Preventing Pneumonia: Vaccination and Public Health Strategies for Children

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Abstract

Among children, pneumonia continues to be a major cause of disease and mortality, especially in low and middle-income countries. Pneumonia affects the respiratory system of children and adults leading to serious complications and death. Reducing the burden of this disease requires efforts, such as vaccination and public health initiatives. Significant decreases in pneumonia related morbidity and mortality have been shown with vaccines such as BCG, Hib, influenza, pneumococcal conjugate vaccine (PCV) and measles vaccines. Public health initiatives emphasizing exclusive breastfeeding, healthy eating, better sanitations and hygiene habits are essential in preventing pneumonia in addition to vaccination. Another important strategy to stop the development of pneumonia is to strengthen the healthcare system and limit exposure to tobacco smoke. Reducing catastrophic outcomes by pneumonia requires early identification and prompt antibiotic therapy. Campaigns for community education and awareness provide parents and other caregivers with more confidence to take preventive action and seek timely medical attention. To significantly lower childhood pneumonia and the deaths it causes, a multifaceted strategy that incorporates vaccination, health promotion, and healthcare access is essential.

Keywords: Pneumonia, Vaccination, Health strategies, Healthcare systems, Prevention, Future strategies, Challenges in prevention

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Introduction

Pneumonia is one type of acute respiratory infection which mainly affects the lungs. Lungs which are made up of small sacs called alveoli. Alveoli fill with air when a person breathes and oxygenation of blood takes place which is crucial in a normal person's body (Kaimakamis & Chasapidou, 2022). In pneumonia, alveoli swell with fluid and pus which restricts oxygen intake and makes breathing difficult. Though its microbiological causes were only discovered with advances in microbiology, pneumonia's origin can be traced back to centuries into human history. Around 460 BC, the Greek physician Hippocrates introduced the term "peripneumonia" to characterize pneumonia (Dias, 2024). He explained its symptoms, which include coughing, fever, and chest pain. It was first characterized as a clinical entity in the late 19th century (Gadsby & Musher, 2022). Globally, pneumonia is the leading infectious cause of mortality for children. According to WHO, in 2019 pneumonia took the lives of 740180 children under the age of five, making up 14 and 22% of all deaths in children 1 to 5 years (Wake, 2024). Children and families worldwide are impacted by pneumonia, although southern Asia and sub-Saharan Africa have the highest mortality rates. Pneumonia in children can be prevented with easy measures, and it can be treated with low-cost, low-tech medication and care. Pneumonia can be caused by bacteria, viruses or fungi. *Streptococcus pneumoniae* is the most common cause of bacterial pneumonia in children. *Haemophilus influenza* type b (Hib) is the second most common cause of bacterial pneumonia (Lai et al., 2022). Viral infections include respiratory syncytial virus (RSV) and influenza. One of the most frequent causes of pneumonia in newborns with HIV is *Pneumocystis jiroveci*, which accounts for at least 25% of all pneumonia-related deaths in these infants (Kanj et al., 2021). Pneumonia can spread in several ways. The viruses and bacteria that are commonly found in children's nose or throat can infect the lungs if inhaled. Additionally, they can spread through airborne droplets from sneezes or coughs. Furthermore, pneumonia may spread through blood, particularly during and soon after birth. Direct contact with infected surfaces or secretions can potentially spread the bacteria. Pneumonia frequently starts as an upper respiratory tract infection which further moves into lower respiratory tract, when enters the lungs it triggers inflammatory response causing pneumonitis (Lung inflammation) (Short et al., 2024). It becomes difficult for oxygen to enter the bloodstream when lung's alveoli (air sacs) swell with fluid and pus. White blood cells

build up in the alveoli as a result of the body's immune system attacking the infection. A series of inflammations brought on by the immunological response can cause the lungs to enlarge and leak fluid (Beretta et al., 2021). Presenting features of viral and bacterial pneumonia are similar mostly. Common signs and symptoms include, cough with phlegm, rapid breathing(tachypnea), chest indrawings, fever (high grade along with chills), chest pain, loss of appetite, wheezing and crackles on auscultation, fatigue and lethargy, hypoxia, cyanosis (bluish discoloration of skin). In neonates (0-28 days) features include poor feeding, lethargy or irritability, respiratory distress, apnea, hypothermia or fever. In infants (1-12 months), rapid breathing (tachypnea) >50 breaths per minute, cough or fever, chest indrawing (retraction of lower chest wall during inspiration), wheezing or crackles on auscultation and cyanosis in severe cases are common presenting features. Presenting features of pneumonia in children less than 5 years of age includes cough and fever along with tachypnea >40 breaths per minute, chest pain, vomiting or refusal to eat and hypoxia (low oxygen saturation levels). In children >5 years of age features are more prominent including High fever and chills, chest pain of discomfort, fatigue and muscle aches, difficulty in breathing during exertion and productive cough with thick mucus(phlegm) (Ebell et al., 2020). Children with weakened immune system are more susceptible to pneumonia, even though majority of healthy kids can battle the virus with their own defenses. Malnutrition or undernourishment can decrease a child's immune system, particularly in newborn who are not nursed exclusively. The risk of pneumonia in children is further increased by pre-existing conditions, such as measles and symptomatic HIV infections (Burrell et al., 2023). Child's vulnerability to pneumonia is further increased by the following environmental factors e.g. living in small apartments, cooking and heating with biomass fuels and parental smoking all contribute to indoor air pollution. A mix of clinical assessment and diagnostic instruments are used to diagnose pneumonia. Due to differences in risk factors and clinical presentation, the strategy may be slightly different for children and older adults. On X-ray, bilateral patchy areas of consolidation can be seen and is useful for confirming pneumonia and assessing severity. Pulse oximetry which measures oxygen saturation to detect hypoxia. Rapid diagnostic tests for viral pneumonia, tests for respiratory syncytial virus (RSV) and influenza. In some cases, CT scans may be needed for detailed lung assessment (Kanwal et al., 2024). Treatment of pneumonia is based on organism whether it's a bacteria or virus or fungi. For bacterial pneumonia in children, the first line antibiotic is amoxicillin 40-45mg/kg/dose, administered twice daily for 5-7 days. In case of penicillin allergy macrolides such as azithromycin can be used. In severe cases like respiratory distress, hypoxia or inability to take oral medications, children should be hospitalized. Supportive care is also required like hydration, antipyretics for fever, and oxygen therapy. For viral pneumonia, supportive care with fluids, oxygen therapy, antipyretics and antivirals can be given. Treatment in adults includes different antibiotics with different dosages and admission in ICU in case of severe respiratory distress (Prazak et al., 2022).

The Role of Vaccination in Pneumonia Prevention

Vaccination is a proven and successful approach to prevent pneumonia, especially in children, older adults, and immunocompromised individuals (Wagner & Weinberger, 2020). Vaccines target pathogens that cause pneumonia, reducing mortality rates (Micoli et al., 2021). Some benefits of vaccination include reduced incidence, herd immunity, lower complication rates, cost-effectiveness, and protection against antibiotic resistance (Hasso-Agopsowicz et al., 2024). The target populations for vaccination are infants, adults above the age of 65, people with chronic diseases, immunocompromised people, and pregnant women.

Pneumococcal Conjugate Vaccine (PCV)

PCV is an important tool in preventing *Streptococcus pneumoniae* infections, the leading cause of many diseases like bacterial pneumonia, meningitis, and sepsis. There are around 100 known strains of *Streptococcus pneumoniae*, and 2 types of PCV, PCV15 and PCV20, covering 15 and 20 strains of the *Streptococcus pneumoniae* species. A non-conjugate option, the pneumococcal polysaccharide vaccine (PPSV23), is also available and covers 23 strains (Scott et al., 2021). The vaccine is recommended for the elderly, adults, and high-risk groups. PCV is used for infants, young children, and people with chronic diseases. Infants require 3 doses, with a 4th dose if vaccinated before 12 months (Lalwani et al., 2021). The elderly and high-risk adults need 1-2 doses, typically receiving the PCV15 followed by the PPSV23. PCV is very effective as it decreases cases of pneumococcal disease by 80–90%, lowers hospitalization, lowers deaths and thus also provides protection (Lewnard et al., 2022). However, there are some side effects which include swelling at the injection site, fever and irritability in infants, and rarely allergic reactions (Garbo et al., 2024).

Haemophilus Influenzae Type B (Hib) Vaccine

The Hib vaccine protects against the B strain of the *Haemophilus influenzae* (Hi) bacteria, the most common Hi strain responsible for severe infections, including pneumonia, meningitis, epiglottitis, and sepsis (Slack et al., 2021). Before its introduction, Hib was a leading cause of bacterial pneumonia in children under 5 years old, however, the incidence of the disease has significantly reduced since its introduction. The Hib vaccine is important because it prevents fatal infections, reduces respiratory infections caused by Hib, decreases hospital admissions and antibiotic usage, and protects against non-respiratory Hib infections (Gilsdorf, 2021). The vaccine is indicated in infants, children, and unvaccinated adults, particularly in those with sickle cell disease, asplenia, HIV, or bone marrow transplants (Sahu et al., 2023). Infants require 2 doses, with an additional 3rd dose and a booster dose if required, whereas adults require 1 dose. The Hib vaccine provides higher than 95% protection against invasive Hib infections, prevents secondary complications, reduces child mortality rates, and contributes to herd immunity (Sanchez et al., 2023). Common side effects of the Hib vaccine include fever, redness, swelling, or pain at the injection site, and rarely anaphylaxis (Akarsu & Polat, 2024). Hib integration into routine childhood immunization programs in most countries plays a key role in reducing infant mortality, and its introduction globally as part of the Expanded Program on Immunization (EPI) has been instrumental in providing herd immunity, benefiting the entire community.

Influenza Vaccine

Influenza viruses belong to the Orthomyxoviridae RNA virus family. They are classified into 3 distinct types based on their major antigenic

differences: influenza A, influenza B, and influenza C. Influenza viruses cause annual human epidemics, seasonal and pandemics, and can cause viral pneumonia and increased susceptibility to secondary bacterial infections like *Streptococcus pneumoniae* (Sender, 2021). The influenza vaccine (IV) protects against the influenza virus. Influenza-related pneumonia leads to severe complications, especially in high-risk groups. To date, three types of influenza vaccines have been licensed: inactivated vaccines (IIV) which are administered by intramuscular or subcutaneous injection, live-attenuated vaccines (LAIV) which can be given intranasally, and recombinant hemagglutinin vaccines (RIV) (Shi & Ross 2024). Everyone above 6 months of age should get the influenza vaccine, especially children under 5, elderly adults, pregnant women, and healthcare workers. Children need 2 doses, 4 weeks apart, followed by an annual dose, while adults require a single yearly shot before flu season. The influenza vaccine is safe to administer in any trimester to pregnant women (Arora & Lakshmi, 2021). The influenza vaccine reduces the risk of influenza-related pneumonia by 50–60% and lowers hospitalization rates, advanced disease, spread of influenza, and chances of secondary bacterial infections (Jones & Ponomarenko, 2022). Side effects may include soreness, redness, or swelling at the injection site, low-grade fever, headache, or muscle ache, and very rarely it could lead to Guillain-Barré Syndrome (GBS) or severe anaphylaxis. Annual vaccination programs have reduced influenza outbreaks, and pneumonia-related deaths globally and are crucial for protecting vulnerable populations in hospitals and care homes (Cheong & Song, 2024). The influenza vaccine also plays a role in pandemic preparedness, as seen during the H1N1 (2009) and COVID-19 pandemics (Harrington et al., 2021).

Measles Vaccine

Measles suppresses the immune system and because of that, people are more susceptible to subsequent bacterial infection. With 50-60% of measles-related deaths coming from pneumonia, it is the most frequent cause of measles related deaths (Rabaan et al., 2022). Children who already suffer from malnutrition or have limited access to healthcare are more susceptible to pneumonia and serious respiratory infections. The vaccine indirectly reduces the incidence of measles-associated pneumonia by avoiding measles. Children's pneumonia-related fatalities have significantly decreased in nations that have widely vaccinated against measles. In areas with robust vaccination programs, measles-related pneumonia cases have decreased, and the Global Measles and Rubella Strategic Plan calls for at least 95% vaccine coverage. A high vaccination rate contributes to outbreak prevention, which lowers the burden of pneumonia by slowing the spread of measles. To guarantee complete protection, the WHO Expanded Programme on Immunization (EPI) suggests receiving two doses of the measles vaccination at 9–12 months and 15–18 months (Ulep & Uy, 2022). WHO recommends carrying out supplementary immunization activities (SIAs) in regions where measles transmission is high in order to bridge immunity gaps. There are recurring measles outbreaks and related pneumonia cases in certain LMICs because vaccination rates for measles are still below the advised 95% (Adamu et al., 2024). Incorporating measles vaccine into larger pneumonia prevention initiatives, like boosting breastfeeding, enhancing nutrition, and guaranteeing access to treatments for bacterial pneumonia, is something that WHO and UNICEF support (le Roux, 2022).

Public Health Strategies to Protect Children

Public health strategies are important in protecting against pneumonia by addressing its root causes. These strategies include immunization programs, early diagnosis, early treatment, breastfeeding promotion, environmental improvements, and programs to increase awareness and implementation of sanitation, hygiene, and nutrition. These strategies ensure long-term health benefits and decrease mortality rates, especially in vulnerable populations (Olatunji et al., 2024).

Nutrition and Immune System Support

Proper nutrition is essential to prevent pneumonia, as it improves the immune system and the ability of our body to fight infections (Shao et al., 2021). Malnourished individuals have a higher risk of developing severe pneumonia due to a weakened immune system, poor respiratory function, and delayed recovery (Morales et al., 2023). Breastfeeding, infant nutrition, adequate micronutrients, a balanced diet, supplementation where needed, proper hydration, electrolyte balance, and maternal nutrition all contribute to the effects and severity of pneumonia. Breastfeeding provides nutrients and antibodies. Micronutrients, such as vitamin A, zinc, iron, vitamin D, and vitamin C, contribute to the prevention of pneumonia by strengthening respiratory barriers, improving the immune system, boosting antibodies, increasing oxygenation wound healing, and reducing inflammation (Kumar et al., 2021). A balanced diet and protein intake aids in the production of antibodies, reduction in inflammation, and improvement in lung and gut health, therefore indirectly boosting immune defenses. Supplementation Programs help prevent malnutrition and deficiency where needed, thus improving survival rates and the body's ability to defend against pathogens and recover. Preventing malnutrition through community feeding programs, growth monitoring, and education helps prevent chronic malnutrition and stunted growth, improving immune function and reducing susceptibility to pneumonia. Hydration and electrolyte balance ensure the mucosal barriers remain moist and effective; it also prevents dehydration which will worsen respiratory symptoms. Maternal nutrition promotes healthy fetal development, boosting immunity in newborns, and protecting against preterm and low-weight births, risk factors for pneumonia, thus reducing mortality and increasing long-term health outcomes (Tharumakunarajah et al., 2024).

Reducing Environmental Risk Factors

Environmental factors have a big role in the development and spread of pneumonia. Environmental risk factors include indoor pollution, outdoor pollution, overcrowding, under-sanitation, climate change, extreme weather, and not adequately protecting vulnerable populations (Ugwuanyi et al., 2024). Indoor air pollution can be reduced by using clean cooking techniques, improving ventilation in homes, and using alternatives to traditional cooking methods. Outdoor air pollution can be combated by reducing emissions, developing green spaces in dense urban areas, and regulating industrial emissions. Both of these strategies lead to decreased exposure to harmful pollutants and thus decreased rates of pneumonia. Overcrowding and poor sanitation can be improved by providing access to better-ventilated spaces, clean drinking water, and improved sanitation practices (Mycoo, 2022). Our response to climate change and extreme weather including disaster preparation, better housing resilience, and reducing carbon emissions, minimize the risk associated with damaging changes to the climate and weather. Protecting

vulnerable populations by implementing targeted public health and systemic interventions and health monitoring reduces pneumonia-related deaths and hospitalizations among vulnerable populations and improves their quality of life and lifespan (Cheong & Song, 2024).

Hygiene and Sanitation Practices

Proper hygiene and sanitation practices are essential to reduce the incidence and spread of pneumonia. Poor hygiene and inadequate sanitation lead to the transmission of harmful pathogens and bacteria. This can be combatted by improving hand hygiene, respiratory hygiene, clean water, sanitation, waste management, disinfection, cleaning practices, promoting personal hygiene at school, and preventing cross-contamination. Hand hygiene can be maintained by washing your hands with soap and proper technique, ensuring access to clean water, soap, and sanitizers, and raising awareness of the importance of hand hygiene in public spaces (Lotfinejad et al., 2021). Respiratory hygiene can be improved by ensuring the implementation of proper coughing and sneezing etiquette, disposal of tissues, public health campaigns, and providing easy access to appropriate tissue and waste bins to promote these behaviors, thus reducing the transmission of pathogens causing pneumonia and ensuring a safer and cleaner environment. Clean water and sanitation efforts by ensuring access to clean water, improved sanitation facilities, water filtration, purification encouragement, and community sanitation projects reduce the spread of infections that could exacerbate conditions like pneumonia and prevent contamination of water sources (Upadhyay et al., 2024). Waste management with proper waste disposal, collection, recycling, composting, and increased awareness prevent the spread of harmful pathogens through waste. Disinfection and cleaning practices, in addition, can ensure that cleanliness is maintained, further reducing the presence of harmful bacteria and viruses on surfaces, limiting their spread, and reducing the risk of pneumonia and other infections. Promoting personal hygiene through school and community hygiene programs instills lifelong hygiene habits that protect against pneumonia and other infectious diseases. Reducing cross-contamination by avoiding close contact with infected individuals, quarantining, and self-isolating prevents the spread of pneumonia and protects high-risk individual (Brodie, 2021).

Strengthening Healthcare Systems

Strong healthcare systems are essential in the prevention and management of pneumonia. Expanding healthcare infrastructure in underserved regions ensures timely access to critical services such as diagnostic tools, oxygen therapy, and vaccines (Jensen, 2024). In addition, training programs for healthcare workers are crucial in equipping personnel with updated knowledge of pneumonia treatment and prevention strategies. The guarantee of secure and well-developed medicine and vaccine supply lines, supported by additional subsidies and health insurance to help vulnerable groups afford available treatments are also key systemic interventions that must be considered by healthcare governing bodies (Aronson et al., 2021) (Figure 1).

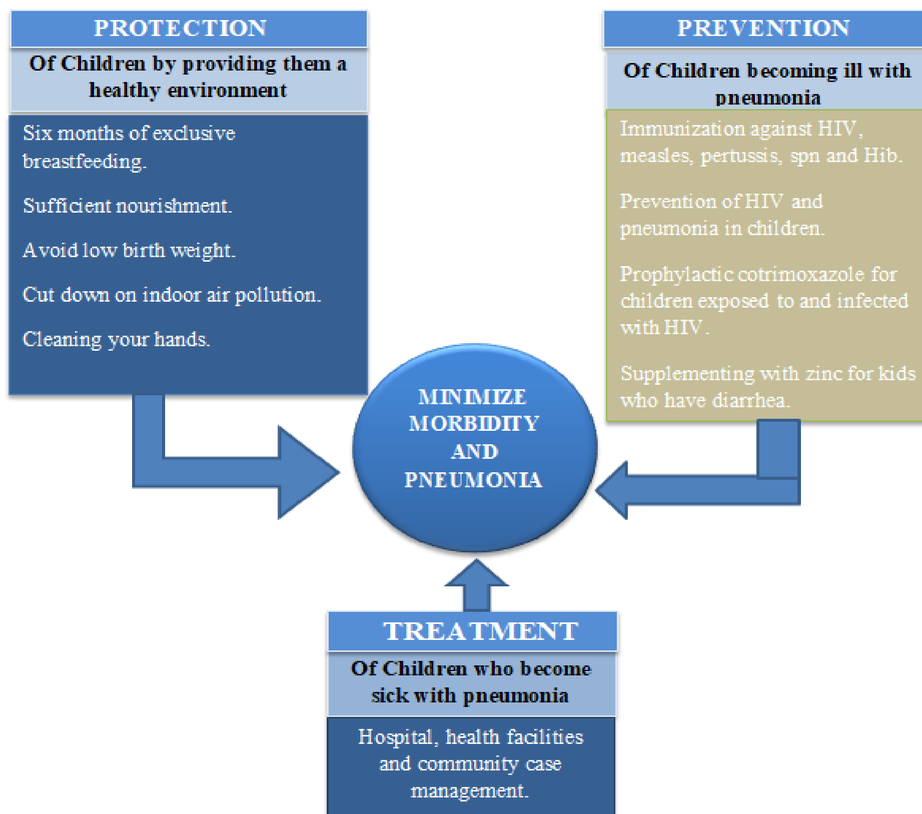

Fig. 1: Integrated global action plan for pneumonia and diarrhea (GAPPD) (Retrieved from Biorender)

Future Strategies of Prevention of Pneumonia

Future strategies to prevent pneumonia mainly involve the development of advanced vaccines, integration with broader health programs, enhanced diagnostic and monitoring tools, addressing environmental risk factors, and establishing nutritional support

programs, all of which are needed in their own aspects (Kant et al., 2024). Development of advanced vaccines requires research into a new generation of pneumococcal vaccines that have broader serotype coverage so that it can protect against more strains of streptococcus pneumoniae creation of a universal pneumococcal vaccine that provides long-term immunity against all strains, and therefore reduces the need for booster doses, and lastly an expansion in the development of combination vaccines to protect against more than one pathogen. Integration with broader health programs involves incorporating pneumonia prevention into the maternal and child health programs that already exist to increase immunization rates and help with early detection and intervention, establishment of community-based education initiatives to raise awareness of pneumonia, its effects, how to prevent it, vaccination against pneumonia, personal hygiene and nutrition (Chebib et al., 2021). Enhanced diagnostic and monitoring tools that use artificial intelligence, use predictive analysis, are portable, are cheaper and capable of early detection will strengthen the health information systems and help with real time monitoring of cases along with vaccination coverage, leading to overall improvement of treatment outcomes in patients with pneumonia, a lot of patients getting diagnosed early and reduced cases of pneumonia (Hsiao et al., 2022). Addressing environmental risk factors by promoting policies to reduce pollution, indoor and outdoor, implementing programs that improve the access of the general population to clean and safe drinking water, along with better sanitation practices, as well as increasing the number of trees planted will all help to reduce pollution, increase overall air quality, make the environment cleaner and safer, and reduce the risk of infections. Nutritional support programs that focus on micronutrient intake in our everyday diet and micronutrient supplementation to improve the immunity of the individual, leading to overall improved immunity in the community (Shao et al., 2021). Another thing that could be done to help improve is to ensure food security in impoverished and vulnerable areas through food distribution and agricultural subsidies.

Challenges in Implementing Preventive Strategies

Challenges in implementing the aforementioned future preventative strategies as well as current preventative strategies being used include financial constraints, vaccine hesitancy, misinformation, logistical barriers, workforce issues, capacity issues, and socioeconomic determinants (Santangelo et al., 2024). Financial constraint is an issue that often arises due to the high costs of new gen vaccines, along with insufficient funding limit the access for rural areas, underserved areas as well as low-income countries leading to a gap in the prevention efforts. Vaccine hesitancy and misinformation due to public mistrust in vaccines due to misinformation campaigns, cultural beliefs as well as a lack of accessible and culturally sensitive communication strategies all create a significant barrier to immunization (Olson et al., 2020). Logistical barriers due to weak infrastructure in low-income countries and geographic challenges such as remote locations or conflict zones limit overall healthcare delivery as well as vaccine delivery in these areas. Workforce and capacity issues due to a shortage of trained healthcare workers, the overburdened healthcare systems lead to a struggle to effectively deliver vaccines, educate the communities, and prioritize pneumonia prevention (Gibson et al., 2023). Socioeconomic determinants like persistent poverty, malnutrition, and overcrowded living conditions not only increase susceptibility of pneumonia in the vulnerable populations, but also increase the risk of other infections, such as other respiratory infections and gastrointestinal infections, further increasing the severity of pneumonia and leading to more complications (El-Koofy et al., 2022).

Addressing the Challenges

To address these challenges there is a need for more funding and investment, increased public awareness, increased education, further strengthening of infrastructure and logistics, empowering healthcare workers, tackling socioeconomic barriers, and global collaboration (Khorram-Manesh et al., 2024). Increased funding and investment can be done by mobilizing global funding from healthcare and charity organizations like WHO, UNICEF, and Gavi, the Vaccine Alliance to subsidize advanced vaccines and healthcare programs (Halabi & Gostin, 2023). Another thing that can be done to increase funding and investment is to the encouragement of public-private partnerships to support vaccine production, infrastructure development and community outreach and efforts. Increasing public awareness and education by developing targeted communication campaigns and integrating pneumonia education into school curricula and community programs will combat all the vaccine hesitancy, eliminate misinformation, and raise awareness about hygiene, vaccination and environmental risks (Hudson & Montelpare, 2021). Strengthening infrastructure and logistics by deploying innovative technologies like solar-powered cold-chain systems to ensure vaccine viability in remote areas, as well as expanding mobile clinics and telemedicine platforms to reach rural, remote and underserved regions will help reduce geographic disparities (Ebulue et al., 2024). Empowering healthcare workers by providing regular training on updated pneumonia prevention and treatment protocols, increasing recruitment and retention of healthcare of staff in rural and low-income areas through incentives and capacity building programs. Tackling socioeconomic barriers by addressing poverty through social safety nets, such as conditional cash transfers, to enable families to afford nutritious food and healthcare. Improving housing conditions and expanding access to clean water and sanitation infrastructure will lead to an improved environment with reduced risk factors. Global collaboration by strengthening international partnerships to ensure equal vaccine distribution and resource allocation, along with advocation for pneumonia prevention as a priority at global conferences and meetings to secure sustained attention and funding for the cause (WHO, 2022).

Conclusion

Pneumonia requires a multi-faceted effort toward vaccination, improvements in the healthcare framework, and public health interventions. A systemic approach can only be addressed by governments, healthcare providers, communities, and international organizations. Reducing the burden of pneumonia worldwide by eliminating barriers to and increasing access to healthcare can limit the spread of pneumonia. Pneumonia can be halted from spreading by proper education and awareness in parents and healthcare workers. Parents should get their children vaccinated on time. Child health can also be strengthened by public health initiatives that support better nutrition, hygiene and disease knowledge. In order to put these methods into practice and eventually help ensure that our children have a healthier future free from the

burden of pneumonia, cooperation between healthcare professionals, families and communities is essential. A coordinated strategy would bring the management of pneumonia in the most vulnerable of populations, bringing about a future in which this preventable disease no longer constitutes a major threat to global health.

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