Pancasakti Journal of Public Health Science and Research
Vol. 5, No. 1 January 2025: Hal. 43–53
Doi: 10.47650/pjphsr.v5i1.1641
ISSN (Online): 2777-1296
OJS: http://journal.unpacti.ac.id/index.php/pjphsr

Measles-Rubella Vaccination: Epidemiological Issue, Immunology, and Ethical Challenges

Ainurafiq[1], Tanti Asrianti[2*], Sartika[3], Eman Salim Ahmed Salim[4], Indar[5]
[1] Avicenna Institute of Technology and Health, Kendari, Indonesia
[2] Mulawarman University, Samarinda, Indonesia
[3] University of Muslim Indonesia, Makassar, Indonesia
[4] National Ribat University, Khartoum, Sudan
[5] Hasanuddin University, Makassar, Indonesia

[*]**Correspondence Address:** tantiasrianti@fkm.unmul.ac.id

Article Info

Article History
Received: Dec 11, 2024
Revised: Dec 31, 2024
Accepted: Jan 10, 2025

Keywords:
Measles-Rubella, Vaccination, Epidemiology, Immunology, Ethic

ABSTRACT / ABSTRAK

This article discusses issues related to measles-rubella vaccination from the perspective of epidemiology, immunology, and ethical challenges faced. Measles and rubella are infectious diseases that have the potential to cause extraordinary events (KLB) throughout the world, including Indonesia. Although measles-rubella vaccination has been proven effective in reducing the incidence of the disease, challenges such as low vaccination coverage due to the COVID-19 pandemic, vaccine hesitancy, and ethical issues related to parental consent and equal access to vaccines are significant obstacles. Research shows that to achieve effective community immunity, a vaccination coverage of at least 95% is required. This article also describes the immunological processes involved in the response to measles and rubella infection and the importance of public health efforts in increasing awareness and access to vaccines. With a comprehensive and inclusive approach, it is hoped that existing challenges can be overcome and community participation in vaccination programs can be increased. Collaboration between the government, health institutions, and the community is essential to create a healthier and safer environment, ultimately supporting the goal of eliminating measles and rubella in the future.

INTRODUCTION

Measles and rubella are two diseases that have been identified as potential outbreaks (Extraordinary Events/EE) worldwide, prompting countries, including Indonesia, to classify them under the same status. Epidemiologically, measles and rubella show patterns of rapid case increases and widespread transmission, resulting in severe consequences. Although both diseases share some similar symptoms, such as skin rashes, they differ in their causes, impacts, and immunological processes. Measles is caused by the Morbilli virus, while rubella is caused by the Rubella virus. Measles infection significantly suppresses the immune system, leading to a reduced immune response, making the body more susceptible to secondary infections. In contrast, rubella infection, although not significantly lowering the immune system, has serious consequences for pregnant women and their fetuses, potentially leading to congenital rubella syndrome and birth defects.

The occurrence of measles and rubella is a health event with a collective dimension, extending beyond individual cases. Both diseases are transmitted through respiratory droplets in close interactions between individuals within the community. Individual capacity is insufficient to prevent their spread and the potential for outbreaks, requiring collective solidarity organized through public health authorities. This is the focus of public health efforts. Collective efforts to address measles and rubella, preventing outbreaks, include achieving herd immunity through vaccination with a 95% coverage rate. Public health initiatives for the control of measles and rubella are not limited to national efforts but have become a global movement. The Measles Initiative, established in 2001, evolved into the Measles and Rubella Initiative (MRI) in 2012, focusing on reducing deaths and eliminating both diseases (Strebel et al., 2024). The World Health Organization (WHO) recommended in 2011 that countries introduce rubella vaccination alongside measles elimination efforts, resulting in a 66% reduction in congenital rubella syndrome cases from 2012 to 2019 (Grant & Zimmerman, 2023). However, challenges such as the COVID-19 pandemic disrupted vaccination campaigns, leading to increased vulnerability among the unvaccinated population, resulting in reduced vaccination uptake and a resurgence of measles cases (Chaklader et al., 2023).

In 2023, Indonesia achieved a 72.7% coverage rate for the Measles-Rubella catch-up immunization, reaching 26.5 million children out of a target of 36.4 million. The highest proportion came from the Java-Bali region, contributing 98% of the total coverage. Meanwhile, the 27 provinces outside Java-Bali achieved only 63.9%. Among the provinces in the Java-Bali region, five provinces—West Java, Central Java, Banten, DKI Jakarta, and East Java—reached the target of 95% coverage. Outside of Java-Bali, only one province, South Sulawesi, achieved the 95% target. Therefore, it is not surprising that the World Health Organization (WHO) reported 2,161 suspected measles cases in Indonesia from January 1 to April 3, 2023, of which 848 cases were confirmed and 1,313 were clinically compatible across 18 out of 38 provinces (Tarmizi, 2023).

There have been several challenges in the implementation of the Measles-Rubella vaccination in recent years. In addition to the obstacles posed by the global COVID-19 pandemic, other challenges include ethical issues such as parental autonomy, equitable access to vaccines, vaccine hesitancy, resource allocation, mandatory vaccination policies, and more. These ethical challenges have significantly impacted the slowdown of the Measles-Rubella vaccination program, thus requiring an ethical perspective to address them. For this purpose, this article will discuss the ethical issues related to the Measles-Rubella vaccination program, along with its challenges and solutions. Furthermore, to highlight the urgency of the Measles-Rubella vaccination, this article also presents the latest epidemiological issues concerning measles and rubella. It also briefly outlines the immunological process of measles-rubella and the importance of vaccination to achieve herd immunity to prevent outbreaks. With this information, it is hoped that this will contribute as an ethical perspective to continue improving Measles and Rubella vaccination coverage.

Epidemiological Issue of Measles

Measles is a highly contagious viral disease with the potential for serious complications, including pneumonia, encephalitis, and even death. Although measles vaccination has been safe and effective in combating the disease for over six decades, outbreaks have resurged in recent

years, posing a threat to young children worldwide. Since 2019, 103 countries have experienced measles outbreaks (Krause, 2024; UNICEF, 2024b). In 2023, only 83% of children globally received the first dose of the measles vaccine through routine healthcare services, while the number of children receiving the second dose slightly increased from the previous year to reach 74%. These figures are still far from the 95% coverage required to achieve herd immunity, prevent outbreaks, reduce unnecessary disease and deaths, and meet measles elimination goals (UNICEF, 2024b; WHO, 2024).

In the last five years, measles outbreaks have occurred in 103 countries. The main factor triggering these outbreaks is low vaccination coverage, which is 80% or lower. Conversely, 91 countries with strong measles vaccination coverage have not experienced similar outbreaks (UNICEF, 2024b). In 2023, nearly half of the reported cases in Europe occurred in children under five years of age. This reflects the situation of children who did not receive routine measles vaccination and other vaccine-preventable diseases, as one of the consequences of the COVID-19 pandemic, compounded by the slow recovery of immunization coverage in 2021 and 2022 (UNICEF, 2024a).

Low- and middle-income countries tend to have lower vaccination coverage compared to high-income countries. A study conducted in several low- and middle-income countries in South Asia found that the coverage of the first dose of the measles vaccine was quite low, with Afghanistan reporting the lowest coverage among South Asian countries at 51.7% (Mahazabin et al., 2024). Indonesia is one of the countries that reported an increase in measles cases. In 2022, 12 provinces in Indonesia declared measles outbreaks. This is linked to a significant decline in measles vaccination coverage due to the COVID-19 pandemic (Ministry of Health of the Republic of Indonesia, 2023).

Epidemiological Issues of Rubella

Rubella is a viral infection that can have fatal consequences, especially for pregnant women, as it can cause congenital abnormalities in unborn babies. Although rubella vaccination has significantly reduced the incidence of the disease, challenges in controlling rubella still exist, particularly in countries with low immunization coverage and limited healthcare systems.

According to a WHO report, while some countries have successfully reduced rubella incidence, certain regions, particularly in Africa and Southeast Asia, still show high incidence rates. Countries with incomplete or ineffective immunization programs face significant challenges in eliminating this disease. For instance, the WHO reported over 100,000 rubella cases in various developing countries in 2023, largely due to low awareness and lack of vaccine availability in remote areas (WHO, 2024). Efforts to address this issue include ensuring equitable vaccine distribution and increasing public awareness about the importance of vaccination, which are crucial steps in controlling rubella.

Although rubella vaccination is highly effective, achieving high immunization coverage remains a challenge. In some countries, particularly developing ones, there are obstacles in vaccine distribution and difficulties in reaching vulnerable groups. These challenges are caused by social, economic, and healthcare infrastructure limitations. A study by Gong et al. (2024) revealed that in many countries, public awareness about the importance of rubella vaccination is still low, especially among young parents who lack sufficient knowledge about the impact of this infection on pregnant women. Another study by Vynnycky et al. (2023) also showed that,

despite strict vaccination policies in some developed countries, low vaccination rates persist in certain communities. The research found that communities with low incomes and limited access to healthcare facilities are at higher risk of not receiving rubella vaccination on time.

WHO and UNICEF have launched several global initiatives to improve rubella immunization coverage, including mass vaccination campaigns in countries with high prevalence rates. These initiatives aim to eliminate rubella by 2025 through more equitable vaccine distribution and educational programs to raise public awareness. In Indonesia, the rubella immunization program, which began in 2017 with the Mass Immunization Campaign, has successfully reduced rubella incidence significantly. However, challenges remain in ensuring that every individual, especially those in remote areas, receives complete vaccination. According to Plotkin (2021), although immunization coverage in major cities is relatively high, significant disparities in vaccination coverage exist in rural areas and regions with limited access to healthcare services.

Immunological Process of Measles and Rubella

Measles and rubella are two highly contagious viral diseases with the potential for serious complications. The combined measles and rubella (MR) vaccine has proven to be effective in preventing both diseases. However, in recent years, the incidence of measles and rubella has been on the rise in various parts of the world. Understanding the immunological processes involved in the response to measles and rubella infections is crucial for the development of better prevention and control strategies.

Causes

Measles is caused by the morbillivirus, while rubella is caused by the rubella virus. Both viruses spread through respiratory droplets and can result in high morbidity, especially in children. The MR vaccine has been widely used and proven effective in reducing the incidence of both diseases. However, declining vaccination coverage in some countries has led to a resurgence of measles and rubella cases.

Immunological Response to Measles and Rubella

Innate Immunity

The innate immune response is the first line of defense against measles and rubella infections. Upon infection, the virus is identified by immune cells, such as macrophages and dendritic cells, which produce cytokines to activate other immune cells. Interferons are also produced to inhibit viral replication (Avota et al., 2010).

Adaptive Immunity

The adaptive immune system develops a more specific response to the measles and rubella viruses (Avota et al., 2010):

1. Humoral Response: B cells play a critical role in producing antibodies. The antibodies generated, primarily IgM and IgG, serve to neutralize the virus and prevent further infection (Alonge et al., 2024).
2. Cellular Immunity: T cells, especially CD4+ T helper cells and CD8+ cytotoxic T cells, are involved in identifying and destroying infected cells. T helper cells assist in activating B cells and antibody production, while cytotoxic T cells directly attack the virus-infected cells (Rudolph et al., 2019).

Virus Evasion Mechanisms

Both measles and rubella viruses have strategies to evade the immune system:

1. Immunosuppression: The measles virus, in particular, can suppress the immune response, potentially leading to secondary infections (Avota et al., 2010).
2. Antigenic Variation: The rubella virus can undergo antigenic changes that affect the immune system's ability to recognize and fight the infection (Haralambieva et al., 2017).

Implications of Vaccination and Public Health

The Measles and Rubella (MR) vaccine is highly effective in generating an immune response and ensuring long-term protection against measles and rubella. High vaccination coverage is essential to prevent outbreaks and protect vulnerable populations. Public health efforts, in the form of measles and rubella vaccination programs, have significantly impacted community immunity, reducing the incidence of diseases and related complications. Vaccination efforts have led to a substantial decline in measles and rubella cases, contributing to herd immunity and preventing epidemics. The implementation of measles and rubella vaccination has drastically reduced the incidence of these diseases in several countries. In the United States, investment in vaccination has prevented approximately 237 million measles infections and 193 million rubella infections, demonstrating the vaccine's effectiveness in reducing morbidity and mortality (Thompson, 2024).

In California, a decline in MMR vaccination rates from 96.5% to 92.6% correlated with an increase in measles, mumps, and rubella outbreaks, highlighting the importance of maintaining high vaccination coverage to sustain community immunity (McGinley & Sakharkar, 2023). In India, the measles-rubella vaccination campaign led to a sharp decline in measles cases, underscoring the success of the campaign in improving community immunity (Chaklader et al., 2023).

Challenges and Ethical Solutions in the Measles Vaccination Program

While the measles and rubella vaccination program has proven to achieve remarkable success, ethical challenges have emerged related to this vaccination program. There are at least five main ethical challenges in implementing vaccination to achieve community immunity against measles and rubella, namely parental consent; equity of access; vaccine hesitancy; resource allocation; and mandatory vaccination policies.

Parental Consent

The challenge of obtaining parental consent for the measles and rubella vaccination involves a complex interaction between parental autonomy, public health obligations, and ethical considerations in the context of measles-rubella vaccination. Parental hesitancy and resistance are fueled by misinformation and social factors, creating significant challenges in achieving optimal vaccination coverage. An ethical framework and informed consent process are crucial in addressing this challenge, while respecting parental rights in decision-making and ensuring the child’s right to health and well-being.

The challenge in obtaining parental consent for measles and rubella vaccination is related to parental doubts and rejection of the vaccine. Most parents who refuse vaccination express doubts or opposition to the MR vaccine, as seen in Jordan, where only 13.8% of parents accepted the vaccine. Factors influencing this include trust in the safety and efficacy of the vaccine, and family considerations (Barakat et al., 2023).

This situation undoubtedly raises ethical tensions. An ethical dilemma arises when the parent's right to make decisions for their children conflicts with the child's right to receive health protection. The ethical obligation to vaccinate children must be balanced with respecting the decision-making rights of parents. Therefore, the process of obtaining parental consent based on informed consent for mandatory vaccination is fraught with challenges, as it is often not voluntary and is more influenced by legal mandates (Zagaja et al., 2018).

An ethical solution to address this challenge can be approached through an ethical framework that utilizes ethical principles to balance the community's obligation to protect children with the concept of respecting parental autonomy. This should be supported by ensuring that the vaccines used meet criteria such as proven efficacy and favorable benefit-risk ratios (Marckmann, 2021). It must also be reinforced by implementing an informed consent model that provides accessible, complete information, addresses parental concerns, and allows for autonomous decision-making without coercion. This process should be improved to better meet ethical standards (Reiss & Karako-Eyal, 2019).

To help shift parental decisions from doubt and resistance, public health interventions, such as mass campaigns to build trust in the safety and efficacy of the vaccine, are necessary (Barakat et al., 2023). Based on this, the implementation of vaccination policies should carefully consider both parental rights and public health obligations. Balancing these aspects requires an approach that respects individual autonomy while prioritizing public health. Ethical discourse should focus on the concept that society owes children the protection they need against preventable diseases.

Equitable Access

Ensuring equitable access to measles and rubella vaccination presents significant challenges, particularly in low- and middle-income countries where the disease burden is highest. These challenges are multifaceted, involving ethical, logistical, and social dimensions. Addressing these challenges requires a comprehensive approach that includes ethical solutions to ensure the fair distribution and access to vaccines.

Vaccination access challenges include geographical and economic barriers, vaccine hesitancy, and distribution inequalities. Many low-income countries face significant barriers to vaccine distribution due to inadequate healthcare infrastructure and economic constraints, resulting in low vaccination coverage and high disease burden (Coulborn et al., 2024; Cutts et al., 2013).

Additionally, misinformation and disinformation contribute to vaccine hesitancy, further complicating efforts to achieve the high vaccination rates necessary for community immunity (Higgins & O'Leary, 2024). The vaccine monopoly by wealthy countries during the COVID-19 pandemic also highlighted clear disparities in vaccine access, which can impact efforts for measles and rubella vaccination (Ortiz-Millán, 2024).

Ethical solutions can be implemented through international cooperation and agreements. By establishing international agreements that recognize healthcare as a human right and emphasize the corporate social responsibility of pharmaceutical companies, fair vaccine distribution can be ensured. Voluntary licensing agreements may also improve access to essential vaccines (Ortiz-Millán, 2024). Additionally, targeted vaccination programs for high-risk groups can help bridge gaps in vaccine access while balancing non-discrimination and

privacy concerns (Luyten et al., 2011). Furthermore, strengthening health systems by integrating measles and rubella vaccination campaigns with broader health system strengthening efforts can improve vaccine uptake and address systemic injustices (Andrus et al., 2016).

Vaccine Hesitancy

Ethical challenges surrounding measles and rubella vaccination primarily revolve around vaccine hesitancy and misinformation. Vaccine hesitancy is exacerbated by incorrect information that has been reinforced by digital communication platforms. This complicates efforts to achieve widespread immunization. Vaccine hesitancy is a significant barrier to achieving the elimination of measles and rubella. It is driven by misinformation and disinformation, which have also been worsened by the COVID-19 pandemic. Therefore, effective communication strategies and behavioral interventions are crucial in addressing vaccine hesitancy. These strategies should be evidence-based and tailored to meet the specific needs of communities (Higgins & O'Leary, 2024).

Resource Allocation

Resource allocation for Measles and Rubella vaccination presents significant challenges, particularly in the context of limited resources and ethical considerations. These challenges are further compounded by the need to balance equitable distribution with prioritizing high-risk populations. Ethical solutions must address this complexity by integrating principles of justice, transparency, and efficiency. Challenges in resource allocation are linked to scarcity and demand management. Vaccine demand often exceeds supply, necessitating rationing protocols that may lead to ethical dilemmas. This scarcity is exacerbated during outbreaks, as seen in the 2018-2019 measles outbreak in Madagascar, where operational costs and vaccine procurement posed significant challenges (Sodjinou et al., 2020). Ensuring equitable access to vaccines remains an ongoing challenge, particularly in low-income countries. The COVID-19 pandemic highlighted disparities in vaccine distribution, which is also relevant for measles and rubella vaccination efforts (Emanuel & Persad, 2023; Steele & Duthie, 2021).

Ethical solutions to this issue involve the implementation of need-based allocation. This way, vaccine distribution priorities can help address gaps. It should involve local needs assessments and apply a well-weighed prioritization approach, as seen during the COVID-19 pandemic (Owen Schaefer, 2023). Additionally, applying an ethical framework that emphasizes core values, such as maximizing benefits, minimizing harm, and ensuring equitable moral concern, can guide resource allocation (Steele & Duthie, 2021). Optimizing the use of technology is also necessary to enhance vaccination strategies and resource allocation, increasing efficiency and effectiveness in reaching target populations (Shi, 2024).

Mandatory Vaccination Policy

The mandatory vaccination policy for measles and rubella presents a complex interaction of ethical, legal, and public health challenges. This policy aims to achieve community immunity and protect public health, but it also raises significant ethical concerns regarding autonomy and individual rights. Ethical solutions to these challenges involve balancing public health benefits with respect for individual freedoms, while also considering broader social implications.

Among the ethical challenges that arise is the fact that mandatory vaccination policies often conflict with the principles of non-discrimination and proportionality. These principles aim to ensure the least restrictive means of achieving public health goals, but in practice, they can lead to paradoxical outcomes where strict policies are required to protect health and life.

There is ongoing debate over whether individuals should have the right to refuse vaccination on moral, religious, or philosophical grounds. This raises questions about the balance between individual conscience and public health needs. As such, the mandatory vaccination policy has challenged the balance between individual rights and the paternalistic role of the state in ensuring public health. This tension is evident in various national approaches to vaccination, ranging from recommendations to mandatory policies with sanctions (Barakat et al., 2023; Marckmann, 2021).

Ethical solutions that can be employed include an approach based on informed consent, the development of a strong legal and ethical framework, and establishing public health efforts like vaccination as a social norm. The first is done by promoting informed decision-making through education. This can help address vaccine hesitancy and ethical concerns. Providing clear information about the benefits and risks of vaccination can empower individuals to make informed choices (Valenzuela-Almada et al., 2020).

The second solution involves developing a robust legal framework that respects individual rights while promoting public health as a critical priority. This includes considering conscience and ensuring that policies are proportional and non-discriminatory. The third solution is to make public health efforts such as vaccination a social norm, similar to the concept of seat belt use, which has become a social norm. This can help improve acceptance and compliance. This approach emphasizes collective responsibility to protect vulnerable populations (Barakat et al., 2023; Marckmann, 2021).

CONCLUSION

In conclusion, this article has outlined various issues related to measles-rubella vaccination from the perspectives of epidemiology, immunology, and the ethical challenges faced. The importance of vaccination as a preventive measure for these infectious diseases cannot be overlooked, especially in the broader context of public health. With an ideal vaccination coverage rate of 95%, we can build an effective community immunity to prevent outbreaks of measles and rubella, which have proven to have serious impacts on child health and the community as a whole.

However, existing challenges, including issues of access, vaccine hesitancy, and mandatory vaccination policies, indicate that a comprehensive and inclusive approach is essential. Efforts to raise public awareness about the benefits of vaccination, as well as addressing misinformation, are crucial steps to increase community participation in vaccination programs. Additionally, the enforcement of fair and ethical policies in vaccine distribution must be prioritized to ensure that all individuals, regardless of social or economic background, have equal access to vaccines.

Therefore, collaboration between the government, healthcare institutions, and the public is necessary to achieve the shared goal of controlling and eliminating measles and rubella. Through strong cooperation and commitment, we can together create a healthier and

safer environment for future generations. Let us increase vaccination coverage and support public health initiatives for the well-being of all.

REFERENCES

Alonge, O. D., Marin, M., Hickman, C. J., Sowers, S. B., Chen, M., Hao, L., Mercader, S., El-Badry, E., McClure, D. L., Icenogle, J. P., Sugerman, D. E., Crooke, S. N., & Nguyen, H. Q. (2024). Long-term Neutralizing Antibody Levels Against Measles and Rubella Viruses Among Adults With 3 Doses of Measles-Mumps-Rubella Vaccine. Open Forum Infectious Diseases, 11(1). https://doi.org/10.1093/ofid/ofad700

Andrus, J. K., Cochi, S. L., Cooper, L. Z., & Klein, J. D. (2016). Combining global elimination of measles and rubella with strengthening of health systems in developing countries. Health Affairs, 35(2). https://doi.org/10.1377/hlthaff.2015.1005

Avota, E., Gassert, E., & Schneider-Schaulies, S. (2010). Measles virus-induced immunosuppression: from effectors to mechanisms. Medical Microbiology and Immunology, 199(3), 227–237. https://doi.org/10.1007/s00430-010-0152-3

Barakat, M., Abdaljaleel, M., Atawneh, N., Alkhazaleh, R., Aburumman, D., Hamed, E., & Sallam, M. (2023). Pervasive Parental Hesitancy and Resistance towards Measles Rubella Vaccination in Jordan. Vaccines, 11(11), 1672. https://doi.org/10.3390/vaccines11111672

Chaklader, B., Banerjee, A., Rathod, H., Srivastava, K., Lakhute, S., & Borgaonkar, C. (2023). Measles Rubella Vaccination Campaign: Pandemic as Speed Breaker. Medical Journal of Dr. D.Y. Patil Vidyapeeth, 16(4). https://doi.org/10.4103/mjdrdypu.mjdrdypu_868_21

Coulborn, R. M., Danet, C., & Alsalhani, A. (2024). Measles and rubella vaccine microneedle patch: new hope to reach the unreached children. The Lancet, 403(10439), 1825–1827. https://doi.org/10.1016/S0140-6736(24)00749-9

Cutts, F. T., Lessler, J., & Metcalf, C. J. E. (2013). Measles elimination: Progress, challenges and implications for rubella control. In Expert Review of Vaccines (Vol. 12, Issue 8). https://doi.org/10.1586/14760584.2013.814847

Emanuel, E. J., & Persad, G. (2023). The shared ethical framework to allocate scarce medical resources: a lesson from COVID-19. In The Lancet (Vol. 401, Issue 10391). https://doi.org/10.1016/S0140-6736(23)00812-7

Gong, X., Zheng, C., Fang, Q., Xu, W., & Yin, Z. (2024). A case of congenital rubella syndrome and epidemiology of related cases in China, 2014–2023. Human Vaccines & Immunotherapeutics, 20(1). https://doi.org/10.1080/21645515.2024.2334917

Grant, G. B., & Zimmerman, L. (2023). Decreases in Congenital Rubella Syndrome Reflect Concerted Efforts Toward Rubella and Measles Elimination. In International Journal of Infectious Diseases (Vol. 137). https://doi.org/10.1016/j.ijid.2023.10.012

Haralambieva, I. H., Gibson, M. J., Kennedy, R. B., Ovsyannikova, I. G., Warner, N. D., Grill, D. E., & Poland, G. A. (2017). Characterization of rubella-specific humoral immunity following two doses of MMR vaccine using proteome microarray technology. PLOS ONE, 12(11), e0188149. https://doi.org/10.1371/journal.pone.0188149

Higgins, D. M., & O'Leary, S. T. (2024). A World without Measles and Rubella: Addressing the Challenge of Vaccine Hesitancy. Vaccines, 12(6), 694. https://doi.org/10.3390/vaccines12060694

Luyten, J., Vandevelde, A., Van Damme, P., & Beutels, P. (2011). Vaccination policy and ethical challenges posed by herd immunity, suboptimal uptake and subgroup targeting. Public Health Ethics, 4(3). https://doi.org/10.1093/phe/phr032

Marckmann, G. (2021). Ethical Aspects of Vaccination. VacciTUTOR. https://doi.org/10.33442/vt202127

McGinley, B. N., & Sakharkar, P. (2023). Investigation of MMR Vaccination Rates and its Relationship with Measles, Mumps, and Rubella Outbreaks in California. ASPET 2023 Annual Meeting Abstract - Pharmacogenomics and Translational Pharmacology, 431. https://doi.org/10.1124/jpet.122.232460

Ortiz-Millán, G. (2024). Ethical and Practical Considerations for an Agreement to Ensure Equitable Vaccine Access Comment on "More Pain, More Gain! The Delivery of COVID-19 Vaccines and the Pharmaceutical Industry's Role in Widening the Access Gap." International Journal of Health Policy and Management, 13, 8516. https://doi.org/10.34172/ijhpm.2024.8516

Owen Schaefer, G. (2023). Fairly and Pragmatically Prioritizing Global Allocation of Scarce Vaccines during a Pandemic. In Pandemic Ethics (pp. 231–247). Oxford University PressOxford. https://doi.org/10.1093/oso/9780192871688.003.0012

Plotkin, S. A. (2021). Rubella Eradication: Not Yet Accomplished, but Entirely Feasible. The Journal of Infectious Diseases, 224(Supplement_4), S360–S366. https://doi.org/10.1093/infdis/jiaa530

Reiss, D. R., & Karako-Eyal, N. (2019). Informed Consent to Vaccination: Theoretical, Legal, and Empirical Insights. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3319395

Rudolph, M. E., McArthur, M. A., Magder, L. S., Barnes, R. S., Chen, W. H., & Sztein, M. B. (2019). Characteristics of regulatory T-cell populations before and after Ty21a typhoid vaccination in children and adults. Clinical Immunology, 203, 14–22. https://doi.org/10.1016/j.clim.2019.04.002

Shi, X. (2024). Deep Reinforcement Learning (DRL) Is Used to Optimize Vaccination Strategies and Resource Allocation. Highlights in Science, Engineering and Technology, 102, 833–842. https://doi.org/10.54097/see7fa88

Sodjinou, V. D., Nimpa, M. M., Douba, A., Masembe, Y. V., Randria, M., & Ndiaye, C. F. (2020). Challenges related to resources mobilization for measles outbreak response: Madagascar experience during the 2018-2019 measles outbreak. Pan African Medical Journal, 36. https://doi.org/10.11604/pamj.2020.36.304.24514

Steele, D., & Duthie, K. (2021). Ethics of resource allocation in a public health emergency context. Healthcare Management Forum, 34(6). https://doi.org/10.1177/08404704211047911

Strebel, P., Grabowsky, M., Hoekstra, E., Gay, A., & Cochi, S. (2024). Evolution and Contribution of a Global Partnership against Measles and Rubella, 2001–2023. Vaccines, 12(6), 693. https://doi.org/10.3390/vaccines12060693

Tarmizi, S. N. (2023, May 2). Suntikan Imunisasi Ganda untuk Cegah Campak. Kemkes.Go.Id. https://www.kemkes.go.id/id/rilis-kesehatan/suntikan-imunisasi-ganda-untuk-cegah-campak

Thompson, K. M. (2024). The Health and Economic Benefits of United States Investments in Measles and Rubella Control and Elimination. Vaccines, 12(11). https://doi.org/10.3390/vaccines12111210

Valenzuela-Almada, M. O., Michel-Izeta, B. E., & Derive, S. (2020). Is keeping my child from getting the MMR vaccine unethical? Bioethical arguments for informed decision-making. Bioethics Update, 6(2), 121–138. https://doi.org/10.1016/j.bioet.2020.03.002

Vynnycky, E., Knapp, J. K., Papadopoulos, T., Cutts, F. T., Hachiya, M., Miyano, S., & Reef, S. E. (2023). Estimates of the global burden of Congenital Rubella Syndrome, 1996-2019. International Journal of Infectious Diseases, 137, 149–156. https://doi.org/10.1016/j.ijid.2023.09.003

WHO. (2024, May 14). Rubella. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/rubella

Zagaja, A., Patryn, R., Pawlikowski, J., & Sak, J. (2018). Informed Consent in Obligatory Vaccinations? Medical Science Monitor, 24, 8506–8509. https://doi.org/10.12659/MSM.910393