PEDIATRIC PNEUMONIA: ETIOLOGY, DIAGNOSIS, MANAGEMENT AND PREVENTION (LITERATURE REVIEW)

BOLALAR PNEVMONIYASI: ETIOLOGIYASI, TASHXISI, DAVOLASH VA OLDINI OLISH (ADABIYOTLAR SHARHI)

ПЕДИАТРИЧЕСКАЯ ПНЕВМОНИЯ: ЭТИОЛОГИЯ, ДИАГНОСТИКА, ЛЕЧЕНИЕ И ПРОФИЛАКТИКА (ОБЗОР ЛИТЕРАТУРЫ)

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Abstract. *Pediatric pneumonia remains a major global health concern, particularly in children under five, contributing significantly to morbidity and mortality, especially in low- and middle-income countries. The etiology of pediatric pneumonia is multifaceted, involving bacterial, viral, fungal, and atypical pathogens, with Streptococcus pneumoniae and respiratory syncytial virus (RSV) being the most common culprits. Diagnosis relies on clinical presentation, visualization methods, and laboratory markers, with emerging technologies such as lung ultrasound and AI-driven diagnostics improving accuracy. Treatment involves antibiotics for bacterial infections, supportive care, and antiviral therapy for specific viral causes, though antimicrobial resistance poses a growing challenge. Prevention strategies, including widespread vaccination, nutritional support, and public health interventions, play a crucial role in reducing disease burden. Recent advancements in microbiome research and artificial intelligence offer promising directions for future management and prevention efforts. Addressing research gaps and improving healthcare accessibility remain critical to achieving better outcomes in pediatric pneumonia.*

Keywords*: pediatric pneumonia, respiratory infections, bacterial and viral pathogens, vaccination, antimicrobial resistance*

Annotatsiya. *Bolalar pnevmoniyasi, ayniqsa besh yoshdan kichik bolalarda, global sog‘liqni saqlashning asosiy muammolaridan biri bo‘lib qolmoqda. Bu kasallik, ayniqsa past va o‘rta daromadli mamlakatlarda kasallanish va o‘lim ko‘rsatkichlariga sezilarli ta’sir ko‘rsatadi. Bolalar pnevmoniyasining kelib chiqish sabablari ko‘p qirrali bo‘lib, unda bakterial, virusli, zamburug‘li va atipik qo‘zg‘atuvchilar ishtirok etadi. Bunda Streptococcus pneumoniae va respirator-sinsitial virus (RSV) eng ko‘p uchraydigan qo‘zg‘atuvchilardir. Tashxis qo‘yish klinik ko‘rinish, vizualizatsion usullari va laboratoriya ko‘rsatkichlariga asoslanadi. O‘pka ultratovush tekshiruvi va sun’iy intellektga asoslangan diagnostika kabi yangi texnologiyalar esa tashxis aniqligini oshirmoqda. Davolash usullari bakterial infeksiyalar uchun antibiotiklar, umumiy qo‘llab-quvvatlovchi parvarish va ma’lum virusli sabablar uchun virusga qarshi terapiyani o‘z ichiga oladi. Biroq, mikroblarga qarshi chidamlilik tobora jiddiy muammoga aylanib bormoqda. Kasallik tarqalishini kamaytirishda profilaktika strategiyalari, jumladan, keng qamrovli emlash, to‘g‘ri ovqatlanishni ta’minlash va jamoat sog‘lig‘ini saqlash chora-tadbirlari muhim ahamiyatga ega. Mikrobiom tadqiqotlari va sun’iy intellekt sohasidagi so‘nggi yutuqlar kelajakda kasallikni boshqarish va oldini olish bo‘yicha istiqbolli yo‘nalishlarni taklif etmoqda. Bolalar pnevmoniyasida yaxshi natijalarga erishish uchun tadqiqotlardagi bo‘shliqlarni to‘ldirish va sog‘liqni saqlash xizmatlaridan foydalanish imkoniyatlarini kengaytirish hal qiluvchi ahamiyatga ega bo‘lib qolmoqda.*

Tayanch so‘zlar: *bolalar pnevmoniyasi, nafas yo‘llari infeksiyalari, bakterial va virusli qo‘zg‘atuvchilar, emlash, mikroblarga qarshi chidamlilik*

Аннотация. *Детская пневмония остается основной глобальной проблемой здравоохранения, особенно у детей до пяти лет, внося значительный вклад в заболеваемость и смертность, в первую очередь в странах с низким и средним уровнем дохода. Этиология детской пневмонии многофакторна и включает бактериальные, вирусные, грибковые и атипичные патогены, причем Streptococcus pneumoniae и респираторно-синцитиальный вирус (РСВ) являются наиболее частыми возбудителями. Диагностика основывается на клинической картине, методах визуализации и лабораторных маркерах, при этом новые технологии, такие как ультразвуковое исследование легких и диагностика с применением искусственного интеллекта, повышают точность. Лечение включает антибиотикотерапию при бактериальных инфекциях, поддерживающую терапию и противовирусное лечение при специфических вирусных причинах, хотя растущая устойчивость к противомикробным препаратам представляет серьезную проблему. Профилактические стратегии, включая широкомасштабную вакцинацию, нутритивную поддержку и меры общественного здравоохранения, играют ключевую роль в снижении бремени заболевания. Последние достижения в исследованиях микробиома и искусственного интеллекта открывают перспективные направления для будущего лечения и профилактики. Устранение пробелов в исследованиях и повышение доступности медицинской помощи остаются критически важными для достижения лучших результатов в лечении детской пневмонии.*

Ключевые слова: *детская пневмония, респираторные инфекции, бактериальные и вирусные патогены, вакцинация, устойчивость к противомикробным препаратам*

Introduction. Pediatric pneumonia remains a significant global health challenge, particularly affecting children under five years of age, and is the leading infectious cause of mortality in this age group, accounting for approximately 14% of child deaths worldwide [1, 2]. The burden of pediatric pneumonia is disproportionately high in low- and middle-income countries (LMICs), where 99% of pneumonia-related child deaths occur [1, 3]. Socioeconomic and environmental factors such as poverty, overcrowding, indoor air pollution, and exposure to tobacco smoke significantly increase the risk of pneumonia in children. Additionally, inadequate vaccination coverage and poor healthcare-seeking behaviors exacerbate the situation, highlighting the need for improved access to preventive measures and healthcare services [4, 5]. Despite advancements in medical science, including the development of vaccines against pathogens like Haemophilus influenzae type b and pneumococcus, gaps in vaccination coverage persist, particularly in resource-limited settings [5, 6]. The mortality rate for severe pneumonia cases admitted to pediatric intensive care units (PICUs) varies significantly across different regions, with higher rates observed in LMICs due to factors such as limited access to quality healthcare and pre-PICU management practices [7]. The complexity of pneumonia's etiology, involving various bacterial, viral, and atypical pathogens, necessitates rapid and accurate diagnostic tests to guide appropriate antimicrobial therapy [8]. However, research funding for pneumonia remains insufficient, with less than 3% of infectious disease research funding allocated to pneumonia, and most of this directed towards vaccine research rather than other critical areas such as diagnosis and treatment [1]. To address these challenges, there is a pressing need for community-based interventions that improve environmental conditions, enhance vaccination coverage, and promote better healthcare-seeking behaviors through education and awareness campaigns [5]. Furthermore, research efforts must focus on the specific needs of LMICs, including operational research and health systems strengthening, to ensure that new tools and technologies are effectively implemented and accessible [1]. Achieving the Sustainable Development Goal of reducing child mortality requires a concerted effort to address the multifaceted determinants of pediatric pneumonia and to invest in research that supports sustainable health system improvements in the regions most affected by this disease [1, 7].

Etiology and pathophysiology. Pediatric pneumonia is a multifaceted disease caused by a variety of pathogens, including bacteria, viruses, fungi, and parasites, with the etiology often influenced by the child's age, geographical location, and underlying health conditions. Bacterial

causes are predominantly due to Streptococcus pneumoniae and Staphylococcus aureus, with the former being a major cause of community-acquired pneumonia, especially in severe cases [9, 10]. Viral pathogens, particularly respiratory syncytial virus (RSV), are the most frequent causes of pneumonia in children under five, with RSV being notably prevalent in severe cases [9, 11]. Other viral agents include adenovirus, influenza, and rhinovirus [11]. Fungal and parasitic causes are less common but can occur, particularly in immunocompromised children [12]. Host factors significantly contribute to the susceptibility and severity of pneumonia. Immune immaturity in young children makes them more vulnerable to infections [13]. Malnutrition, particularly severe acute malnutrition, is a critical risk factor, exacerbating the incidence and severity of pneumonia and contributing to higher mortality rates [14]. Underlying medical conditions such as congenital heart disease, cystic fibrosis, and developmental delays also increase the risk of recurrent pneumonia [15]. Environmental and socioeconomic factors, including overcrowding, indoor pollution, and lack of breastfeeding, further compound the risk [16]. The interplay of these host factors with pathogenic agents underscores the complexity of pediatric pneumonia, necessitating comprehensive prevention strategies, including vaccination and improved nutrition, to mitigate the disease burden [10, 16].

Clinical presentation and diagnosis. Pediatric pneumonia can be clinically identified through a combination of symptoms, severity assessment, and diagnostic tools. Common symptoms include fever, cough, and tachypnea, although in young children, these may be nonspecific [16]. Severe pneumonia is characterized by hypoxia, acidosis, and complications such as sepsis and multiple organ dysfunction [17]. Clinical predictors of severe community-acquired pneumonia (CAP) include vomiting, tachypnea, chest wall retractions, and wheezing, with respiratory distress being a significant indicator [18]. Diagnostic tools for pediatric pneumonia encompass clinical evaluation, laboratory tests, and imaging techniques. Chest X-rays are a standard diagnostic tool, providing reliable imaging for pneumonia, although they are not always essential [16]. Lung ultrasound (LUS) has emerged as a more sensitive and specific alternative to chest X-rays, offering the advantage of being radiation-free and less expensive [19]. The modified lung ultrasound score (MLUS) is particularly useful in distinguishing between Mycoplasma and viral pneumonia and assessing severity [20]. Laboratory tests, including complete blood count (CBC) and C-reactive protein (CRP), are commonly used, although their role in predicting severity is limited [18, 21]. Emerging diagnostic methods include the use of biomarkers such as C-reactive protein and procalcitonin, and novel imaging techniques like Lung Shear-Wave Elastography (LSWE) and Superb Microvascular Imaging (SMI), which enhance diagnostic accuracy for bacterial pneumonia [22]. Additionally, deep learning models, such as Masked Autoencoders, have shown promise in improving diagnostic accuracy by leveraging large datasets, although challenges remain due to the scarcity of pediatric-specific data [23]. Non-invasive techniques using wearable sensors are also being explored for their potential in providing rapid and accurate diagnosis [24]. Overall, a combination of clinical assessment, imaging, and laboratory tests, supplemented by emerging technologies, is essential for the accurate diagnosis and management of pediatric pneumonia.

Current Treatment and Management Strategies for Pediatric Pneumonia. The treatment and management of pediatric pneumonia have evolved significantly in recent years, with a focus on optimizing antibiotic therapy, supportive care, and addressing the growing concern of antibiotic resistance. Community-acquired pneumonia (CAP) remains a leading cause of morbidity and mortality in children worldwide, with viral infections being the most common etiology, particularly in young children, while bacterial pathogens like *Streptococcus pneumonia* are also prevalent [25–27]. The management of pediatric pneumonia involves a combination of empirical antibiotic therapy, supportive care, and targeted approaches for viral pneumonia, with a strong emphasis on antimicrobial stewardship to mitigate the rise of antibiotic resistance.

Antibiotic therapy remains a cornerstone of treatment for bacterial pneumonia, with guidelines recommending the use of aminopenicillins, such as amoxicillin, as the first-line treatment for non-severe cases [27–29]. However, the choice of antibiotics and the route of administration (oral vs. intravenous) depend on the severity of illness, local pathogen prevalence, and resistance patterns. Studies have shown that oral antibiotics can be as effective as intravenous antibiotics for many cases

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of CAP, reducing the need for hospitalization and promoting outpatient management [30]. For severe cases, particularly those requiring hospitalization, broader-spectrum antibiotics such as third-generation cephalosporins may be necessary [31, 32].

Supportive care plays a critical role in the management of pediatric pneumonia, particularly in resource-limited settings. This includes ensuring adequate hydration, oxygen therapy for hypoxemia, and nutritional support [27, 33]. The World Health Organization (WHO) case management approach, which emphasizes early antibiotic treatment and referral for severe cases, has been instrumental in reducing mortality in high-burden areas [33]. However, challenges such as poor adherence to guidelines and limited access to care persist, particularly in low- and middle-income countries [34, 35].

Viral pneumonia, which accounts for a significant proportion of pediatric pneumonia cases, presents unique management challenges. Antiviral therapy is reserved for specific viral etiologies, such as influenza or respiratory syncytial virus (RSV), while supportive care remains the mainstay of treatment for most viral infections [26, 36]. The use of advanced diagnostic tools, such as next-generation sequencing, has improved the ability to identify viral pathogens and reduce unnecessary antibiotic use [37].

Antibiotic resistance is a growing concern in the management of pediatric pneumonia. The overuse and misuse of antibiotics have contributed to the emergence of resistant pathogens, such as penicillin-resistant *Streptococcus pneumonia* and macrolide-resistant *Mycoplasma pneumonia* [31, 38]. To address this, antimicrobial stewardship programs (ASPs) have been implemented to promote judicious antibiotic use, with studies demonstrating their effectiveness in reducing inappropriate prescribing without compromising clinical outcomes [39, 40]. Additionally, shorter courses of antibiotics (e.g., 5 days) have been shown to be as effective as longer courses for uncomplicated CAP, further reducing the risk of resistance [41].

Prevention strategies. The effectiveness of pneumococcal conjugate vaccines (PCVs) in preventing invasive pneumococcal disease (IPD) among children under five is well-documented across various studies, with both PCV10 and PCV13 showing significant protective benefits. In Quebec, Canada, the PCV13 demonstrated a vaccine effectiveness (VE) of 62% for at least one dose and 76% for three doses against serotype 19A IPD, while a mixed schedule of PCV10 and PCV13 showed an even higher VE of 86% for three doses [42]. In the United States, PCV13 was found to have a VE of 86% for at least one dose against vaccine-type IPD, with a higher effectiveness of 87.8% for three doses, particularly against serotypes 19A and 19F [43, 44]. A meta-analysis further supports the high effectiveness of PCV13, reporting an 83.91% VE against serotype 19A IPD in children under five [45]. In Bangladesh, the introduction of PCV10 led to a 77% reduction in vaccine serotype-IPD incidence and a 54% decline in severe pneumonia hospitalizations, with a VE of 63.1% after the second or third dose [46, 47]. Comparative studies indicate that PCV13 generally offers superior immunogenicity and seroefficacy over PCV10 for several serotypes, contributing to a more rapid reduction in IPD cases [48]. The introduction of newer vaccines like PCV15 and PCV20 is anticipated to further enhance protection, with PCV15 showing comparable immunogenicity to PCV13 for most shared serotypes [49]. Overall, the evidence underscores the substantial impact of PCVs in reducing the burden of IPD among young children, highlighting the importance of widespread vaccination to prevent serious pneumococcal infections [50].

Recent advances and future perspectives. Recent advances in pediatric pneumonia research have focused on improving diagnostic accuracy, vaccine development, and leveraging artificial intelligence (AI) for early detection, alongside exploring microbiome-based interventions. A significant breakthrough in diagnostics is the identification of a 5-transcript signature that distinguishes between viral and bacterial pneumonia with high accuracy, potentially reducing unnecessary treatments and diagnostic delays in clinical practice [51]. AI and deep learning have been pivotal in enhancing pneumonia detection, with models like PneumoNet achieving high classification accuracy in distinguishing between healthy and infected cases, as well as differentiating bacterial from viral pneumonia [52]. These AI models, including those utilizing chest X-rays and other patient data, offer non-invasive, cost-effective solutions that surpass traditional radiological methods, thus

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facilitating timely interventions [53, 54]. The integration of AI in medical imaging, such as the use of deep learning models for automated detection, has shown promising results, with models like VGG16 achieving impressive accuracy and recall scores [53]. Vaccine development remains a critical area, with ongoing efforts to enhance coverage and effectiveness, particularly in low-resource settings where pneumonia burden is highest [7]. The role of the microbiome in pneumonia pathogenesis is also being explored, with the potential for microbiome-based interventions to offer novel therapeutic avenues [8]. Despite these advancements, significant gaps remain in research funding and priorities, particularly in low- and middle-income countries, where the majority of child pneumonia deaths occur. Addressing these gaps through increased investment in implementation research and health system strengthening is crucial to achieving global health targets and reducing the burden of pediatric pneumonia [1]. Overall, the integration of novel diagnostic tools, AI, and microbiome research, alongside improved vaccine strategies, represents a comprehensive approach to tackling pediatric pneumonia, with the potential to significantly improve outcomes and reduce mortality rates globally.

Conclusion. Pediatric pneumonia continues to be a leading cause of childhood morbidity and mortality worldwide, disproportionately affecting low-resource settings. Despite advancements in diagnostics, treatment, and prevention, significant challenges remain, including antimicrobial resistance, gaps in vaccination coverage, and disparities in healthcare access. The integration of novel diagnostic tools, artificial intelligence, and microbiome-based therapies offers hope for more effective disease management in the future. To combat this persistent global health threat, a concerted effort is needed—strengthening vaccination programs, promoting research on innovative treatment approaches, and improving healthcare delivery. Investing in these strategies will not only reduce the burden of pediatric pneumonia but also contribute to achieving broader child health and survival goals.

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