

Pediatric Infectious Diseases, Vaccines, and Immune Health: An Evidence-Based Scholarly Overview

Munther Abdelrahman Saleh Khdairat^{1*}, Khalil Essam Abutouq¹

¹PHCC, Doha, Qatar

DOI: <https://doi.org/10.36347/sjams.2025.v13i11.018>

| Received: 29.09.2025 | Accepted: 12.11.2025 | Published: 15.11.2025

*Corresponding author: Munther Abdelrahman Saleh Khdairat
PHCC, Doha, Qatar

Abstract

Review Article

Infectious diseases account for one of the highest burdens of morbidity and mortality in children worldwide: they remain an essential cause of death in children <5 years of age and contribute substantially to the global disability-adjusted life years burden in children and adolescents aged 5–14 years. Understanding the immune ontogeny in childhood reveals particular immunological characteristics and windows of susceptibility and resilience. Vaccination is a cornerstone of worldwide public health programs and creates herd immunity, reducing the risk of infection in non-vaccinated individuals. Moreover, the administration of vaccines has effects beyond the specific pathogen against which the vaccine is administered, including the stimulation of the entire immune system in infancy, long-term effects on the immune system, and non-specific immune benefits. Nevertheless, specific groups of children premature infants, those with chronic diseases, immunosuppression, and the immunocompromised may have altered immunological maturation, impaired immune responses, or respond poorly to vaccination. Ethical, legal, and policy aspects relevant to vaccination in the pediatric population must also be considered. The available evidence for these different aspects of infectious disease and vaccination in the pediatric population is systematically reviewed to provide a useful reference summary. Discussion of pediatric infections is, evidently, replete with statistics on the associated morbidity and mortality. Available data indicate that vaccines are effective in highly vulnerable populations, such as HIV-infected children, children from low-income or middle-income countries, and children with immune-mediated conditions receiving immunosuppressive therapies. Attention from researchers and practitioners extend further than the infectious diseases themselves: questions abound concerning the immunocompromised, children living with chronic diseases, or preterm infants' populations for whom vaccination may impose greater risk than in the general cohort or the monitoring of long-term individual and herd-community results from relaxed vaccine schedules. Disparate societies employ differing laws and policies for immunization and vaccination coverage in children, from persistent recommendations to outright mandates.

Keywords: Pediatric infectious diseases; Childhood immunization; Immune ontogeny; Immunocompromised children; Vaccine policy and ethics.

Copyright © 2025 The Author(s): This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY-NC 4.0) which permits unrestricted use, distribution, and reproduction in any medium for non-commercial use provided the original author and source are credited.

1. INTRODUCTION

Infectious diseases remain the most prominent causes of global morbidity and mortality in children (Baral *et al.*, 2024). Pathogen- and host-specific interaction patterns suggest that the burden of infection is largely concentrated in the youngest and most vulnerable populations (Brown *et al.*, 2023). The effect of social determinants (e.g., health care access, nutrition, early-life experiences) still takes shape in many regions, where poverty, resource availability, and hygiene continue to modulate community dynamics of pathogen circulation (Khan *et al.*, 2022). In parallel, the age-specific challenges posed by an evolving immune system may influence the outcome of infection and vaccination,

and deficits in innate, adaptive, or integrated responses may compromise early-life immunity, vaccine efficacy, or both (Strong *et al.*, 2021). Such considerations are particularly relevant for premature or low-birthweight infants and those with chronic illness, congenital immune deficiency or dysregulation, and receipt of pharmacological immune suppression (Manetu *et al.*, 2021). Specific populations also include those under national vaccination programs in low-income and middle-income settings with high burdens of disease and continued deficiencies in vaccine access and coverage (Bassat *et al.*, 2023). These contexts highlight the need for evidence-based, age-specific, and population-specific analyses of the epidemiology and immunology

of infectious disease and their intersection with vaccines (Hamson *et al.*, 2023).

Vaccines, immunization, and herd immunity reduce the risk of disease, hospitalization, and death due to the target organism, thus decreasing the overall risk in the population (Doherty *et al.*, 2022). In subgroups with chronic diseases or unstable immune systems, vaccination against specific pathogens also reduces the risk of secondary infections (Carter *et al.*, 2024). Beyond these general principles lies a more complex discussion of the immunological effects of vaccination (or of childhood infections) considered independently of the target pathogens (Talbird *et al.*, 2022). For infants and young children, the maturation of the innate and adaptive immune compartments and functions may be complemented by vaccination, and key vaccination-related mechanisms or milestones may set the stage for the next phases of life (Jansen *et al.*, 2021). In the early years of life, when adapting to the presence of non-self, the risk of severe disease due to common pathogens is high, and the immune system still remains sensitive to a multitude of (non-)pathogenic stimuli (Mohammed *et al.*, 2022). Using the precept of “training” the immune system, the response to different (but clinically important) pathogens can indeed be optimized and might also extend beyond the obvious targets to non-specific benefits (Micoli *et al.*, 2021).

3. Pediatric Infectious Diseases: Landscape and Emerging Trends

A renewed focus on pediatric injuries will not only improve child health, but also reduce population morbidity and mortality from infectious diseases more broadly (Khan *et al.*, 2022). New insights into the epidemiology, host response, and social determinants of infection in early life will facilitate such an effort. Despite historical progress, infectious diseases remain a leading cause of childhood morbidity, disability, and mortality in many populations (Besnier *et al.*, 2021). A changing world is reshaping the landscape. Human behaviours and natural ecosystems are undergoing rapid transformation, many due to climate change; these changes are altering long-standing relationships between pathogens and human hosts (Brown *et al.*, 2023). New virulence factors and pathogen-host interactions have emerged, particularly in pandemic settings (Paul, 2024). Such trends underscore the need to sustain, not relax, efforts to reduce the incidence and impact of disease-causing infectious agents in children (Baker *et al.*, 2022).

3.1. Epidemiology and Burden of Disease in Children

Available global data corroborates that infectious diseases remain a substantial cause of death in children, accounting for ~1.7 million fatalities per year (2.4 million when including fatalities from vaccine-preventable diseases in non-children) (Brown *et al.*, 2023). Moreover, when assessing infant mortality specifically, ~50% of deaths can be attributed to infectious diseases (Khan *et al.*, 2022). Sepsis,

pneumonia, and diarrhoea represent leading causes of fatality within this age group and are commonly associated with immunosuppression/upstream risk factors, malnutrition, and/or prematurity (Muhammad, 2022). A small number of different pathogens are responsible for most of the infections that lead to severe disease and death among young children (Baral *et al.*, 2024). Indeed, almost 90% of childhood deaths are due to either one of the major bacteria-associated enteric diseases, one of the leading respiratory diseases, both together, or a handful of additional specific diseases (Wang *et al.*, 2021).

3.2. Pathogen-Host Interactions in Early Life

Pediatric infectious diseases have long been associated with high morbidity and mortality, especially in children under five (Long *et al.*, 2022). Passive immune protection from transplacental immunoglobulin transfer, together with maternal vaccinations, supports the infant in the early months of life (Buonsenso *et al.*, 2022). However, crucial components of the immune system undergo remodeling during early childhood, which is associated with increased susceptibility to infections, including invasive disease from encapsulated bacterial and viral infections (Wald *et al.*, 2021). Soon after birth, the diversity of skin and mucosal microbiota increases and a functional immune system develops, which provides broad-spectrum protection against different pathogens (Romandini *et al.*, 2021). In developed countries, vaccination in infancy prevents childhood diseases and complications that were previously common, but natural or vaccine-induced antiviral immunity remains incomplete (Melvin *et al.*, 2022). Continuing research demonstrates that social determinants of health, including early childhood environment, nutrition, and caregiving, affect susceptibility to infectious diseases (Hamson *et al.*, 2023). The incidence of invasive infections with encapsulated bacteria is higher in children of low socioeconomic status and with a lack of breastfeeding, while the lifespan of immune memories appears shorter in children raised in adverse environments (Blanchard and Waters, 2022). In countries with inadequate access to pneumococcal and meningococcal vaccinations, increased disease incidence emphasizes that immunization is essential for young children (Abdulla *et al.*, 2022).

4. Immunology of Childhood: Developmental Considerations

During infancy and childhood, the human immune system undergoes a series of evolutionary adaptations (Urlacher, 2023). Although the immune system is established soon after birth, maturation of specific components continues throughout the early years of life, resulting in differential infection susceptibility at the various age milestones (Hong and Medzhitov, 2023). Immune dysfunction in children manifests either as primary immunodeficiency or as immune dysregulation and results in unfavorable health

outcomes (Metcalf *et al.*, 2025). In both cases, vaccination underscores the need to understand the normal development of the pediatric immune system and the expected response to vaccines (Brodin, 2022).

Pediatric infectious disease research has shown that the immature immune system, uniquely different from that of adults, affects susceptibility to infections and diseases (Semmes *et al.*, 2021). Examination of children's responses to immunomodulatory events, particularly immunizations, during the developmental phase informs understanding of the immunologic experience that shapes the responses of older children and adults (Pieren *et al.*, 2022). The pediatric immune response evolves through three distinct periods, with both innate and adaptive systems maturing at different rates (Donald and Finlay, 2023). Training of the immature immune system is an important consideration, particularly in the first year of life, when vaccination schedules offer multiple stimuli that provide instruction to the hematopoietic, myeloid, and lymphoid systems (Liston *et al.*, 2021).

The immune system comprises two functional compartments: the innate and adaptive systems (Wang *et al.*, 2024). Components of the innate response are present at birth and function to defend against infection; however, the magnitude of response is often suboptimal (Kiboneka, 2021). Dysregulation of the innate response is associated with the subsequent onset of allergic diseases, chronic inflammatory diseases, autoimmune disease, and childhood cancers (Weng *et al.*, 2023). The inherent differences in the teleological purpose of infection susceptibility in infants and young children must also be considered relative to the relatively proinflammatory state of the innate immune system at ≤ 12 months of age (Pieren *et al.*, 2022). The maturation of adaptive immunity is gradual, with a reduction in susceptibility to both specific and non-specific infections typically observed by ≥ 4 years of age (Molofsky and Locksley, 2023). Poor responses to vaccination in children with primary immunodeficiency also highlight the importance of age-matched vaccine responses (Anaegoudari *et al.*, 2021).

5. Vaccines in Pediatrics: Principles, Efficacy, and Safety

Five principles underpin vaccination recommendations in the pediatric population: (i) vaccines are offered according to the immunization schedule; (ii) efficacious vaccines afford herd immunity; (iii) immunization is a community-wide and population-level health intervention; (iv) vaccine public health policies adhere to the precautionary principle; and (v) the risk of potential serious adverse events is recognizably vanishingly small relative to the alternative of serious disease (Rus and Groselj, 2021). For individual patients, the immunocompromised face special issues of risk-benefit evaluation; the very young and old in the short term, and many during the COVID-19 pandemic, can

experience vaccines remediating not the pathogenic agent but dysregulated host defense; and medically needy children, such as those born very preterm or with chronic illness or treatment, can respond poorly (Ogugua *et al.*, 2024). Special attention is warranted for the infectious disease consequences of immune deficiency, dysregulation, and treatment (Rus and Groselj, 2021).

The unprecedented success of modern vaccination has resulted in remarkably safe vaccines being rulefully assumed to be undeniably beneficial: that there are no longer any "vaccine-preventable" diseases, only "vaccine-preventable" mortalities – which parochially assumes that SARS-CoV-2 vaccines offer widespread protection from symptomatic COVID-19 and are universally desirable for all classes of individuals – has been elsewhere documented (Donald and Finlay, 2023). Nevertheless, during early infancy, the developing immune system lacks sufficient resources for a wide-ranging pathogen-directed response; and, along with treatment-related dysregulation, this places medically needy children at heightened infectious disease risk and warns that any vaccination considered may not be as definitively beneficial as in the healthy school-aged child (Moraes-Pinto *et al.*, 2021). In contradistinction, prior evidence-based analysis has indicated that successful SARS-CoV-2 vaccines do not satisfactorily replicate the natural disease pattern of infection or consequently revert immune homeostasis (Morales *et al.*, 2023).

6. Vaccines and Immune Health Outcomes: Beyond Infection Prevention

Overwhelming evidence confirms that vaccines protect against the vaccine-preventable infectious diseases they target and their associated complications (Hall and for Disease Control and Prevention, 2021). However, there is growing immunological and clinical evidence that vaccines may also influence the development and function of the immune system beyond the diseases they prevent (Majstorovic and Weatherspoon, 2024). In infancy, the rapid maturation of key innate immune components and the developing adaptive immune system contribute to decisive windows when vaccination may influence the immune system beyond inducing pathogen-directed memory (Al-Jabri *et al.*, 2023). Recent studies suggest that vaccination early in life shapes the functional capacity of the immune system and suppresses unnecessary responses in early childhood; both consequences may persist into later life (Kolobova *et al.*, 2022). Vaccination may also exert important influences beyond protection against targeted diseases, providing non-specific benefits against other infectious diseases, particularly in low-income and middle-income countries (Sinumvayo *et al.*, 2024).

Early childhood is a time of rapid development (Donald and Finlay, 2023). The innate immune system develops significant competence over the first few months of life, with maturation accelerating in relation to

the heightened risk of severe disease in early infancy (Pieren *et al.*, 2022). By contrast, the adaptive immune system is not fully functional until the early years of life, with immune responses to pathogens influenced by the presence of maternal antibody and the diversity of exposures (Laupèze and Doherty, 2023). Such preparatory changes may be reflected in studies describing vaccination in infancy as a Tanner event training the immune system for subsequent responses (Laupèze *et al.*, 2021). These reviews summarize the immunological evidence that vaccination early in life may influence subsequent immune-system development and function, with a focus on the immune system's capability for protection beyond the classic pathways (Cinicola *et al.*, 2021).

7. Special Populations and Considerations

Two main groups of pediatric patients require special considerations regarding routine vaccination: those with chronic diseases or impairments of the immune system processes and those at increased risk of various infectious diseases such as preterm births (Langel *et al.*, 2022). Chronic illness and especially chronic pulmonary, cardiac, or renal diseases reduces the availability of pathogen-specific protective antibodies, resulting in a higher risk of hospitalization and also of a reduced rate of vaccine antibody formation (Galván *et al.*, 2025). These patients remain at risk for an extended period, leading to the idea of “prolonged asplenia” after splenectomy (Josyula *et al.*, 2022). In these patients, delayed antibody formation is observed, and therefore booster doses should be administered 1–2 years earlier than routine patients (Grace *et al.*, 2022).

Patients who are immunosuppressed through therapy or disease itself may not generate adequate responses to live vaccines (Alnaimat *et al.*, 2023). For so-called immunosuppressed patients, immunization with live attenuated virus vaccines is usually contraindicated (Kamei, 2023). Infection with varicella virus can be serious in such patients, but active immunization in normal subjects can also pose a risk for the susceptible patient (Bemben and Berg, 2022). As a consequence of these observations, vaccination with the live attenuated vaccine has been restricted to healthy children and adults who are coming into close contact with an immunosuppressed child (Shoham *et al.*, 2023). Furthermore, the occurrence of so-called secondary transmission in the immunosuppressed patient is restricted to the excretion of measles virus by the vaccinee in the first week after vaccination (Righi *et al.*, 2021).

At a global scale, access to vaccinations as well as rates of delivery remain inequitable (Clouston *et al.*, 2023). The high-risk returnees to formerly polio-endemic areas and residents of these countries who are unvaccinated seem particularly susceptible to poliomyelitis, despite the fact that the current oral poliovaccine is given universally to children in many

parts of the world (Gayle and Childress, 2021). The same holds for all the diseases for which safe vaccines are available: measles, rubella and mumps; diphtheria; tetanus; whooping cough; hepatitis A; and hepatitis B (Gates *et al.*, 2021). The risk of acquiring these diseases is thus correspondingly increased in immunization camps for the detection of new cases, screening for contacts or newly diagnosed patients with infectious syphilis or any type of viral hepatitis, and so on (Jean-Jacques and Bauchner, 2021).

CONCLUSION

The effect on health and development of immune-related diseases during childhood and early infancy remains a global concern, and vaccination programs constitute an important part of public health strategies to limit infectious diseases in children (Besnier *et al.*, 2021). Vaccination strategies for the prevention of infectious and non-infectious diseases are now available but should not only be guided by burden of disease studies and assessment of the protective role of vaccines against such diseases (Alanazi *et al.*, 2024). Informed and appropriate use of the immunization services currently available could also lead to a sustainable decrease in the incidence, morbidity, and mortality associated with immune-related diseases of other etiologies (Ogugua *et al.*, 2024). Pediatricians, family doctors, and all health care workers caring for immunized children should be aware of the impact vaccination has on subsequent immune response to non-vaccine-preventable infections other than those studied in post-marketing surveillance of vaccines (Excler *et al.*, 2021).

Pediatric infectious diseases, and specifically vaccination programs, are crucial public health strategies in reducing the global burden of disease associated with these conditions (Alanazi *et al.*, 2024). In addition to the main aim of preventing targeted diseases, vaccination has other, sometimes unexpected effects on general health, development, and the immune response to other infections (Peter, 2024). Nevertheless, even the best public health services cannot guarantee complete, sustained, and lasting vaccine coverage of childhood populations in every country a fact that jeopardizes the full achievement of herd immunity (Larson *et al.*, 2022). Premature infants, those with chronic diseases, and patients receiving immunosuppressive treatment are at higher risk of severe complications from infections and may be at increased risk when vaccinated (Ogugua *et al.*, 2024).

REFERENCES

- Abdulla, Faruq, *et al.*, "Likelihood of infectious diseases due to lack of exclusive breastfeeding among infants in Bangladesh." PLoS One 17.2 (2022): e0263890

- Alanazi, Faiz Thani H., *et al.*, "The impact of vaccinations on disease prevention: A comprehensive analysis of their role in enhancing global public health and reducing morbidity and mortality rates." *International journal of health sciences* 8.S1 (2024): 1885-1907.
- Al-Jabri, M., Rosero, C., and Saade, E. A. "Vaccine-preventable diseases in older adults." *Infectious Disease Clinics*, 2023. binasss.sa.cr
- Alnaimat, Fatima, *et al.*, "Vaccination in the Era of Immunosuppression." *Vaccines* 11.9 (2023): 1446. mdpi.com
- Anaeigoudari, Akbar, *et al.*, "severe acute respiratory syndrome coronavirus 2: The role of the main components of the innate immune system." *Inflammation* 44.6 (2021): 2151-2169. springer.com
- Baker, Rachel E., *et al.*, "Infectious disease in an era of global change." *Nature reviews microbiology* 20.4 (2022): 193-205.
- Baral, Bhagyashree, *et al.*, "Infectious diseases and its global epidemiology." *Nanostructured Drug Delivery Systems in Infectious Disease Treatment*. Academic Press, 2024. 1-24.
- Bassat, Quique, *et al.*, "Causes of death among infants and children in the child health and mortality prevention surveillance (CHAMPS) network." *JAMA network open* 6.7 (2023): e2322494-e2322494.
- Bemben, Nina M., and Melody L. Berg. "Efficacy of inactivated vaccines in patients treated with immunosuppressive drug therapy." *Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy* 42.4 (2022): 334-342. nih.gov
- Besnier, Elodie, *et al.*, "Which public health interventions are effective in reducing morbidity, mortality and health inequalities from infectious diseases amongst children in low-and middle-income countries (LMICs): an umbrella review." *PLoS One* 16.6 (2021): e0251905.
- Blanchard, Ana C., and Valerie J. Waters. "Opportunistic pathogens in cystic fibrosis: epidemiology and pathogenesis of lung infection." *Journal of the Pediatric Infectious Diseases Society* 11. Supplement_2 (2022): S3-S12
- Brodin, P. "Immune-microbe interactions early in life: A determinant of health and disease long term." *Science*, 2022.
- Brown, Alex, *et al.*, "The unfinished agenda of communicable diseases among children and adolescents before the COVID-19 pandemic, 1990–2019: a systematic analysis of the Global Burden of Disease Study 2019." *The Lancet* 402.10398 (2023): 313-335.
- Brown, Alex, *et al.*, "The unfinished agenda of communicable diseases among children and adolescents before the COVID-19 pandemic, 1990–2019: a systematic analysis of the Global Burden of Disease Study 2019." *The Lancet* 402.10398 (2023): 313-335.
- Buonsenso, D., Di Gennaro, L., De Rose, C., Morello, R., D'Iorio, F., Zampino, G., Piazza, M., Boner, A. L., Iraci, C., O'Connell, S., Cohen, V. B., Esposito, S., Munblit, D., Reena, J., Sigfrid, L., & Valentini, P. (2022). Long-term outcomes of pediatric infections: from traditional infectious diseases to long Covid. *Future microbiology*, 17, 551–571. <https://doi.org/10.2217/fmb-2022-0031>
- Carter, Austin, *et al.*, "Modeling the impact of vaccination for the immunization Agenda 2030: Deaths averted due to vaccination against 14 pathogens in 194 countries from 2021 to 2030." *Vaccine* 42 (2024): S28-S37.
- Cinicola, Bianca, *et al.*, "The protective role of maternal immunization in early life." *Frontiers in pediatrics* 9 (2021): 638871. frontiersin.org
- Clouston, S. A. P., Hanes, D. W., and Link, B. G. "Social inequalities and the early provision and dispersal of COVID-19 vaccinations in the United States: A population trends study." *Vaccine*, 2023. sciencedirect.com
- Doherty, Mark T., *et al.*, "Capturing the value of vaccination: impact of vaccine-preventable disease on hospitalization." *Aging Clinical and Experimental Research* 34.7 (2022): 1551-1561. springer.com
- Donald, K. and Finlay, B. B. "Early-life interactions between the microbiota and immune system: impact on immune system development and atopic disease." *Nature Reviews Immunology*, 2023. aaiito.it.
- Excler, J. L., Saville, M., Berkley, S., and Kim, J. H. "Vaccine development for emerging infectious diseases." *Nature medicine*, 2021. nature.com
- Galván, C., Durán, R., Matos, C., Indolfi, C., and Klain, A. "Recurrent Infections in Allergic Pediatric Patients: An Immune System Problem? A Narrative Review." *Children*, 2025. mdpi.com
- Gates, Allison, *et al.*, "Health inequities related to vaccination: an evidence map of potentially influential factors and systematic review of interventions." *Vaccine* 39.29 (2021): 3825-3833. sciencedirect.com
- Gayle, H. D. and Childress, J. F. "Race, racism, and structural injustice: equitable allocation and distribution of vaccines for the COVID-19." *The American Journal of Bioethics*, 2021.
- Grace, P. S., Gunn, B. M., and Lu, L. L. "Engineering the supernatural: monoclonal antibodies for challenging infectious diseases." *Current Opinion in Biotechnology*, 2022. nih.gov
- Hall, E. and for Disease Control and Prevention, C. "Epidemiology and prevention of vaccine-preventable diseases." 2021. merle-arbeitsmedizin.de
- Hamson, Elizabeth, *et al.*, "Impact of pandemics and disruptions to vaccination on infectious diseases

- epidemiology past and present." *Human Vaccines & Immunotherapeutics* 19.2 (2023): 2219577.
- Hong, J. Y. and Medzhitov, R. "On developmental programming of the immune system." *Trends in Immunology*, 2023.
 - Jansen, Kathrin U., *et al.*, "The impact of human vaccines on bacterial antimicrobial resistance. A review." *Environmental chemistry letters* 19.6 (2021): 4031-4062. [springer.com](https://www.springer.com)
 - Jean-Jacques, M. and Bauchner, H. "Vaccine distribution equity left behind?" *Jama*, 2021. jamanetwork.com
 - Josyula, Srirama, *et al.*, "Pathogen-specific humoral immunity and infections in B cell maturation antigen-directed chimeric antigen receptor T cell therapy recipients with multiple myeloma." *Transplantation and cellular therapy* 28.6 (2022): 304-e1. [sciencedirect.com](https://www.sciencedirect.com)
 - Kamei, K. "Live attenuated vaccines in patients receiving immunosuppressive agents." *Pediatric Nephrology*, 2023. [springer.com](https://www.springer.com)
 - Khan, Durray Shahwar A., *et al.*, "Interventions for high-burden infectious diseases in children and adolescents: a meta-analysis." *Pediatrics* 149.Supplement 6 (2022).
 - Kiboneka, A. "Principals of innate and adaptive immunity. Immunity to microbes & fundamental concepts in immunology." *World J. Adv. Res. Rev*, 2021.
 - Kolobova, Irina, *et al.*, "Burden of vaccine-preventable diseases among at-risk adult populations in the US." *Human vaccines & immunotherapeutics* 18.5 (2022): 2054602. [tandfonline.com](https://www.tandfonline.com)
 - Langel, S. N., Blasi, M., and Permar, S. R. "Maternal immune protection against infectious diseases." *Cell Host & Microbe*, 2022. [cell.com](https://www.cell.com)
 - Larson, Anna, *et al.*, "Addressing an urgent global public health need: strategies to recover routine vaccination during the COVID-19 pandemic." *Human vaccines & immunotherapeutics* 18.1 (2022): 1975453. [tandfonline.com](https://www.tandfonline.com)
 - Laupèze, B. and Doherty, T. M. "Maintaining a 'fit' immune system: the role of vaccines." *Expert Review of Vaccines*, 2023. [tandfonline.com](https://www.tandfonline.com)
 - Laupèze, B., Del Giudice, G., Doherty, M. T., and Van der Most, R. "Vaccination as a preventative measure contributing to immune fitness." *npj Vaccines*, 2021. [nature.com](https://www.nature.com)
 - Liston, A., Humblet-Baron, S., Duffy, D., and Goris, A. "Human immune diversity: from evolution to modernity." *Nature immunology*, 2021. [nature.com](https://www.nature.com)
 - Long, S. S., Prober, C. G., Fischer, M., and Kimberlin, D. "Principles and practice of pediatric infectious diseases E-Book." 2022. [booksdo.com](https://www.booksdo.com)
 - Majstorovic, Martina, and Darien Weatherspoon. "Vaccines, Vaccinations, and the Re-emergence of and Vaccine-Preventable Diseases." *Infection Control in the Dental Office in the Era of COVID-*
 - 19. Cham: Springer Nature Switzerland, 2024. 109-135.
 - Manetu, W. M., M'masi, S., and Recha, C. W. "Diarrhea disease among children under 5 years of age: a global systematic review." 2021.
 - Melvin, Ann J., *et al.*, "Neonatal herpes simplex virus infection: epidemiology and outcomes in the modern era." *Journal of the Pediatric Infectious Diseases Society* 11.3 (2022): 94-101.
 - Metcalf, C. J. E., Graham, A. L., Yates, A. J., and Cummings, D. A. T. "Convergence and divergence of individual immune responses over the life course." *Science*, 2025
 - Micoli, Francesca, *et al.*, "The role of vaccines in combatting antimicrobial resistance." *Nature Reviews Microbiology* 19.5 (2021): 287-302. [nature.com](https://www.nature.com)
 - Mohammed, Ibrahim, *et al.*, "The efficacy and effectiveness of the COVID-19 vaccines in reducing infection, severity, hospitalization, and mortality: a systematic review." *Human vaccines & immunotherapeutics* 18.1 (2022): 2027160. [tandfonline.com](https://www.tandfonline.com)
 - Molofsky, A. B. and Locksley, R. M. "The ins and outs of innate and adaptive type 2 immunity." *Immunity*, 2023. [cell.com](https://www.cell.com)
 - Moraes-Pinto, M. I., Suano-Souza, F., and Aranda, C. S. "Immune system: development and acquisition of immunological competence." *Jornal de Pediatria*, 2021. [scielo.br](https://www.scielo.br)
 - Morales, Fátima, *et al.*, "Effects of malnutrition on the immune system and infection and the role of nutritional strategies regarding improvements in children's health status: A literature review." *Nutrients* 16.1 (2023): 1. [mdpi.com](https://www.mdpi.com)
 - Ogugua, Jane Osareme, *et al.*, "Ethics and strategy in vaccination: A review of public health policies and practices." *International Journal of Science and Research Archive* 11.1 (2024): 883-895. [researchgate.net](https://www.researchgate.net)
 - Paul, J. "Introduction to infectious diseases." *Disease Causing Microbes*, 2024.
 - Peter, J. "The Impact of Vaccination Campaigns on Public Health a Comprehensive Analysis." *Health Science Journal*, 2024. [HTML]
 - Pieren, D. K. J., Boer, M. C., and de Wit, J. "The adaptive immune system in early life: The shift makes it count." *Frontiers in immunology*, 2022. [frontiersin.org](https://www.frontiersin.org)
 - Righi, Elda, *et al.*, "A review of vaccinations in adult patients with secondary immunodeficiency." *Infectious Diseases and Therapy* 10.2 (2021): 637-661. [springer.com](https://www.springer.com)
 - Romandini, Alessandra, *et al.*, "Antibiotic resistance in pediatric infections: global emerging threats, predicting the near future." *Antibiotics* 10.4 (2021): 393

- Rus, M. and Groselj, U. "Ethics of vaccination in childhood A framework based on the four principles of biomedical ethics." *Vaccines*, 2021. mdpi.com
- Semmes, Eleanor C., *et al.*, "Understanding early-life adaptive immunity to guide interventions for pediatric health." *Frontiers in immunology* 11 (2021): 595297. frontiersin.org
- Shoham, Shmuel, *et al.*, "Vaccines and therapeutics for immunocompromised patients with COVID-19." *EClinicalMedicine* 59 (2023). thelancet.com
- Sinumvayo, Jean Paul, *et al.*, "Vaccination and vaccine-preventable diseases in Africa." *Scientific African* 24 (2024): e02199. sciencedirect.com
- Strong, Kathleen L., *et al.*, "Patterns and trends in causes of child and adolescent mortality 2000–2016: setting the scene for child health redesign." *BMJ global health* 6.3 (2021): e004760.
- Talbird, Sandra E., *et al.*, "Impact of routine childhood immunization in reducing vaccine-preventable diseases in the United States." *Pediatrics* 150.3 (2022): e2021056013. aap.org
- Urlacher, S. S. "The energetics of childhood: Current knowledge and insights into human variation, evolution, and health." *American Journal of Biological Anthropology*, 2023. wiley.com
- Wald, E. R., Schmit, K. M., & Gusland, D. Y. (2021). A Pediatric Infectious Disease Perspective on COVID-19. *Clinical infectious diseases: an official publication of the Infectious Diseases Society of America*, 72(9), 1660–1666. <https://doi.org/10.1093/cid/ciaa1095>
- Wang, Ruyuan, *et al.*, "The interaction of innate immune and adaptive immune system." *MedComm* 5.10 (2024): e714. wiley.com
- Wang, X., Li, Y., Mei, X., Bushe, E., Campbell, H., & Nair, H. (2021). Global hospital admissions and in-hospital mortality associated with all-cause and virus-specific acute lower respiratory infections in children and adolescents aged 5-19 years between 1995 and 2019: a systematic review and modelling study. *BMJ global health*, 6(7), e006014. <https://doi.org/10.1136/bmjgh-2021-006014>
- Weng, J., Couture, C., and Girard, S. "Innate and adaptive immune systems in physiological and pathological pregnancy." *Biology*, 2023.