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The Second Brain: The Mysterious Power Of The Intesties

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Abstract – The intestines serve as more than just organs for digestion; they act as a "second brain." They represent one of the most intricate and enigmatic regions within our body, closely intertwined with the brain. Nerve cells and networks in the intestines have the capacity to influence our thoughts, emotions, and even our mood. We will delve into the role of the intestines as a "second brain," its impact on emotional well-being and cognitive abilities, as well as the crucial implications of gut health on our overall physical well-being**.**

Keywords – Brain, Intestine, Microbiota, Diet, Flora

I. Introduction

More than a century ago, researchers explored the connection between the brain and intestines, discovering that changes in mood can impact gastric secretion in individuals. Towards the late 1900s, investigations focused on the relationship between stress biology, its effects on human health, and intestinal functions. During the early 19th to the early 20th century, some physiologists, psychiatrists, and psychologists critically analyzed this link, positing a two-way relationship between the brain and intestines. Later studies have revealed that this interaction occurs through neuronal, immunological, and hormonal mechanisms [1].

Our intestines, typically viewed solely as digestive organs, are in fact among the most captivating and remarkable regions of our body. Beyond digestion, the intestines function as a "second brain." Through nerve cells and networks, they maintain close communication with the brain, influencing our thoughts, emotions, and even mood, significantly contributing to our overall well-being.

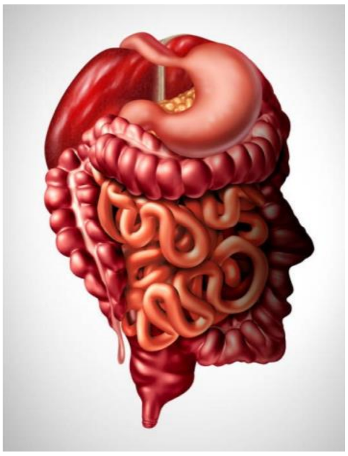

Fig. 1 [2]

II. Microbial flora

The human body has approximately 2 m² of skin and 300 m² of mucosal surfaces. The number of bacteria on these surfaces surpasses the count of human cells, resulting in a complex structure of around 10^{14} microorganisms and 10^{13} mammalian cells [3]. These microorganisms form various groups that reside in different areas of the body and provide benefits without causing harm to the host, collectively known as the body's normal flora. Microbial flora is divided into two categories [4].

Permanent Flora: This group comprises microorganisms that typically remain constant in specific areas, capable of reestablishing themselves even after temporary elimination. Among their activities, certain members in the intestines contribute to vitamin K synthesis and nutrient absorption. On mucosal and skin surfaces, they prevent the colonization of pathogenic bacteria through a mechanism called "bacterial interference." Additionally, they inhibit the growth of specific bacteria by producing bacteriocins.

Transient Flora: Alongside the permanent flora, there exists a group of microorganisms that generally do not cause diseases but can occasionally become pathogenic, persisting for varying periods ranging from a few hours to a few weeks. When members of the permanent flora are removed, the transient flora colonizes, multiplies, and may acquire disease-causing properties [5], [6].

III. MICROBIOTA

Microbiota encompasses the collective population of microorganisms found in a particular organism or living habitat. Different living environments, like the human body, possess their distinct microbiota. These microbial communities can be found in various areas, including the intestines, skin, mouth, respiratory tract, and other tissues.

A. *Intestinal Microbiota, Formation and Maturation*

The collection of naturally occurring microbial organisms in the gastrointestinal system is known as the intestinal microbiota. Functioning in the host's physiological development and defense, the intestinal microbiota is often considered a hidden organ. An essential feature of the microbiota is the presence of host-specific species within its composition [6].

The intestinal microbiota forms a complex ecosystem closely linked to the host's physiological environment [7]. It matures during early life and maintains relative stability thereafter [4], [7]. Mammals host both commensal and pathogenic bacteria, with the adult intestine estimated to harbor nearly 10 trillion microorganisms, weighing around two kilograms, surpassing the weight of all body cells [4]. The intestinal microbiota exerts molecular-level influences on the intestine, liver, brain, and other organs. Additionally, it acts as a barrier and can impact metabolism by regulating absorption, digestion, intestinal motility, and mucosal immunity [4], [8].

The microbiota also displays diversity across various segments of the same organ, leading to variations in functions based on organ segments [9].

The gastrointestinal system is heavily innervated by neurons, both within the intestine (enteric) and beyond. As a result, the intestinal microbiota regulates numerous body functions and collaborates with the central nervous system [10]. By producing various metabolites, the microbiota affects neurons in the enteric nervous system, influencing neurons in the central nervous system, and governing the host's physiology and metabolism [7],[10], [11]. This bidirectional neural communication also impacts autonomous functions, brain function, motor coordination, emotions, heat regulation, behavior, and cognition, functioning through the gut-brain axis [10].

The gastrointestinal tract contains the most densely populated microbial community (10^{12}) after the skin. Within the human intestine, the colon houses the largest number of microorganisms (10^{14}), and the combined weight of microorganisms in an adult's intestinal tract is roughly equivalent to that of the human brain [12], [13]. The formation of the intestinal microbiota begins during the intrauterine period and develops gradually, influenced by factors such as the method of delivery and dietary choices. The host's genetic makeup, living environment, early use of oral antibiotics, and diet all play significant roles in shaping the intestinal microbiota [7], [8]. Although there is some evidence of microbial communities in the placenta [14], it is widely accepted that during birth, breastfeeding, and interactions, we are exposed to microorganisms. Furthermore, it has been observed that babies born vaginally have a different microbial composition compared to those born via cesarean section [13],[15].

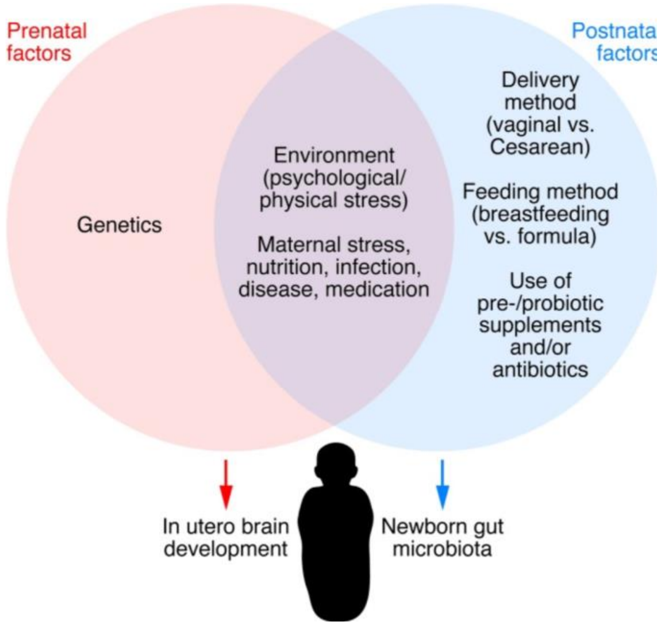

Fig. 2 The effects of gut microbiota on the brain-gut axis during the perinatal period [16].

Perinatal factors have a significant impact on the nervous system's development, and it is well-known that early-life influences on the brain-gut axis can have negative consequences. There is a suggestion that the intestinal microbiota also plays a crucial role in this developmental process. Studies on animals have indicated that prenatal and postnatal stress can affect the enteric microbiota. Adverse events during this period can modify the gut microbiota, which, in turn, can affect an individual's behavior in adulthood. Research has demonstrated that perinatal stress factors, such as maternal stress and maternal separation, play a role in shaping the development of the gut microbiota, leading to changes in behavior [8],[16].

B. *Diet and Gut Microbiota*

Diet plays a crucial role in determining the composition of the gut microbiota, which refers to the community of microorganisms in the intestines. Even small changes in the diet can result in modifications to the gut microbiota within a relatively short period, around three weeks. It is suggested that these dietary changes can lead to shifts in the number and types of microorganisms present in the microbiota, potentially contributing to conditions such as inflammatory bowel disease, irritable bowel syndrome, Crohn's disease, and ulcerative colitis [17]. Notably, there are differences in the gut microbiotas of individuals who follow a meat-based diet compared to those who adhere to a vegetarian diet. Certain carbohydrates that are not fully digested in the small intestine undergo fermentation in the colon. This fermentation process, particularly involving starch, can influence the gut microbiota and may contribute to the development of chronic inflammatory conditions and obesity [9].

IV. THE BRAIN-GUT AXIS

The gut microbiota interacts primarily with the central nervous system, which regulates the gastrointestinal system through the autonomic nerves (sympathetic and parasympathetic) [8], [16]. Research suggests that the brain can, in turn, influence the microbiota and behavior through the autonomic nervous system after signaling with the gut microbiota [8].

The intestinal microbiota and its metabolites have an impact on various gastrointestinal functions, including gut permeability, mucosal immune function, intestinal motility, sensitivity, and activities of the enteric nervous system. Moreover, the microbiota's metabolites affect brain processes and behavior modulation, stress response, depressive behavior, pain modulation, digestion, and brain biochemistry.

While serotonin (5-HT) is a crucial neurotransmitter in the brain, more than 90% of serotonin in mammalian hosts is found in the gut. Serotonin release in the gut is influenced by the diet and plays a role in regulating gut movement, mood, appetite, sleep, and cognitive functions [18]. Some studies suggest that altering intestinal colonization can manage stress responses. Animal experiments have shown that the gut microbiota influences emotional behavior, stress, pain modulation, and various systems involving neurotransmitters in the brain, as well as learning, memory, social interactions, and eating behavior [16].

Disturbances in the microbiota-gut-brain axis are believed to potentially contribute to the development of autism. Short-chain fatty acids (SCFAs) play a crucial role in this axis and can cross the blood-brain barrier to directly modulate brain activity [19]. Some studies indicate that stool samples of autistic children have lower levels of SCFAs [20], while others report increased SCFAs and ammonia concentrations in the stool [21]. Foley and colleagues (2015) have reported that the gut microbiota of the mother may influence the risk of autism development in their offspring [22].

Gastrointestinal dysfunctions associated with Parkinson's disease include constipation, malnutrition, dental problems, difficulty swallowing, delayed gastric emptying, difficulties with defecation, nausea, vomiting, increased salivation, Helicobacter pylori infection, and bacterial overgrowth in the small intestine [13],[23].

V. CONCLUSION

The gut microbiota, often called the "second brain," forms during prenatal development and affects the central nervous system, while signals from the central nervous system also influence the gut microbiota. Several studies have highlighted the important role of the gut microbiota in the maturation of the immune system, brain, and nervous system, as well as in shaping behaviors. When investigating the connection between the gut microbiota and diseases, researchers have observed that changes in the microbiota coincide with the development of diseases. Numerous studies have indicated that interventions targeting the gut microbiota are a vital approach in modifying disease conditions.

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