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Defense Mechanisms In Invertebrates: A Comparative Insight

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***Abstract*-**The immune system is a complex network that defends the body against pathogens and maintains homeostasis. It is broadly classified into innate and adaptive immunity, each with distinct mechanisms and roles. Innate immunity serves as the first line of defense, providing rapid, non-specific protection through physical barriers, phagocytic cells, and inflammatory responses. In contrast, adaptive immunity is highly specific, involving antigen recognition, memory formation, and long-lasting protection mediated by T and B lymphocytes. This comparative study explores the key differences and interconnections between innate and adaptive immunity, highlighting their complementary roles in immune defense. While innate immunity offers immediate response and recognizes conserved pathogen-associated molecular patterns (PAMPs), adaptive immunity requires antigen presentation and clonal expansion, leading to a delayed but highly specific response. The study also examines the role of antigen-presenting cells (APCs) in bridging innate and adaptive immunity, ensuring a coordinated immune response. Recent advancements in immunology, including molecular and genetic insights, have provided a deeper understanding of how these systems interact in health and disease. Dysregulation in either system can lead to autoimmune diseases, immunodeficiency, or chronic inflammatory conditions. The integration of new diagnostic tools and immunotherapies targeting innate and adaptive pathways offers promising therapeutic advancements.

This paper aims to provide a review on comprehensive comparison of innate and adaptive immunity of fish, reptile, mulluscs and amphibia.

***Index Terms*:** Innate immunity, Adaptive immunity, Immune response, Antigen presentation, Invertebrates

I. INTRODUCTION

Immunity refers to the body's ability to protect itself against various foreign substances, including bacteria, viruses, and toxins. Every day, the human body encounters numerous pathogens, but it can defend itself by producing antibodies that target these harmful invaders, preventing diseases. This natural defense mechanism is known as immunity (Ashim K. Chakravarty, 2007). Comparative Immunology has become widely accepted in biology as a branch of immunology and a fusion of immunology and zoology. The pioneering experiments of Metchnikoff on phagocytosis in invertebrates during the 19th century led to the division of immunology into two main components: cellular and humoral immunity. There is significant interest in the immune systems of invertebrates, as they represent early models or precursors of the innate immune system found in vertebrates. In contrast, vertebrates possess both an innate immune system and a more advanced adaptive immune system (Edwin L. Cooper, 2002). According to an earlier interpretation, immune evolution can be categorized into three major phylogenetic levels: quasi-immune recognition, primordial cell-mediated immunity, and integrated cell-mediated and humoral antibody immunity, sometimes referred to as surveillance systems. Quasi-immune recognition, observed in both invertebrates and vertebrates, is particularly evident in coelenterates (cnidarians), tunicates, and mammals, generally manifesting as allogeneic incompatibilities. The second level, primordial cell-mediated immunity, is exemplified by advanced invertebrates such as annelids and echinoderms. This stage is also broadly demonstrated as allograft incompatibility. However, a short-term specific immune response with memory can be observed at this level (Cooper, E.L,1986).

Innate Immunity: Innate immunity serves as the body's first line of defense against infections and foreign invaders. It is a non-specific immune response that is present from birth and does not require prior exposure to a pathogen. This immunity is activated immediately upon pathogen attack and includes various barriers and defense mechanisms that prevent foreign particles from entering the body. It provides natural resistance through components such as salivary enzymes, natural killer cells, intact skin, and neutrophils, which produce an initial response against infection at birth, even before exposure to a pathogen or antigen (P. Madhavee Latha,2016).

Acquired or Adaptive Immunity: Acquired or adaptive immunity refers to the resistance developed by an organism over the course of its life. It is pathogen-specific and is characterized by immunological memory. This type of immunity is mediated by antibodies or lymphocytes (Punt J *et al*, 2019). Comparative Immunology takes an evolutionary approach to understanding immunity, revealing the immune system as a fundamental and widespread mechanism necessary for survival. Although many immunology textbooks and courses focus primarily on medicine and related professions, comparative immunology serves as an essential introduction for advanced undergraduate students in biology, zoology, and immunology (Edwin L. Cooper, 2015).

II.METHODOLOGY

Review Published Literatures

III.RESULT

Fish have a strong innate "immune system, but their adaptive immunity is less developed, with weak immunological memory. But Reptiles have a slightly more advanced adaptive immune system, including a greater range of antibodies and a more efficient immune memory than fish. Mollusks rely entirely on innate immunity, with haemocytes, antimicrobial peptides, and simple inflammatory response But Amphibians have both innate and adaptive immunity, with T and B lymphocytes, antibodies and a more develop immune memory.

Table 01-Comaparative Study of Immune System

Feature	Fish	Reptiles
1. Physical Barriers	Mucous-covered skin, scales and gills help prevent infections.	Tough Keratinized skin and scales act as a barrier
2.Antimicrobial Peptides (AMPS)	Found in mucus and skin, play a crucial role in defense	Present in skin secretions and other body fluids
3.Complement system	Well-developed, involved in opsonization and pathogen lysis	Present in reptiles but less developed compared to fish
4.Lymphoid organs	Thymus, kidney, spleen, no bone marrow	Thymus, no lymph nodes, bone marrow
5.Inflammatory Response	Produce cytokine, acute phase proteins	Only cytokines
6. Memory response	Weak and short-lived	More developed
7. Antibody types	Mainly IgM with IgI, IgT/Z.	IgM, also IgY Similar to IgH
	Mulluscs	**Amphibians**
1.Physical Barriers	Mucus-covered sheels or soft tissue with antimicrobial factors	Mucous-covered skin trap pathogen
2.Haemocytes Or Phagocytic cells	Haemocytes engulf Pathogens	Macrophages, neutrophils and dendritic cells function similarly to those in mammals
3.Antimicrobial Deptides (Amps)	Produced in hemolymph and tissues crucial for pathogen defense	Found in skin section, with antifungal properties.

IV.DISCUSSION

Cellular immune responses encompass both innate and adaptive cell-mediated mechanisms, involving all leukocyte subpopulations. These include essential processes such as cell-mediated cytotoxicity and phagocytosis. The primary cellular components of the fish immune system include macrophages, granulocytes, dendritic cells, and cytotoxic T cells (Mokhtar D. et al., 2023). In fish, innate immunity serves as the first line of defense, responding rapidly to pathogens but lacking long-term protective effects (Turkey S.E. *et al*., 2010). The cellular components of innate immunity in reptiles consist of basophils, eosinophils, heterophils, monocytes, and macrophages (Ghorai M.S. and Priyam M., 2018). Similar to other invertebrates, mollusks exhibit internal immune responses against foreign substances and organisms. Their innate immune system provides a non-specific, first-line defense. The humoral components of molluscan immunity include nitric oxide, lysozyme activity, lectins, and the phenoloxidase system (Khalaifah A.H. &Nasser A.A., 2018). The immune system of adult amphibians closely resembles that of mammals. Amphibians possess lymphoid organs such as the thymus, where T cells differentiate, and the spleen, where both B and T cells accumulate within the white pulp (Yaparla A. *et al*., 2017).

Evolutionary immunology has entered a new phase. Traditional studies, which relied on a limited number of model animal species along with clinical observations, established the foundational understanding of how innate and adaptive immunity work together to maintain tissue homeostasis and coordinate immune responses against infections. However, groundbreaking advancements in cellular and molecular biology, genomics, and genetic modification techniques now provide unprecedented opportunities. These developments allow immunologists to examine, on an unparalleled scale, the influence of the vast phenotypic diversity of vertebrates on immune system function. This perspective aims to highlight several intriguing yet largely unexplored biological phenomena related to immune function across approximately 60,000 known vertebrate species (Boehm T, 2025).

All multicellular organisms employ sophisticated immune defenses to protect themselves against pathogens. Functionally interconnected humoral and cellular mechanisms ensure immune homeostasis in the absence of infection and regulate the initiation and resolution of immune responses targeting pathogens. Invertebrates, such as flies, rely on innate immune responses that are generally fixed and predictable, whereas vertebrates—including species as diverse as jawless fish and humans—possess an additional adaptive immune component. This allows for a faster and more efficient response upon subsequent exposure to the same pathogen. Many characteristics that were traditionally used to differentiate innate from adaptive immunity are, in reality, shared by both, demonstrating their evolutionary connection and co-development. These insights shed light on the evolutionary origins of somatic diversification of antigen receptors and enhance our understanding of complex human immune disorders. Furthermore, by incorporating phylogenetic insights and leveraging an improved understanding of immune system interactions, new pathways for innovative therapeutic strategies are emerging (Boehm T, 2012).

Vertebrates, which represent only a small fraction of all known animal species, are classified into two main groups: jawless vertebrates, comprising about 100 species of hagfish and lampreys, and jawed vertebrates, which include tens of thousands of species, such as mammals (Boehm T, 2012). Previously, it was believed that vertebrate immune systems were distinguished from those of invertebrates by their exclusive acquisition of adaptive immune functions. However, recent discoveries regarding invertebrate immunity, along with new findings on the innate arm of vertebrate immune systems, have blurred the functional distinctions between innate and adaptive immunity. In fact, the continued use of these terms—both in developmental (ontogenetic) and evolutionary (phylogenetic) contexts—has been argued to hinder conceptual progress (Boehm T, 2012). Vertebrates utilize highly efficient somatic diversification processes to create a broad repertoire of structurally diverse antigen receptors. These receptors are expressed by two distinct lymphocyte lineages: B cells, which produce antibodies, and T cells, which are involved in cytotoxic and helper functions (Boehm T, 2012). As jawed vertebrates, mammals possess an immune system divided into two primary branches based on function. The innate immune response is the older of the two, with origins tracing back to invertebrates (Yoshida *et al*., 1986). Innate immune defenses are inherited, encoded in the germline, and non-specific. They include protective barriers such as the skin and mucosal surfaces, antimicrobial peptides, phagocytic activity by immune cells like macrophages and neutrophils, and inflammatory responses (Janeway and Medzhitov, 2002).

V.CONCLUSION

The immune systems of different organisms have evolved in response to their environmental challenges and physiological constraints. While reptiles and fish possess both innate and adaptive immunity, their adaptive responses are relatively slower compared to mammals. Mollusks and annelids rely solely on innate defenses, whereas amphibians exhibit a transition between innate and adaptive immunity. Mammals, particularly humans, have the most sophisticated immune system, integrating highly specific and long-lasting immune responses. Understanding these diverse immune mechanisms provides valuable insights into evolutionary biology, disease resistance, and medical advancements.

VI.CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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