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Research Paper

# From Womb to World: Immunological Pathways Influencing Stunting and 2030 Sustainability

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**Abstract**
Stunting affects 150 million children globally, indicating an existing inequality in nutrition and health; despite focusing on nutrient deficiencies, the immunological continuum from prenatal to postnatal needs to be better described. This study synthesized the literature analyzing the role of immune functions in stunting from prenatal to early childhood and its implications for the 2030 Sustainable Development Goals. The database search was performed on PubMed, Scopus, Web of Science, and Google Scholar, in accordance with the PRISMA 2020 guidelines. The objective of the current narrative review was to determine immunological factors and stunting using peer-reviewed English research published from 2000 to 2024. The review also reveals that stunting is a complex process involving immune and nutritional factors, but the significant determinants of growth are prenatal immune priming and early-life infection. Some findings are related to the knowledge of the interrelation between nutritional deficiencies and immune system dysfunctions, cytokine patterns, and gut microbiota dynamics. Thus, this study provides a general definition of stunting and recommends additional research in immunology and the need for public health measures involving nutritional and immunological interventions. The assessment provides recommendations for preventing stunting and ensures that the actions are aligned with the 2030 Sustainable Development Goals for improving children's well-being.

**Keywords** *immunological pathways, stunting, sustainable development, nutritional immunology, maternal-fetal health*

## INTRODUCTION

This article presents a picture of today's world, where it is estimated that approximately 22% of children under the age of five are stunted because of chronic malnutrition and poor health (Ssentongo et al., 2021). Stunting is broadly characterized as the state whereby a child's height is approximately two standard deviations less than the recommended child growth level by the World Health Organization. IThisindicates inadequate nutrition standards and ithefailure of various health care systems, societal health determinants, and immune systems (Noori et al., 2022). Due to poverty, food shortage, and disease, cases of stunting remain high in some parts of Sub-Saharan Africa and South Asia, where the prevalence rates are 29% and 32%, respectively (Ssentongo et al., 2021). Current studies have revealed that feeding children appropriate nutrients and strengthening their defenses within the body can significantly decrease the prevalence of stunting. However, existing research has the following limitations: immunological factors are analyzed without considering the overall nutritional situation, and long-term research is lacking (Mutasa et al., 2022). This study seeks to fill these gaps by describing how specific immunological processes stunt development and the consequences for sustainable development. In this study, we aimed to elaborate the theoretical frameworks, develop coherent approaches, and implement evidence-based recommendations that align with the 2030 Sustainable Development Goal by integrating the knowledge of immunological processes with nutritional approaches. This approach has the potential to enrich global health approaches and provide a better model for fighting stunting and supporting the ethical growth of


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children.

## LITERATURE REVIEW

### Introduction to Stunting And Its Global Health Impact

Stunting is defined as height-for-age below World Health Organization standards and affects 150 million children under five years old, mostly in nations with middle and low incomes (Ssentongo et al., 2021). This condition is common throughout South Asia and Sub-Saharan Africa and is caused by malnutrition, persistent infections, poor hygiene, and environmental enteric dysfunction. It affects cognitive development, educational outcomes, and economic productivity, thus ensuring that children and families remain poor. To this end, tackling stunting is vital for attaining Sustainable Development Goals for hunger, health, and well-being (Scott et al., 2020). This study aimed to establish the immunological mechanisms that contribute to stunting with the hope of identifying better strategies and solutions.

Stunting severely affects SDG 2 (Zero HungerHunger) and SDG 3 (Good Health and Well-being), as chronic undernutrition affects children's growth and development of the mind and body (Komarulzaman et al., 2023). This condition not only impacts educational achievements and future income generation but also makes people more vulnerable to chronic diseases, which, in turn, placesa burden on health care services. The consequences of stunting on the next generation will worsen inequality in society and hinder productivity and development. Thus, combating stunting is essential for sustainable development, and novel solutions that encompass immunological findings must strengthen intervention measures and align with the SDG agenda (Scott et al., 2020).

### Immunological Pathways Influencing Stunting: From Womb to World

#### Prenatal Immunological Factor

The maternal immune system is also a critical factor that influences the health of offspring and participates in fetal programing. Fetal tolerance is a critical aspect of the maternal immune system because it has to ensure that the mother's immune system does not reject the fetus, it also needs to protect the fetus from diseases that may be present in the body through the interaction of immune cells, cytokines, and molecular signals. Diseases of the mother affect the growth of the fetus, leading to IUGR and growth restriction. Inflammation in the mother occurs due to conditions such as obesity and infections and may alter the fetal immunological system and predispose the child to type 2 diabetes in the future. Such risks can be reduced by nutritional and immunological measures that target the mother's immune system and therefore the development of the fetus, reinforcing the notion that both the short- and long-term impacts of immune dysregulation on the health of offspring should be considered (Parisi et al., 2021; Grot et al., 2022).

Maternal pathogens such as malaria, HIV, influenza, and cytomegalovirus induce placental inflammation through the upregulation of pro-inflammatory cytokines and adhesion molecules, which reduce nutrient transport and placental functionality. Chronic immune activation affects fetal growth and contributes to stunting and neurodevelopmental disorders (Elgueta et al., 2022). It is crucial to know the immunological and molecular relationships that are present to be able to devise programs that will be effective. These include antenatal care and interventions that aim to prevent complications caused by variations in maternal immune regulation, which can positively influence the infant's prenatal and postnatal health.

Prenatal immunology is limited by molecular research, small participant numbers, and retrospective data. Future research should use molecular and cellular experiments, longitudinal studies, and "-omics" data to understand immune programing's impact on fetal growth and identify new biomarkers and targets for intervention.

#### Postnatal Immunological Factors

Early childhood infections, which mainly involve the respiratory and gastrointestinal systems, affect growth and are related to stunting through the immune system. These infections lead to pro-inflammatory cytokines and systemic inflammation, which in turn affects nutrient absorption and utilization (Gizaw et al., 2022). Consequently, pathogen-host interactions activate pathways such as NF-κB, leading to chronic inflammation that interferes with growth processes and hormone secretion (Cirillo et al., 2017). Through a longitudinal analysis of children's development, repeated infection leads to stunting, thus capturing the interaction between inflammation and growth. Chronic immune activation is also known to cause epigenetic modification, which involves the genes regulating growth and therefore, intensifies the impact on growth indices (González-Fernández et al., 2023).

The main negative factors that affect growth in children include inflammation and immune system activation, which increase the levels of pro-inflammatory cytokines, disrupting the usual metabolic and growth processes in children (Gizaw et al., 2022). This disruption affects the growth hormone and IGF-1 axis, affecting bone and muscle growth and engaging inflammatory pathways such as NF-κB and JAK-STAT, causing persistent immune activation and systemic inflammation (Cirillo et al., 2017). Diseases such as inflammatory bowel disease, chronic respiratory infections, and juvenile idiopathic arthritis have low growth rates due to immune compromise, tissue inflammation, and poor nutrient absorption.

This study highlights the link between postnatal immunological factors, infections, and growth consequences. This study identifies the linkages between early childhood infections, chronic inflammation, and stunting, with inflammation impacting the GH-IGF axis and directly affecting growth. However, limitations in the observational study design and the lack of cohort studies hinder the understanding. The study suggests an integrated, interprofessional approach to effective public health strategies.

**Integrating Nutritional and Immunological Insight**

Deficiencies of micronutrients like vitamins A, C, D, E, and Zinc weaken the immune system, making individuals prone to infections and inflammation. This, in turn, hampers nutrient absorption in the body through the intestinal walls, leading to stunting. For instance, vitamin A deficiency reduces the immune system and increases inflammation, which in turn affects the GH-IGF axis and growth (Amimo et al., 2022). These aspects include nutritional deficiencies and immune dysregulation because they are connected.

It becomes possible to combine approaches based on nutrition and immunology. The PROBIT results confirmed that exclusive breastfeeding lowered the stunting prevalence in six-month-old babies to 44% because of improved nutrition and protection against infections. The interventions applied in the SHINE trial in Zimbabwe included water, sanitation, and hygiene (WASH) and nutritional supplementation for environmental enteric dysfunction (EED) prevention. The iLiNS Project in Malawi showed that providing women with lipid-based nutrient supplements during their pregnancy and lactation enhanced the nutrition and health status of women and infants and decreased chronic inflammation (Mutasa et al., 2022).

The analysis of the literature reveals that nutrition, and immunity, is strongly connected to stunting. A lack of micronutrients weakens the immune system, and individuals are bound to be prone to illnesses. Zinc, iron, and vitamin A deficiencies affect the immune system in cases of infection and inflammation. Thus, supplementation increases immune cell development and reduces inflammation (Tourkochristou et al., 2021). However, the present studies have some methodological limitations, including the inability to prove cause-and-effect relationships and the lack of co-sectional data. Subsequent research should use more sensitive techniques and involve people of different ages and genders to establish a connection between diet and the immune system.

**Implications for Sustainability and Policy Recommendation**

Incorporating immunological aspects into public health strategies is vital for the development of any nation. Thus, incorporating immunology knowledge into health care plans can lead to better interventions, better child health, and achievement of SDGs. Policies that manage and strengthen the immune system can also help reduce poverty and increase the efficiency of disease prevention and health promotion in line with the SDG goals for improving overall public health (Harries et al., 2018). This approach improves public health strategies, their efficiency, and their sustainability, hence enhancing the population's health status.

More research and policy should be directed toward the application of immunological findings in the prevention of stunting. Key recommendations include examining the relationship between immune system function and dietary health. System dysfunction in the context of cohort studies (Taofik, J et al., 2024); identification and application of mixed nutrition and immunological treatments (Morasa et al., 2022); creation of a holistic approach for risk assessment and geographical-specific prevention; strengthening data collection and surveillance systems for better strategies and results. These measures will achieve the Sustainable Development Goals by efficiently tackling stunting and enhancing child health standards worldwide.

Therefore, a combination of nutritional and immunological interventions, early identification of children, and country-specific policies are needed to address stunting. The strategies include micronutrient supplementation, targeted therapies, and WASH interventions based on information on EED and the immune system (Mbuya & Humphrey, 2016). Thus, such interventions can enhance child health, prevent stunting, and contribute to achieving sustainable development goals in low- and middle-income countries by modulating immunological processes.

## RESEARCH METHOD

This narrative review explores the immunological pathways influencing stunting within the context of the 2030 Sustainable Development Goals. Literature was extensively searched using Google Scholar, PubMed, Scopus, and Web of Science, following principles adapted from the PRISMA 2020 guidelines (Page et al., 2021) to ensure methodological rigor and transparency, despite being a narrative review rather than a systematic review. Keywords such as "immune responses," "stunting," and "immunological factors" were used to identify peer-reviewed articles published in English from January 2000 to December 2024. The content was screened based on its relevance to immune mechanisms and stunting, and duplicates were removed. Data extraction focused on immunological indicators, subject populations, and study design. Quantitative data were summarized descriptively, while qualitative findings were synthesized through thematic analysis to explore critical themes in depth. This review was based on publicly available data; thus, ethical approval was not required. No conflicts of interest were declared. This approach ensures transparency and reproducibility, providing a comprehensive understanding of immunological processes involved in mitigating early childhood stunting.

## FINDINGS AND DISCUSSION

### Finding

### Overview of Immunological Pathways in Stunting

Stunting is a condition that entails poor growth and development and has multiple immunological factors associated with it. The primary areas of immunology are immune system development, inflammation, and immune tolerance during sensitive periods of development. For instance, malaria, HIV, and other diseases that women acquire during pregnancy through intrauterine immune programing lead to IUGR and stunting. In the postnatal period, acute childhood infections, mainly in the respiratory and gastrointestinal tracts, stimulate the release of cytokines that promote inflammation and result in chronic inflammation, affecting nutrient intake and growth. Chronic

immune activation worsens these effects, influences the growth hormone and IGF-1 axis, and causes epigenetic modification, which affects growth-related genes (Amimo et al., 2022; Mutasa et al., 2022).

**Integration with Nutritional Insight**

Malnutrition is another factor that weakens the immune system and causes stunting. This is primarily due to inadequate intake of essential micronutrients, such as zinc, A, C, D, and E. Findings from other studies such as PROBIT and SHINE, reveal that both immunologic and nutritional treatments can be used together to reduce stunting. The findings also show that simultaneously tackling immunological health and nutritional deficiencies is crucial for effectively managing stunting (Amimo et al., 2022; Mutasa et al., 2022).

**Comparison with Previous Literature**

Recent studies on the relationship between nutritional and immunological determinants of stunting have fewer methodological strengths than earlier studies. Observational studies are often limited in that they cannot prove causality and do not explain the molecular basis of interventions. However, some tissues require further elucidation at specific molecular levels and the consequences of long-term immune shaping for growth (Buckner, 2023).

**Implication of the Literature Gaps**

The shortcomings of the literature review include a lack of longitudinal studies and traditional measures, which restrict the understanding of immunological pathways that affect stunting. The following gaps can be identified as necessary to fill in the existing literature and contribute to the development of the field. Future research should use more sophisticated immunological approaches and make the study samples more heterogeneous to capture these intricate relationships. Thus, incorporating immunological knowledge into public health policies is crucial for sustainable development because it can improve child health and decrease stunting rates (Harries et al., 2018).

**Discussion**

**Significant and Implications of the Finding**

This study enhances current theoretical frameworks for stunting by including immune dysregulation as a component of the nutritional status. Conventional models fail to address the development and inflammatory and critical regulatory processes of the immune system, especially during the growth stages. Based on the results of this study, it is recommended that the research has a dual objective, which includes both nutritional and immunological concerns. New theoretical approaches that include cytokine patterns and gut microbiome dynamics help explain the complexity of the stunting problem and its multifactorial nature (Tourkochristou et.al., 2021), and they can be used to design more efficient interventions.

The conclusions propose incorporating immunological knowledge into approaches to combat nutritional and immunity deficits. Some of these utilizations are routine assessment of immunity, supplemental feeding, and immunization in maternal and child health interventions (Amimo et al., 2022). Some policy implications include maternal and nutrition health policies, infection control policies, better hygiene measures, and integration of immunological assessment into children's health policies. Such strategies could help decrease the stunting rate and are by the SDGs intended to enhance future child health.

**CONCLUSIONS**

This review enriches the literature on the immunological mechanisms of childhood stunting and

its relevance to the United Nations Sustainable Development Goals 2030. This view underlines stunting as an immunological and nutritional problem that calls for a change in the approach to the problem. Public health measures that should be adopted include nutritional care and immune modulation. Although there are limitations concerning the methodology used in this review, the study offers significant findings and reveals essential research gaps. Further research on the relationship between nutrition, immunity, and specific immune processes. Incorporating these findings into stunting interventions and global child health objectives is crucial.

## LIMITATION & FURTHER RESEARCH

Some of the limitations of this review include the fact that not all published literature was included, methodological bias due to variations in study design, patient characteristics, and definitions used for stunting and immunological markers, and the majority of the study was cross-sectional, for which caution should be used when interpreting the results. Future research should focus on the conception of early childhood immune development and growth, interactions between nutrition and immunization protocols, sample inclusions of different populations, and methodological approaches such as multi-omics and bioinformatics. Filling these gaps will enhance theoretical models, guide the formulation of timely and appropriate interventions, and benefit children's health (Morasa et al., 2022; Taofik, J et al., 2024).

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