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Review

Nutritional Strategies for Enhancing Neurological Function: A Diet-Based Approach to Cognitive Health

Huzaifa[1], Shah Alam[2], Shalini Patel[3], Richa Bajaj[4], Namita[5], Km. Shiva[6]*

[1]*Assistant Professor, NGI College of Pharmacy, Meerut, Uttar Pradesh*
[2]*Lecturer, NGI College of Pharmacy, Meerut, Uttar Pradesh*
[3]*Research Scholar, Translam Institute of Pharmaceutical Education and Research, Meerut, Uttar Pradesh*
[4]*Associate Professor, DPG college of pharmacy, Sector 34 Gurugram*
[5]*Assistant Professor, Gurugram Global College of Pharmacy, Gurugram*
[6]*Assistant Professor, Gurugram Global College of Pharmacy, Gurugram*

Corresponding Author:
Km. Shiva

Email:
shiva.pharma2630@gmail.com

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Abstract:
The human brain, despite constituting only 2% of body weight, consumes approximately 20% of the body's energy, underscoring its reliance on adequate nutrition for optimal function. Emerging evidence highlights the profound impact of diet on cognitive health, with specific nutrients and dietary patterns influencing neuroprotection, synaptic plasticity, and neuroinflammation. This review explores the role of macronutrients (carbohydrates, proteins, fats) and micronutrients (omega-3 fatty acids, polyphenols, vitamins) in supporting brain health, emphasizing their ability to mitigate oxidative stress and inflammation, key contributors to neurodegenerative diseases. Dietary patterns such as the Mediterranean and ketogenic diets are examined for their neuroprotective benefits, including improved cognitive performance and reduced risk of Alzheimer's and Parkinson's diseases. Additionally, the gut-brain axis is discussed as a critical pathway through which diet modulates brain function, with prebiotics, probiotics, and fiber-rich foods promoting a balanced microbiome and reducing neuroinflammation. This paper underscores the importance of personalized nutrition strategies in optimizing cognitive health and preventing neurological disorders, offering a comprehensive overview of diet-based approaches to enhance neurological function.

Keywords: Cognitive health, neuroinflammation, oxidative stress, Mediterranean diet, ketogenic diet, gut-brain axis, omega-3 fatty acids, polyphenols, antioxidants, personalized nutrition.

Introduction

The human brain, although it comprises only 2% of the body's total weight, consumes about 20% of the body's energy expenditure. This disproportionate energy consumption highlights the brain's critical reliance on adequate nutrition and its vulnerability to dietary influences. Given the significant role diet plays in influencing brain function, an increasing body of research has shed light on how specific nutrients and dietary patterns can impact cognitive health and neurological resilience. As the prevalence of neurological disorders continues to rise, especially neurodegenerative diseases like Alzheimer's and Parkinson's, understanding how nutrition influences cognitive function has become a key area of investigation [1].

A growing body of research suggests that nutrition directly affects brain structure and function. Diet-related factors can influence cognitive performance through various pathways, including neurotransmitter regulation, synaptic plasticity, neurogenesis, and neuroinflammation. It has become clear that a well-balanced diet is vital not only for general health but also for optimizing brain performance and long-term neurological function. On the other hand, poor dietary patterns, characterized by excessive consumption of processed foods, refined sugars, and unhealthy fats, have been linked to various cognitive impairments and an increased risk of developing neurological disorders [2].

Dietary components like omega-3 fatty acids, polyphenols, antioxidants, and essential vitamins have been identified as key players in supporting and maintaining optimal brain health. Omega-3 fatty acids, particularly docosahexaenoic acid (DHA), are integral components of neuronal membranes and play a crucial role in synaptic plasticity, which is the ability of synapses to strengthen or weaken over time, contributing to learning and memory. Polyphenols, which are abundant in foods like fruits, vegetables, and certain beverages such as tea, exhibit strong antioxidant properties. These compounds help protect the brain from oxidative stress, a condition where the production of reactive oxygen species (ROS) exceeds the body's ability to neutralize them, leading to cellular damage and the promotion of neuroinflammation [3][4].

Moreover, essential vitamins, particularly B vitamins like folate, B6, and B12, are involved in neurotransmitter synthesis and the maintenance of brain function. These nutrients help maintain the health of neurons and support cognitive performance. A deficiency in any of these nutrients can lead to cognitive dysfunction and impair brain development and function. Additionally, antioxidants such as vitamins C and E contribute to reducing oxidative damage, while polyphenols found in dark chocolate, berries, and red wine have been associated with improved brain function and a reduction in age-related cognitive decline [5][6].

The Mediterranean diet, which is rich in fruits, vegetables, whole grains, legumes, nuts, and olive oil, has emerged as one of the most well-researched dietary patterns linked to cognitive health. This diet is not only nutrient-dense but also emphasizes the intake of foods with strong antioxidant and anti-inflammatory properties. The high consumption of omega-3 fatty acids and polyphenols in the Mediterranean diet has been shown to reduce oxidative stress and inflammation in the brain, which are central mechanisms contributing to neurodegeneration. Numerous studies have found that adherence to the Mediterranean diet is associated with a lower risk of developing Alzheimer's disease, cognitive decline, and even depression. This dietary pattern's ability to preserve cognitive function is also supported by evidence suggesting it helps maintain brain volume, particularly in regions involved in memory and learning [7][8].

In contrast, the standard Western diet, often characterized by high intake of processed foods, refined carbohydrates, saturated fats, and sugars, has been found to have a detrimental effect on brain health. Such diets contribute to the promotion of neuroinflammation, impaired blood-brain barrier function, and an increased risk of cognitive decline. The overconsumption of refined sugars and unhealthy fats leads to elevated levels of insulin and glucose, which may disrupt the brain's ability to regulate neurotransmitter activity, impair synaptic plasticity, and result in neuronal damage. Additionally, high-fat diets are known to increase the accumulation of amyloid plaques, a hallmark of Alzheimer's disease, in the brain [9][10].

The ketogenic diet, which is low in carbohydrates and high in fats, has gained popularity in recent years for its potential neuroprotective benefits. The ketogenic diet works by inducing a metabolic state called ketosis, where the body shifts from using glucose as its primary energy source to utilizing ketones, which are derived from fats. This shift has been shown to enhance mitochondrial function, reduce oxidative stress, and improve brain function. Ketones are thought to have neuroprotective properties, particularly in individuals with neurological disorders. Studies have indicated that the ketogenic diet can improve cognitive function in patients with epilepsy, Alzheimer's disease, and Parkinson's disease, potentially providing an alternative therapeutic strategy for these conditions [11][12].

Understanding the interplay between diet and brain function is essential for developing effective nutritional strategies to promote cognitive health and prevent neurological diseases. While dietary interventions like the Mediterranean and ketogenic diets, along with the inclusion of essential micronutrients, have demonstrated neuroprotective effects, it is critical to note that individual responses to diet may vary based on genetics, lifestyle factors, and existing health conditions. Therefore, future research should focus on personalized nutrition strategies that optimize brain health across diverse populations, taking into consideration not only the intake of specific nutrients but also the overall dietary pattern and its impact on the gut-brain axis and inflammation [13][14].

Macronutrients and Cognitive Health

The brain, as an energy-intensive organ, relies heavily on macronutrients—carbohydrates, proteins, and fats—for maintaining cognitive functions. Each macronutrient plays a distinct yet interconnected role in supporting brain activity, neurotransmitter function, and neuronal integrity. Understanding how these nutrients contribute to brain health can help design dietary strategies to optimize cognitive function and mitigate cognitive decline.

Carbohydrates

Carbohydrates are the brain's primary energy source, with glucose being its preferred fuel. The brain consumes about 120 grams of glucose daily, which accounts for around 60% of the body's glucose utilization [15]. This glucose is used by neurons to generate ATP, the primary energy currency required for maintaining ion gradients, synaptic transmission, and overall neuronal function. Diets rich in complex carbohydrates, such as whole grains, legumes, fruits, and vegetables, are vital because they provide a slow, steady release of glucose, preventing significant fluctuations that could impair cognitive performance.

Complex carbohydrates, with their low glycemic index, help maintain consistent blood sugar levels, which is crucial for brain health. On the other hand, high-glycemic diets—those rich in refined sugars and simple carbohydrates—causes rapid spikes and crashes in blood glucose. These fluctuations can lead to oxidative stress and inflammation in the brain, both of which have been linked to cognitive impairments and neurodegenerative diseases. Studies have found that high-glycemic diets can lead to hippocampal atrophy, which affects memory consolidation and learning. The hippocampus, a brain region critical for learning and memory, is particularly vulnerable to such fluctuations in glucose levels [16][17]. Furthermore, diets that induce a constant state of hyperglycemia are associated with an increased risk of Alzheimer's disease and other forms of dementia [18].

Proteins

Proteins are essential for the synthesis of neurotransmitters, which are crucial for mood regulation, memory formation, and cognitive function. Amino acids, the building blocks of proteins, play a pivotal role in this process. For example, tryptophan is a precursor to serotonin, a neurotransmitter that modulates mood, cognition, and sleep. Similarly, tyrosine is a precursor to dopamine and norepinephrine, which are involved in attention, motivation, and memory formation [19].

The availability of these amino acids is directly influenced by dietary protein intake. Animal-based proteins, such as those found in meat, dairy, and eggs, contain all the essential amino acids required for neurotransmitter synthesis. However, plant-based proteins, found in legumes, nuts, seeds, and whole grains, are also rich in essential amino acids and may have additional benefits for brain health. For example, plant-based diets are associated with reduced neuroinflammation, a key factor in the development of cognitive decline and neurodegenerative diseases like Alzheimer's [20]. Moreover, plant-based proteins often come with high levels of fiber and antioxidants, which support overall brain health by reducing oxidative stress and inflammation [21].

Interestingly, excessive intake of animal protein, particularly red and processed meats, has been linked to higher levels of neuroinflammation and the production of harmful compounds that may accelerate brain aging. Conversely, plant-based diets, which are lower in saturated fats and contain fewer inflammatory agents, may help reduce the risk of cognitive decline and neurodegenerative diseases [22].

Fats

Fats, particularly omega-3 fatty acids, play a critical role in maintaining cognitive health. Omega-3s, especially docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), are structural components of neuronal membranes. DHA, in particular, is concentrated in the brain and is essential for maintaining neuronal membrane fluidity, which is vital for synaptic transmission and plasticity. Synaptic plasticity refers to the ability of synapses to strengthen or weaken over time, which is fundamental for learning and memory formation. A deficiency in omega-3 fatty acids has been linked to impaired cognition, increased risk of depression, and neurodegenerative diseases like Alzheimer's and Parkinson's [23][24].

Omega-3 fatty acids are primarily found in fatty fish such as salmon, mackerel, and sardines. However, plant-based sources such as flaxseeds, chia seeds, and walnuts contain alpha-linolenic acid (ALA), a precursor to DHA and EPA, which can be converted in the body to the active forms, although at a lower efficiency. Increasing omega-3 intake has been shown to improve cognitive performance, enhance learning, and even reduce symptoms of depression and anxiety, which are often associated with cognitive decline [25].

Conversely, diets high in saturated fats, found in red meat, butter, and processed foods, have been shown to have detrimental effects on brain health. Saturated fats contribute to increased levels of amyloid-beta plaques, which are associated with the development of Alzheimer's disease. These fats also exacerbate neuroinflammation, leading to neuronal damage and impaired brain function. Chronic consumption of saturated fats has been linked to an increased risk of cognitive decline and neurodegeneration [26]. Additionally, high intake of trans fats, commonly found in processed and fried foods, has been shown to negatively affect brain function, particularly in areas related to memory and attention.

Carbohydrates, proteins, and fats are all essential for maintaining optimal cognitive health. A diet rich in complex carbohydrates helps provide a steady supply of glucose, supporting energy production in the brain. Proteins, through their role in neurotransmitter synthesis, are essential for mood regulation, cognitive function, and overall brain health. Fats, particularly omega-3 fatty acids, are vital for maintaining neuronal membrane integrity and supporting synaptic plasticity, both of which are crucial for learning and memory.

To support cognitive health, it is essential to focus on a balanced, nutrient-dense diet that provides adequate amounts of these macronutrients. Diets that emphasize whole grains, lean plant-based proteins, healthy fats from omega-3-rich sources, and limit the intake of refined sugars and unhealthy fats can promote brain health, enhance cognitive performance, and reduce the risk of neurodegenerative diseases. Future research should continue to explore the intricate mechanisms through which these macronutrients affect brain health and identify specific dietary strategies that can prevent cognitive decline across different populations.

Dietary Patterns and Brain Health

Mediterranean Diet

The Mediterranean diet has long been associated with a range of health benefits, including improved brain function and a reduced risk of neurodegenerative diseases. This dietary pattern is characterized by high intake of fruits, vegetables, whole grains, legumes, nuts, and olive oil, while also emphasizing moderate consumption of fish and limited intake of red meat. Rich in polyphenols, antioxidants, and omega-3 fatty acids, the Mediterranean diet plays a significant role in reducing oxidative stress and inflammation, two key contributors to cognitive decline.

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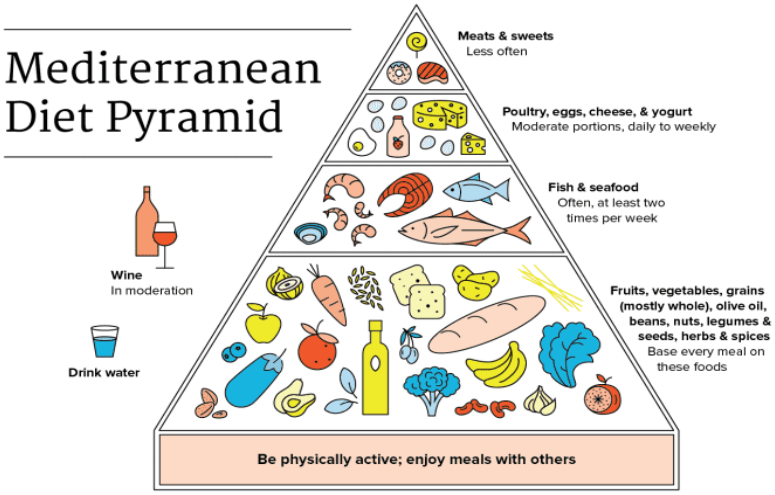

Fig 1: Mediterranean Diet Pyramid

Polyphenols found in foods such as berries, grapes, and leafy greens have strong antioxidant properties that help protect neurons from oxidative damage. Omega-3 fatty acids, particularly DHA and EPA, contribute to neuronal membrane fluidity, synaptic plasticity, and neurogenesis, promoting overall brain health. Research indicates that adherence to the Mediterranean diet correlates with a lower incidence of Alzheimer's disease, improved memory retention, and better cognitive performance in aging adults [27]. Longitudinal studies have shown that older individuals who follow a Mediterranean diet are less likely to develop cognitive decline or dementia compared to those with a diet high in processed foods and saturated fats [28].

Moreover, the Mediterranean diet's beneficial effects extend beyond just cognitive function. It also supports cardiovascular health, which in turn improves cerebral blood flow and further protects the brain. This dietary pattern has been widely recommended as part of a holistic approach to reducing the risk of age-related neurodegenerative diseases.

Ketogenic Diet

The ketogenic diet, which involves a high-fat, low-carbohydrate intake, promotes the production of ketone bodies as an alternative energy source for the brain. In the absence of glucose, the brain relies on ketones for fuel, which are derived from the breakdown of fats. This metabolic shift not only supports energy production but also offers neuroprotective effects, particularly by enhancing mitochondrial efficiency and reducing oxidative stress.

Research has demonstrated that the ketogenic diet may benefit individuals with neurological conditions such as epilepsy, Alzheimer's disease, and Parkinson's disease. Ketones help to stabilize neuronal membranes, reduce inflammation, and promote mitochondrial health, all of which contribute to improved brain function. For example, in patients with epilepsy, the ketogenic diet has been shown to reduce the frequency and severity of seizures by improving synaptic function and increasing GABAergic activity, a key inhibitory neurotransmitter in the brain [29].

In Alzheimer's and Parkinson's diseases, the ketogenic diet may help mitigate neurodegeneration by reducing amyloid-beta plaque accumulation and improving overall synaptic plasticity. Studies suggest that ketones enhance neuronal resilience, enabling the brain to function more efficiently despite the presence of neurodegenerative damage [30].

Neuroinflammation and Oxidative Stress

Chronic neuroinflammation and oxidative stress are fundamental contributors to the pathogenesis of various neurodegenerative diseases, including Alzheimer's, Parkinson's, and multiple sclerosis. Neuroinflammation occurs when the brain’s immune cells, particularly microglia, become activated in response to injury, infection, or other stimuli. This activation leads to the release of pro-inflammatory cytokines and reactive oxygen species (ROS), which

in turn cause neuronal damage, exacerbate disease progression, and impair synaptic function.

Oxidative stress, caused by an imbalance between the production of ROS and the brain's ability to neutralize them, further compounds the damage. ROS, such as superoxide radicals and hydrogen peroxide, are highly reactive molecules that can damage cellular components like lipids, proteins, and DNA, leading to neuronal apoptosis (cell death) and mitochondrial dysfunction.

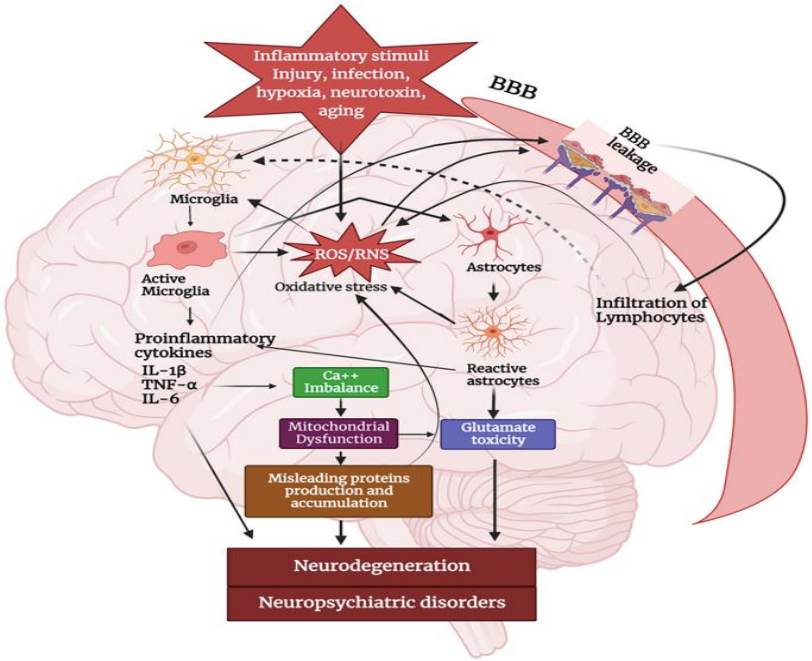

Fig 2: Role of Neuroinflammation and Oxidative Stress in Brain Disorders [31]

Nutritional interventions can play a significant role in counteracting these harmful processes. Certain dietary compounds, particularly antioxidants, have been shown to neutralize ROS and reduce oxidative damage. For example, flavonoids, found abundantly in foods like berries, apples, and citrus fruits, are potent antioxidants that help reduce oxidative stress in the brain [32]. Similarly, vitamins such as vitamin C and vitamin E act as powerful free radical scavengers, protecting neurons from oxidative damage and improving brain health. Vitamin C, which is abundant in citrus fruits and leafy greens, also enhances the activity of other antioxidants and supports the synthesis of neurotransmitters involved in cognitive function.

The role of antioxidants in reducing oxidative stress is supported by numerous studies that link high-antioxidant diets with better cognitive performance and a reduced risk of neurodegenerative diseases [33]. Diets rich in antioxidants, including polyphenols, flavonoids, and vitamins, have been shown to enhance brain resilience, improve synaptic plasticity, and preserve cognitive function. Furthermore, these compounds exert their effects by modulating various cellular pathways, including reducing the activity of pro-inflammatory enzymes such as cyclooxygenase (COX) and lipoxygenase (LOX), which are responsible for producing inflammatory mediators like prostaglandins and leukotrienes.

Table 1: Dietary Impact on Pathways

Diet Component	Mechanism	Outcome
Omega-3s	Inhibit COX-2/iNOS in microglia	↓ TNF-α, IL-6, ROS
Polyphenols	Scavenge ROS, block NF-κB	↓ Neuron injury, ↑ mitochondrial function
Probiotics/Fiber	↑ SCFAs, ↓ gut permeability	↓ Lymphocyte infiltration, ↓ BBB disruption

Mediterranean Diet	Synergistic antioxidant/anti-inflammatory	↓ Activated astrocytes, ↓ IL-18

By modulating these inflammatory pathways, antioxidants can reduce the chronic neuroinflammation that underlies many neurodegenerative conditions. Thus, diets rich in antioxidants and anti-inflammatory compounds can significantly contribute to neuroprotection by mitigating oxidative damage and enhancing the brain's ability to combat neuroinflammation.

Gut-Brain Axis

The gut-brain axis represents the bidirectional communication system between the gastrointestinal (GI) tract and the brain, a concept that has gained considerable attention in recent years due to its potential role in neurological health. The gut microbiome, a complex community of trillions of microorganisms living in the digestive tract, plays a pivotal role in maintaining homeostasis and influencing brain function. Emerging research suggests that the gut microbiota significantly impacts brain health by modulating inflammatory responses, neurotransmitter production, and neuroplasticity.

Prebiotics and probiotics are essential dietary components that can promote a healthy gut microbiota and support brain health. Prebiotics are non-digestible fibers found in foods like garlic, onions, bananas, and whole grains, which stimulate the growth and activity of beneficial gut bacteria. Probiotics, on the other hand, are live microorganisms present in fermented foods such as yogurt, kefir, and kimchi. These probiotics, along with fiber-rich foods, can help maintain a balanced gut microbiome, which is crucial for optimal brain function.

Dysbiosis, or an imbalance in the gut microbiome, has been implicated in a variety of neurological conditions, including cognitive decline, depression, and anxiety. When the gut microbiota is disturbed, it can lead to increased intestinal permeability (often referred to as "leaky gut"), which allows harmful substances such as toxins and inflammatory mediators to enter the bloodstream and reach the brain. This systemic inflammation can contribute to neuroinflammation, impairing brain function and potentially leading to neurodegenerative diseases [34]. Additionally, the gut microbiome influences the production of neurotransmitters such as serotonin and dopamine, which are critical for mood regulation, cognitive function, and overall brain health. Studies have shown that certain gut bacteria can influence the synthesis and release of these neurotransmitters, thereby affecting brain signaling and mood regulation. For example, approximately 90% of the body's serotonin is produced in the gastrointestinal tract, and the composition of gut microbiota plays a key role in modulating serotonin levels.

Furthermore, the gut-brain axis affects brain function via the vagus nerve, which is a major communication pathway between the gut and the brain. Signals from the gut can activate the vagus nerve, which in turn sends messages to the brain, influencing cognitive processes and emotional responses. Evidence suggests that a balanced gut microbiome can help regulate this communication, enhancing cognitive resilience and reducing the risk of neurological disorders [35].

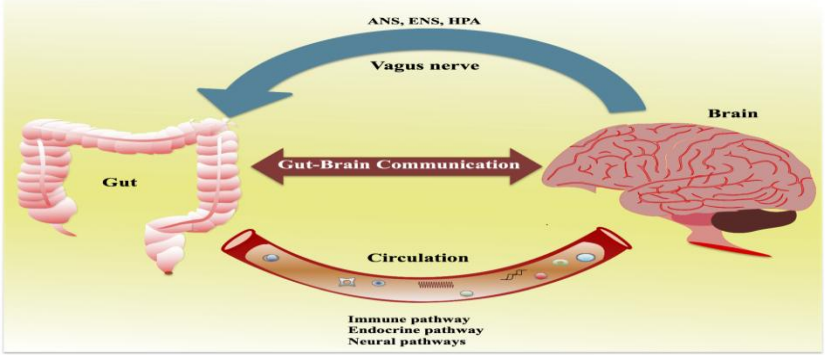

Fig 3 . Schematic diagram showing the bidirectional communication between the gut and brain, involving pathways such as the autonomic nervous system (ANS), enteric nervous system (ENS), HPA axis, immune system, and endocrine pathways [36].

Table 2: Nutritional Impact on Gut-Brain Pathways

Pathway	Nutrients/Foods	Mechanism
ANS/ENS	Fiber, polyphenols, omega-3s	Enhance gut motility, vagal tone, and neuronal signaling.
HPA Axis	Probiotics, magnesium, complex carbs	Regulate cortisol levels and stress responses.
Vagus Nerve	Prebiotics, omega-3s, fermented foods	Activate vagal signaling via SCFAs and microbiome balance.
Circulation	Antioxidants, nitrates, omega-3s	Improve blood flow and protect vascular health.
Immune Pathway	Probiotics, polyphenols, zinc, selenium	Reduce systemic inflammation and neuroinflammation.
Endocrine Pathway	Healthy fats, proteins, vitamin D	Support hormone production and neurohormonal balance.
Neural Pathways	B vitamins, choline, flavonoids	Enhance neurotransmitter synthesis, synaptic plasticity, and neurogenesis [37].

Conclusion

The intricate relationship between nutrition and neurological function underscores the critical role of diet in maintaining cognitive health and preventing neurodegenerative diseases. This review highlights the profound impact of macronutrients and micronutrients on brain function, emphasizing their roles in reducing oxidative stress, modulating neuroinflammation, and supporting synaptic plasticity. Diets rich in omega-3 fatty acids, polyphenols, and antioxidants, such as the Mediterranean diet, have demonstrated significant neuroprotective effects, including improved cognitive performance and a reduced risk of Alzheimer's and Parkinson's diseases. Conversely, the Western diet, characterized by high intake of processed foods and unhealthy fats, has been linked to cognitive decline and increased neuroinflammation.

The ketogenic diet, with its ability to induce ketosis, offers an alternative therapeutic approach for neurological conditions by enhancing mitochondrial function and reducing oxidative stress. Furthermore, the gut-brain axis has emerged as a pivotal pathway through which diet influences brain health, with prebiotics, probiotics, and fiber-rich foods promoting a balanced microbiome and reducing systemic inflammation. Dysbiosis, on the other hand, has been implicated in cognitive decline and mood disorders, highlighting the importance of maintaining gut health for optimal brain function.

While dietary interventions show promise in enhancing cognitive health, individual responses to diet vary based on genetics, lifestyle, and existing health conditions. Future research should focus on personalized nutrition strategies that optimize brain health across diverse populations, integrating dietary patterns with lifestyle factors and genetic predispositions. Public health initiatives should promote brain-healthy diets, such as the Mediterranean diet, to reduce the global burden of neurodegenerative diseases. By understanding and leveraging the interplay between diet and brain function, we can develop effective nutritional strategies to enhance cognitive resilience and improve quality of life across the lifespan.

Future Directions

The future of nutritional neuroscience presents exciting opportunities for advancing cognitive health through personalized nutrition, mechanistic insights, and innovative research. Key areas include exploring genetic factors and microbiome profiles to tailor dietary interventions, studying the molecular effects of nutrients on brain function, and conducting long-term studies to assess the impact of specific diets on cognitive decline. Integrating multi-omics approaches, developing evidence-based public health guidelines, and leveraging technologies like wearable devices will further enhance our understanding. Addressing global health disparities and combining diet with lifestyle factors will contribute to more comprehensive strategies for improving brain health. Ultimately, these advancements promise to reduce the global burden of neurological disorders.

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