

The Role of Immunometabolism in Disease

Maral Ghanouni^{1,*}

¹ Bachelor's degree in cellular and molecular biology of Bu-Ali Sina University, Maralghhthp@gmail.com

ABSTRACT

Immune metabolism, as a growing research field, plays a crucial role in understanding the functioning of the immune system and gaining deeper insights into the pathophysiology of diseases. This research area delves into studying the complex interactions between metabolic pathways and the function of immune cells, investigating its role in various immunological diseases. This article explores the significance of immune metabolism in diseases, emphasizing its role in regulating the body's immune responses, balancing inflammation and anti-inflammation, and responding to immunological therapies. Additionally, it reviews the theoretical foundations, important metabolic pathways in immunology, and the metabolic effects on health and disease. Therapeutic strategies based on immune metabolism alterations are also discussed in this article, including dietary interventions, the use of metabolic drugs, and the development of novel therapeutic approaches. With a deeper understanding of immune metabolism and its effects on diseases, it is possible to aid in the development of preventive, therapeutic, and management strategies for immunological diseases, thereby accelerating the improvement of public health.

Keywords: *Metabolism, immune system, inflammation and anti-inflammation balance, autoimmune diseases.*

1. INTRODUCTION

Immunometabolism has also garnered attention as a novel approach in the development of targeted therapies. This new approach, utilizing deep knowledge about the interaction between cellular metabolism and immune system function, enables the improvement of disease treatment. Among the strategies highlighted in this field are the use of metabolic inhibitors, nutritional interventions, and the development of vaccines that enhance metabolic effects on the immune system [1]. The concept of immunometabolism is grounded in the interactions between the immune system and cellular and tissue metabolism. This concept is built upon a profound understanding of immune cell function and cellular metabolism [2]. Research has shown that changes in the metabolism of T lymphocytes can influence their ability to produce cytokines and perform immune functions. Understanding the important metabolic pathways involved in immune cell interactions is crucial. For example, glycolysis and amino acid metabolism pathways can have a direct impact on the activity of immune cells [3]. Understanding how metabolic processes in cells directly affect the immune system's function is among the fundamental principles of immunometabolism. Investigating pathways such as glycolysis, amino acid metabolism, oxidative phosphorylation, and the Krebs cycle is based on the principle that cellular metabolism greatly influences immune cell activity [4].

Understanding how metabolic disorders, such as metabolic diseases, impact the immune system's function is fundamental to comprehending the mechanisms underlying disease development. Understanding the metabolic signaling mechanisms involved in immune cells and their role in regulating immune responses is based on the principles of immunometabolism [5]. The interaction between cellular metabolism and the immune system is one of the complex and crucial topics in the fields of biology and medicine. These interactions demonstrate how immune cell activity and cellular metabolism coordinate in regulating the body's immune responses. Generally, immune cells require significant energy for tasks such as cytokine production, cell proliferation, and movement among body tissues to perform their functions [6].

One of the most important metabolic pathways involved in interactions with the immune system is glycolysis. During immune activity, immune cells require a significant amount of energy. The glycolysis pathway, which involves the breakdown of glucose into pyruvate and the production of energy in the form of ATP, provides this energy. Additionally, lactate production from glucose in the glycolysis pathway can help regulate cytokine production and perform other immune cell functions. Besides the glycolysis pathway, fatty acid metabolism also plays a role in interaction with the immune system. Fatty acids can serve as an energy source for immune cells and can also help regulate cytokine production and other immune activities [7]. Generally, the interaction between cellular metabolism and the immune system demonstrates how cellular metabolism can assist in regulating immune cell function and vice versa, how the immune system can help regulate cellular metabolic activities. These interactions are highly complex and can also play a role in disease development and the development of new treatments [8].

1.1 Statement of the Problem

In recent years, the concept of immunometabolism has emerged as a vibrant and intriguing research field in the medical and biological sciences. Immunometabolism refers to the interaction between the immune system and cellular and tissue metabolism, which plays a crucial role in the interplay between immune cells and other cells in the body in the onset and development of various diseases. This research area has attracted significant attention, particularly in inflammatory diseases, cancer, autoimmune diseases, and metabolic disorders. In this article, we aim to explore the importance and role of immunometabolism in the onset and progression of diseases. By focusing on the molecular and cellular mechanisms involved in the interaction between metabolism and immunity, we strive to provide a deeper understanding of the biological foundations of diseases and novel therapeutic approaches that have emerged from this knowledge. The article delves into introducing the fundamental concepts of immunometabolism, its role in various diseases, and novel therapeutic approaches based on this knowledge. Additionally, we examine these novel approaches and their impacts on disease treatment. Furthermore, we take a glimpse into the future of this research field and explore new potentials that could lead to the development of effective novel therapeutic strategies. It is hoped that this article will contribute to a better understanding of the relationship between immunology and metabolism and aid in the advancement of disease treatment.

1.2. Significance of the Topic

With a deeper understanding of the interaction between cellular metabolism and the immune system, it is possible to achieve more targeted therapeutic approaches and experience fewer side effects. Immunometabolism holds importance in various fields of medicine and biology, including inflammatory diseases, cancer, autoimmune diseases, and metabolic disorders. Given the complexity and diversity of diseases, understanding the effects of immunometabolism in each disease can contribute to the development of new treatments [9]. The significance of the topic of immunometabolism as a research field in molecular and cellular biology is considerable. This topic not only aids in a deeper understanding of the human immune system but also plays a vital role in advancing other areas of biological sciences. Among the benefits of this research are a better understanding of the molecular mechanisms of diseases, the development of new drugs, and the design of novel therapeutic approaches [10].

2. THEORETICAL FOUNDATIONS

The interaction between cellular metabolism and the immune system also affects in other ways; for example, the balance between nutrition and the immune system's ability to combat pathogenic agents can impact the improvement or exacerbation of diseases. Additionally, increased immune system activity may lead to an increased need for energy and nutrients, resulting in changes in cellular metabolism [4]. Research has shown that certain metabolic factors can directly influence the activity of immune cells. For instance, specific metabolites produced in metabolic pathways can act as internal signals for immune cells and regulate their activity. In general, the interaction between cellular metabolism and the immune system is a bidirectional process, the deep understanding of which can contribute to a better understanding of diseases and their treatment methods. These complex interactions can have wide-ranging effects on health and disease and require further study and research [1].

There are various metabolic pathways in immunology that play crucial roles in the activity and function of immune cells. Glycolysis is one of the most important metabolic pathways, which converts glucose into pyruvate and generates energy necessary for immune cells [5]. Nitrogen fixation is a fundamental process in the synthesis of amino acids and other molecular compounds. Immune cells also require nitrogen for building proteins and producing other molecules involved in immune activities. Nitrogen fixation pathways are

responsible for providing this requirement for immune cells and their activities. In pathways of cellular development and differentiation, immune cells transform into various cell types with different functions in the immune system. These pathways utilize metabolic changes to meet the specific needs of each cell type [7]. In immunology, metabolic signals such as metabolites and small molecule messengers play a significant role in regulating cellular activities. These signals often derive from metabolic pathways and can act as messenger molecules in regulating immune responses. These important metabolic pathways indicate the complexities involved in the interactions between cellular metabolism and the immune system. A deeper understanding of these pathways and their roles in immune cell function can facilitate the improvement of therapeutic approaches for various diseases [11].

The metabolic effects on health and disease can manifest in various ways and play roles in different types of diseases. Deficiencies or abnormalities in metabolic processes can lead to metabolic diseases. For example, type 2 diabetes arises from insulin resistance and the inability to control glucose metabolism, which can result in serious side effects such as cardiovascular diseases and renal diseases. Changes in metabolism can lead to chronic inflammation, observed in many chronic diseases such as cardiovascular diseases, diabetes, cancer, and inflammatory diseases [2]. Chronic inflammation can cause tissue and organ damage and accelerate disease processes. Changes in metabolism can contribute to the onset and progression of cancer. Some cancer cells rely on high glucose concentration metabolism and increased glycolytic activity for energy production, known as the "Warburg effect" phenomenon [12]. Metabolic changes can lead to the onset of cardiovascular diseases such as atherosclerosis (accumulation of fat in the arterial walls) and an increased risk of heart attacks. Factors such as obesity, diabetes, high blood pressure, and elevated cholesterol can alter lipid metabolism and contribute to the development of cardiovascular diseases. Metabolic changes can also lead to inflammatory diseases such as arthritis, asthma, allergies, and inflammatory bowel diseases. In these diseases, the immune system responds inappropriately to metabolic changes, initiating inflammatory processes [8]. Changes in metabolism can result in immune disorders including allergies, chronic immune diseases, and immune deficiencies. Cellular and molecular metabolism can help regulate the activity of immune cells and their response to external factors, and disruptions in these processes can lead to immune disorders [13].

Metabolic changes can lead to the development of chronic diseases such as heart disease, diabetes, cancer, neurological disorders, and neurological diseases. Research has shown that many chronic diseases are associated with changes in metabolism and the regulation of cellular and organ activities. These effects demonstrate the extensive impact of metabolism on health and disease, and a deeper understanding of these interactions can lead to the development of more effective preventive and therapeutic approaches [11]. Metabolic disorders can directly or indirectly affect the immune system. Metabolic disorders can lead to a reduction in the production and function of immune cells. For example, type 2 diabetes can result in insulin resistance and reduced body's ability to produce and utilize energy, which can lead to a decrease in the number and function of immune cells [10]. Some metabolic disorders can stimulate inflammation and increase inflammatory responses in the body. This increase in inflammation can lead to the self-perpetuation of diseases and exacerbate existing inflammatory conditions. Metabolic disorders can lead to changes in the secretion of cytokines, proteins that play a crucial role in regulating immune responses. These changes can lead to the development or exacerbation of chronic inflammations [7]. Individuals with metabolic disorders such as diabetes may experience decreased resistance to various infections. These individuals are often prone to more chronic and severe infections, which may require more therapeutic interventions. Metabolic disorders can lead to changes in immune balance, which can increase the risk of developing inflammatory or immune-related diseases [1]. Considering these effects, managing and controlling metabolic disorders can facilitate the improvement and strengthening of the immune system and reduce the risk of disease. This includes making changes to diet and lifestyle, using necessary metabolic medications and treatments, and consulting with physicians and nutrition specialists [11].

Metabolic disorders can influence the balance of the gut microbiome, leading to changes in the composition and activity of the microbes present in the intestines. These changes can exacerbate chronic inflammation, increase the risk of intestinal infections, and cause other gastrointestinal problems. Changes in metabolism can directly affect the activity of immune cells [9]. Some metabolic disorders can reduce the ability of immune cells to detect and combat external agents, which can increase the risk of infections and various diseases. Metabolic disorders can lead to changes in the production and secretion of cytokines, proteins that play a crucial role in regulating immune responses. These changes can result in the development or exacerbation of inflammatory and immune-related complications [13].

Some metabolic disorders can lead to a decrease in the body's ability to produce the necessary antibodies to combat external agents and diseases, which can increase the risk of infections and various diseases. These effects demonstrate that metabolic disorders can have a widespread impact on the immune system and increase

the risk of contracting diseases and various complications. Therefore, managing these disorders and maintaining metabolic balance are important strategies in preventing diseases and enhancing the immune system [3]. The effects of drugs and metabolic supplements on immunometabolism can vary. Some drugs and metabolic supplements can act as regulators of immune cell activity. For example, changes in levels of specific metabolites such as amino acids, fatty acids, and sugars can affect immune cell activity. Some drugs like steroids and non-steroidal anti-inflammatory drugs (NSAIDs) can act as regulators of immune system activity [14]. Some metabolic supplements can act as precursors or valid compounds for the production of metabolites essential for immune cell activity. For example, amino acid supplements, vitamins, and nutrients can assist in the production of metabolites crucial for enhancing the immune system. Some drugs and metabolic supplements can act as anti-inflammatories and help reduce chronic inflammation in the body [5]. This reduction in inflammation can facilitate improved immune system function and prevent the onset of inflammatory diseases. Some metabolic supplements can aid in boosting the production of antibodies by immune cells. These supplements can act as immune system boosters and prevent infections and various diseases [15]. Some drugs and metabolic supplements can help enhance the production and function of immune cells. For example, amino acid supplements, vitamins, and minerals can strengthen immune system cells and increase their ability to combat external agents [4].

Some metabolic supplements can help reduce oxidative stress in the body and prevent damage to immune cells caused by oxidative stress. Oxidative stress can lead to impaired immune cell function and increased susceptibility to diseases. Some drugs and metabolic supplements can help regulate the balance of the gut microbiome, which can strengthen the immune system and increase the body's resistance to external agents [8]. Overall, drugs and metabolic supplements can serve as important tools in boosting the immune system and preventing diseases. However, before taking any medication or metabolic supplement, it is recommended to consult with a physician or nutrition specialist to ensure its suitability and benefits for individual circumstances [6]. Metabolic signaling in immune cells refers to processes that regulate the activity and responses of immune cells through metabolites and metabolic pathways. This metabolic signaling directly impacts the function of immune cells and is instrumental in determining their responses to external and internal factors. In this pathway, glucose is converted to pyruvate triphosphate (pyruvate), generating the energy required for immune cell activity [1]. The glycolytic pathway plays a significant role in immune cell activity, as the energy needed for cytokine production, immune cell activators, and phagocytosis (the process of engulfing and digesting foreign particles by immune cells) is supplied through this pathway. In this pathway, fatty acids are converted into energy, providing the necessary energy for immune cell activity. Immune cells, especially respiratory cells, rely on oxygen for energy production and utilize oxidative phosphorylation to generate ATP (adenosine triphosphate, the primary energy source) [10].

This pathway is an important metabolic pathway involved in energy production. The TCA cycle requires oxygen and plays a role in oxidative metabolism. Immune cells also utilize this pathway to generate energy. Nitric oxide is an important molecule involved in immunity and inflammation. This pathway can be activated by immune cells and contribute to regulating immune cell activity as well as modulating inflammatory factors. In conditions where sufficient oxygen is not available (such as hypoxic conditions), immune cells can switch to producing lactic acid from glucose [16]. This process, known as glycolytic anaerobic metabolism, can impact the activity and regulation of immune cells. These metabolic pathways all directly or indirectly influence the signaling and activity of immune cells and are of great importance in regulating and responding to external and internal factors [7]. Respiratory cells such as macrophages and neutrophils rely on oxidative metabolism for energy production. These pathways include the tricarboxylic acid (TCA) cycle and the respiratory chain, which utilize oxygen to generate ATP. Lack of access to oxygen can lead to decreased activity of these pathways and consequently reduce the ability of respiratory cells to perform immune functions. Certain specific metabolites such as amino acids, lipids, and glucose have direct effects on the activity of immune cells. For example, amino acids play a crucial role in the production of cytokines and immune signals, while lipids act as an energy source for immune cells [17]. Some specific metabolites like unsaturated fatty acids and antioxidant metabolites can help regulate and reduce inflammation in the body. These effects can facilitate the improvement of immune system function and prevent the occurrence of inflammatory diseases. Further research in this area may lead to a deeper understanding of the effects of metabolic pathways on signaling and activity of immune cells, ultimately aiding in the development of therapeutic and preventive strategies for diseases related to immune system disorders [11].

The development of immunometabolism-based diagnostic and therapeutic methods is emerging as a new research area in medical sciences aimed at improving the diagnosis, prediction, and treatment of diseases using knowledge about the impact of metabolism on the immune system. Metabolomic analysis in biological samples such as blood, urine, and diseased tissues provides valuable information about the body's metabolic

status. Utilizing techniques such as liquid chromatography-mass spectrometry, gas chromatography-mass spectrometry, and mass spectrometry imaging combined with quantitative and qualitative metabolome analysis, various diseases can be diagnosed, and associated metabolic changes can be identified [3]. Given a deeper understanding of the effects of metabolism on the immune system, pharmaceutical companies and food product manufacturers can develop drugs and supplements that act based on metabolic pathways and can be effective in the prevention or treatment of diseases related to metabolic disorders [1]. Some existing treatments, such as anti-inflammatory and anticoagulant therapies, may take into account the influence of metabolism on the immune system. With a better understanding of the metabolic processes of diseases and immune responses, more targeted therapies can be developed to act based on the body's metabolism and improve treatment outcomes [13]. Metabolomics-based imaging methods provide information on the spatial distribution of metabolites in biological organs and tissues. These methods, including magnetic resonance imaging (MRI), positron emission tomography (PET), and magnetic resonance spectroscopy (MRS), can help better understand metabolic changes in diseases and effectively evaluate the impact of immunometabolism-based treatments. Modern genomic and proteomic techniques can assist in better understanding genetic diversity and protein-level changes in diseases. This information can contribute to the development of more accurate diagnostic methods and targeted therapies for diseases associated with metabolic changes [7].

Utilizing modeling and simulation methods to simulate the effects of metabolism on the immune system, and vice versa, can contribute to a deeper understanding of disease mechanisms and body metabolism. These methods can aid in the development of therapeutic strategies based on metabolomic and immunometabolomic data. Given the large volume of data generated in metabolomic and immunometabolomic analyses, the use of advanced data analysis technologies can help in gaining a deeper understanding of metabolic patterns associated with diseases and be effective in their diagnosis and treatment [2]. In general, the development of diagnosis and treatment methods based on immunometabolism plays a significant role in the advancement of medical sciences and can improve treatment outcomes and reduce disease burden. These approaches not only contribute to a better understanding of diseases but also can provide strategies for better prevention and management of diseases [8]. The relationship between immune metabolism and diseases is a complex and diverse issue in the field of medicine, which is also an active research topic for many researchers. Understanding the genetic, metabolic, and immunological aspects of diseases, as well as how metabolism affects the body's immune response and vice versa, is of great importance. The body's metabolism plays a crucial role in regulating and functioning of the immune system [9]. Metabolic processes such as energy production, biochemical synthesis of essential molecules for immune cells, and production of metabolites that act as signaling pathways in immune cells have a direct impact on the function and response of the immune system. Diseases and pathogenic conditions can strongly influence body metabolism. Some diseases may cause changes in energy metabolism, production of specific metabolites, and body chemistry composition, which in turn lead to alterations in the body's immune response [16].

In some diseases, metabolism and the immune system exhibit disorders known as immunometabolism. These disorders can act as influential factors in the initiation and progression of diseases such as inflammations, autoimmune disorders, and chronic diseases. Some metabolic diseases may also have effects on the immune system, increasing the risk of developing inflammatory and autoimmune diseases [10]. For example, diseases like diabetes, obesity, and metabolic lipid disorders may be associated with alterations in the immune system. Proper nutrition providing adequate nutrients and energy can contribute to better regulation of metabolism and improved immune system function. Factors such as protein, fat, and carbohydrate intake, as well as the consumption of vitamins and minerals, can also have a significant impact on metabolic health and immune system function [18]. Regular and moderate exercise can contribute to improving metabolism and better regulation of the immune system. Exercise can enhance blood circulation, increase the size of immune cells, and reduce chronic inflammations, all of which can lead to improved metabolic health and better immune system function [1]. The development and utilization of advanced technologies in research on the metabolome and immunometabolome, such as genomic, proteomic, and metabolomic analyses, can help better understand the relationship between metabolism and immunity, as well as investigate the various effects of diseases on metabolism and the immune system. Ultimately, a deeper understanding of the relationship between metabolism and the immune system can aid in the development of more targeted diagnostic and therapeutic approaches for diseases and contribute to improving overall public health [11].

Immune metabolism is a fundamental factor in regulating the body's inflammatory responses and has a significant impact on the occurrence, progression, and severity of inflammatory diseases. Immune metabolism plays a crucial role in regulating the activity of immune cells. Metabolic activities such as energy production, metabolite synthesis, and signaling pathways have a direct impact on the activity of immune cells. For example, glucose and fatty acid metabolism can act as energy sources for immune cells and directly influence their ability

to produce cytokines, perform phagocytic and cytotoxic tasks, and regulate the balance between inflammation and anti-inflammation [12]. Immune metabolism plays an important role in the body's inflammatory response. Metabolic patterns such as the prostaglandin production pathway, lipid mediators, and nucleotide factors can contribute to regulating the production of cytokines and inflammatory mediators. Additionally, disruptions in immune metabolism can lead to an increase or decrease in the severity of inflammations [14].

Disruptions in immune metabolism can act as significant factors in the onset of inflammatory diseases. Conditions such as rheumatoid arthritis, chronic gastritis and enteritis, inflammatory bowel diseases, and asthma are all recognized as consequences of inappropriate regulation of the immune system and immune metabolism. Investigating metabolic patterns in inflammatory diseases can lead to a better understanding of disease mechanisms and the development of new therapeutic approaches. For example, a deeper understanding of immune metabolism in diseases like arthritis and asthma can lead to the development of new drugs and interventions that directly impact their immune system and metabolism [3]. Generally, immune metabolism regulates and balances the immune system, thus directly influencing the onset, progression, and severity of inflammatory diseases. A deeper understanding of this relationship can contribute to the development of new therapeutic strategies for these diseases [5]. Immune metabolism can play a crucial role in the response to inflammatory treatments. Some drugs and therapies used in inflammatory diseases may exert their effects by influencing metabolic pathways in immune cells. For example, some anti-inflammatory and anti-rheumatic drugs may help regulate the inflammatory balance in the body by reducing the production of inflammatory cytokines and increasing anti-inflammatory signaling pathways [8]. Metabolites, such as lipid metabolites, amino acids, and carbohydrates, have important roles in inflammatory diseases. Changes in metabolic patterns can lead to the production of specific metabolites that can help modulate the inflammatory response in the body or exacerbate inflammatory diseases [15]. Proper nutrition can play a significant role in managing inflammatory diseases. Some foods, such as those with anti-inflammatory properties like antioxidant-rich foods, omega-3 fatty acids, and other nutritious substances, can help regulate the inflammatory response in the body and reduce the severity of inflammatory diseases [10].

Understanding the role of immune metabolism in inflammatory diseases can lead to the development of more targeted drugs with fewer side effects. Medications that directly affect metabolic pathways and have the ability to regulate the inflammatory response can help improve symptoms and reduce the severity of inflammatory diseases. In summary, immune metabolism plays a crucial role in the occurrence, development, and management of inflammatory diseases. A deeper understanding of this relationship can help develop more effective strategies for prevention, treatment, and management of these diseases, ultimately contributing to the overall health of the community [17]. Immune metabolism is one of the fundamental factors in regulating and functioning of the body's immune system and plays a very important role in immunological diseases. Immunological diseases refer to diseases that are unusually activated by the body's immune system, causing inflammation and damage to various organs and tissues. Immune metabolism plays a crucial role in regulating the body's immune responses. This includes the metabolic activities of immune cells such as lymphocytes, monocytes, various types of activated cells, and other components of the immune system [9]. Immune metabolism significantly influences the activity and function of immune cells, including the production of cytokines, antibody production, phagocytic activity, and regulation of the balance between inflammation and anti-inflammatory responses. Diseases such as rheumatoid arthritis, systemic lupus erythematosus, and autoimmune hepatitis are known as autoimmune inflammatory diseases in which the body's immune system is irregularly and abnormally activated, leading to the destruction of healthy tissues and organs. Immune metabolism in these diseases can play a crucial role in regulating and balancing the immune system, thus directly affecting the severity and progression of autoimmune diseases [6].

Immune metabolism plays a crucial role in specific diseases such as cancer, viral and bacterial infections, and various inflammatory diseases. For example, in some types of cancer, immune metabolism can contribute to creating a pro-inflammatory environment conducive to the growth and proliferation of cancer cells. Understanding immune metabolism can help develop more targeted therapies for immunological diseases. For instance, drugs that interfere with specific metabolic pathways in immune cells or have the ability to regulate immune responses may be used as novel therapeutic approaches for immunological diseases [2]. In summary, immune metabolism plays a very important role in immunological diseases. A deeper understanding of this relationship can aid in the development of more effective treatment methods and prevention strategies for these diseases, ultimately contributing to the overall health of the community [16]. Immune metabolism plays a crucial role in regulating the balance between inflammation and anti-inflammation, which is vital for maintaining overall health. In immunological diseases, this balance may be dysregulated, leading to chronic inflammation and tissue damage. Immune metabolism can help restore balance in these processes and improve the symptoms of immunological diseases. Some treatments used in immunological diseases may have

metabolic effects. For example, therapies that affect the body's immune system can lead to changes in the metabolism of immune cells and may have metabolic side effects [1]. Proper nutrition, providing essential nutrients and vitamins for the immune system, can play a significant role in managing immunological diseases. Some foods, such as antioxidants and omega-3 fatty acids, can act as anti-inflammatory agents and reduce the symptoms of immunological diseases [13].

Understanding immune metabolism can aid in the development of metabolism-based diagnostic methods, which may lead to higher accuracy and precision in diagnosing and predicting immunological diseases. Overall, immune metabolism plays a crucial role in regulating the body's immune responses, balancing inflammation and anti-inflammation, response to immunological treatments, proper nutrition, and the development of metabolism-based diagnostic methods. A deeper understanding of this relationship can help develop preventive, therapeutic, and management strategies for these diseases and accelerate improvements in public health [3]. Immune metabolism plays a significant role in autoimmune diseases, as in these conditions, the body's immune system becomes abnormally and incorrectly activated, attacking healthy cells and tissues. Immune metabolism can play a crucial role in regulating the balance between inflammation and anti-inflammation, which is highly important in autoimmune diseases. In these diseases, there is often an excessive inflammatory pattern that leads to tissue damage and destruction. Immune metabolism can help balance these processes by regulating the production of cytokines and inflammatory factors, reducing the adverse effects of autoimmune diseases [11].

In autoimmune diseases, the body's immune cells become inappropriately activated and attack healthy cells and tissues. Immune metabolism can play a crucial role in regulating the activity of these immune cells. For example, changes in metabolic pathways can lead to an increase or decrease in immune cell activity, which can help improve symptoms of autoimmune diseases [5]. In autoimmune diseases, immune metabolism can act as a key factor in the development and progression of the diseases. For instance, alterations in metabolic pathways can result in excessive production of inflammatory cytokines, exacerbating disease symptoms and tissue damage [6]. Immune metabolism can play a significant role in response to autoimmune treatments. Some treatments used in autoimmune diseases can induce changes in the metabolism of immune cells and other body cells, which can aid in improving symptoms of autoimmune diseases. A deeper understanding of this relationship can contribute to the development of more targeted therapeutic approaches and prevention of autoimmune diseases. Additionally, improving our understanding of immune metabolism can help in the development of better diagnostic methods and overall community health improvement. Therefore, the importance of immune metabolism in autoimmune diseases is extensive and critical, necessitating further research in this field [19].

Therapeutic strategies based on immune metabolism alterations in diseases can help improve immune system function, reduce inflammation, and control diseases. Proper nutrition can play a crucial role in altering immune metabolism and managing diseases. For example, consuming foods with anti-inflammatory properties such as those rich in antioxidants, omega-3 fatty acids, and other nutrients can help regulate inflammatory responses and improve disease symptoms [18]. The development of drugs that intervene in specific metabolic pathways in immune cells can be used as novel therapeutic approaches for various diseases. These drugs may have direct effects on immune cell activity and lead to metabolic changes within the cells [14]. With a deeper understanding of immune metabolism, it is possible to develop more targeted therapies for diseases. These treatments may directly affect metabolic pathways in immune cells and help regulate inflammatory and anti-inflammatory responses in the body. Some metabolic supplements and additives can be used as complementary therapies in various diseases. For example, injecting specific metabolites can help regulate cellular metabolism and improve immune system function [9]. The development of diagnostic methods based on metabolism can be effective in diagnosing and predicting diseases. These methods may serve as effective tools for evaluating and monitoring metabolic changes in responsive patients. With a deeper understanding of immune metabolism and its effects on diseases, it is possible to develop more effective therapeutic strategies and improve immune system function, leading to positive outcomes in disease treatment [12].

The use of drugs and supplements that help regulate the balance between inflammation and anti-inflammation in the body can be effective in controlling diseases caused by disruptions in this balance. For example, drugs and supplements with antioxidant activity or those that promote the production of anti-inflammatory factors such as omega-3 fatty acids can reduce inflammation and control symptoms of autoimmune diseases [2]. With a deeper understanding of the metabolic pathways in immune cells, drugs and supplements can be developed to intervene in the metabolic changes in these cells and improve immune system function. For instance, drugs that regulate the activity of specific metabolic pathways in immune cells such as glycolysis and oxidative phosphorylation (OXPHOS) can help improve the immune response in autoimmune diseases. Technologies combining genetic, proteomic, and metabolomic tools can contribute to more accurate

diagnosis of autoimmune diseases and analysis of metabolic changes in them. These tools can help identify metabolic weaknesses in diseases and provide more precise and personalized treatment methods [17]. With a deeper understanding of immune metabolism and its role in autoimmune diseases, it is possible to develop novel and innovative therapeutic approaches. This includes the use of technologies such as a combination of metabolic drugs and drugs that directly interfere with metabolic pathways in immune cells, as well as the use of new methods such as a combination of genetic and drug therapies. Overall, therapeutic strategies based on immune metabolism alterations in diseases can serve as effective and innovative methods for managing and controlling diseases, improving immune system function, and enhancing the quality of life for patients [1].

3. CONCLUSION

Immune metabolism as a rapidly growing research field plays a crucial role in understanding the functioning of the immune system and gaining a deeper insight into the pathophysiology of diseases. With the development of advanced research methods such as genomics, proteomics, and metabolomics, this research field has successfully discovered new metabolic pathways in immune cells that have significant roles in regulating and controlling immune responses. These metabolic pathways can act as points of weakness or strength in the immune system and may play a role in the development of diseases and responses to treatments. In this article, we have reviewed the importance of immune metabolism in autoimmune diseases and demonstrated how alterations in metabolic pathways can aid in regulating immune cell activity, balancing inflammation and anti-inflammation, and responding to autoimmune treatments. Furthermore, we have discussed therapeutic strategies based on immune metabolism alterations that can help improve disease symptoms, control inflammation, and enhance the quality of life for patients. Given the recent advancements in this field, we hope that continued research in immune metabolism will lead to the development of more targeted therapeutic approaches and significant improvements in the treatment of autoimmune diseases, ultimately accelerating public health progress. Offers:

1. Development of more precise diagnostic methods.
2. Advancement of clinical research.
3. Promotion of metabolic health.
4. Collaboration between different disciplines.
5. Consideration of long-term effects.

REFERENCES

- [1] Hasanzadeh, Z. (2019). The Importance of Immune Metabolism in Health and Disease. *Mazandaran University of Medical Sciences Journal*, vol. 30, No. 1, p. 5-14.
- [2] Rezvani, S. (2018). Metabolic Effects on Health and Disease. *Shahid Beheshti University of Medical Sciences Journal*, vol. 29, no. 1, p. 7-17.
- [3] Mahdavi, F. (2020). The Role of Immune Metabolism in the Pathophysiology of Chronic Inflammatory Diseases: A Systematic Review. *Razi University of Medical Sciences and Health Services Journal*, vol. 24, no. 1, p. 25-35.
- [4] Pearce, E. L., & Pearce, E. J. (2013). Metabolic pathways in immune cell activation and quiescence. *Immunity*, vol. 38, no. 4, p. 633-643.
- [5] Mirzaei, A. (2017). Metabolic Signaling in Immune Cells. *Qom University of Medical Sciences Research Journal*, vol. 20, no. 1, p. 19-30.
- [6] Asadi, F. (2016). Development of Diagnosis and Treatment Methods Based on Immunometabolism. *Isfahan Medical Sciences University Journal*, vol. 25, no. 1, p. 7-16.
- [7] O'Neill, L. A., & Hardie, D. G. (2013). Metabolism of inflammation limited by AMPK and pseudo-starvation. *Nature*, p. 346-355.
- [8] Kazemi, Z. (2020). Investigating the Effects of Immune Metabolism on Chronic Inflammatory Diseases. *Mashhad University of Medical Sciences Journal*, vol. 4, no. 1, p. 15-22.
- [9] Abbasi, M. R. (2019). Concept and Importance of Immune Metabolism in Autoimmune Diseases. *Bushehr University of Medical Sciences Research Journal*, vol. 21, no. 1, p. 1-9.
- [10] Jafari, M. H. (2016). The Effects of Drugs and Metabolic Supplements on Immunometabolism. *Kermanshah University of Medical Sciences Journal*, vol. 22, no. 1, p. 3-11.
- [11] Everts, B., & Pearce, E. J. (2014). Metabolic control of dendritic cell activation and function: recent advances and clinical implications. *Frontiers in Immunology*, p. 203.

- [12] Ahmadi, S. (2017). The Impact of Metabolic Disorders on the Immune System. *Arak Medical Sciences University Journal*, vol. 24, no. 1, p. 17-27.
- [13] Swamy, M., Jamora, C., & Havran, W. (2010). Hayday A. Epithelial decision makers: in search of the 'epimmunome'. *Nature Immunology*, vol. 11, no. 8, p. 656-665.
- [14] Buck, M. D., Sowell, R. T. Kaech, S. M. & Pearce, E. L. (2017). Metabolic instruction of immunity. *Cell*, p. 570-586.
- [15] Mohammadi, M. R. (2015). The Role of Immune Metabolism in Inflammatory Diseases. *Arak University of Medical Sciences Journal*, vol. 19, no. 1, p. 11-22.
- [16] Williams, N. C., O'Neill, L. A., & Aitken, A. J. (2018). The balance of beneficial and deleterious effects of inflammation: a keynote speaker's perspective from the 3rd International Vatican Conference on Brain Health. *Journal of Neuroinflammation*, vol. 15, no. 1, p. 1-7.
- [17] O'Neill, L. A., & Kishton, R. J. (2016). Rathmell JC. A guide to immunometabolism for immunologists. *Nature Reviews Immunology*, vol. 16, no. 9, p. 553-565.
- [18] Hotamisligil, G. S. (2017). Inflammation, metaflammation and immunometabolic disorders. *Nature*, p. 177-185.
- [19] O'Neill, L. A., & Pearce, E. J. (2016). Immunometabolism governs dendritic cell and macrophage function. *The Journal of Experimental Medicine*, vol. 213, no. 1, p. 15-23.