants revealed decreases in LDL (–4.49 mg/dL) and TC (–4.45 mg/dL). Green tea also significantly decreased TG in individuals with elevated baseline triglycerides, and HDL increased in obese subjects. (Li et al., 2023).

Obesity (Tea catechins as a potential intervention in obesity via gut microbiota modulation)

Research has demonstrated the positive impact of tea catechins in reducing obesity. In C57BL/6J mice given a high-fat diet (HFD), the current study aims to investigate the underlying processes relating the intestinal microbiota and the anti-obesity properties of green tea, oolong tea, and black tea catechins.(Liu et al., 2023) Changes in PPAR

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Signaling: Peroxisome proliferator-activated receptors (PPARs) in adipose tissues are impacted by green tea catechins (GTCs). In obese rats fed a high-fat diet, GTCs: elevated PPARγ (Peroxisome Proliferator-Activated Receptor Gamma) in subcutaneous fat, which encourages better fat storage, and reduced visceral fat. PPARγ and PPARδ were upregulated in brown, visceral, and subcutaneous fat. Increased expression of genes involved in fatty acid oxidation in fat. These modifications aid in lowering triglyceride levels and body.(Guo et al., 2023) Microbial metabolism of catechins → active metabolites: Low parent-compound bioavailability means much of the action occurs in the colon, where microbes convert catechins to smaller phenolics that may drive metabolic benefits (e.g., anti-inflammatory, redox, energy harvest effects. Green tea catechins offer metabolic health benefits through intestinal-level bioactivities, including lipid absorption, inflammation reduction, gut barrier dysfunction, and modulation of mucosal nuclear receptor signaling. Clinical studies support these benefits, but current understanding is challenged.(Sidhu et al., 2024) GTE (Green Tea Extract) led to a small decline in diastolic BP.(Zamani et al., 2023)

Anti-inflammatory properties

The study found that oral EGCG improved the anti-inflammatory response and colon barrier health in mice, while rectal delivery did not. Oral EGCG also altered gut bacteria, raising Akkermansia levels and boosting butyrate, a short-chain fatty acid. Mice given EGCG before DSS had less severe colitis and more short-chain fatty acid-producing bacteria. Both early EGCG treatment and FMT supported these findings, suggesting that EGCG administered orally reduces colitis. (Wu et al.) Green tea supplementation dramatically improves oxidative-stress markers, such as lower malondialdehyde (MDA), higher total antioxidant capacity (TAC), superoxide dismutase (SOD), and glutathione peroxidase (GPX), according to a meta-analysis of randomized controlled trials in adults. However, aside from a slight decrease in IL-1β, it did not affect the majority of inflammatory cytokines (CRP, IL-6, and TNF-α). (Dehzad et al., 2025) Green tea dramatically lowered TNF-α levels in metabolic syndrome patients, but not CRP or IL-6. Interestingly, CRP rose in trials lasting less than eight weeks, and treatment duration was associated with higher IL-6 levels. (de Oliveira Assis et al., 2024) Modulation of Signaling Pathways: Inflammatory pathways like NF-KB, MAPK (including ERK, JNK, and p38), AP-1, and STAT1 are suppressed by catechins, particularly EGCG. They activate the Keap1/Nrf2/ARE protective pathways while inhibiting COX enzymes and suppressing pro-inflammatory cytokines (TNF-α, IL-1, IL-6, and IL-8). (Radeva-Ilieva et al., 2025) Synovial Cells in Rheumatoid Arthritis: Targeting important inflammatory drivers, EGCG and EGC—but not EC—downregulated TAK1, p38, and NF-KB and decreased the production of IL-6, IL-8, and MMP-2 in human rheumatoid arthritis synovial fibroblasts. The effects of EGCG were reversible and might have been less harmful.(Fechtner et al., 2017) Protection of the Gut Epithelium: The mechanism by which green tea may maintain gut integrity and reduce inflammation is suggested by the fact that EGCG shields intestinal epithelial cells from cytokine-induced barrier damage. (Rosenthal et al., 2025)

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Gut-Related Disorders (Modulation of gut microbiota in conditions like irritable bowel syndrome (IBS), Crohn's disease, and ulcerative colitis)

Tea polyphenols (TP) interact with gut bacteria, promoting a healthy balance. Understanding the relationship between TP –full and gut bacteria can help address sleep problems and support overall health.(Hong et al., 2022)The body absorbs aglycones from the small intestine, but polyphenols in food need to be broken down by gut bacteria or enzymes. These bacteria influence the metabolism of polyphenols and can alter the composition of the gut microbiota." Absorption processes in the small intestine and liver facilitate their elimination through urine.(Andrade et al., 2024)Chronic inflammatory illnesses of the gastrointestinal tract, inflammatory bowel diseases (IBD), include Crohn's disease and ulcerative colitis. In recent years, their prevalence has increased globally. IBD is linked to disruption of the gut microbiota, and individuals with IBD showed a marked decrease in certain bacteria that produce short-chain fatty acids (SCFAs). (Wu et al., 2021)In DSS-induced colitis mice, treatment with both tea polysaccharides (TPS) and polyphenols (TPP) restored body/colon health, reinforced mucosal barriers, and increased Lactobacillus abundance while reducing Proteobacteria and Enterobacteriaceae—key markers of dysbiosis in IBD (Chen et al., 2022) Tibetan Tea Extract (TTE) mitigated ulcerative colitis symptoms in mice by upregulating beneficial bacteria (e.g., Lactobacillus reuteri and Bifidobacterium choerinum) and downregulating inflammatory pathways like TLR4/MyD88/NF-κB (N. Wang et al., 2022). Tea catechin Polyphenols in UC Model: A study using tea catechin polyphenols found they activate the Nrf2–HO-1–NQO-1 antioxidant pathway, and that they help restore microbial balance disrupted in ulcerative colitis(Chen et al., 2023). Theabrownin from Fu Brick Tea. Though the detailed evidence isn't accessible, this compound reportedly ameliorates UC by shaping the gut microbiota and influencing tryptophan metabolism—a key immune regulator. (Yang et al., 2023) Liupao tea modulated microbiota composition and SCFA production, with correlations showing reduced inflammatory markers (IL-1β, IL-6, TNF-α) and oxidative stress—suggesting therapeutic potential in colitis. (Ming et al., 2025) In this pathogenic colitis model, GTE showed antibacterial effects, preserved epithelial structures, and dampened inflammatory signals (e.g., TNF-α, COX-2, iNOS), while boosting epithelial proliferation markers.(Kim et al., 2021)

Neuroprotective Effects (Potential effects of tea catechins on brain health via microbiota modulation)

The intestinal metabolites of TP are essential for preventing injury to the brain neurons and preserving the stable state of intestinal flora. We will be able to increase the therapeutic uses of TP if we have a thorough understanding of the relationship between TP and intestinal microbiota, its impact on protecting brain nerves, and the underlying mechanism involved. (Y. Zhang et al., 2021) Down syndrome, a genetic disorder causing intellectual disability, causes abnormal brain connections, resulting in learning and memory difficulties.(Li et al., 2024) Tea polyphenols alter gut flora to have an indirect effect on the central nervous system. Catechins restore microbiota balance and have neuroprotective effects through vagal, immune, neuroendocrine, and microbial metabolite pathways. (Z. Zhang et al., 2021) Inhibition of Microglial Activation: Catechins (notably EGCG) inhibit microglial activation—suppressing

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TNF-α, IL-1β, IL-6 via NF-KB, Nrf2, and TLR4/NF-KB pathways—thus reducing neuroinflammation and potentially slowing neurodegeneration.(Farkhondeh et al., 2020) Broad-Spectrum Neuroprotection: In relation to Alzheimer's, Parkinson's, multiple sclerosis, and cognitive impairments, catechins exhibit a number of neuroprotective mechanisms, including anti-inflammatory, antioxidant, metal chelation, inhibition of tau phosphorylation and amyloid-β aggregation, decrease in alpha-synuclein, and dopamine enhancement. (Afzal et al., 2022) Microbiota, polyphenols, aging, and brain health: The interaction of polyphenols and gut microbiota is crucial for brain aging. Through the gut microbiota, polyphenols (including the catechins found in tea) regulate age-related neuroinflammation.(Sarubbo et al., 2023) It should be noted that certain phytochemicals, such as tea polyphenols, alter the gut microbiota and interact with the immune and neurotransmitter systems to affect neurological conditions like Parkinson's disease, multiple sclerosis, depression, anxiety, and autism spectrum disorders. (Yang et al., 2025)

Immunoregulatory Effects

Enhancement of $CD4^+$ T-cell and NK cell activity. Green tea catechin metabolites such as EGC-M5 significantly boost $CD4^+$ T-cell function and NK cell cytotoxic activity in vivo.(Kim et al., 2016)Modulation of Th1/Th17 vs. Treg balance: In models of autoimmune conditions like experimental colitis, EGCG suppresses pro-inflammatory cytokines (IL-6, IL-17) while elevating anti-inflammatory mediators (IL-10, TGF-β1), shifting the immune balance toward Treg dominance. It also inhibits NF-KB and AP-1 signaling.(Moudgil & Venkatesha, 2022) Dendritic cell and plasmacytoid dendritic cell (PDC) modulation: Recent research shows EGC-M5 (a catechin metabolite) increases PDC populations, enhances MHC-II expression, and induces IL-12 and type-I interferon production—key drivers of powerful T-cell and NK-cell immunity. (Kumazoe et al., 2025)

Regulation of signaling molecules secretion:

Effect of green tea on CRP:A meta-analysis of 13 studies reported that green tea supplementation did not significantly affect C-reactive protein (CRP) levels (0.2613 mg/dL; 95% CI: −0.1401 to 0.6626; P = 0.2021). However, the findings were limited by considerable between-study heterogeneity ($P \leq 0.0001$; $I^2 = 88.69\%$).Effect on TNF-α:A meta-analysis of three randomized controlled trials (RCTs) demonstrated that green tea supplementation significantly reduced tumor necrosis factor-alpha (TNF-α) levels (−0.4293 pg/mL; 95% CI: −0.7821 to −0.0764; P = 0.0171). No heterogeneity was observed (P = 0.4106; $I^2 = 0\%$).Green tea's impact on IL-6: Green tea supplementation did not significantly alter serum IL-6 levels (-0.6409 pg/mL; 95% CI, -1.6139 to 0.3321; P=0.0722), according to a meta-analysis involving five studies. There was also between-study heterogeneity (P=0.0002, 12=81.70%) (Fig. 4). Heterogeneity was not significantly caused by mean age, research design, treatment duration, dose, sex, or kind of intervention, according to subgroup analysis.(de Oliveira Assis et al., 2024)

Grape seed proanthocyanidin extract (GSPE) is a natural source of flavan-3-ols, including catechin and epicatechin monomers along with their oligomers. GSPE has

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been reported to provide protective effects against obesity and metabolic syndrome, partly by modulating the enteroendocrine system. Not all compounds in GSPE are absorbed in the small intestine; some reach the colon, where they undergo microbial metabolism. Both unmetabolized forms (such as catechin, epicatechin, and oligomers) and their metabolites can interact with enteroendocrine cells distributed throughout the gastrointestinal tract. In animal models, GSPE treatment has been shown to acutely reduce food intake, partly mediated by an increase in glucagon-like peptide-1 (GLP-1). Ex vivo studies further demonstrated that GSPE directly stimulates the release of GLP-1 and peptide YY (PYY). However, the specific compounds responsible for these effects remain uncertain, as monomeric and polymeric molecules may have distinct roles in hormone regulation. GSPE influenced entero-hormone secretion in pig intestinal segments. At 50 mg/L, GSPE increased peptide YY (PYY) secretion in the duodenum. At 50 and 100 mg/L, it enhanced basolateral glucagon-like peptide-1 (GLP-1) secretion in the ascending colon. In the descending colon, 100 mg/L GSPE significantly elevated PYY but had no effect on GLP-1. Catechin and epicatechin, purified phenolic forms of GSPE, were also found to stimulate cholecystokinin (CCK) secretion.(Grau-Bove et al., 2020)

Beyond gut hormone regulation, epigallocatechin gallate (EGCG), the most abundant catechin in green tea, has been extensively studied for its anti-inflammatory and anticancer effects. Cyclooxygenase-2 (COX-2) overexpression is strongly linked with cancer progression. In animal models, oral administration of EGCG-enriched green tea extract (GTE) inhibited COX-2 expression in mouse skin exposed to the tumor promoter TPA (12-O-tetradecanoylphorbol-13-acetate). Similarly, in human mammary epithelial cells, EGCG downregulated COX-2 following TPA stimulation. This effect was mediated through inhibition of upstream signaling enzymes, including p38 mitogen-activated protein kinase (MAPK) and extracellular signal-regulated kinase (ERK). Pretreatment with EGCG or GTE suppressed ERK activation and reduced the catalytic activity of both p38 MAPK and ERK.(Zheng et al., 2024)

EGCG suppresses the nuclear transcription factor NF-κB, thereby reducing cytokine-driven inflammatory responses. In human bronchial epithelial cells, EGCG inhibited NF-κB-p65 binding to κB sites, decreasing transcriptional activity. This inhibition occurred through covalent interaction with cysteine residues, as confirmed by blocking sulfhydryl groups with S-carboxymethylation. EGCG also reduced phosphorylation of IκBα and suppressed ERK and p38 MAPK activity. (Lakshmi et al., 2020)Furthermore, in melanoma models, EGCG inhibited nuclear translocation of NF-κB subunits p65 and p50, suppressed cell proliferation, and reduced melanin accumulation and secretion. GTE catechins also influenced ERK signaling and inhibited the transcription factor MiTF.(Zheng et al., 2024)

The mechanisms by which EGCG regulates matrix metalloproteinase (MMP) activity include:

Suppressing MMP gene expression
Preventing activation of proMMPs to active MMPs
Directly inhibiting MMP enzymatic activity
Modulating tissue inhibitors of metalloproteinases (TIMPs)
Reducing growth factor receptor signaling
Controlling cytokine release from cancer cells.

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By downregulating NF-κB, EGCG decreases MMP-9 gene expression, contributing to reduced tumor invasion and metastasis(Tanabe et al., 2023).
In addition to its anti-inflammatory and anticancer effects,EGCG also exhibits neuroprotective effects by inhibiting microglial activation, thereby reducing cytokine release and receptor signaling. It suppresses inducible nitric oxide synthase (iNOS) activity by blocking NF-κB binding to the iNOS promoter, lowering NO production and protein levels in LPS-induced microglia. In addition, EGCG enhances antioxidant defense through activation of the Nrf2-ARE (nuclear factor erythroid 2-related factor 2/antioxidant response element) pathway, which upregulates antioxidant molecules and enzymes. Together, these actions decrease neuroinflammation and improve cellular protection.(Xiao et al., 2025)

Human and Animal trials

Several clinical trials show strong evidence of how catechins balance the gut microbiota and improve the intestinal barrier. In healthy adults and those with metabolic disorders, a double-blind, placebo-controlled trial was carried (Zeng et al., 2024). The study found that the daily intake of green tea extract (GTE) confection delivering catechins, without increasing systemic inflammation in either group, lowered the level of glucose and circulating endotoxins, which reduced gut inflammation and small intestinal permeability. These effects were associated to favorable changes in fecal inflammatory markers.
A randomized, double-blind study was conducted which assessed the effects of matcha green tea on human fecal microbiota. The results showed a significant increase in the number of beneficial bacteria such as Coprococcus, as well as a decrease in the number of potentially pathogenic taxa like Fusobacterium. Mechanistic evidence of modulated gut microbiota is also provided by this trials (Morishima et al., 2023). This aligns with a review by Khairudin et al. (2021), which observed that tea polyphenols, specifically catechins, consistently improved the diversity of microorganisms and beneficial taxa in animal trials. Due to the different composition of the gut microbiota from individual to individual, the results from human trials were more deviated. Despite that, the overall evidence demonstrated increased levels of Bifidobacterium and positive ratios of Firmicutes and Bacteroidetes, which manifested the prebiotic role of catechins.
In obese mice, co-administration of green tea catechins and citrus-cryptoxanthin reduced pro-inflammatory agents and body weight, which indicated that they are involved in anti-inflammatory and anti-obesity effects. Both together showed improved levels of M2 macrophages-associated cytokines (anti-inflammatory) and adiponectin, and reduced levels of M1 macrophages-related cytokines (pro-inflammatory) (Nakadate et al., 2023). Another trial demonstrated that by restoring microbial balance, reducing lipid accumulation, iron loading and hepatic injury, EGCG protected mice from nonalcoholic steatohepatitis caused by a diet deficient in choline and methionine (Ning et al., 2020). White tea stored in mice improved DSS (Dextran Sodium Sulfate)-induced ulcerative colitis and showed positive results. Changes in the composition of the gut microbiome, increased SCFA levels, and decreased pathogenic bacteria such as Bacteroides and Escherichia-Shigella significantly reduced the pathological symptoms caused by DSS (Lin et al., 2024).

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Systemic effects and effects on the gastrointestinal tract are also widely emphasized in further studies. At the cellular level, EGCG has been shown to maintain intestinal barrier and lessen cell deaths, by protecting intestinal epithelial cells from pro-inflammatory cytokines like INF-γ and TNF-α (Rosenthal et al., 2025). The supplementation of tea catechins in poultry showed improved intestinal morphology by removing free radicals and reducing oxidative damage. It also decreased harmful bacteria such as Clostridium, Enterococcus, and Escherichia coli and enhanced the production of Bifidobacterium (Tian et al., 2025). The better local immune responses had been shown in mice with cutaneous leishmaniasis when treated topically with ECGC (Sosa et al., 2020). This suggests that there are systemic benefits of catechins linked to the gut-immune connection.

The pharmacological and toxicological aspects of catechins also received consideration. Del Carmen Garcia-Rodriguez & Kacew (2025), when they assessed genotoxic plus antigenotoxic effects of catechins, reported that catechins protect DNA by reducing oxidative damage or they damage it by acting as pro oxidants at higher doses. Thus, in exploiting gut health benefits in clinical practice, dose and bioavailability play important roles. Even though catechins are important for the prevention of intestinal diseases, their systemic absorption and potential interactions with certain drugs should be carefully considered (Radeva-Ilieva et al., 2025). The other properties of catechins include anticancer, antibacterial and systemic effects, but gut microbiota modulation is one of the core mechanism of catechins (Zhao et al., 2022).

Overall, evidence from human and animal trials firmly supported the function of tea catechins particularly EGCG in maintaining gastrointestinal well-being by modulating microbiota. By increasing beneficial bacteria populations, decreasing pathogenic taxa, enhancing gut barrier integrity, and overall suppress inflammatory states, catechins are able to show a similar regulatory pattern across health and disease states. The convergence of clinical, animal, and cellular studies emphasizes the potential significance of catechins as microbiota-targeted therapies supporting gut health.

Challenges and Future Directions

Catechins have been studied for many years, and their health benefits are well recognized, but several issues still limit their real use in medicine or food products. One of the biggest issue is their poor bioavailability and stability. To address this issue, Rashidinejad et al. (2021) examined nanodelivery systems, while Ruengdech et al. (2025) used foam-mat freeze drying and encapsulation. Both approaches showed encouraging results, but the concern is that the experiments were carried out in vitro and that there are a limited number of human studies validating their effectiveness. Until human trials validate these methods, there will remain a gap between laboratory findings and practical application. The moderate amounts of ECGC are safe. But a study reported that higher doses of EGCG could cause hepatotoxicity in some women of reproductive age, which created the need for more long term studies to evaluate the safe limit for every person (Siblini et al., 2023). Ferrari & Naponelli (2025) also noted that clinical trials often measure different outcomes as some clinical trials focused on metabolism, others on cancer, and many were conducted on a small scale. Hence, it is difficult to build a strong overall picture.

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Due to differences in the composition of gut microbiota and metabolism in individuals, catechin supplementation produces different outcomes (Wang et al., 2022; Zhang et al., 2022). This variability complicates reproducibility, which suggests that the microbiome profiling should be incorporated in future research to determine which individuals are most likely to benefit and to develop tailored strategies. Moreover, different extraction and purification methods alter the structure of catechins (Cioanca et al., 2024). This reduces the comparability of studies and hinders the development of standardized formulations.

These challenges provide clear directions for future research. Innovation in delivery methods, such as nanodelivery and encapsulation, should advance from laboratory testing to clinical studies. This will help determine the most effective strategies for improving stability and absorption. Long-term and well-structured human trials are needed to clarify safe dosage and efficacy. To ensure reproducibility, reporting protocols and standardized extraction are also required. Subgroups most likely to benefit will be identified with the help microbiome-aware designs through the incorporation of metagenomics and metabolomics. The reliability of catechins to use in prevention of diseases and health promotion can be increased by addressing the gaps in bioavailability, reproducibility, and safety.

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