

VACCINATION PRACTICES AND ANTIMICROBIAL USE IN PEDIATRICS: REDUCING INFECTION BURDEN AND RESISTANCE

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ABSTRACT

Vaccination is a highly effective public health measure for preventing infectious illnesses in children and mitigating the burden of antimicrobial resistance (AMR). Paediatric populations exhibit significant susceptibility to bacterial and viral illnesses, resulting in numerous antibiotic prescriptions, many of which are unwarranted or unsuitable. Immunisation programs markedly reduce the prevalence of vaccine-preventable diseases, including pneumococcal infections, Haemophilus influenzae type b infections, pertussis, measles, and influenza, thereby diminishing antibiotic usage and curtailing the development of resistant organisms. Vaccines indirectly enhance antimicrobial stewardship by decreasing hospitalisations, limiting the transfer of infectious organisms, and reducing the use for broad-spectrum antibiotics. In recent years, the escalating issue of antimicrobial resistance (AMR) has underscored the necessity of combining immunisation tactics with judicious antimicrobial utilisation in paediatric healthcare. Notwithstanding significant advancements, obstacles such as vaccine hesitancy, inequitable access to immunisation services, inadequate vaccination coverage, and improper antibiotic prescribing persistently impede global infection control initiatives. Innovative vaccine technology and enhanced immunisation policies may significantly bolster global efforts against antimicrobial resistance (AMR). This study examines contemporary vaccination practices in paediatrics, trends in antimicrobial utilisation, the correlation between immunisation and resistance mitigation, and approaches to enhance infection prevention and antimicrobial stewardship in children.

Keywords: Vaccination, Pediatrics, Antimicrobial Resistance, Antibiotic Stewardship, Immunization, Pediatric Infections, Vaccine-Preventable Diseases, Antimicrobial Use, Infection Control, Childhood Vaccines.

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INTRODUCTION

Antimicrobial resistance (AMR) has arisen as a significant global public health menace of the twenty-first century. Infections caused by antimicrobial-resistant bacteria are linked to heightened morbidity, death, extended hospital stays, and escalating healthcare expenditures globally. In 2019, around 1.95 million fatalities and 47.9 million disability-adjusted life-years were ascribed to antimicrobial resistance (AMR) worldwide, with the burden anticipated to rise significantly in the forthcoming decades if effective preventive measures are not enacted[1]. Notwithstanding significant progress in contemporary medicine, the advancement of novel antibiotics has markedly diminished over the last

three decades, while resistance among prevalent bacterial infections continues to grow[2]. Reports of extensively drug-resistant and pan drug-resistant pathogens have elevated antimicrobial resistance from a scientific issue to a significant medical crisis [3,4].

Antimicrobials, in conjunction with immunisation and enhanced sanitation, have historically been pivotal in diminishing mortality from infectious diseases and augmenting life expectancy[5]. Nonetheless, improper and excessive use of antimicrobials in humans and animals has hastened the establishment and dissemination of resistant infections. Research indicates that a considerable percentage of antibiotic prescriptions, especially for respiratory tract infections and diarrhoeal disorders, are either unwarranted or lack adequate clinical

justification[6,7]. In paediatric populations, the abuse of antimicrobials is particularly prevalent due to the high incidence of respiratory and gastrointestinal infections, many of which are viral and self-limiting. Irrational prescribing methods significantly exacerbate the increasing burden of antimicrobial resistance (AMR).

Vaccination is among the most effective and sustainable methods for decreasing antibiotic usage and curbing the emergence of resistance. Immunisation mitigates the necessity for antibiotic treatment by averting vaccine-preventable illnesses, hence diminishing the spread of resistant organisms and lessening selective pressure for resistant strains[8]. Vaccines targeting pathogens such as *Streptococcus pneumoniae*, *Haemophilus influenzae* type b, *Bordetella pertussis*, and the influenza virus have shown substantial decreases in disease burden, hospitalisation rates, and antibiotic consumption in paediatric populations [9]. Moreover, extensive vaccination indirectly safeguards unvaccinated individuals via herd immunity, therefore facilitating a comprehensive reduction in antimicrobial usage at the community level.

The use of vaccination techniques into antimicrobial stewardship initiatives has garnered heightened global interest. Vaccines not only diminish infections from susceptible pathogens but also curtail the dissemination of resistant strains by reducing bacterial carriage and transmission [10]. In paediatric healthcare, enhancing vaccine coverage can significantly diminish prevalent infections such as acute otitis media, pneumonia, and invasive bacterial disorders that often necessitate antibiotic intervention.[11]. Nonetheless, obstacles such as insufficient immunisation coverage, vaccine reluctance, inequitable healthcare access, and a deficiency in awareness persist in impeding the comprehensive efficacy of vaccination in addressing AMR.

Consequently, enhancing paediatric immunisation protocols in conjunction with judicious antimicrobial utilisation is crucial to mitigate infection prevalence and maintain the efficacy of current medications. This review is to examine the correlation between vaccination practices and antibiotic usage in paediatrics, emphasising the significance of immunisation in diminishing infectious illnesses and addressing antimicrobial resistance.

METHODOLOGY

This narrative review was conducted to evaluate the relationship between vaccination practices and antimicrobial use in pediatric populations, with particular emphasis on reducing infection burden and antimicrobial resistance (AMR). Relevant literature was identified through a comprehensive search of electronic databases including PubMed, Google Scholar, Scopus, and Web of Science.

Articles published in English between 2000 and 2025 were considered for inclusion.

The search strategy used combinations of keywords and Medical Subject Headings (MeSH) terms such as “vaccination,” “immunization,” “pediatrics,” “children,” “antimicrobial resistance,” “antibiotic use,” “antimicrobial stewardship,” “vaccine-preventable diseases,” and “pediatric infections.” Reference lists of selected articles were also manually screened to identify additional relevant studies.

The review included original research articles, systematic reviews, narrative reviews, clinical guidelines, WHO and CDC reports, and policy documents focusing on vaccination practices, antimicrobial prescribing patterns, and the impact of immunization on reducing infectious diseases and antibiotic consumption in children. Studies addressing vaccine-preventable bacterial and viral infections, pediatric antimicrobial stewardship, and the epidemiology of AMR were prioritized.

Articles unrelated to pediatric populations, non-English publications, conference abstracts without full text, and studies lacking relevance to vaccination or antimicrobial use were excluded. The collected literature was reviewed and synthesized narratively under major thematic areas including the burden of AMR in children, inappropriate antimicrobial use, the role of vaccination in reducing infections and antibiotic prescriptions, challenges in vaccine implementation, and future strategies for combating AMR through immunization.

This narrative approach was chosen to provide a broad overview of existing evidence and current perspectives regarding vaccination practices and antimicrobial use in pediatrics.

LITERATURE REVIEW

Vaccination is among the most effective public health measures for decreasing childhood morbidity and mortality globally. In paediatric populations, immunisations not only avert infectious illnesses but also significantly reduce unnecessary antimicrobial usage and address the escalating challenge of antimicrobial resistance (AMR). Children are especially susceptible to recurrent respiratory, gastrointestinal, and systemic illnesses, resulting in frequent antibiotic exposure. Inappropriate and excessive use of antimicrobials considerably contributes to the formation of resistant bacterial strains, rendering vaccination a crucial method for infection prevention in paediatric healthcare.

Vaccines diminish the prevalence of bacterial and viral infections that frequently result in antibiotic prescriptions. Vaccination against pathogens including *Streptococcus pneumoniae*, *Haemophilus influenzae* type b (Hib), *Bordetella pertussis*, measles virus, rotavirus, and influenza virus has significantly reduced hospitalisation rates, severe

complications, and subsequent bacterial infections in children. Pneumococcal conjugate vaccinations (PCVs) have shown substantial decreases in invasive pneumococcal illness and antibiotic-resistant pneumococcal infections. Likewise, influenza vaccination diminishes the occurrence of viral respiratory illnesses, thereby lowering the superfluous prescriptions of antibiotics frequently administered for febrile respiratory infections.

Effective antimicrobial stewardship in paediatrics is crucial for mitigating the development of resistance. Antibiotics are often used empirically in paediatric patients owing to diagnostic ambiguity, parental anticipations, and concerns over potential consequences. Irrational use, such as improper dose, unwarranted broad-spectrum therapy, and insufficient treatment regimens, exacerbates resistance patterns. Paediatric antimicrobial stewardship initiatives prioritise evidence-based prescribing, suitable drug selection, narrow-spectrum therapy when feasible, and compliance with treatment guidelines. Educational initiatives for healthcare professionals and parents are crucial to enhance awareness about the prudent use of antibiotics.

Vaccination indirectly enhances antimicrobial stewardship by diminishing healthcare visits, curtailing the transfer of infectious pathogens, and lessening the demand for medicines. Herd immunity attained with extensive vaccination coverage provides additional protection for at-risk paediatric groups, such as babies and immunocompromised children. Enhancing national immunisation systems in low- and middle-income nations might markedly diminish the incidence of vaccine-preventable infections and the corresponding use of antimicrobials.

Notwithstanding the established advantages, obstacles persist in attaining optimal immunisation coverage. Vaccine hesitancy, misinformation, restricted healthcare access, supply chain disruptions, and socioeconomic inequalities persistently influence worldwide immunisation patterns. Overcoming these obstacles necessitates synchronised public health policy, community involvement, and ongoing surveillance of immunisation results and antibiotic resistance patterns.

Why is vaccination an effective technique for combating antibiotic resistance?

Antibiotics are not being created rapidly enough to match the progression of bacterial antimicrobial resistance (AMR), with only 13 novel medications in Phase III clinical trials as reported in March 2021. Over 20 novel classes of antibiotics were introduced into clinical practice before the 1960s, with few new classes released since then[12]. Given the diminishing antibiotic arsenal, some have proposed that we are entering a “post-antibiotic era.” Strategies are essential to conserve

these medications for critical situations. Non-vaccine strategies encompass the enforcement of infection control measures and antibiotic stewardship programs to ensure the judicious use of current antibiotics. Antibiotics can be co-formulated with agents like β -lactamase inhibitors, which augment antibiotic efficacy by inhibiting hydrolysis by bacterial enzymes, or streptazolin, which promotes macrophage-mediated cytotoxicity, hence potentiating antibiotic action through host cell targeting[13]. In addition, there is a mounting interest in the use of phage therapy as an alternative treatment to antibiotics.

Vaccination is a crucial technique for preventing antimicrobial resistance (AMR) and diminishes illnesses from both antibiotic-susceptible and -resistant bacteria, thereby lowering the overall use of antibiotics. The efficacy of vaccinations in mitigating disease burden during the past century is evident; immunisations against *Corynebacterium diphtheriae*, *Neisseria meningitidis*, *Haemophilus influenzae* type b (Hib), and *Bordetella pertussis* have led to significant reductions in incidence[14]. The implementation of pneumococcal vaccines has led to a reduction in both invasive illness and a drop in nasopharyngeal carriage of *S. pneumoniae* (including antibiotic-resistant strains), exemplifying the efficacy of immunisation in countering antimicrobial resistance[15]. In addition to human health, vaccines have proven to be a highly successful intervention for animal health, significantly decreasing antibiotic usage across several species, including fish, pigs, and poultry. Vaccines targeting resistant bacterial species also combat antimicrobial resistance by diminishing the prevalence of drug-susceptible variants that may develop resistance via horizontal gene transfer[16]. This reduction in resistance proliferation maintains the effectiveness of antibiotics with antimicrobial stewardship policies. Employing one of the most efficacious medical innovations of the past century (vaccines) to preserve another (antibiotics) is a commendable pursuit that will enable future generations to benefit from both.

2. Who would benefit the most from immunizations against antimicrobial-resistant bacteria?

As the global burden of antimicrobial resistance (AMR) escalates, interventions should target populations at the greatest risk of infection and mortality, particularly individuals in low- and middle-income countries (LMICs), immunocompromised persons, those with comorbidities, and children, who are frequently omitted from studies on novel antimicrobials. Infection prevention is crucial; in certain locations, restricted access to antibiotics and inadequate antibiotic regulation impede the effective treatment of drug-sensitive infections. In 2019, the estimated all-age mortality rate due to antimicrobial

resistance (AMR) was 98.9 deaths per 100,000 in western sub-Saharan Africa, approximately double that of high-income countries. *K. pneumoniae* accounted for the highest percentage of deaths due to antimicrobial resistance in this region, with 19.9% of AMR-related fatalities. The urgent development of vaccinations aimed at resistant infections linked to significant morbidity and mortality should be prioritised.

Individuals with comorbidities have higher risk of infection not only as a direct result of their disease and treatments of it, but through increased hospital exposure, frequent invasive procedures, and as a result, increased antimicrobial usage [17]. Diabetes mellitus exemplifies this phenomenon, demonstrating a significant correlation with heightened vulnerability to *E. coli* infection and an increased bacterial load. Patients with diabetes may exhibit compromised granulocyte function, and elevated glucose levels affect epithelial barrier integrity, rendering these patients more susceptible to heightened *E. coli* presence in the bladder. Drug-resistant *E. coli* account for the highest mortality rate among resistant bacteria globally, and the heightened susceptibility to *E. coli* infection in individuals with diabetes exemplifies a situation where vaccinations targeting resistant bacteria should be prioritised for particular populations.

Specialised formulations of antibiotic medications designed for paediatric usage are frequently developed subsequent to the marketing of the antibiotic for adults, resulting in delayed access to effective antibiotics for children. The development of paediatric antimicrobials has numerous obstacles, including the necessity for varying dosages and formulations, which result in scientific and regulatory issues [18]. Children are among the largest consumers of antibiotics in any age demographic, excluding the elderly. Vaccination against bacterial antimicrobial resistance is especially beneficial for populations that have limited access to antimicrobials or experience elevated rates of bacterial infections due to regional and individual health determinants.

3. How do antimicrobial-resistant bacteria challenge vaccine development?

Although vaccination is an effective approach to address antimicrobial resistance (AMR), bacteria provide challenges to vaccine production due to their extensive genetic diversity, a multitude of possible antigens, and the capacity to induce various illnesses with varied consequences based on the host's condition. The genetic heterogeneity of numerous bacterial diseases results in a variety of architectures in protein and polysaccharide antigens, complicating vaccine production and diminishing the likelihood of strain cross-protection [19]. Multicomponent vaccines are frequently employed against bacteria to target numerous antigens, hence enhancing vaccine

coverage and mitigating the risk of vaccine resistance due to changes; yet, the identification of multiple conserved and immunogenic antigens presents significant challenges. Examine the case of *K. pneumoniae*, a significant contributor to sepsis with rising rates of antimicrobial resistance. Given the existence of over 70 capsular serotypes globally, achieving sufficient strain coverage with a capsule-based vaccination, similar to those employed for other bacteria like *S. pneumoniae*, may prove impractical. *Bacillus Calmette–Guerin* (BCG) has been used as a vaccine against *M. tuberculosis* (TB) for nearly a century and is effective in protecting very young children [20]. Nonetheless, its efficacy in older children and adults is inconsistent, ranging from 0% to 80%. The variation in efficiency may be partially attributed to the heterogeneous nature of tuberculosis, as the best immune response for eradicating the infection differs between children and adults. Therefore, while developing vaccines aimed at combating antimicrobial resistance (AMR), it is essential to address both the host and the pathogen. Identifying the target population for the vaccine and comprehending the protective immune responses within that population are essential. Furthermore, it is essential to comprehend which strains impose the most burden, conduct high-quality molecular epidemiological research, and employ suitable antigen selection approaches.

4. Which vaccine platforms have been used for bacterial vaccine development and where might they lead?

Various methodologies are employed in bacterial vaccines presently incorporated into standard immunisation protocols, encompassing entire inactivated bacteria, live-attenuated strains, and subunit vaccines, which comprise toxoid and conjugate formulations. These strategies may encompass monovalent or multivalent formulations aimed at multiple antigens. Recent clinical research has examined alternative platforms, including the use of nanoparticles, such as outer bacterial membrane vesicles (OMVs), and nucleic acid vaccines, which may comprise DNA-based plasmids or RNA-encoding target antigens. [21]. The use of mRNA technology into immunisation campaigns with COVID-19 vaccines has the capacity to transform the field of vaccinology. mRNA vaccines utilise host cells for antigen expression, allowing enabling facile adaptation to novel infections and/or antigens [21]. The production of bacterial proteins in eukaryotic cells following mRNA immunisation remains unexamined in clinical trials. It is probable that this issue will soon be resolved, as mRNA-based vaccine candidates aimed at Group A or Group B Streptococci have proven efficient in providing protection in murine models [22]. Ultimately, the

ideal vaccine approach for a specific pathogen must be tailored to the pathology of the specific bacterium.

5. Which types of bacterial antigens have been investigated for vaccine development and can they be applied in AMR vaccines?

Current bacterial vaccines have proven to effectively diminish illness burden and, as a result, mitigate antimicrobial resistance by decreasing drug consumption. Both pneumococcal and Hib vaccines aim at the capsular polysaccharides (CPS) of their respective bacterial species, *S. pneumoniae* and *H. influenzae*. The pneumococcal conjugate vaccine is projected to be 86% to 97% effective against invasive pneumococcal illness, and the incidence of Hib cases has markedly declined worldwide since the implementation of Hib vaccination in routine children immunisation programs. Consequently, the CPS is among the most extensively targeted and effective bacterial antigens in vaccine development. By 2021, other vaccines targeting bacterial species with significant antimicrobial resistance burdens, specifically against CPS, were undergoing clinical trials, including a 12-valent vaccination for extraintestinal pathogenic *E. coli* (ExPEC [23]). Bioinformatics pipelines facilitate the identification of conserved antigens across diverse populations that may elude detection using conventional vaccinology methods, utilising whole-genome sequencing of pathogens or convalescent post-infection samples. This methodology has proven effective for *N. meningitidis* and is currently being applied to other vaccines, potentially aiding in the management of the extensive diversity of antimicrobial-resistant strains.

DISCUSSION

Antimicrobial resistance (AMR) has arisen as a significant worldwide health problem, especially within paediatric populations, where infectious illnesses continue to be a primary source of antibiotic exposure. Children often receive antibiotics for respiratory tract infections, otitis media, diarrhoeal disorders, and febrile illnesses, many of which are viral and self-limiting. Excessive and irrational use of antimicrobials considerably leads to the establishment of resistant bacterial strains. Murray et al [24] AMR was linked to around 1.95 million deaths worldwide in 2019, highlighting the critical necessity for preventive measures to diminish reliance on antimicrobials. Vaccination has become one of the most effective interventions for reducing infection burden and antimicrobial consumption in children. Klugman et al [25] proven that current vaccines significantly diminish antibiotic-resistant illnesses by lowering both disease incidence and bacterial transmission. Similarly, Lewnard et al [26] observed that childhood vaccination programs significantly

lowered antibiotic use in low- and middle-income countries, highlighting the indirect role of vaccines in antimicrobial stewardship.

Pneumococcal conjugate vaccines (PCVs) have demonstrated significant efficacy in decreasing invasive pneumococcal illness and infections caused by antimicrobial-resistant *Streptococcus pneumoniae*. Reyburn et al [27] reported that the introduction of PCV10 and PCV13 vaccines significantly reduced resistant pneumococcal carriage and disease among children. Fireman et al [28] Further evidenced a significant reduction in acute otitis media occurrences and antibiotic prescriptions subsequent to pneumococcal immunisation. These findings underscore the importance of immunisation in reducing unnecessary antibiotic exposure in paediatric care. Vaccination also contributes indirectly to AMR reduction by preventing viral infections that commonly result in unnecessary antibiotic prescriptions. Bloom et al [29] stressed that immunisations for influenza and other viral diseases diminish subsequent bacterial infections and the necessity for empirical antibiotic administration. The World Health Organization projected that enhanced worldwide vaccination deployment might decrease antibiotic consumption by billions of doses each year, therefore mitigating selective pressure for resistant diseases[30].

Despite these benefits, several barriers continue to limit the effectiveness of vaccination programs. Incomplete immunization coverage, socioeconomic inequalities, vaccine hesitancy, and limited healthcare accessibility remain major concerns, especially in developing countries. Johnson et al [31] highlighted that continued surveillance and development of next-generation vaccines are essential due to emerging non-vaccine serotypes and evolving antimicrobial resistance patterns. The evidence unequivocally endorses vaccination as an essential element of antimicrobial management in paediatrics. Enhancing routine immunisation procedures, augmenting vaccine knowledge, and amalgamating vaccination tactics with judicious antimicrobial prescribing will substantially diminish infection prevalence and safeguard antibiotic efficacy for future generations.

CONCLUSION

Vaccination is essential for diminishing infection prevalence and addressing antibiotic resistance (AMR) in paediatric populations. Childhood immunisation programs efficiently avert vaccine-preventable infections, diminish hospitalisation rates, and curtail the inappropriate utilisation of antibiotics, hence restricting the formation and dissemination of resistant bacteria. Vaccines targeting pathogens like *Streptococcus pneumoniae* and *Haemophilus influenzae* type b have proven effective in reducing antibiotic usage and resistant illnesses in children. Notwithstanding these

advantages, obstacles such as insufficient vaccination coverage, vaccine hesitancy, irrational antibiotic prescribing, and healthcare inequities persist in exacerbating the escalating AMR epidemic. Enhancing routine immunisation practices, fostering public awareness, and executing efficient antimicrobial stewardship programs are crucial for maintaining antibiotic efficacy. Moreover, innovations in vaccine technology and continuous monitoring of resistant organisms may offer further avenues to combat antimicrobial resistance in the future. An integrated strategy that merges immunisation with judicious antibiotic utilisation is crucial for enhancing paediatric health outcomes and mitigating the worldwide impact of antimicrobial resistance. The scientific community must uphold equitable production and distribution as a core component of the vaccine development process. This will guarantee that vaccines aimed against bacterial antimicrobial resistance will be delivered to the populations most in need.

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