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REVIEW

Recent updates regarding the management and treatment of pneumonia in pediatric patients: a comprehensive review

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Abstract
Pneumonia remains one of the leading causes of illness and death among children, particularly in low- and middle-income countries. This review presents a comprehensive update on pediatric pneumonia, covering recent advances in etiology, clinical presentation, diagnostic tools, treatment strategies, and prevention efforts. We explore both traditional and emerging diagnostic methods, including the use of biomarkers like C-reactive protein and procalcitonin, molecular testing, and point-of-care lung ultrasound. Treatment approaches are discussed in detail, with a focus on appropriate antibiotic use, antiviral and antifungal therapies, supportive care such as oxygen therapy and fluid management, and newer interventions like high-flow nasal cannula therapy. Preventive measures, including the introduction and global rollout of pneumococcal, influenza, and RSV vaccines, are also emphasized. In addition, the review highlights ongoing challenges such as antimicrobial resistance, healthcare disparities, and the limited accessibility of advanced diagnostic tools in resource-poor settings. Finally, we outline research gaps and stress the need for strong public health policies, global collaboration, and continued innovation to reduce the burden of pediatric pneumonia and improve outcomes for children worldwide.

Highlights

- Pediatric pneumonia continues to cause high morbidity and mortality, especially in low- and middle-income countries.
- Advances in diagnostics, including lung ultrasound, procalcitonin testing, and molecular tools, have improved early detection.
- Rational antibiotic use and stewardship programs are vital to addressing rising antimicrobial resistance.
- New preventive tools, such as pneumococcal, influenza, and RSV vaccines, play a key role in reducing disease burden.
- Health disparities and limited access to care remain major challenges, highlighting the need for policy reforms and global health initiatives.

Keywords Pediatric pneumonia · Management strategies · Antibiotic resistance · Supportive care · Molecular diagnostics · Clinical presentation

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Abbreviations

PCR	Polymerase Chain Reaction.
RSV	Respiratory Syncytial Virus.
CAP	Community-Acquired Pneumonia.
HAP	Hospital-Acquired Pneumonia.
AMR	Antimicrobial Resistance.
CFPNGS	Cell-Free Plasma Next-Generation Sequencing.
MRSA	Methicillin-Resistant Staphylococcus Aureus.
CRP	C-Reactive Protein.
CT	Computed Tomography.
LUS	Lung Ultrasound.

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CXR Chest X-Ray.
PEEP Positive End-Expiratory Pressure

Introduction

Pneumonia is the inflammation of the air sacs in the lungs (alveoli) and the tissue around them. Characteristically, it is marked by sudden high fever, feeling like you are sick, a cough, and a shortness of breath [1]. Pneumonia in pediatric patients has an etiology from a wide array of pathogens: bacteria, viruses, fungi, and, on rare occasions, even some parasites. The etiology of pneumonia in the pediatric population can be classified into age-specific versus pathogen-specific organisms [2].

The World Health Organization defines pediatric pneumonia based on cough, difficulty breathing, and rapid breathing. Pneumonia is the single largest infectious cause of death among children worldwide. Children are more susceptible to pneumonia due to their developing immune system and immature respiratory system [3]. Pneumonia is the single largest infectious cause of death in children worldwide. In 2019, it killed 740,180 children under the age of five, accounting for 14 percent of all deaths of children under five years old and 22 percent of all deaths in children aged one to five years. Pneumonia affects children and families everywhere, but most deaths are in Southern Asia and sub-Saharan Africa. The incidence in children less than 5 years old is about 0.29 episodes per child-year in the developing world and about 0.05 episodes per child-year in the developed world [3].

This translates to some 156 million new cases annually worldwide, of which 151 million occur in the developing world. Most cases are found in India, followed by China with 21 million and Pakistan with 10 million, and thereafter significant numbers were found in Bangladesh, Indonesia, and Nigeria, all in the range of 6 million [3, 4]. Among all community cases, 7–13% are severe enough to pose a life-threatening risk and hence require hospitalization. More than 90% of all the deaths of children below 5 years due to pneumonia occur in 40 countries. Even more significantly, as estimated by the WHO for the year 2000, two-thirds of these deaths are confined to only 10 countries: India with 408,000 deaths, Nigeria with 204,000, the Democratic Republic of the Congo with 126,000, Ethiopia with 112,000, Pakistan with 91,000, Afghanistan with 87,000, China with 74,000, Bangladesh with 50,000, Angola with 47,000, and Niger with 46,000 [4]. Although the prognosis for pneumonia is better in the developed world, with fewer lives claimed, the burden of disease caused by it is extreme, roughly 2.5 million cases yearly, with a third to almost half resulting in hospitalization [5].

This review offers a comprehensive update on the management and treatment of pediatric pneumonia, highlighting recent advancements and best practices. It will explore the latest guidelines, new therapies, and preventive measures. By bringing together current information, this review aims to guide healthcare professionals, policymakers, and researchers in effectively addressing and reducing the impact of pediatric pneumonia.

A proactive approach to treating pediatric pneumonia is vital because children can deteriorate quickly and develop complications. Effective management requires prompt and accurate diagnosis, suitable antimicrobial therapy, and supportive care. The increasing problem of antimicrobial resistance (AMR) highlights the importance of selecting the right antibiotics and strictly following treatment guidelines.

Key questions addressed

- What are the latest diagnostic methods and criteria for identifying pediatric pneumonia?
- In what ways have recent treatment guideline updates influenced the management of pediatric pneumonia?
- What new antimicrobial treatments are being developed for pediatric pneumonia, and how do they tackle the issue of antimicrobial resistance?
- What are the most effective practices for providing supportive care to children with pneumonia?
- How can vaccines and other preventive strategies lower the incidence of pediatric pneumonia?
- What are the remaining challenges in managing pediatric pneumonia, and what future directions should research and policy focus on?

Methodology

We conducted a comprehensive literature review using PubMed, Scopus, and Web of Science databases, with the initial search performed in February 2024, and an updated search conducted in January 2025, to include all relevant literature published up to that date. No restrictions were applied regarding the date of publication, study design, or language. Search terms included “pneumonia,” “pediatric pneumonia,” “childhood pneumonia,” “management,” “treatment,” “antibiotics,” “antiviral therapy,” “antifungal therapy,” “supportive care,” “oxygen therapy,” “fluid therapy,” “imaging,” “diagnostic techniques,” “molecular diagnostics,” “PCR,” “antibiotic resistance,” “vaccination,” “prevention,” “public health,” “epidemiology,” “clinical presentation,” “community-acquired pneumonia,” “hospital-acquired pneumonia,” “artificial intelligence,” “emerging therapies,” and related combinations. Two reviewers (YM and SF) independently screened the articles for relevance based on title and abstract, followed by full-text review of selected studies. A total of 312 articles were identified as relevant to the study aim. Priority was given to recent publications, systematic reviews, randomized controlled trials, and official guidelines that addressed diagnostic advancements, management strategies, supportive care, prevention, and global health challenges related to pediatric pneumonia.

Etiology and pathophysiology

Etiology

The etiology of pneumonia in pediatric patients can be classified by age-specific and pathogen-specific organisms [2]. In neonates, the risk of contracting pneumonia is heightened due to exposure to bacterial pathogens present in the birth canal. Common organisms responsible for neonatal pneumonia include *group B streptococci, Klebsiella, Escherichia coli, and Listeria monocytogenes* [6]. These pathogens can lead to severe respiratory infections in newborns shortly after birth. Additionally, Streptococcus pneumoniae, Streptococcus pyogenes, and Staphylococcus aureus are frequently identified in cases of late-onset neonatal pneumonia, which typically occur after the first week of life [6].

In infants and children under 5 years old, the primary cause of pneumonia shifts towards viral infections. Respiratory viruses such as *respiratory syncytial virus, parainfluenza virus types 1, 2, and 3, influenza virus types A and B, adenovirus, rhinoviruses*, and less commonly, herpes simplex virus and enteroviruses are the leading culprits in this age group, leading to a high incidence of viral pneumonia [7, 8].

Moreover, there has been an observed increase in pneumonia cases caused by bacterial pathogens such as Streptococcus pneumoniae and *Hemophilus influenzae type B (Hib)* in young children. This rise in bacterial pneumonia cases highlights the importance of vaccination programs targeting these pathogens [9, 10]

Mycoplasma pneumoniae commonly affects school-aged children (5–15 years), although colonization may occur without active infection, especially in younger children. [11]; however, *S. pneumoniae* is still the most identified organism, adolescents typically face similar infectious risks as adults. Recent studies, including those by Meyer-Sauteur et al., highlight the challenge in distinguishing Mycoplasma pneumoniae infection from asymptomatic colonization, especially in infants and young children [12].

Tuberculosis (TB) remains a significant cause of pediatric pneumonia in many parts of the world, not limited to immigrant populations. Children in TB-endemic regions are particularly vulnerable, especially those with HIV or malnutrition. Additionally, children with chronic diseases are at increased risk for certain pathogens. For example, in children with cystic fibrosis, pneumonia commonly results from infections with Staphylococcus aureus and *Pseudomonas aeruginosa*, which are frequently encountered and can cause significant respiratory complications [12]. Like adults, adolescents are susceptible to a broad range of respiratory infections due to similar exposure and immune response patterns. High-risk groups, such as immigrants from regions where TB is prevalent or those with known exposure to TB, need careful evaluation for this disease due to the potential for latent TB infection reactivating or active TB spreading, which can have significant public health implications. Children with chronic illnesses often have compromised immune systems or other conditions that make them more susceptible to infections [13].

Patients with sickle cell disease are at increased risk for infections caused by encapsulated organisms due to compromised splenic function. Sickle cell disease often leads to functional asplenia or hypo-splenism because sickled red blood cells obstruct splenic vasculature, resulting in reduced spleen function. This impairment affects the spleen's ability to filter and clear encapsulated bacteria, such as Streptococcus pneumoniae*,* Hemophilus influenzae *type b*, and *Neisseria meningitidis*. These pathogens are particularly virulent due to their polysaccharide capsules, which help them evade the immune system [14].

Pathophysiology

Pneumonia involves the invasion of the lower respiratory tract, below the larynx, by various pathogens. These pathogens can infiltrate the lungs through several mechanisms, including inhalation of airborne microorganisms, aspiration of oropharyngeal contents, direct invasion through the respiratory epithelium, or via hematogenous spread from distant infection sites [15]. Several barriers prevent infections in the respiratory tract, including anatomical structures and components of both humoral and cellular immunity. Anatomical defenses include nasal hairs, which filter out large particles; turbinates, which trap pathogens in mucus; the epiglottis, which prevents aspiration; and cilia, which move mucus and trapped pathogens out of the airways. Humoral immunity involves antibodies produced by B cells, such as IgA in mucosal secretions, which neutralize or mark pathogens for destruction. Cellular immunity includes macrophages and dendritic cells that engulf pathogens, helper T cells that coordinate immune responses, cytotoxic T cells that kill infected cells, and natural killer (NK) cells that destroy abnormal cells [16]. Once these barriers are breached, infections can occur through different pathways, such as fomite or droplet transmission, which is common for viruses, or nasopharyngeal colonization, typical for bacteria. The pathogens invade and infect the respiratory tract, leading to inflammation and damage or destruction of the surrounding epithelial cells and alveoli. This invasion triggers the body's immune response, resulting in the migration of inflammatory cells to the site of infection [14].

These inflammatory cells release various substances that cause an exudative process, where fluid and cellular debris accumulate in the alveoli. This accumulation impairs the normal gas exchange process, leading to reduced oxygenation of the blood. As a result, the individual may experience symptoms such as difficulty breathing, decreased oxygen levels, and other signs of respiratory distress. This inflammatory response, while part of the body's defense mechanism, can further contribute to the severity of pneumonia and its impact on respiratory function [17].

Complications

Empyema is a condition characterized by the accumulation of purulent (pus-containing) fluid in the pleural space, the cavity between the lungs and the chest wall. It typically results from an infection, that spreads to the pleural space, leading to an inflammatory response and formation of a thick, viscous fluid. Empyema often necessitates drainage and antibiotic therapy to resolve the infection and prevent complications. It often requires prolonged antibiotic therapy (typically 2–4 weeks depending on severity and drainage) in addition to drainage procedures [17].

Lung abscess is a localized collection of pus within the lung parenchyma, usually resulting from a bacterial infection. It often presents as a cavitary lesion on imaging studies. Lung abscesses can arise from aspiration of foreign material or bacteria, particularly anaerobic organisms. Treatment typically involves prolonged antibiotic therapy and, in some cases, surgical intervention [17].

Necrotizing pneumonia is a severe form of pneumonia where there is extensive tissue necrosis in the lung parenchyma. This condition is often associated with virulent pathogens such as Staphylococcus aureus (including MRSA) or certain anaerobic bacteria. It can lead to the formation of lung abscesses and requires aggressive antibiotic therapy and possibly surgical debridement to manage the infection and prevent complications [17].

Sepsis is a systemic inflammatory response syndrome triggered by an infection, which can lead to widespread organ dysfunction and failure. It occurs in approximately 10–20% of hospitalized children with severe pneumonia and is associated with higher mortality, particularly in neonates and immunocompromised patients [17].

Clinical presentation

Signs and Clinical manifestations

Pneumonia at any age, but especially in pediatrics, is a life-threatening condition and presents a spectrum of signs and symptoms which determine the severity of the disease. In general, it presents with signs of systemic inflammation such as fever, lethargy, and anorexia, as well as signs of respiratory infection such as productive cough, tachypnea, shortness of breath, grunting and retractions [18].

The clinical manifestations of pneumonia can vary between individuals, but many of the general signs and symptoms are present in most cases. Fever is present in the majority of the cases, particularly in bacterial pneumonia, which can cause the body temperature to go as high as 105 degrees F, and is associated with profuse sweating, chills and rigor [19]. Mycoplasma pneumonia, a gram-negative spindle shaped pleomorphic bacterium, which typically causes lung disease with low grade fever, is also reported to cause pneumonia without fever, particularly in younger children. However, the impact of fever on disease course is questionable, as suggested by studies which concluded a similar level of lung function impairment in children with and without fever [20]. Viral pneumonia often tends to initiate as a flu like illness, progressing to the clinical picture of pneumonia within a few days. Important indications of pneumonia and respiratory distress include signs of increased work of breathing. These include nasal flaring, tachypnea, and subcostal and intercostal retractions [2]. The signs of respiratory distress, as well as other signs such tachycardia and cyanosis, directly correlate with the severity of disease. Grunting is an important indicator of respiratory distress, particularly in newborns [18]. According to the guidelines laid out by the "integrated management of childhood illnesses", stridor indicates 'very severe disease' as it reflects upper airway involvement, not pneumonia-specific lower respiratory pathology [21]. Cough is an expected symptom in a case of pneumonia and is usually associated with production of phlegm. Persistent, copious amounts of pus with cough points strongly towards progression to lung abscess [22].

Age specific differences

The presentation of pneumonia can vary amongst children of different age groups and considering these differences during evaluation is vital in making a clinical diagnosis. A newborn with pneumonia is expected to present with symptoms that are distinct to symptoms that would be seen in an older child [23]. Pneumonia in newborns is an extremely critical condition. According to a UNICEF report in 2019, it accounts for 6.1% of the total neonatal mortalities globally [24]. Newborns typically present with signs of respiratory distress such as tachypnea {defined as respiratory rate > 60 breaths/minute), hypoxia, and evidence of increased work of breathing such as nasal flaring and intercostal/subcostal retractions [25]. Grunting, which is an expiratory sound produced by the glottis to preserve the functional residual capacity (FRC), is a unique sign of respiratory distress seen in neonates and is a strong indication of respiratory distress. Systemic symptoms, such as irritability and poor feeding are also expected, while the presence of cough and fever is unpredictable [25]. Additionally, neonates may have the unique presentation of Chlamydia Trachomatis pneumonia, a congenital infection which presents with the characteristic "staccato" cough. Cough is a common presenting symptom after 1 month of life, and wheezing might also be present, in addition to the signs of distress [26].

In infants and toddlers, pneumonia commonly presents with cough, fever, nasal congestion, and signs of respiratory distress such as nasal flaring, grunting, and intercostal retractions. Wheezing may also occur, especially with viral etiologies. Adolescents typically present with an adult like picture of pneumonia, with fever, cough, chest pain, dehydration, lethargy, headache, pleuritis and abdominal pain [25]. Mortality remains a major concern for children with this illness, even outside of neonatal period, with over 700,000 deaths in children under 5 years of age every year [27].

Diagnostic criteria

While diagnostic tests can assist, pneumonia is often diagnosed clinically, especially in low-resource settings following IMCI or WHO guidelines. Careful history taking is essential, particularly in newborns or infants due to communication barrier, where parental history becomes vital [28]. The presenting symptoms in such patients may not be obvious, therefore careful examination is essential. Tachypnea is the most important sign to look for, as it not only indicates respiratory distress but also has an established correlation with the level of hypoxemia, radiographic deterioration, and clinical severity of the disease [28]. Tachypnea refers to a respiratory rate of: > 60/minute in children < 2 months old; > 50/minute in children 2–12 months old; > 40/minute in children 1–5 years old; and > 20/minute in children > 5 years old [29]. Other signs to look for include low oxygen saturation, visible respiratory distress, and fever. Chest auscultation is an integral part of early evaluation, and the presence of inspiratory crackles is a strong indicator of consolidation due to an underlying lung infection, and it may be localized to a single lobe in lobar pneumonia or be present in a diffuse pattern bilaterally [29]. Reduced air entry in the affected segment is also a common finding. Other findings on a physical examination include asymmetric chest expansion, egophony, bronchial breath sounds and dullness to percussion [29].

Important laboratory investigations include complete blood count {CBC}, C-reactive protein levels {CRP}, procalcitonin levels, blood culture and sensitivity (C/S) and sputum C/S, thoracentesis, and bronchoscopy. A CBC is the initial test done in every case, to look for hematologic parameters. An elevated Total Leucocyte count (TLC) is expected with levels reaching over 15,000 cells/microliter [30]. This indicates a healthy immune system which reacts appropriately to an infectious source. An elevated CRP count is expected, and it indicates active inflammation. Procalcitonin is an advanced laboratory measurement which is predictive of the need of antibiotics and is being increasingly used in suspected infectious illnesses. Its levels have been found to be increased in bacterial but reduced in viral etiologies. CBC and CRP may support the diagnosis but are not definitive. CRP is often elevated in bacterial infections, though it may remain low in viral etiologies. Procalcitonin (PCT) has shown higher specificity in distinguishing bacterial from viral pneumonia and is increasingly used in decision-making [30].

Cultures may be required for accuracy in management, such as administering the appropriate antibiotics. Sputum culture is an important investigation in detecting the causative pathogen [31]. However, sputum cultures tend to be contaminated from sources such as the normal oral flora, which can give false positive results and make the diagnosis challenging. Mouth rinsing is a necessary step prior to sample collection, as it has shown to reduce the rates of contamination from 22% to as low as 7%. Blood cultures are a more reliable method of pathogen detection and indicate the spread of infection from the lung parenchyma to the blood. For viral causes of pneumonia, a polymerase chain reaction (PCR) testing is typically conducted on nasopharyngeal swabs, but detection of pathogens—particularly viruses or Mycoplasma pneumoniae—may represent colonization rather than active infection, especially in asymptomatic children [31.32].

Radiological and laboratory findings

Chest radiography plays a pivotal role in the evaluation of pneumonia, with a high sensitivity. Chest x-rays are often used in the workup of suspected pneumonia, and provide the necessary confirmation needed for the establishment of a definitive diagnosis. Despite its high sensitivity in diagnosing pneumonia, a negative chest x-ray should not be used as a basis to override the clinical impression, and the clinical evaluation should be given more weight than the radiographic findings. While there is widespread use of x-rays in the diagnosis of pneumonia, current guidelines suggest that chest radiography should not be routinely performed in every case, particularly in patients with mild uncomplicated disease who do not require admission [32]. Although the radiation dose of a single chest X-ray is low, cumulative exposure in children may pose a risk. Estimated lifetime cancer risk from a single pediatric chest X-ray is approximately 1 in 300,000 to 1 in 1,000,000 exposures. Indications for performing radiography include insufficient clinical evidence, refractory cases, severe disease, progression to empyema or other complications, and prolonged disease [33]. If an x-ray is inconclusive or if finer details are to be visualized, a computed tomography scan may be performed to evaluate the airway more thoroughly. However, it is not routinely performed. A chest ultrasonography may also be performed when parapneumonic effusions are suspected. Lung ultrasound is a valuable tool in differentiating bacterial from viral pneumonia, especially when performed at the bedside. It offers a radiation-free alternative with comparable diagnostic accuracy to chest radiography and is increasingly used in both inpatient and outpatient pediatric care [34].

The diagnosis of pneumonia is made when there is a high level of clinical suspicion, and the laboratory tests and radiography findings are consistent with the findings expected in pneumonia. However, not all tests have a 100% level of sensitivity, and some parts of the evaluation may be divergent from the typical pneumonia presentation. Additionally, the diagnostic workup may vary from one individual to another based on their age and status of severity. Therefore, it is important to look at the bigger picture of complete evaluation rather than a single diagnostic parameter to arrive at a definitive conclusion [33, 34].

Recent updates in diagnostic methods

Pneumonia is a significant cause of morbidity and mortality in pediatric populations worldwide. Early and accurate diagnosis is critical for effective treatment and management. Recent advances in diagnostic methods have improved the ability to detect pneumonia in children, incorporating molecular techniques, rapid antigen detection tests, point-of-care testing, and advanced imaging techniques [2]. One major diagnostic challenge in pediatric pneumonia is the absence of a universally accepted gold standard, which complicates comparisons between diagnostic tests and limits accuracy benchmarks [35].

Molecular diagnostic techniques

Molecular diagnostics have become a cornerstone in the identification of pathogens responsible for pneumonia. These techniques allow for the rapid and specific identification of bacterial and viral pathogens, which is crucial for timely and appropriate treatment. A recent article by Bălan et al. (2023) emphasizes the evolution and critical role of PCR-based methods in diagnosing nosocomial pneumonia. Traditional PCR techniques, while highly accurate, often require extensive time and specialized laboratory settings. In contrast, point-of-care (POC) PCR technologies have significantly reduced the time to diagnosis, facilitating timely and appropriate therapeutic interventions [35]. It is paramount to integrate these molecular diagnostic tools in clinical practice to enhance patient outcomes and streamline pneumonia management.

Cell-free plasma next-generation sequencing (CFPNGS)

Cell-free plasma next-generation sequencing (CFPNGS) was introduced to Pediatric Infectious Diseases physicians on June 1, 2017, to enhance standard-of-care diagnostic methods. CFPNGS allows for the comprehensive identification of pathogens from plasma, providing a broad-spectrum diagnosis that can guide treatment decisions. This method, while not yet compared extensively with other diagnostic tests like real-time PCR, shows promise for its ability to detect a wide range of pathogens efficiently [36].

A study by Vlaminck et al. (2015) described cell-free plasma sequencing as a noninvasive diagnostic assay capable of simultaneously monitoring for acute rejection and a wide range of infections in a contemporary lung transplant cohort [36].

A study by Farnaes et al. (2019) explores the application of CFPNGS in community-acquired pneumonia (CAP) among children. Fifteen hospitalized children with CAP, who had no other underlying medical conditions, underwent CFPNGS. This technique identified a pathogen in 13 out of the 15 children (86%). As a direct result of CFPNGS, antibiotic selection in seven children was refined to beta-lactams, instead of continuing with lincosamides or glycopeptides. Notably, none of the children who received the targeted antimicrobial therapy based on CFPNGS results were readmitted for late complications of CAP due to inappropriate antibiotic treatment [37]. Next-generation sequencing (NGS) has shown promise in pathogen identification, especially in immunocompromised patients or culture-negative pneumonia, but its use is currently limited by high cost, need for technical expertise, and a lack of large-scale validation studies [36].

PCR and IgM tests for mycoplasma pneumoniae

A stepwise approach combining IgM serology and PCR enhances diagnostic accuracy, particularly in the early phase of illness. This combination improves the accuracy of early diagnosis, which is particularly beneficial in pediatric patients where rapid diagnosis can significantly impact treatment outcomes [13]. Based on the study, patients showing suspected clinical symptoms and one of the following three laboratory findings might be diagnosed with acute mycoplasma infection:

1. Seroconversion, indicated by a change from a negative to a positive result for specific M. pneumoniae IgM.
2. A significant rise in specific antibodies, such as a two-fold increase in M. pneumoniae IgM or a four-fold increase in specific IgG through titer or dilution testing, observed within a two-week period.
3. Positive PCR results [38].

Most PCR-based tests are performed on nasopharyngeal swabs or aspirates, though blood or bronchoalveolar lavage samples may be used in severe or hospitalized cases. It is important to note that PCR positivity, particularly for respiratory viruses and Mycoplasma pneumoniae, may represent asymptomatic colonization rather than active infection, especially in infants [38].

Rapid antigen detection tests

Rapid antigen detection tests and point-of-care (POC) testing have revolutionized the diagnosis of pneumonia by enabling quick and reliable results at the bedside. A study by Aguilera-Alonso et al. (2020) demonstrates that rapid virology diagnostic techniques can optimize antibiotic use in pediatric patients with CAP. In this study involving children admitted for CAP, those who had respiratory syncytial virus (RSV) detected early in a respiratory sample received fewer antibiotics and had a shorter duration of antibiotic therapy [39]. The ability to quickly identify viral pathogens reduces unnecessary antibiotic prescriptions, which is crucial in combating antibiotic resistance.

Biomarker-based POC tests

Florin et al. (2020) discuss the use of biomarkers like C-reactive protein (CRP) and procalcitonin in differentiating bacterial from viral pneumonia in children. These biomarkers, used in conjunction with clinical symptoms, enhance the accuracy of pneumonia diagnosis, facilitating more targeted therapy [40].

In a study of 100 children with CAP, Don et al. found that procalcitonin levels were higher in those who were hospitalized and in those with alveolar CAP compared to interstitial CAP [41].

Additionally, a study conducted in Italy involving 265 children aged 4 months to 14 years, who were hospitalized for suspected CAP, found that both CRP and procalcitonin were linked to severe disease, as defined by the British Thoracic Society pneumonia guidelines. The study also showed that in children with CAP, blood levels of sTREM-1, MR-proANP, and MR-proADM were less effective at distinguishing between bacterial and viral infections or identifying severe cases, underscoring that procalcitonin remains the most reliable marker in this context [42].

Emerging transcriptomic approaches, such as ImmunoXpert, aim to differentiate bacterial from viral etiologies with high sensitivity, but clinical implementation remains limited. While point-of-care diagnostics offer rapid results, their availability remains limited in many low-resource settings due to cost, infrastructure, and supply chain challenges [42].

Imaging techniques

Despite the emergence of new technologies, chest X-rays continue to be a key diagnostic tool, especially in resource-limited settings. Advances in digital imaging technologies and improved radiographic techniques have enhanced the accuracy of radiographic diagnosis. Mardieva and Ashurov (2022) examined the role of radiography in diagnosing pneumonia in newborns. The requirement for mandatory X-ray confirmation of pneumonia in the diagnostic gold standard allows for early verification of the pathological process, enabling timely and targeted therapy that significantly improves disease outcomes. X-ray examination remains the primary radiographic method for suspected pneumonia in children [43].

Moreover, combining temperature, respiratory rate, and oxygen saturation enhances the specificity of diagnosing radiographic pneumonia [44]. However, the Infectious Disease Society of America does not recommend the routine use of chest radiography for diagnosing childhood pneumonia in outpatient settings [45].

Berce et al. (2019) discovered that lung ultrasound is particularly effective in distinguishing bacterial CAP from CAP caused by other etiologies in children. Lung ultrasound offers a non-invasive, radiation-free alternative to chest X-rays, with studies demonstrating comparable diagnostic accuracy [46].

Computed tomography (CT) is not typically used as the first-line imaging tool for children with suspected uncomplicated community-acquired pneumonia. However, CT should be considered for cases involving parenchymal and pleural complications, necrotizing pneumonia, regions with high prevalence of HIV and tuberculosis, and foreign body aspiration pneumonia [47]. Duan et al. (2020) provided insights into the CT features of COVID-19 pneumonia in children, noting that pediatric patients exhibit different radiographic patterns compared to adults. These distinctions are critical for accurate diagnosis and management of COVID-19 in children [48].

MRI of the lung offers detailed information on both morphology and function, making it an excellent non-radiation diagnostic tool for children [49]. It can effectively visualize alveolar infiltrations and exudate patterns associated with pulmonary infections. MRI images are often clearer than chest X-rays in cases of bronchopneumonia and segmental pneumonia [50]. However, access to MRI facilities is quite limited. Additionally, a significant number of very young children may develop dorsal atelectasis due to sedation during the MRI, which can potentially obscure pathological processes [51].

Advanced techniques in artificial intelligence and machine learning

The automatic detection of pneumonia features using CXR, CT, and LUS images has leveraged the powerful feature extraction capabilities of deep learning techniques. Over the past three years, researchers worldwide have made significant efforts to develop reliable diagnostic methods amid the global pandemic. Numerous studies have applied machine learning to radiographic images in their attempts to enhance diagnostic accuracy. The Table 1 below summarizes the results of a few of these studies.

An IEEE study published in 2020, retrospectively analyzed chest CT images and clinical data from 815 patients to develop and test NCIP-Net, an algorithm for diagnosing COVID-19. Data from two hospitals were used, with patients from Hospital A (531 cases) for development and from Hospital B (293 cases) for independent testing. NCIP-Net consists of three stages: lung segmentation, lesion detection, and disease classification [52].

The model showed superior performance over the Mask-R-CNN-SVM method, with higher area under the receiver operating characteristic (ROC) curve values in both test and external validation sets, particularly in differentiating NCIP from lung nodules and other pneumonia [53].

Comprehensive diagnostic approaches

Combining various diagnostic modalities can enhance the overall diagnostic accuracy and provide a more comprehensive understanding of the etiology and severity of pneumonia. Bhuiyan et al. (2019) reported the effectiveness of combining clinical symptoms with blood biomarkers to differentiate between bacterial and viral pneumonia [54].

Another study conducted by Mardian et al. (2021) explored the use of multiplex PCR and sequencing to identify causative pathogens of CAP in children. Molecular diagnostics, including polymerase chain reaction (PCR) and next-generation sequencing (NGS), offer a more precise and rapid identification of pathogens by detecting their genetic material directly from clinical specimens. The

Table 1 shows the biomarkers used in the diagnosis and management of pediatric pneumonia

Study	Technique	Accuracy		Specificity	Sensitivity
A preliminary prediction model of pediatric Mycoplasma pneumoniae pneumonia based on routine blood parameters by using machine learning method [127]	GBDT classification model built using seven machine learning (ML) algorithms to develop an integrated prediction tool for diagnosing MPP	0.928		0.929	0.926
An advanced approach for accurate pneumonia detection using combined deep convolutional neural networks [128]	Concatenation model combining two CNNs depending on the transfer learning (TL) technique for detecting pediatric pneumonia from CXR images	0.985		NR	0.984
Texture-Based Classification to Overcome Uncertainty between COVID-19 and Viral Pneumonia Using Machine Learning and Deep Learning Techniques [129]	Classification of chest X-ray images into normal, COVID-19, and viral pneumonia categories utilizing RF (random forest), SVM (support vector machine), and DLNN (deep learning neural network) techniques	RF	0.85	NR	0.85
		SVM	0.70	NR	0.74
		DLNN	0.92	NR	0.93
Diagnosis of Pediatric Pneumonia with Ensemble of Deep Convolutional Neural Networks in Chest X-Ray Images [130]	CNN models trained with the appropriate transfer learning and fine-tuning strategies on the chest X-ray dataset	0.9071		NR	0.9776
A transfer learning method with deep residual network for pediatric pneumonia diagnosis [52]	Deep learning framework combining residual thought and dilated convolution to diagnose and detect childhood pneumonia	0.905		NR	0.967

study emphasizes the use of a combination of molecular techniques with traditional methods to improve diagnostic accuracy, reduce the overuse of antibiotics, and enhance patient outcomes [55].

Recent advances in diagnostic methods for pneumonia in pediatric patients have significantly improved the accuracy and speed of diagnosis. Molecular techniques, rapid antigen detection tests, POC testing, and advanced imaging methods have all contributed to this progress. The integration of AI and ML into diagnostic processes further enhances these capabilities, promising even greater improvements in the future. By combining various diagnostic approaches, clinicians can achieve more accurate diagnoses, leading to better treatment outcomes [55, 56].

Management strategies and advancements

The management of pneumonia involves stabilizing the patient, prevention of deterioration of symptoms and complications, eradicating the infection, and ensuring patients' return to the usual state of health. Achieving each of these individual goals requires a vast variety of medical and surgical treatment modalities. The approach to treatment of pneumonia is not straightforward, but rather it involves the use of appropriate formula for treatment which is best suited for the type and severity of symptoms being experienced by the patient. There has constantly been changes and updates concerning the management of pneumonia throughout the course of time, and it is crucial to stay updated with the latest management standards to ensure the patient receives the best possible treatment [57].

Antibiotic therapy

Pneumonia is infection of the lung parenchyma, and as with any infection, antibiotics are the mainstay of treatment in bacterial pneumonia. For mild cases of pneumonia, the patients are managed in the outpatient setting and oral antibiotics are the preferred method of treatment in such patients [57]. However, an initial intravenous (IV) dose of antibiotics may be administered before discharging the patient with oral medication, depending upon the patient's condition. The most prescribed antibiotic in such patients is amoxicillin. Most patients with mild symptoms move towards recovery within 2–3 days of antibiotic therapy. Antibiotic selection should be based on patient age, disease severity, suspected etiology, and local antimicrobial resistance patterns. Empirical therapy must align with regional guidelines and surveillance data [58].

A study has shown that a two-phase intervention, which comprise educational sessions and clinical decision support, led to lasting improvements in the selection and duration of antibiotics for children with community-acquired pneumonia [59, 60]. Thought must be given to the pharmacokinetics of amoxicillin and other beta lactam antibiotics. There is evidence that a frequent, regular dosing demonstrates superior results to fewer, larger doses and discussions have been held regarding the implementation of this method in all cases of community acquired pneumonia (CAP) [61]. Bielicki et al. stated that in children with CAP discharged within 48 h, lower-dose, and shorter-duration (3-day) oral amoxicillin was noninferior to higher-dose and longer-duration (7-day) regimens regarding antibiotic re-treatment. However, interpretation requires caution due to factors like disease severity and prior antibiotic use [60].

Despite its widespread use in clinical practice for the management of pneumonia, amoxicillin is very limited in its activity against numerous disease-causing pathogens, and other options must be explored, which include cephalosporins, macrolides, fluoroquinolones, monobactams, and combination drugs such as trimethoprim-sulfamethoxazole [59]. The choice of antibiotic depends on the physician, and the complete clinical workup must be kept in mind when choosing an antibiotic for the patient, including the results of culture and sensitivity. It is important to choose an alternative to amoxicillin when treating pneumonia caused by organisms such as H influenza, M catarrhalis, P aeruginosa and other gram-negative organisms due to the presence of beta lactamase [61, 62]. Evidence supports shorter antibiotic courses for uncomplicated community-acquired pneumonia. Randomized trials have shown that 3-day courses of amoxicillin are non-inferior to 5- or 7-day regimens in mild-to-moderate pediatric CAP [62].

Antibiotic stewardship is vital in pediatric pneumonia management. Recent studies show that, in select cases—especially with mild disease and strong viral indicators—antibiotics can be safely withheld. Stewardship programs emphasizing narrow-spectrum antibiotic use, guided by biomarkers and clinical algorithms, have been effective in reducing resistance [63].

Piperacillin-tazobactam {pip-taz) is a commonly used combination regimen used for severe nosocomial pneumonias caused by beta lactam resistant strains of staph aureus and other gram-negative organisms [63]. A study focusing on the pharmacology of pip-taz has given substantiation that the current treatment guidelines for the use of pip-taz are inadequate in pediatrics due to higher clearance rates and it has shown that multiple daily dosing also results in higher trough levels of the drug in the bloodstream, providing a valid reason for suggesting exploration of more optimized dosing strategies [64]. Intravenous doses of Fosfomycin (a phosphonic antibiotic), administered in addition with other broad-spectrum antibiotics, such as meropenem, has also shown beneficial effects in children for treating pneumonia, particularly that caused by pseudomonas aeruginosa. Agents such as meropenem and fosfomycin should be reserved for severe cases with suspected multidrug-resistant (MDR) organisms or treatment failure with first-line antibiotics. Their use must be justified based on microbiological data or strong clinical suspicion [65].

Mycoplasma pneumoniae pneumonia (MPP), which causes atypical or walking pneumonia, is most frequently treated with macrolides, including azithromycin for treatment [65]. However, studies have shown that not all cases of MPP are susceptible to azithromycin, and azithromycin resistant strain with A2063/2064G mutations (which entail mutations in 23S subunit of rRNA) are associated with an increased risk of progression to refractory MPP, which was indicated by clinical and radiological worsening despite antibiotic treatment and prolonged hospital stays, and a higher incidence of bronchiolitis obliterans and bronchiectasis within a year [66]. This points towards the potential usefulness of detection of macrolide resistance genes in patients with MPP by performing PCR on the bronchoalveolar lavage fluid or nasopharyngeal aspirates [67]. In refractory cases, or in cases with mutations diagnosed via PCR, it is necessary to switch from macrolides to other antibiotics which are effective against MPP, including doxycycline (which targets the 30 s subunit of ribosome), and fluoroquinolones such as levofloxacin (which target the DNA gyrase enzyme) [38, 68]. In MPP cases with impaired pulmonary function test, antibiotics combined with inhaled terbutaline have shown significant clinical improvement and could be used regularly in such patients after additional trials have been performed and more evidence has been gathered [69].

Antiviral and antifungal therapies

Viral pneumonia is generally much less severe than bacterial pneumonia and as such, its management is also not as aggressive. Usually, only supportive treatment is given to such patients and the infection is expected to go away on its own; however, in unusual cases of severe pneumonia an antiviral may be prescribed, including oseltamivir, zanamivir, peramivir etc. [70]. Oseltamivir should be reserved for confirmed or highly suspected influenza infections, especially in high-risk children, within 48 h of symptom onset. However, these antivirals have been associated with an increase in resistance, and resistance patterns must be considered when administering these drugs [31]. Supportive management includes the use of oxygen if needed, increased fluids, corticosteroids and using humidified air [70].

SARS-CoV-2, or coronavirus disease 19 (COVID-19) is a usual viral pathogen involved in lower respiratory infections in all age groups. Therapies have been explored which target the point of entry of the virus into the lung tissue and reduce the risk of infection [71]. Surfactant therapy also seems to exert its effects over a wide range of virulent components, including signal transduction, viral resistance, dampening of systemic inflammatory cytokine production, and minimizing apoptosis [71]. Other methods to prevent transmission are also being studied, such as the nanoSTING nanoparticle, which acts as a local immune activator and reduces the transmission of multiple viral infections [72]. While preventing viral entry could prove to be a breakthrough for preventing viral infections in the future, currently vaccination is the mainstay of disease prevention by such pathogens, and while the long-term effects of vaccination remain somewhat obscure, studies have shown that hybrid immunity achieved by administering 2 + doses vaccine followed by SARS-CoV-2 infection have higher and longer lasting antibody levels than patients who acquired the infection before being vaccinated, or only had the vaccine or the infection [73]. Therefore, there is a clear established short-term benefit of being vaccinated prior to having the infection. Shufeng Jiedu capsule, a traditional Chinese medicine, has had widespread use for treating COVID-19 infection, and has also been used in other viral pneumonias, such as influenza. It is associated with reduction in inflammation and tissue injury, and preservation of B and T-cell mediated immunity, thereby aiding in the eradication of viruses from lungs [74].

In severe pediatric COVID-19 cases, supportive care remains the cornerstone of therapy. Adjunctive treatments may include corticosteroids (e.g., dexamethasone), monoclonal antibodies, or antiviral agents like remdesivir, depending on severity, patient age, and comorbidities [75].

There is a variety of fungal pathogens which can cause pulmonary disease, and while treatment for each of these fungi is distinct, their treatment falls within the same spectrum of medications. Amphotericin B has been widely accepted as the mainstay of treatment for severe cases of fungal pneumonia, and its use for such cases has been widespread [76]. Voriconazole has displayed superiority over amphotericin B for treating fungal pneumonia; therefore, it is now the standard for treating invasive aspergillosis [76]. Care must be taken when administering voriconazole, as it is reported to cause periostitis in patients receiving allogenic stem cell transplantation; discontinuation of the drug resulted in resolution of symptoms [77]. Posconazole is another antifungal agent which has been implicated in the prophylaxis of invasive aspergillosis and candidiasis in immunocompromised patients [78]. Nano micelles have been developed for the delivery of posconazole and other antifungal agents, which exhibited sustained cumulative drug release and resulted in a high level of bioavailability, significantly inhibiting invasive fungal infections [79].

Supportive management

The supportive management of pneumonia in children includes oxygen supplementation for hypoxia, fluid therapy for dehydration, antipyretics for fever, and in some cases corticosteroids and humidified air [80]. While this treatment regimen is employed in all cases of severe pneumoniae, it especially plays a pivotal role in the treatment of viral pneumoniae, which is not treated by antibiotics and the role of antiviral medications is only limited [80]. Therefore, it is important to ensure that the child is constantly always monitored and is vitally stable. In case the child becomes unstable, it is crucial that the supportive therapy is stepped up to counteract the deteriorating condition of the child. Cough is a prominent symptom of lower respiratory tract infections, and cough suppressants are often used in the symptomatic management. However, these drugs are not always recommended, as cough is an important mechanism of airway clearance, and such medications might hamper this mechanism. Additionally, while these medications help in reducing cough, they have no overall effect on the health of patients and do not change the course of the disease [81].

Fluid therapy is essential in pneumonia as in any other severe infection to prevent morbidity and mortality, despite it being a relatively benign therapy [81]. While maintenance of adequate hydration is essential in dealing with disease, fluid disbalance has been proven to be significantly detrimental to the health of critically ill patients, being directly linked to longer hospital stays, longer duration of mechanical ventilation, and higher risk of mortality [82]. While the evidence is lacking, there are various studies which suggest that employing management plans which limit the need for administration of fluids is likely to result in lower risks of adverse outcomes [83]. Fluid overload is particularly a major problem in treating critically ill children and is associated with significant risk of mortality in children with more than 10% fluid overload [84]. A study suggests a possible clinically significant level of fluid overload of even below 10% in such patients [39]. There is an urgent need for revised guidelines for fluid administration in all cases of pediatrics, which consider the clinical assessment and hemodynamic status of children and address the malpractice of over-administering fluids [84].

Oxygen therapy plays a pivotal role in the management of pneumonia patients with hypoxemia and is associated with a ~ 20% decrease in mortality in these patients. However, affordability and sustainability significantly limit the provision of this facility in many areas across the globe. Respiratory distress and/or cyanosis are direct indications for oxygen supplementation even if there is difficulty in confirming hypoxemia or there is no hypoxemia [85]. Mechanical ventilation is an important aspect of oxygen therapy, and it is given to children with severe disease who are progressing to respiratory failure. It aids the child by preserving the airway and gas exchange and performing the work of breathing [86]. While it is universally used in patients with respiratory failure, there is a lack of proper guidelines and protocol on the usage of mechanical ventilation on the type of mechanical ventilation that is to be used [87]. This poses a problem which requires attention as it concerns severely ill patients, and more optimized strategies and protocol might result in a reduced mortality rate in these patients. Positive end expiratory pressure (PEEP) is a type of mechanical ventilation which, despite provide improvements in arterial oxygen saturation, has been associated with decrease cardiac output, oxygen delivery, and respiratory system compliance in children with respiratory distress [87]. This might cause deterioration of overall and long-term health in the patient. High-flow nasal cannula (HFNC) therapy has emerged as an effective oxygen delivery method in children with moderate to severe respiratory distress. Studies report reduced need for intubation and improved comfort in pediatric patients with CAP [88].

While corticosteroids are well known for their anti-inflammatory properties, their use is not indicated in the guidelines for treatment of pneumonia. They are classically used in the treatment of asthma [89]. However, numerous studies have been conducted regarding the use of steroids in pneumonia, with variable results. Medical professionals and experts have differing views on the use of steroids in cases of pneumonia, and the choice to implement this medication is solely based on the clinician's decision [90]. There have been reports of significant reduction in mortality in severely ill patients being treated in intensive care unit who had received hydrocortisone. One noteworthy conclusion from these reports is that steroids proved to be beneficial only in patients with a C-reactive protein (CRP) level of greater than 15 mg/dL [89]. CRP is a marker of inflammation and cases with raised CRP would be expected to improve with steroids administration. This finding suggests that steroids could potentially be indicated in patients with very severe pneumonia with high levels of CRP. The beneficial effects of steroids on mild/moderate cases of pneumonia remain a mystery for now, and further trials need to be conducted in order to draw a confident conclusion [90].

Prevention strategies

Vaccination

Consequently, pneumonia prevention in children forms an integral part of the National Immunization Strategy for the reduction of child mortality. Such may be best attained through immunization against Hib, pneumococcus, measles, and whooping cough or pertussis. Pneumococcal organisms are germs that often cause severe pneumonia, in addition to other conditions such as meningitis and blood stream infections. This pathogen has a vaccine, administered in a shot to infants and toddlers that prevents infection by the bacteria.

It helps to prevent pneumococcal disease and can also stop the spread of the disease from person to person [91].

Three doses are given in the first year, preferably at 6 weeks, 10 weeks, and 14 weeks of age, and the fourth dose is given at 15 months of age. In case it is not given at the ages mentioned above, it can be given later as well [91].

Updates on pneumococcal and influenza vaccines

PNEUMOCOCCAL:

The pneumococcal conjugate vaccine (PCV) is widely recommended by WHO for all children under 5 years and has been incorporated into national immunization programs in over 150 countries. CDC recommends routine pneumococcal vaccination for all children younger than 5 years old [91].

Administer a 4-dose PCV series, 1 dose at each of the following ages:

- 2 months
- 4 months
- 6 months
- 12 through 15 months

Catch-up guidance

Vaccinate children younger than 5 years of age who miss their shots or start the series later than recommended. Recommended number of doses and intervals between doses will depend upon the age the child begins vaccination. PCV13 (pneumococcal conjugate vaccine) is used primarily in young children, while PPSV23 (pneumococcal polysaccharide vaccine) may be indicated in children over 2 years with underlying health conditions [91].

INFLUENZA:

Annual vaccination against influenza is recommended for all persons aged ≥ 6 months who do not have contraindications. Children 6 months through 8 years who require 2 doses should receive the first dose as soon as vaccine is available. Vaccination during July and August can be considered for children of any age who require only 1 dos.

• Children 6 months through 8 years who have not previously received ≥ 2 total doses of trivalent or quadrivalent influenza vaccine ≥ 4 weeks apart from previous one, or whose influenza vaccination history is unknown, need 2 doses of influenza vaccine, given ≥ 4 weeks apart.

•For children aged 8 years who require 2 doses, the second dose should be given even if the child will turn age 9 years between dose 1 and dose 2.

•Persons aged ≥ 9 years require only one dose [91].

Respiratory Syncytial Virus (RSV):

Respiratory Syncytial Virus (RSV) is a major cause of severe respiratory illness in infants and young children. Recently approved RSV vaccines and long-acting monoclonal antibodies (e.g., nirsevimab) have demonstrated a significant reduction in RSV-related hospitalizations in neonates and infants and are now being implemented in high-risk populations [92].

Emerging vaccines and their efficacy

Although currently available vaccines can prevent most pneumonia deaths in children, additional research is needed to define the cause of the remaining cases of pneumonia and to develop vaccines against these pathogens. The next agent preventable by vaccination may be type H influenzae. A new pneumococcal conjugate vaccine that uses H influenzae protein-D as a conjugate protects against acute otitis media caused by H. influenzae [92] and is currently being evaluated for efficacy against both pneumococcal and H. influenzae pneumonia. Non-typeable H. influenzae is a pathogen for pneumonia in Asia [93]. Other pathogens against which vaccines are currently in development include respiratory syncytial virus [94], the most common viral pathogen identified in children with pneumonia and bronchiolitis, present in 25–35% of cases [95, 96] and parainfluenza virus type 3 [97].

Additionally, better vaccines against pulmonary tuberculosis would also contribute to prevention of the current pandemic of childhood pneumonia. Mycobacterium tuberculosis as a cause of pneumonia, is estimated to account for approximately 8% of HIV-infected and HIV non–infected children who are admitted with very severe pneumonia in sub-Saharan African countries [97].

Emerging evidence suggests that early-life exposure to environmental biodiversity — such as rural living, pet ownership, and natural microbiota — may enhance immune resilience and reduce the risk of respiratory infections, including pneumonia [97].

Public health measures, infection control and community health interventions

Exclusive breastfeeding for the first six months provides safe, clean, and nutritionally adequate food and protection from illness, potentially preventing nearly half of diarrhea cases and one-third of respiratory infections in developing countries. Continued breastfeeding with proper complementary feeding from 6 months to 2 years supports nutrition, immunity, and disease protection [97]. Immunizations such as Haemophilus influenzae type b, pneumococcal conjugate, measles, and pertussis vaccines significantly reduce ARI incidence and mortality. Reducing household air pollution, which nearly doubles ARI risk, through improved stoves and better indoor air quality can prevent severe ARIs. Preventing and treating HIV with antiretrovirals and co-trimoxazole prophylaxis helps reduce ARI risk and AIDS-related deaths [97, 98]. Prompt recognition and treatment of ARIs, including danger signs like fast or difficult breathing and cough, are essential. While antibiotics are effective and affordable for serious ARIs, WHO and UNICEF guidelines recommend them only for pneumonia or severe ARIs as diagnosed by health workers, acknowledging that not all such classifications indicate true ARI, especially where diagnostic tools are limited [98].

Challenges and controversies

The treatment of pneumonia in pediatric patients presents various challenges and controversies, despite the advances in management techniques. Lack of evidence, unanswered questions, ever-evolving degree of virulence, limitations in treatment modalities across different areas of the world, and diverging guidelines require action to be taken in the form of further clinical trials on larger scales, discussions, raising awareness, and drawing appropriate conclusions, while keeping in view the ever-growing literature [99].

Diagnostic challenges

While there are many different diagnostic methods that can be used to confirm the presence of pneumonia, there are still some challenges faced by clinicians to confirm the diagnosis, particularly in infants in which the signs of infection aren't as obvious as patients from the older population, and there is a communication barrier. While in adults' pneumonia may present with conspicuous signs such as fever, lethargy, myalgias, shortness of breath, fatigue, low energy, and cough, these symptoms are not necessarily present in infants which makes the detection of other signs of infection extremely important and missing these signs could result in misdiagnosis with catastrophic outcomes [06]. The most typical presentation is signs of respiratory distress. However, these signs tend to overlap with other different types of respiratory diseases, such as asthma, neonatal respiratory distress syndrome, transient tachypnea of newborn, persistent pulmonary hypertension, meconium aspiration syndrome, and congenital heart diseases [100]. Careful evaluation becomes necessary to exclude these causes and arrive at a definitive diagnosis of pneumonia. Radiological investigations are also an important part of diagnostic workup; however, the interpretation of the diagnostic images can vary between clinicians, and they are not always definitive. It is also important to distinguish between viral and bacterial causes of pneumonia, as treatment varies greatly between these two conditions, the former requiring aggressive use of antibiotics while the latter demanding a more supportive method of management. However, due to the overlapping signs and symptoms, the diagnosis might become difficult if the highly specific tests of bacterial cultures and viral PCR have not been performed [101].

Several clinical decision tools, such as the FeverKids algorithm, assist in distinguishing bacterial from viral infections in children under 5. These models integrate clinical signs with biomarkers (e.g., CRP, PCT) and have demonstrated improved diagnostic accuracy and reduced antibiotic overuse [102].

Antibiotic resistance

As mentioned before, antibiotics are the mainstay of treatment of bacterial pneumonia. The growing antibiotic resistance is an alarming challenge to treatment of any infection. The main reason for the development of resistance is the overuse of antibiotics (particularly due to their ease of accessibility over the counter and online) and high percentage of incorrect prescription [103]. Antibiotics are associated with the filtering of drug sensitive pathogens, leaving behind only the resistant strains, thereby contributing to dissemination of antibiotic resistance within a community. Broad spectrum antibiotics are a type of antibiotics that cover a wide variety of microorganisms, including gram negative, gram positive, and anaerobic bacteria, due to their ability to penetrate the bacterial lines of defense [104]. As such, these drugs tend to often be misused in clinical settings and overprescribed for many different infections without proper culture sensitivity testing, which contributes greatly to the development of resistance [105]. Increased level of resistance leads to the usage of drugs which have significantly higher clinical side effects and places a heavy burden on the patient [103]. Antibiotic resistance is a global crisis and attention needs to be directed towards the management of this issue. One possible method is to synthesize new antibiotics which are highly sensitive and counteract the problem of antibiotic resistance, however the emergence of such new drugs in the market is not at a pace as rapid as the spread of resistance. Therefore, prevention strategies are best suited to tackle the problem, including taking the antibiotics only on prescription and as prescribed, using the antibiotics rationally, not taking antibiotics prescribed for another individual, ensuring hygiene, preventing infection, performing surveillance of antibiotic resistance, raising awareness etc. [106].

Vaccine implementation

Despite their proven efficacy, vaccines continue to face public skepticism in some regions, often fueled by misinformation and lack of awareness. As described above, vaccines play a pivotal role in prevention of many illnesses, particularly the viral agents which are linked to development of respiratory illnesses. Research conducted by world health organization (WHO) demonstrated a reduction of mortality by up to 75% after the implementation of COVID-19 vaccination program, during the period of Omicron variant [107]. Unfortunately, despite their proven benefit, vaccines are often viewed as negative health influences by many people due to the surrounding influences, which has led to reduced rates of vaccinations [108]. Vaccine literacy is also a major issue in some of the underdeveloped parts of the world and play a big role in vaccine hesitancy in such areas [109]. The key to eradication of these problems is raising awareness and promoting science-based knowledge with facts and evidence about the benefits of vaccines [110].

There are challenges to provision of vaccines in low-to-middle-income countries (LMCs) which significantly limit the rates of immunizations in these countries. These challenges include financial crises, reduced awareness, improper management, poor infrastructure, and lack of regional policy on the subject [110]. Ongoing efforts to implement universal vaccination programs in many countries remain hindered by armed conflict and political instability. As a result, there are significantly high mortalities due to vaccine preventable infections in such areas. According to a report, in 2018 almost 70,000 children died of vaccine preventable diseases worldwide, and over 99% of them were from low to middle income areas [111].

Healthcare disparities

The above paragraph shed some light on the disparities in vaccinations between high income, and low-to-middle-income countries. Such discrepancies are not only limited to the immunizations, but rather to the entire healthcare system overall. The LMCs face shortages primarily in advanced medical equipment, such as mechanical ventilators, radiological machines, and incubators etc. [112]. The high cost of advanced procedures and lack of affordability of these facilities is a cause of frustration for the general population [113]. Hospitals might face a shortage of medications, supplemental oxygen, and other basic needs of the patients. In addition to shortage of equipment, the standard of care may not be up to the level of developed countries, including improper nursing care, poor sterilization techniques and lack of hygiene [114]. These factors could contribute to an increased risk of development of nosocomial infections, which are a major cause of health deterioration and negative outcomes for children admitted into a hospital. Lack of medical professionals and overburdening due to high flow of patients are also common drawbacks in these areas, which promote malpractices and inadequacy in provision of care. Therefore, healthcare disparities play a major role in poor outcomes in LMCs as compared to high income countries [115].

Future directions

Pneumonia remains a significant health challenge in pediatric populations, with ongoing research refining its management and treatment. Recent studies on PubMed provide insights into research priorities, emerging therapies, and policy implications. This review highlights key findings and future directions based on the latest research.

Recent studies highlight urgent research priorities in pediatric pneumonia, including optimizing antibiotic use, addressing resistance, and developing pathogen-specific therapies. Khan et al. emphasized rising antibiotic resistance and the need for alternative strategies [116], while Lassi et al. called for targeted therapies to reduce broad-spectrum antibiotic use [117]. When selecting empirical antibiotics, factors such as severity, patient characteristics, and local resistance patterns should be considered [118]. Advances in respiratory microbiota and transcriptional signatures offer promise for distinguishing bacterial from viral infections [119]. However, gaps remain in understanding genetic susceptibility [120], long-term outcomes of early lower respiratory infections, and the cost-effectiveness of POC diagnostics like ultrasound and PCR [121]. Emerging therapies such as corticosteroids [122] and palivizumab prophylaxis [123] show potential in specific cases. Policy implications include updating guidelines to reflect emerging evidence, ensuring surveillance of CAP pathogens and resistance [124], and promoting access to new vaccines, antibiotics, and oxygen therapy—particularly in low-resource settings [125]. Additional strategies include improving nutrition, reducing air pollution, promoting hygiene, and enhancing public awareness. The Forum of International Respiratory Societies (FIRS) recommends strengthening health systems, expanding access to diagnostics and treatment, and investing in pneumonia prevention and research to reduce the global burden of disease [126].

Limitations

This review offers a broad summary of recent developments in pediatric pneumonia care, but a few limitations should be noted. Since it is a narrative review and not a systematic one, there is a possibility of selection bias in the studies we chose to include. Although we aimed to incorporate the most relevant and current literature, some important studies, especially those specific to certain regions, may have been missed. Additionally, while we discussed a wide range of diagnostic methods and treatment approaches, we did not explore their cost-effectiveness or practical application in low-resource settings in depth. Some of the tools and strategies mentioned may not be equally accessible or applicable in all healthcare systems. Lastly, although we touched on policy recommendations, detailed economic or implementation strategies were beyond the scope of this paper and should be addressed in future research.

Conclusion

Pneumonia remains a major cause of illness and death among children, especially in low- and middle-income countries. While progress has been made in diagnosis, treatment, and prevention—such as the use of newer vaccines and improved antibiotics—challenges like limited access to healthcare, antibiotic resistance, and the need for affordable diagnostic tools persist. Continued research, better implementation of current guidelines, and stronger public health efforts are essential to reduce the global burden of pediatric pneumonia.

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