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Dietary Strategies for Better Immune Function: Evaluating the Role of Diet in Immune Function

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ABSTRACT

It is commonly known that inadequate nutrition can affect immunological function. Increased consumption of several nutrients over the currently advised levels may assist optimize immunological activities, such as enhancing defence function and, consequently, infection resistance, while preserving tolerance, according to mounting data. Nutrition serves a vital part in maintaining immune function, shaping the possibility to infections, autoimmune diseases, and chronic conditions. This review thoroughly analyzes nutritional plans and their effect on defense efficiency, merging evidence from clinical, biochemical and epidemiological studies. It explores how malnutrition damage defense response and interfere with gut barrier stability and modify microbiota formation. Specific reinforcement is on vital micronutrients including Vitamin A, C, D, E, B6, B12, folate, iron, zinc, selenium, and copper, and their functional part in aiding innate and adaptive response. It also analyzes the gut-immune axis and the part of probiotics and prebiotics in improving mucosal defense by microbial maintenance. Dietary epigenetics are examined in the setting of maternal and infant life nutrition, evaluating how availability of adequate nutrients during first 2 years of life can outline defense mechanism and prolonged well-being. Recent findings on nutritional polyphenols, bioactive peptides and omega-3 FAs are analyzed, specifically about capacity in reducing inflammation and autoimmunity. Nutritional strategies for immunocompromised communities, like old age people or persons with chronic diseases are also analyzed.

INTRODUCTION

Immune Function

An optimal environment free of nutritional inadequacies that are essential for immune cell triggering, interaction, differentiation, or functional expression influences the immune system, which is a complex system. The immunological response comes in two varieties. The initial immune response to foreign substances or invasive diseases is called innate immunity, and it is prompt yet nonspecific. Innate immune responses include neutrophils, mast cells, eosinophils, phagocytes such as monocytes and macrophages, and others. The adaptive immune response is the longer-lasting and more focused immune response. The specialized cells for long-term immunity are T and B cells. These cells quickly trigger specialized immune responses against certain diseases after recognizing the antigen. T helper cells with CD4 receptors aid other immune cells, while cytotoxic T cells with CD8 receptors destroy tumor or infected cells. Different antibody or immunoglobulin (Ig) types that target antigens and eliminate infections or foreign antigens are produced by B cells. Infection severity varies by age and gender and is associated with comorbidities; consequently, the immune system grows. The immune system and its effectiveness are influenced by a number of factors, including nutrition (37). The defense mechanism of the body is known as Immune System. It helps body identify between the things that belong to it (self) and those which do not belong to it (non-self). Our bodies only survive because of Immune System as without it, harmful things could easily attack. The human immune system is more advanced and vital for living (1). The two main types of immune system that help fight invaders are: Innate immune response and adaptive immune response. Innate response is considered a quick response to a toxic invasion. It executes quickly, however is not particular

about what it is defending. Innate response includes cells such as phagocytes, macrophages, neutrophils, dendrites, mast cells and eosinophils. Adaptive immune response is body's targeted protection system that detects foreign species. It has an ability to recall previous antigens. The defense system adapts to identify these targeted antigens. The core members of adaptive immune response are T-cells (helper T cells and Cytotoxic T cells), B cells (plasma cells, and memory B cells) (2). One type of B cells is Lymphocytes, also known as white blood cells, take a vital part in adaptive immune response. Their primary role is to synthesize defensive proteins. When B cell detects an immune trigger, it begins to work. Plasma cells is one type that has a brief lifespan but execute immediately to synthesize plenty of defensive proteins. Memory B cells is another type which has a longer lifespan and can recall the virus (3). Especially for food antigens, IgA has a vital duty in preventing infections as well as tolerance to self-antigens (4).

The defense mechanism is critical for hygiene practices and keeping the immune response balanced. It is of equal significance for defense mechanism to defend against pathogens and to rectify the response fully and immediately. If the immune defense persists or becomes excessive, it can disrupt healthy tissues. Cytokines are the signaling molecules utilized by the defense mechanism engage a vital part in managing this procedure.IL-10 is one crucial cytokine in this context. It is synthesized by a range of defensive cells, like regulatory T cells (Tregs), these help in regulation of defense mechanism. IL-10 has inflammation-reducing response (5). It is commonly known that a balanced diet and physical activity (PA) are essential lifestyle choices that enhance body composition, musculoskeletal health, and cognitive and physical performance, all of which have an impact on long-term health. Preventing metabolic illnesses including obesity, diabetes mellitus, and cardiovascular disease also requires adequate nutrition and optimal physical activity. Lack of physical activity has been recognized by the WHO as a major risk factor for mortality worldwide.

Even though research on the health benefits of physical activity and nutrition is common, it is now becoming more and more evident that combining the two can have more positive health effects and strengthen the immune system than approaches that only concentrate on one or the other. It has been demonstrated that regular, moderate exercise lowers the risk of infection when compared to a sedentary lifestyle (37).

The immune system's primary roles include defending the host against infection by pathogenic microbes, removing damaged tissue, and providing ongoing monitoring of cancerous cells that proliferate within the body. The immune system also builds up the necessary tolerance to prevent an unwarranted reaction to either harmless alien substances or healthy tissues of the self. Due in great part to genetics, environment, lifestyle, nutrition, and the interplay of these factors, there is significant variation in the strength of an individual's immune system. For several decades, researchers have examined how nutrition affects immune function. This field of study has grown into the prestigious field of nutritional immunology. The immune system requires enough nourishment to operate effectively, just like other body systems. It is commonly known that immunity and host resistance to infection are strongly correlated with dietary health. There is little doubt that immune function impairment brought on by deficiencies in both macronutrients and micronutrients can be overcome by nutritional replacement. In less developed areas, nutritional deficiencies are still common and a major cause of the high rates of infectious illness morbidity and mortality. Nutritional problems include specific vitamin deficits, less-than-ideal food composition, and excessive calorie consumption persist even in affluent nations where broad nutritional deficiencies are uncommon (43).

Nutrition for Immune Functions

As nutrition is an important aspect for a healthy defense mechanism, our body requires correct quantity of essential nutrients such as vitamins (essentially assists numerous bodily functions), minerals (maintain bone health, fluid balance, nerve signaling and muscle function) and other distinct compounds that maintain well- being of the body. These nutrients assist the defense mechanism to combat infections. If a person is deficient in them, the immune system can't function efficiently (20).

All cells, including those in the immune system, need proper and sufficient nutrients to operate at their best. During times of infection, a "activated" immune system further raises the need for energy, resulting in higher baseline energy expenditure, for instance, during fever. Therefore, the optimum nutrition for the best immunological results would be one that supports immune cell functioning, enabling them to launch efficient defenses against pathogens, as well as to quickly resolve those defenses as needed and prevent any underlying chronic inflammation.

The immune system can obtain the energy and nutrients it needs from exogenous sources, such as the diet, or from endogenous sources, such as body storage, if dietary sources are insufficient. Certain dietary components and micronutrients play very specific functions in lowering chronic inflammation or in the formation and maintenance of a healthy immune system throughout life. For instance, the micronutrients zinc and vitamin A control cell division and are therefore necessary for a good proliferative response within the immune system, whereas the amino acid arginine is necessary for macrophages to produce nitric oxide (42).

Fatty Acids and Protein

The immune system is dependent on proteins for support, and a protein deficiency may disrupt immunological function. A deficit can damage the body's defenses against infections by affecting the generation of antibodies, which is essential for adaptive immunity. Additionally, proteins assist control the synthesis of cytokines, which govern immunological responses, and are necessary for the healthy operation of immune cells like T and B cells. Sufficient protein levels are also necessary for the complement system, which causes inflammation and eliminates infections. Proteins are also necessary for wound healing, and a lack of them might make it more difficult for the body to recover damaged tissue. Conversely, the immune system depends on dietary fats,

particularly important fatty acids like omega-3 and omega-6. Cell membrane shape is influenced by fats, which aid immune cells in identifying and combating pathogens. Chronic inflammation and unbalanced immunological responses can result from a deficiency in omega-3 fatty acids, which have anti-inflammatory properties and aid in immune system regulation. Additionally, phagocytosis, the process by which immune cells consume pathogens, the creation of antibodies, and the absorption of fat-soluble vitamins, all of which are critical for immunological health, all depend on fats. Fat deficiencies can interfere with these functions, making it more difficult for the body to fight off infections and keep its immune system functioning normally (24).

Vitamin D

Unlike other vitamins, vitamin D may be produced by the human body in the skin from the precursor 7-dehydrocholesterol when exposed to sunshine. Vitamin D from both diet and sunshine is first hydroxylated to 25(OH)D mostly in the liver and then further hydroxylated to the active form 1,25(OH)2D primarily in the kidney under the action of 1-α-hydroxylase. It has long been known that vitamin D's traditional role is to regulate calcium homeostasis and bone health. Nevertheless, additional extra-skeletal effects of vitamin D have been identified, and the finding that vitamin D-activating enzymes (hydroxylases) and the vitamin D receptor (VDR) are found in tissues and cells unrelated to mineral and bone metabolism further supports the vitamin's varied functions (43).

Vitamin E

All tocopherols and tocotrienols that possess the biological action of α-tocopherol are collectively referred to as vitamin E. The primary forms of vitamin E, α- and γ-tocopherols, are equally prevalent in the food; yet, because of their distinct preferences for bioavailability and metabolism, α-tocopherol is approximately 5–10 times more plentiful in the blood than γ-tocopherol. The bodily tissues contain very little or no trace of the other forms of vitamin E. In published investigations, α-tocopherols in both synthetic and natural forms are frequently used (43).

Zinc

Zinc is a crucial mineral for the defense mechanism. It assists several proteins in the body to function efficiently, by helping in chemical processes and by assisting proteins keep their shape. Even when somebody has moderate zinc shortage, it can cause difficulties with defense system. This way, both sections of immune system, innate and adaptive, do not function properly. Zinc is important for healthy defense system (16), (17).

Copper

Copper has been linked to the synthesis and response of IL-2 and has been demonstrated to have a part in the innate immune response to bacterial infections. High copper concentrations may be harmful to invasive microorganisms and seem to be used by macrophages as a defensive tactic, which may contribute to subsequent infections after viral infection. Copper also has a role in cellular immunity, antibody synthesis, and T cell proliferation. Aiding in the defense against a number of bacterial illnesses, such as Salmonella, E. coli, and TB, has been linked to a healthy copper status. Nonetheless, copper shortage is very uncommon because of its extremely low requirements (it is frequently regarded as an ultra-trace element) and widespread distribution (44).

Selenium

Selenium is a mineral present in trace amounts in the body and only a little quantity is required. However, it is crucial for well-being. Just as zinc, selenium also has a vital role in the number of proteins in the body work, specifically in assisting the enzymes and keeping the proteins intact (18).

Glutamine

Glutamine is one of the building blocks of protein i.e amino acid. It is known as a non-essential amino acid because the body can synthesize this amino acid by itself. Even then it has a crucial role in immune system. It plays a main role as the source of energy for numerous cells, including the ones included in immune response (19).

Carbohydrates

Due to a large intake of processed carbohydrates (white flour, refined sugar), a high glycemic index causes acute hyperglycemia and an abrupt insulin response, which overloads the mitochondria's capacity and increases the generation of free radicals. C-reactive protein and inflammatory cytokines have been shown to rise instantly after even one high glycemic index meal. Higher glycemic index/glycemic load (GI/GL) has also been linked to elevated TNF-α and IL-6 levels. Selecting better-quality carbohydrates, even if they are isocaloric, can reduce inflammation and enhance postprandial glycemia. The majority of dietary fibers are complex carbohydrates, and they play a significant role in how carbohydrates affect inflammation. Increased fiber consumption (i.e., 3.3 g/MJ or around 30 g/d) has been shown to significantly lower hs-CRP concentrations. Although it is commonly advised that men and women consume 25 and 38 grams of fiber, respectively, the actual intake is typically lower (about 15 to 20 grams per day), at least in Westernized nations. Consuming whole grains also has the benefit of improving the composition of the gut microbiota, which reduces inflammation in the gut and throughout the body. Even modest increases in fiber consumption, such as 5 g per day, can have positive effects (43).

Metabolic Syndrome

Ingesting a lot of sugars can have indirect and adverse impact on the immune system. Food high in refined sugar is related to chronic inflammation, insulin resistance, nutrient imbalances and alterations in gut microbiota, all these can weaken the defense mechanism and make the body more susceptible to infections (25**).**

Autoimmune diseases and Fatty Acids

Diabetes Type-1

In T1DM, the body's immune system raids itself and ruin the pancreatic β-cells, reliable for insulin production. It occurs in early years of life (infancy or childhood). Defense mechanism malfunction takes place prior to disease genuinely advances. Studies recommend Omega-3 FA might assist in encouraging strong immune responses in early months of life, possibly performing a secure role in

inhibiting the inception of T1DM. (29)

Diabetes Type-2

T2DM is identified by hyperglycemia (high blood glucose levels), owing to two key elements: affected insulin release from pancreatic β-cells and insulin resistance in tissues. Even so, studies advise that chronic poor- quality inflammation performs a major role in onset of T2DM. This inflammation is notable by abnormal cytokine production and the initiation of inflammatory signaling pathways within insulin sensitive tissues, which aids to the disease. (30)

Rheumatoid Arthritis

Rheumatoid Arthritis is a persistent autoimmune disorder notable by continuous inflammation of the joints, and demolition of cartilage, triggered by initiation of pro-inflammatory cells. Research advises that increased consumption of Omega-3 PUFAs is related to lower levels of both severe and persistent pain in RA patients. Furthermore, the composition of n-3 in synovial fluid is categorically connected with n-3 PUFA consumption. PUFA consumption is adversely corresponds to suffering, specifying that these FA might assist in bringing down the pain in joints in Rheumatoid Arthritis. (31).

Multiple Sclerosis

MS is a disease of central nervous system, also known as inflammatory disease, origins demyelination and growth of lesions because of lymphocyte infiltration. The autoimmune character of Multiple Sclerosis is related to dysregulation of pro and anti-inflammatory defenses. Research utilizing animal models of Multiple Sclerosis, like trial autoimmune encephalomyelitis, have revealed that FAs can have favorable impact on shifting macrophages from a pro-inflammatory M-1 like condition to an anti-inflammatory M-2 like condition. This switch assists in avoiding demyelination, aids nerve protection, and motivates remyelination, providing possible therapeutic advantages (32), (33), (34).

Under Nutrition

Undernourishment affects growth and bodily processes when the body does not receive enough vital nutrients. A poor diet, poor nutritional absorption, economic factors, and illnesses are some of the causes of this. The immune system is weakened by malnutrition, which decreases its capacity to protect the body from diseases by attacking various pathways. Poverty, restricted access to food, unhealthy eating patterns, medical issues, and illiteracy are among the risk factors. As one of the primary causes of the worldwide burden of disease, disability, and mortality among children, childhood malnutrition poses a significant danger to their morbidity and mortality, according to the World Health Organization (WHO) (45).

Insufficient nutrition occurs either due to lack of food in or during times of inpatient care in under-developed countries. The level of dysfunction due to malnutrition relies on following factors:

Intensity of Shortage

The higher the shortage of vital nutrients, the bigger the effect on the defense mechanism.

Nutrient Exchanges

Several nutrients function collaboratively to assist the defense mechanism. If a nutrient is insufficient, it might interfere the utilization of others.

Existence of invasion

Infection, on its own puts unusual pressure on the defense mechanism since the body is striving to defend against foreign invaders.

Impact of Age

Young kids are growing their defense mechanisms. If they are nutrient-deficient, they might not have the defensive strength required to defend against infections. Even small insufficiency in the diet can have intense outcome.

Elderly frequently has an impaired defense system to start with growing older, this procedure is known as immunosenescence (6).

Over Nutrition

Over nutrition is another crucial form of malnutrition, where people, including children and adults ingest excess calorie dense food, like refined sugar and unhealthy fats. This results in obesity or overweight. Extra fat around abdomen may lead to chronic inflammation, which adversely influences the defense mechanism. Therefore, people with increased BMI might be more prone to infections. And might have low response to vaccines (21).

Motivating hygienic dietary patterns, supporting physical activity and building a helpful atmosphere for children and adults to make hygienic options are crucial phases in handling childhood and adult obesity. By proceeding to execute precautionary actions and delivering resources for interference, we can lower the prolonged results of obesity (22). The close link between overnutrition and infection has been acknowledged for 50 years, as was explained originally. This link prominent how bad nutrition weakens defense system, making the body susceptible to infections (23).

The Impact of Nutritional Interventions on the Defense System

PEM reduces the functioning of immune system by destroying humoral immunity, which utilizes specific immune cells to shield the body. On the other hand, this immunological impairment can be overturned with adequate nutrition. Studies have also shown if a mother encounter hunger prior to or at the time of conception, it can trigger epigenetic shifts in the fetus. These alterations can adversely influence the growth of the fetus's defense system. With this, from conception to two years of life becomes a critical period (26).

Ready-to-use therapeutic foods (RUTFS) are complete meals developed by the formula of F-100 liquid diet; this is the recent suggested formula by WHO for young children suffering from severe acute PEM. These pre- made foods have verified to be strongly efficient for both malnourished adults and children (27).

Demand of Micronutrients and Disclosed Deficiencies

The advancement, sustenance and adequate functioning of defensive cells depend on proper nutrition, this is critical at every phase of life. Adequate nutrition assures that the defense system has the essential nutrients to process efficiently, whether childhood, adulthood or old age. If there's no adequate nutrition, the defense system might be

weakened, making the body prone to diseases and infections. Vitamin A, C, D, B2, and B12 together with micronutrients such as folic acid, iron, zinc, selenium, and these all perform crucial part in regulating immune system and serving as antioxidants. These nutrients effect how susceptible the body is to viruses and can affect the development and result of an infection. By assisting immune function and securing cells from destruction, these micronutrients aid the body's immunity against diseases (40).

Connection between immune system and physical activity

The majority of chronic illnesses have inadequate daily PA as an underestimated underlying cause. The idea that a reduction in daily physical activity is the main cause of chronic illnesses and the treatment of dysfunctions brought on by inactivity is supported by a large body of research. Even though "exercise" and "physical activity" are commonly used interchangeably, it's important to know the distinctions. The Centers for Disease Control (CDC) define PA as any movement of the body caused by skeletal muscle contraction that raises baseline energy expenditure. The purpose of exercise is to increase physical fitness through planned and executed physical activity. On the other hand, there is growing evidence that both innate and adaptive immunity are negatively impacted by physical inactivity and its aftereffects, including muscular weakness and the buildup of adipose tissue. Furthermore, it is now generally acknowledged that vigorous exercise strengthens the immune system and that advantageous modifications take place after the healing process is finished. Neutrophils were reduced and CD4 T cells and salivary immunoglobulin IgA were increased after engaging in physical exercise three to five times a week for an average of thirty minutes. The most prevalent white blood cells, neutrophils are the first white blood cells to be recruited during an infection and the main effectors of pathogen clearance (37).

Association between aging and immune system

The immune system is a defense mechanism that guards the body from external threats like bacteria and viruses as well as changes internal substances like cancer cells. The primary player in the immunological response is the bone marrow. It contains the hematopoietic cells that produce immune cells, which then move to peripheral lymphoid organs to finish maturing and acquire the ability to identify non-self components. The term "innate immunity" describes a quick and non-specific system that can identify and eliminate common microbiological components. The number of receptors it can use to identify certain diseases is constrained, though. Anatomical and physiological barriers like skin and low stomach pH, as well as the phagocytosis mechanism, which is mediated by a variety of cells such macrophages and natural killers (NK), are the key components of the innate response. Adaptive immunity, on the other hand, is a more intricate reaction that is usually mediated by T and B cells, which express a wide variety of receptors to enable antigen recognition. Immune cells must migrate to infection sites in order for this highly particular form of immunity to come into contact with external pathogens (37).

Growth of Immune System in Neonate and Fetus

The defense mechanism of a growing fetus and infant is not completely formed. This conveys that infant's body has difficulty forming sufficient antibodies and cannot respond efficiently when it is exposed to infections. As long as the fetus is so far in the uterus, it gets security from the mother. Mother's antibodies can go through the placenta to the fetus, providing the fetus some protection before its birth (10). Human Milk Oligosaccharides are special sugars composed of lactose in the mother's breast tissue. The categories and quantity of HMOs can vary for every mother and can alter based on things such as level of breastfeeding (11). Throughout infantile stage, numerous external factors can impact how the defense mechanism grows. Few of these elements consist regardless of whether the baby ages with pets, if the baby has consumed antibiotics, and when specific foods are initially introduced in their diet (12).

Immunosenescence in Adults

As people age, their defense mechanism turns weak and ineffective at combating infections. This process is known as immunosenescence. This elaborates that both sections of immune system, the innate and the adaptive fail to work. Due to this decrease, elders are more susceptible to infections as well as more apparent to encounter intense problems from those infections (13).

With aging, Thymus is an organ crucial for synthesizing T cells also known as T cells, are small and have low activity. this process is known as thymic involution. Due to this, the body synthesizes lesser naive T cells that assist in combating infections the body has never experienced before (14).

Numerous Immunological Impact

One nutrient can impact the defense system in several ways. This indicates one nutrient can perform numerous tasks or have several roles for assisting or influencing the defense response. Nutrients play their role in numerous ways, conditioning on the way they engage with the body (7).

Probiotics

Probiotics are living microorganisms that are positive for the well-being when ingested in correct quantities. These microorganisms give well-being advantages to the body, specifically to the gut (8). Lactobacillus is a advantageous probiotic bacterium that performs a crucial part in managing the immune function of the intestinal lining. Probiotics have well-being benefits particularly for the cure of diarrhea, which directs to malnutrition. Rocha-Ramirez analyzed the impact of heat-killed Lactobacillus Casei on the immune function of macrophages on malnourished children. This study evaluates how probiotics can possibly enhance immune response in children going through malnutrition (28).

Prebiotics

Prebiotics are the substances that ingest the healthy bacteria in the gut. They are indigestible substances located in specific foods, and when ingested, they assist these good microorganisms expand and rise (9).

CONCLUSION

At last, our defense mechanism is not just a submissive protector, it's a complex, responsive network that depends on us to provide it the appropriate aid it requires to role at its peak. Our nutrition plays a special role in this. The vitamins, minerals, and fatty acids we ingest aren't only crucial for basic bodily processes, they're necessary for our defense system to do its tasks efficiently. When we provide our bodies with the right nutrients, we aid our immune system stay keen, tough and ready to encounter any dangers to come its way. However, when we ignore these dietary requirements, we're not only attracting diseases, we're declining our body's skill to keep stability and well-being. From the initial ages of life to elder age, the link between nutrition and defense system cannot be neglected. It's easy to get caught up in trends and quick fixes, but the real key to sustaining a strong immune system is consistency and balance. Nourishing our bodies with the right nutrients isn't just about avoiding sickness, it's about investing in a long-term healthy defense system that helps us navigate the challenges life throws at us. Taking care of what we put into our bodies is a crucial step in ensuring our immune system remains as effective as possible, helping us live healthier and more vibrant lives.

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