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Antibiotic Prescribing Practices and Antimicrobial Resistance in Pediatric Pneumonia

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ABSTRACT

Background: Antimicrobial resistance (AMR) among pediatric pneumonia patients presents a significant challenge, particularly in low- and middle-income countries such as Pakistan, where empirical antibiotic use is prevalent and stewardship interventions remain limited. Comprehensive knowledge of local prescribing practices, resistance patterns, and treatment outcomes is essential for effective stewardship and enhanced patient care.

Objective: To determine the prevalence and antimicrobial susceptibility patterns of bacterial pathogens isolated from pediatric pneumonia patients and to evaluate antibiotic prescribing practices in a tertiary care hospital.

Methodology: This prospective observational study enrolled 423 pediatric patients diagnosed with pneumonia. Data collection included antibiotic prescribing patterns, specimen microbiology, antimicrobial susceptibility, and clinical outcomes. Respiratory specimens underwent bacterial identification and susceptibility testing. Associations among prescribing practices, resistance, and clinical outcomes were analyzed.

Results: Nearly all patients (98.3%) received antibiotics, with 59.8% receiving combination therapy and 87.3% treated intravenously. Clinically significant bacteria were isolated from 41.9% of processed specimens. Among these isolates, 68.3% demonstrated resistance to at least one antibiotic, and 34.5% were classified as multidrug-resistant. Streptococcus pneumoniae was the most frequently identified pathogen, exhibiting substantial resistance to ampicillin-cloxacillin and penicillin. Inappropriate initial empirical therapy was observed in 57.2% of culture-positive cases and was associated with increased antibiotic switching and prolonged hospital stays.

Conclusion: This pediatric pneumonia cohort showed antibiotic resistance. Improved antimicrobial stewardship, guided by local surveillance data, is urgently required to optimize therapy, mitigate resistance, and improve patient outcomes.

Keywords: Antimicrobial Resistance; Pediatric Pneumonia; AMR; Pakistan

Introduction

Pneumonia remains a leading cause of morbidity and mortality among children globally, particularly in low- and middle-income countries. Although advances in vaccination, nutrition, and healthcare access have been made, pneumonia still imposes a significant burden on pediatric health services. The World Health Organization (WHO) estimates that pneumonia and diarrhoeal diseases together account for nearly a quarter of deaths among children under five, highlighting the persistent need for timely diagnosis and effective treatment. Pneumonia often presents with non-specific symptoms, and distinguishing bacterial from non-bacterial etiologies based solely on clinical findings is challenging, particularly in hospitalized children. This diagnostic uncertainty complicates clinical management and may contribute to inappropriate antibiotic use.[1,2]

Antibiotics are essential for treating suspected or confirmed bacterial pneumonia in children; however, their effectiveness depends on appropriate selection, dosing, and duration. WHO guidelines emphasize rational, severity-based treatment and underscore the importance of antimicrobial stewardship and diagnostic support.[1,3] Inappropriate use, including unnecessary broad-spectrum therapy, empirical regimens without microbiological confirmation, and prolonged courses, contributes to antimicrobial resistance (AMR). AMR threatens the efficacy of standard treatments and increases treatment failure, prolongs hospital stays, and raises healthcare costs.[4,5] The global burden of bacterial AMR is substantial, with an estimated 4.95 million deaths associated with resistance in 2019, and lower respiratory tract infections accounting for the largest proportion of this burden.[4] Key pathogens, including Escherichia coli, Staphylococcus aureus, Klebsiella pneumoniae, Streptococcus pneumoniae, Acinetobacter baumannii, and Pseudomonas aeruginosa, are frequently implicated in both severe pediatric pneumonia and AMR-related mortality.

In Pakistan, this issue is particularly severe. Studies have documented high rates of antibiotic use among hospitalized children with respiratory tract infections. For instance, a multicenter study from Punjab reported that ceftriaxone-based regimens were among the most frequently prescribed, with many children receiving inappropriate dosing or administration routes.[6] Point-prevalence surveys indicate that over 90% of hospitalized pediatric patients are prescribed at least one antibiotic, often empirically and without supporting microbiological evidence.[7,8] These prescribing patterns underscore the urgent need for local data to inform evidence-based prescribing and stewardship initiatives.

Empirical antibiotic treatment is often necessary in severely ill children, as delays in therapy may be life-threatening. However, stewardship principles require reviewing and adjusting empirical therapy once microbiological data become available to minimize unnecessary exposure to broad-spectrum agents.[9,10] Local microbiological surveillance is essential, as resistance patterns can vary significantly between regions, hospitals, and patient populations. Recent surveillance in Pakistan has documented substantial resistance among key respiratory pathogens, including S. pneumoniae and H. influenzae, and systematic reviews indicate a growing AMR burden in the country's pediatric population.[1]

To address these challenges, the present study evaluated children with pneumonia. Unlike studies that infer resistance solely from clinical outcomes, this investigation incorporated laboratory-confirmed microbiological culture and antimicrobial susceptibility testing to provide a robust assessment of resistance patterns. Additionally, antibiotic prescribing practices, empirical treatment choices, antibiotic switching, clinical response, and the relationship between initial therapy and susceptibility findings were evaluated. The objective is to generate institution-specific evidence to support rational antibiotic prescribing, enhance antimicrobial stewardship, and improve empirical treatment strategies for pediatric pneumonia.

Objective

To determine the prevalence and antimicrobial susceptibility patterns of bacterial pathogens isolated from pediatric pneumonia patients and to evaluate antibiotic prescribing practices in a tertiary care hospital.

Methodology

A prospective observational study was conducted over 20 months, from January 2024 to August 2025, in the Department of Pediatrics at Aziz Fatima Hospital, Faisalabad. Clinical assessment, diagnosis, treatment, and follow-up of eligible patients occurred within the pediatric department. Clinical specimens collected from enrolled patients were transported to the University Laboratory at the University of Faisalabad for microbiological processing, bacterial identification, and antimicrobial susceptibility testing.

The minimum required sample size was calculated using the single-population proportion formula with a 95% confidence level (1.96), an anticipated prevalence of antimicrobial resistance of 50%, and a desired absolute precision of 5%. The resulting minimum sample size was 384 patients. To account for an estimated 10% loss due to inadequate or unusable clinical specimens, incomplete laboratory results, or incomplete clinical records, the sample size was increased to 423 patients. Thus, a total of 423 pediatric pneumonia patients were targeted for enrollment.

Children were eligible for inclusion if they were diagnosis

of pneumonia, had an appropriate specimen available for microbiological testing, could be monitored for antibiotic treatment and clinical outcomes, and had written informed consent provided by a parent or guardian. Exclusion criteria included incomplete records, inadequate or contaminated specimens, receipt of antibiotics for another infection indistinguishable from pneumonia treatment, subsequent establishment of a non-infectious respiratory diagnosis, or refusal of consent.

Upon enrollment, demographic and clinical data, including age, sex, presenting symptoms, clinical signs, comorbidities, prior antibiotic exposure, and illness severity were recorded, as well as the need for hospitalization as determined by the pediatric team. Details of antibiotic treatment, such as drug names, class, dose, route, frequency, duration, combination therapy, and regimen modifications, were extracted from prescription charts and medication records. Additional variables, including length of hospital stay, clinical response, escalation or de-escalation of therapy, and treatment outcomes, were documented. Prescribing practices were evaluated using adapted WHO/INRUD indicators, with emphasis on the proportion of patients receiving antibiotics, the average number and classes of antibiotics per patient, use of combination therapy, administration routes, and the frequency of switching or escalation to broader-spectrum agents. Where available, these prescribing patterns were further analyzed in relation to microbiological results and patient outcomes.

Respiratory specimens, including sputum and endotracheal aspirate, were prospectively collected from all cases. Specimens were labeled with patient and collection details and promptly transported to the study laboratory. The timing of specimen collection in relation to prior antibiotic exposure was documented. Standard microbiological techniques, including both routine and automated identification using VITEK, were employed to assess specimens for clinically significant bacterial growth. Only pathogens deemed relevant based on laboratory criteria and clinical context were included in the antimicrobial susceptibility analysis. Contaminants and non-significant colonizers were excluded. Patients without significant bacterial recovery were classified as microbiologically negative and included in overall prescribing analyses, but excluded from organism-specific susceptibility results.

Antimicrobial susceptibility testing (AST) was performed on clinically significant bacterial isolates using either the Kirby–Bauer disk diffusion method or the VITEK automated system, selected according to the organism and laboratory workflow. For the Kirby–Bauer method, standardized bacterial inoculum were applied to testing media containing appropriate antibiotic disks, incubated, and zones of inhibition measured according to Clinical and Laboratory Standards Institute (CLSI) criteria. The VITEK system was operated following manufacturer protocols, with results interpreted using current CLSI breakpoints. Antibiotic panels were selected based on the organism and laboratory availability, and results were categorized as susceptible, intermediate, or resistant. Quality control procedures utilized appropriate reference strains throughout testing.

Antimicrobial resistance was determined through laboratory-confirmed susceptibility testing, with resistance classified according to Clinical and Laboratory Standards Institute (CLSI) criteria for each antimicrobial agent. The prevalence of resistance was calculated for each pathogen and antibiotic, with overall rates representing the proportion of significant isolates resistant to at least one tested agent. Resistance patterns specific to each organism were reported separately, and multidrug resistance was evaluated using established definitions when sufficient data were available. Antibiotic switching and clinical non-response were documented as treatment variables but were not considered evidence of resistance unless confirmed by susceptibility testing. Changes in antibiotic therapy, including the reasons for switching such as microbiological findings, non-response, adverse reactions, or clinical judgment, were prospectively recorded. Clinical response was evaluated based on improvements in fever, respiratory symptoms, oxygen requirements, and general condition. Antibiotic switching was analyzed as a treatment variable and was only considered indicative of resistance when supported by laboratory data.

All data were entered and analyzed using SPSS version 25. Continuous variables were summarized as means with standard deviations or medians with interquartile ranges, whereas categorical variables were reported as frequencies and percentages. The prevalence of antimicrobial resistance was determined as the proportion of relevant isolates or patients exhibiting resistance, and susceptibility results were summarized by pathogen and antimicrobial agent. Prescribing patterns were described using frequencies, percentages, and either means or medians. Differences between groups were assessed using the chi-square test or Fisher's exact test for categorical variables, and the t-test or Mann–Whitney U test for continuous variables. For comparisons involving multiple groups, analysis of variance (ANOVA) or the Kruskal–Wallis test was applied. Regression analyses were conducted to examine associations between patient characteristics, prescribing patterns, and resistance, with results presented as effect estimates and 95% confidence intervals. Statistical significance was defined as $p<0.05$.

Ethical approval (IEC/106-23/2024) was obtained from the relevant institutional ethical review committee before commencement of the study. The study was conducted in accordance with the principles of the Declaration of Helsinki and applicable institutional requirements.

Results

A total of 423 pediatric patients diagnosed with pneumonia were enrolled prospectively in this study. The mean age of participants was 14.2 ± 11.8 months (median: 9 months; IQR: 4–24 months), with ages ranging from 1 month to 12 years. Among study cases, 247 (58.4%) were Male, yielding a male-to-female ratio of 1.4:1 (Figure 1).

The highest proportion of cases (42.3%) was observed in infants aged 1–6 months, followed by children aged 7–12 months which was 24.1%. Participants faced different symptoms with Fever was the most frequently reported symptom (89.6%), followed by cough (86.8%), the least 133 (31.4%) experienced wheezing. A history of previous antibiotic exposure within the preceding two weeks was documented in 121 (28.6%) cases. Comorbid conditions were present in 67 (15.8%) of cases, with malnutrition being the most common found in 35 (8.3%). The mean duration of hospitalization was 5.4 ± 2.8 days (median: 5 days; IQR: 3–7 days) (Table 1).

A total of 98.3% of patients received at least one antibiotic, with an average of 2.7 antibiotics administered per patient. Combination therapy was observed in 59.8% of cases, most frequently involving two antibiotics, whereas monotherapy was utilized in 38.5% of cases. Penicillins represented the most commonly prescribed antibiotic class. Intravenous administration accounted for 87.3% of cases, and the most frequently initiated regimen was ampicillin-cloxacillin. The average duration of antibiotic therapy was 6.8 days (Table 2).

Respiratory specimens were obtained from 423 patients, with 68.3% comprising sputum samples and 31.7% endotracheal aspirates. Of these specimens, 81.8% were processed successfully, and 41.9% demonstrated clinically significant bacterial growth. Streptococcus pneumoniae represented the most common isolate (34.5%), while 41.7% of Staphylococcus aureus isolates were identified as methicillin-resistant Staphylococcus aureus (MRSA). Extended-spectrum beta-lactamase (ESBL) production was observed in 38.5% of Klebsiella pneumoniae and Escherichia coli isolates. Further details are presented in Table 3. Among the 145 clinically significant bacterial isolates, Streptococcus pneumoniae was the most prevalent pathogen, accounting for 50 isolates (34.5%). Other Gram-negative organisms, including Acinetobacter species and Enterobacter species, constituted 3.4% (n = 5) of isolates. Among Staphylococcus aureus isolates, 41.7% (n = 15) were MRSA, while 58.3% (n = 21) were methicillin-sensitive Staphylococcus aureus (MSSA). Among Gram-negative isolates, ESBL production was detected in 38.5% (n = 15) of Klebsiella pneumoniae and Escherichia coli isolates (Table 3).

Antimicrobial susceptibility testing was performed on all 145 clinically significant bacterial isolates. Overall, antimicrobial resistance was observed in 99 (68.3%) of isolates, with resistance to at least one tested antimicrobial agent. The prevalence of multidrug resistance, defined as resistance to antimicrobial agents belonging to three or more antimicrobial classes, was observed in 50 (34.5%) of isolates. Among Gram-positive isolates,

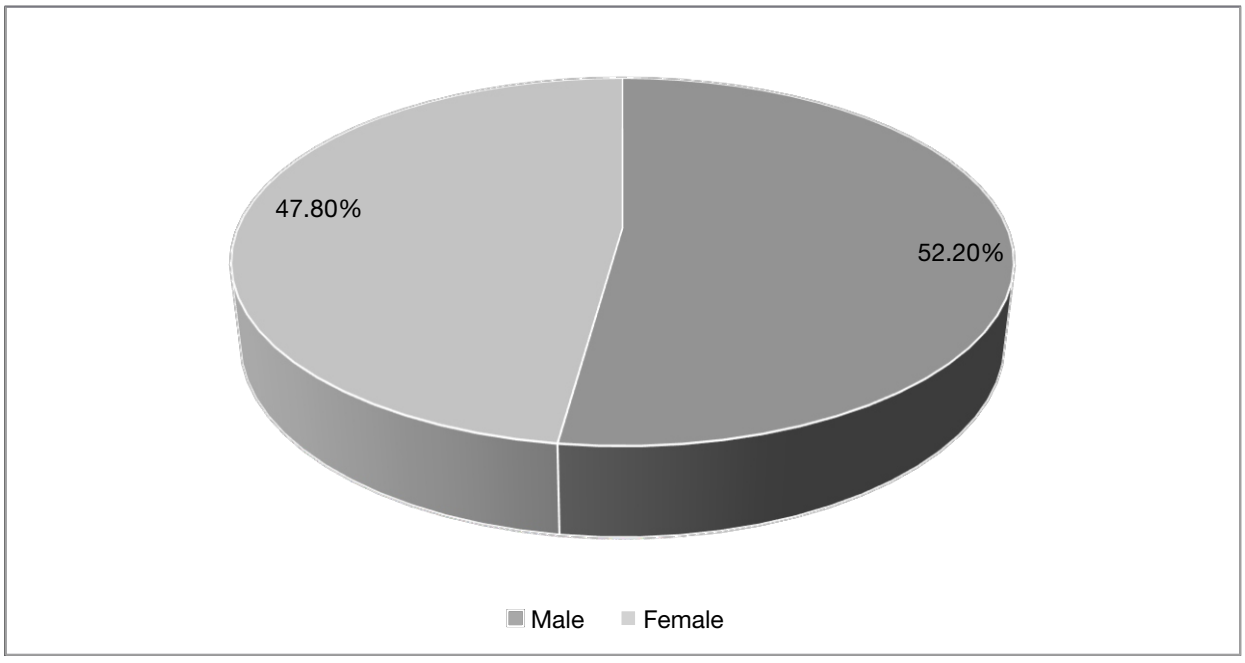

Figure 1. Gender base distribution of study cases

Table 1. Demographic and Clinical Characteristics of Pediatric Pneumonia Patients

Characteristic	Category	n (%)/Mean ± SD
Age (months)	Mean ± SD	14.2 ± 11.8
	Median (IQR)	9 (4–24)
	Range	1–144
Age groups	1–6 months	179 (42.3)
	7–12 months	102 (24.1)
	1–6 years	92 (21.7)
	7–12 years	50 (11.9)
Presenting symptoms	Fever	379 (89.6)
	Cough	367 (86.8)
	Difficulty in breathing	306 (72.3)
	Chest indrawing	206 (48.7)
	Wheezing	133 (31.4)
Previous antibiotic exposure	Yes	121 (28.6)
	No	302 (71.4)
Comorbid conditions	Any	67 (15.8)
	Malnutrition	35 (8.3)
	Congenital heart disease	15 (3.5)
	Chronic respiratory conditions	9 (2.1)
Hospital stays (days)	Mean ± SD	5.4 ± 2.8
	Median (IQR)	5 (3–7)

Streptococcus pneumoniae demonstrated the highest susceptibility to vancomycin 48 (96.0%), while resistance was most frequently observed against penicillin 21 (42.0%). All MRSA isolates were susceptible to vancomycin and linezolid, while 11 (73.3%) demonstrated resistance to cefoxitin and other beta-lactam agents. Among Gram-negative isolates, Haemophilus influenzae showed highest susceptibility to ceftriaxone 19 (90.5%), with resistance observed against ampicillin-cloxacillin 9 (42.9%) and clarithromycin 6 (28.6%) (Table 4).

Antibiotic switching was observed in 47.3% of patients, primarily due to clinical non-response (68.5%). Among patients initially treated with ampicillin-cloxacillin alone, 62.3% required a switch, most frequently to third-generation cephalosporins. In contrast, combination therapy with ampicillin-cloxacillin and cefotaxime was associated with a lower switching rate (34.6%). Clinical improvement occurred in 78.8% of patients, with a mean time to improvement of 3.2 days. However, 21.2% required escalation to broader-spectrum antibiotics.

Treatment failure occurred in 14.2% of cases, and overall mortality was 2.8%, exclusively among patients with confirmed bacterial infections (Table 5).

Initial empirical antibiotic therapy was appropriate in 42.8% of patients, whereas 57.2% received inappropriate therapy. Patients who received inappropriate therapy experienced longer hospital stays (6.8 ± 3.1 days compared to 4.2 ± 1.8 days, $p < 0.001$) and required more frequent antibiotic switching (73.5% versus 26.5%). For Streptococcus pneumoniae, ampicillin-cloxacillin was the most frequently prescribed antibiotic, but only 52.0% of isolates were susceptible. In contrast, ceftriaxone and linezolid demonstrated higher susceptibility rates (88.0% and 94.0%, respectively). For Staphylococcus aureus, susceptibility to ampicillin-cloxacillin was 36.1%. Among Gram-negative isolates, third-generation cephalosporins were commonly administered, with susceptibility rates of 68.8% for Klebsiella pneumoniae and 70.0% for Escherichia coli (Table 6).

Bivariate analysis identified antibiotic exposure within the preceding two weeks, malnutrition, hospitalization within the past three months, and age younger than 6 months as factors significantly associated with antimicrobial resistance. Resistance was observed in 82.9% of patients with prior antibiotic exposure, 86.7% of malnourished patients, 84.6% of those previously hospitalized, and 77.1% of infants younger than 6 months.

Resistance was observed in 82.9% of patients with

Table 2. Antibiotic Prescribing Patterns in Pediatric Pneumonia Patients (N = 423)

Prescribing Variable	Category	n (%)/Mean ± SD
Patients receiving antibiotics	Yes	416 (98.3)
	No	7 (1.7)
Total antibiotic prescriptions		1,142
Antibiotics per patient	Mean ± SD	2.7 ± 1.2
	Median (IQR)	3 (2–3)
Therapy type	Monotherapy	163 (38.5)
	Combination therapy	253 (59.8)
	Not receiving antibiotics	7 (1.7)
Number of antibiotics in combination	Two antibiotics	179 (42.3)
	Three antibiotics	60 (14.2)
	Four or more antibiotics	14 (3.3)
Antibiotic class	Penicillins	493 (43.2)
	Third-generation cephalosporins	327 (28.6)
	Glycopeptides	130 (11.4)
	Oxazolidinones	116 (10.2)
	Aminoglycosides	66 (5.8)
	Macrolides	49 (4.3)
	Carbapenems	37 (3.2)

Most prescribed individual antibiotics	Ampicillin-cloxacillin	375 (32.8)
	Cefotaxime	187 (16.4)
	Ceftazidime	99 (8.7)
	Vancomycin	130 (11.4)
	Linezolid	116 (10.2)
	Ceftriaxone	40 (3.5)
	Amikacin	66 (5.8)
	Meropenem	37 (3.2)
	Clarithromycin/Azithromycin	49 (4.3)
Initial empirical regimens	Ampicillin-cloxacillin alone	138 (32.6)
	Ampicillin-cloxacillin + cefotaxime	78 (18.4)
	Ampicillin-cloxacillin + ceftazidime	53 (12.5)
	Cefotaxime alone	44 (10.4)
	Ceftriaxone alone	22 (5.2)
	Ampicillin-cloxacillin + ceftriaxone	20 (4.7)
	Vancomycin-containing regimens	13 (3.1)
	Other regimens	55 (13.0)
Route of administration	Intravenous	997 (87.3)
	Oral	145 (12.7)
Duration of antibiotic therapy (days)	Mean ± SD	6.8 ± 2.4
	Median (IQR)	7 (5–9)
Duration of IV therapy (days)	Mean ± SD	5.2 ± 1.9
Duration of oral therapy (days)	Mean ± SD	3.6 ± 1.4
Polypharmacy (≥5 medications)	Yes	133 (31.4)

previous antibiotic exposure compared with 49.2% of those without such exposure (COR: 5.01, 95% CI: 2.34–10.73; $p < 0.001$). Malnutrition was also significantly associated with resistance, with resistant isolates identified in 86.7% of malnourished patients compared with 65.4% of patients without malnutrition (crude OR: 3.46, 95% CI: 1.11–10.78; $p = 0.032$). Similarly, previous hospitalization within three months was associated with a higher frequency of resistance (84.6% vs 64.4%; COR: 3.04, 95% CI: 1.06–8.72; $p = 0.038$).

In the multivariable logistic regression analysis, previous antibiotic exposure and age younger than 6 months

Table 3. Distribution of Bacterial Isolates from Pediatric Pneumonia Patients (n = 145)

Bacterial Pathogen	n (%)
Streptococcus pneumoniae	50 (34.5)
Staphylococcus aureus	36 (24.8)
MRSA	15 (41.7)
MSSA	21 (58.3)
Haemophilus influenzae	21 (14.5)
Klebsiella pneumoniae	16 (11.0)
Escherichia coli	10 (6.9)
Pseudomonas aeruginosa	7 (4.8)
Other Gram-negative organisms*	5 (3.4)
Total	145 (100.0)

*Includes Acinetobacter species and Enterobacter species. MRSA = methicillin-resistant Staphylococcus aureus; MSSA = methicillin-sensitive Staphylococcus aureus. ESBL production was detected in 38.5% (n = 15) of Klebsiella pneumoniae and Escherichia coli isolates.

remained independently associated with antimicrobial resistance. Previous antibiotic exposure was linked to more than fourfold higher adjusted odds of resistance (AOR: 4.21, 95% CI: 1.89–9.38; $p < 0.001$), and children under 6 months had approximately twice the adjusted odds of resistance compared to older children (AOR: 2.18, 95% CI: 1.01–4.71; $p = 0.047$). After adjustment, malnutrition, previous hospitalization, and comorbid conditions were no longer statistically significant predictors (Table 7).

The assessment of antibiotic prescribing practices, based on adapted WHO/INRUD core indicators, showed that the average number of drugs prescribed per encounter was 6.4, exceeding the WHO recommendation of 1.6–1.8. The average number of antibiotics per patient was 2.7, also higher than the standard. Only 18.7% of drugs were prescribed by generic name, and injectable drugs were prescribed in 87.3% of cases, both substantially deviating from WHO recommendations. Additionally, 98.3% of patients received at least one antibiotic, while combination antibiotic therapy accounted for 59.8% of prescriptions. Most drugs (91.2%) were from the Essential Drug List (Table 8).

Clinical outcomes for the study population were evaluated at discharge or upon completion of therapy. Of the patients, 333 (78.8%) achieved complete recovery without complications and were discharged in stable condition. Clinical improvement with residual symptoms was noted in 66 patients (15.6%), whereas 12 patients (2.8%) died during hospitalization.

Discussion

The present study involving 423 pediatric pneumonia patients, antibiotic exposure was nearly 98.3%, and combination therapy was common (59.8%). Clinically significant bacteria were isolated from 41.9% of processed specimens, with 68.3% of these isolates demonstrating resistance to at least one antibiotic. Inappropriate initial empirical therapy was observed in over half of confirmed infections, resulting in more frequent antibiotic switching and extended hospital stays. Infants constituted 42.3% of the cohort, and two-thirds were under 1 year of age, underscoring their increased vulnerability. Fever, cough, and respiratory distress were the most prevalent clinical features.

The predominance of infants in this study is clinically significant. Children aged 1 to 6 months accounted for 42.3% of the cohort, and nearly two-thirds of participants were younger than 1 year. This age distribution aligns with the established vulnerability of young children to severe respiratory infections due to immature immune responses, smaller airways, and increased susceptibility to complications. The frequent occurrence of fever,

Table 4. Antimicrobial Susceptibility Patterns of Bacterial Isolates (n = 145)

Bacterial Isolate	Antimicrobial Agent	Susceptible n (%)	Resistant n (%)
Streptococcus pneumoniae (n = 50)	Vancomycin	48 (96.0)	2 (4.0)
	Linezolid	47 (94.0)	3 (6.0)
	Ceftriaxone	44 (88.0)	6 (12.0)
	Penicillin	29 (58.0)	21 (42.0)
	Amoxicillin-clavulanic acid	32 (64.0)	18 (36.0)
	Ampicillin-cloxacillin	26 (52.0)	24 (48.0)
Staphylococcus aureus (n = 36)	Vancomycin	36 (100.0)	0 (0.0)
	Linezolid	36 (100.0)	0 (0.0)
	Amikacin	31 (86.1)	5 (13.9)
	Ampicillin-cloxacillin	13 (36.1)	23 (63.9)
	Cefotaxime	19 (52.8)	17 (47.2)
	Ceftriaxone	21 (58.3)	15 (41.7)
Haemophilus influenzae (n = 21)	Ceftriaxone	19 (90.5)	2 (9.5)
	Cefotaxime	18 (85.7)	3 (14.3)
	Amoxicillin-clavulanic acid	16 (76.2)	5 (23.8)
	Ampicillin-cloxacillin	12 (57.1)	9 (42.9)
	Clarithromycin	15 (71.4)	6 (28.6)
Klebsiella pneumoniae (n = 16)	Meropenem	14 (87.5)	2 (12.5)
	Amikacin	13 (81.3)	3 (18.8)
	Ceftazidime	11 (68.8)	5 (31.3)
	Ampicillin-cloxacillin	3 (18.8)	13 (81.3)
	Cefotaxime	7 (43.8)	9 (56.3)
	Ceftriaxone	8 (50.0)	8 (50.0)

Escherichia coli (n = 10)	Meropenem	9 (90.0)	1 (10.0)
	Amikacin	8 (80.0)	2 (20.0)
	Ceftazidime	7 (70.0)	3 (30.0)
	Ampicillin-cloxacillin	2 (20.0)	8 (80.0)
	Cefotaxime	4 (40.0)	6 (60.0)
Pseudomonas aeruginosa (n = 7)	Meropenem	6 (85.7)	1 (14.3)
	Amikacin	5 (71.4)	2 (28.6)
	Ceftazidime	4 (57.1)	3 (42.9)
	Ampicillin-cloxacillin	0 (0.0)	7 (100.0)
	Cefotaxime	1 (14.3)	6 (85.7)
	Ceftriaxone	2 (28.6)	5 (71.4)

cough, respiratory difficulty, and chest indrawing further demonstrates the considerable clinical burden of pneumonia in this population.

Previous antibiotic exposure was documented in 28.6% of patients. This observation is significant for interpreting subsequent resistance patterns, as antibiotic exposure exerts selective pressure that favors resistant organisms. While the present study does not establish causality based solely on prior exposure, the observed association is biologically plausible and aligns with existing literature that links previous antimicrobial exposure to resistant bacterial infection.[4,12] Malnutrition was identified in 8.3% of children, which is clinically significant. Malnutrition impairs host defenses and increases susceptibility to infectious diseases, potentially complicating recovery from pneumonia. The coexistence of malnutrition and antimicrobial resistance presents a substantial clinical challenge for pediatric populations in resource-limited settings.

Antibiotics were prescribed to 98.3% of children in this study, with an average of 2.7 antibiotics per patient. Combination therapy was documented in 59.8% of patients. These findings indicate substantial antimicrobial exposure and align with the high rates of antibiotic utilization previously reported in Pakistani pediatric hospitals. Mustafa et al., in a multicenter study of hospitalized children with lower respiratory tract infections in Punjab, identified extensive antibiotic use and frequent administration of ceftriaxone-containing regimens. They also reported significant issues with antibiotic dosing and administration routes.[6] Similarly, Arif et al. found that 94.6% of hospitalized children in their repeated point-prevalence survey received at least one antibiotic.[7] Another study also suggested the same findings.[8] The 98.3% antibiotic-use rate observed in the present pneumonia-specific cohort is therefore consistent with the high levels of antibiotic exposure previously documented among hospitalized Pakistani children. The high frequency of combination therapy warrants further consideration. Combination treatment may be appropriate in cases of severe pneumonia, suspected polymicrobial infection, or when coverage of resistant Gram-positive and Gram-negative organisms is clinically indicated. However, routine use of multiple antibiotics increases antimicrobial exposure and may elevate selection pressure without necessarily improving clinical outcomes. International pediatric stewardship guidelines recommend regular review of empirical regimens and advocate for narrowing or discontinuing therapy when supported by clinical and microbiological evidence.[9,10]

This study identified that 87.3% of antibiotic prescriptions were administered intravenously, with substantial reliance on broad- and reserve-spectrum agents, including cefotaxime, ceftazidime, vancomycin, linezolid, and meropenem. Similarly high rates of parenteral and broad-spectrum antibiotic use have been documented in other Pakistani pediatric hospitals, where 85.6%–92.3% of antibiotics are administered parenterally and ceftriaxone or vancomycin are frequently prescribed.[8,13] The high rate of intravenous administration in this cohort likely reflects a population comprising infants or critically ill children, as indicated by 31.7% of specimens obtained as endotracheal aspirates. These findings also underscore the need to evaluate opportunities for transitioning to oral therapy.

Table 5. Antibiotic Switching and Clinical Response in Pediatric Pneumonia Patients

Variable	Category	n (%)/Mean ± SD
Antibiotic switching	Yes	200 (47.3)
	No	223 (52.7)
Reason for switching	Clinical non-response	137 (68.5)
	Microbiological susceptibility results	36 (18.0)
	Adverse drug reaction	15 (7.5)
	Deterioration	12 (6.0)
Switch from ampicillin-cloxacillin alone (n = 138)	Required switching	86 (62.3)
	Switched to 3rd-gen cephalosporins	42 (48.8)
	Switched to vancomycin	20 (23.3)
	Switched to linezolid	14 (16.3)
	Switched to meropenem	10 (11.6)
Switch from ampicillin-cloxacillin + cefotaxime (n = 78)	Required switching	27 (34.6)
	Switched to vancomycin	11 (40.7)
	Switched to linezolid	8 (29.6)
	Switched to meropenem	8 (29.6)
Clinical improvement	Improved without escalation	328 (78.8)
	Required escalation	88 (21.2)
Time to clinical improvement (days)	Mean ± SD	3.2 ± 1.4
	Median (IQR)	3 (2–4)
Treatment failure	Yes	59 (14.2)
Mortality	Yes	12 (2.8)

Of the 346 processed respiratory specimens, 41.9% demonstrated clinically significant bacterial growth. Streptococcus pneumoniae was the most frequently isolated organism, followed by S. aureus (41.7% MRSA), H. influenzae, K. pneumoniae, E. coli, and P. aeruginosa. The presence of ESBL-producing K. pneumoniae and E. coli was notable and complicates empirical treatment decisions.[12] The predominance of S. pneumoniae is consistent with findings from previous studies conducted in Pakistan.[11,14,15]

In total, 68.3% of bacterial isolates exhibited resistance to at least one tested antimicrobial, and 34.5% were classified as multidrug resistant. This substantial resistance burden was observed among the 145 clinically significant isolates, rather than the entire cohort of 423 enrolled children. These findings are consistent with

Table 6. Appropriateness of Initial Empirical Antibiotic Therapy and Associated Outcomes

Variable	Category	n (%)/Mean ± SD	p-value
Appropriateness of initial therapy (n = 145)	Appropriate	62 (42.8)	
	Inappropriate	83 (57.2)	
Antibiotic switching	Appropriate therapy	22 (26.5)	<0.001*
	Inappropriate therapy	61 (73.5)	
Hospital stay (days)	Appropriate therapy	4.2 ± 1.8	<0.001**
	Inappropriate therapy	6.8 ± 3.1	

*Chi-square test; **Independent-samples t-test.

national pediatric antimicrobial resistance (AMR) data, which report high resistance rates among Gram-negative organisms and MRSA, as well as frequent empirical antibiotic prescribing.[12]

Among S. pneumoniae isolates, resistance was highest to ampicillin-cloxacillin (48.0%), penicillin (42.0%), and amoxicillin-clavulanic acid (36.0%), while susceptibility to ceftriaxone, linezolid, and vancomycin remained high.[11,15] S. aureus demonstrated substantial resistance to ampicillin-cloxacillin (36.1% susceptible), and all MRSA isolates were susceptible to vancomycin and linezolid.[9,10] Gram-negative organisms, including K. pneumoniae and E. coli, exhibited high resistance to ampicillin-cloxacillin and cephalosporins; however, meropenem and amikacin retained greater activity. P. aeruginosa demonstrated the highest susceptibility to meropenem. These results highlight the necessity for pathogen-specific susceptibility data.

Globally, K. pneumoniae, E. coli, and P. aeruginosa are significant contributors to resistance-associated mortality,[4] and the World Health Organization (WHO) designates resistant Gram-negative organisms as surveillance priorities.[16] The resistance patterns observed in this study support the need for continued institutional surveillance.

Antibiotic switching was observed in nearly half of patients, most commonly due to clinical non-response. Switching occurred more frequently among those initially treated with ampicillin-cloxacillin alone (62.3%) compared to those receiving combination therapy (34.6%). Elevated switching rates reflect uncertainty in empirical treatment selection but do not necessarily indicate antimicrobial resistance, as clinical non-response may result from factors such as viral infection or disease severity. In contrast to previous studies,[17] this research differentiates between clinical non-response and laboratory-confirmed resistance by providing actual susceptibility profiles.

Inappropriate initial empirical therapy, observed in 57.2% of the 145 culture-positive patients, was significantly associated with increased frequency of antibiotic switching and prolonged hospitalization. These results underscore the importance of local susceptibility surveillance and prompt reassessment of empirical therapy, as recommended by the WHO and pediatric stewardship guidelines.[1,9] However, observational data cannot establish causality between inappropriate therapy and extended hospitalization potential because of confounding clinical factors.

Identified risk factors for resistance in this cohort included prior antibiotic exposure (the strongest association), malnutrition, young age, previous hospitalization, and comorbidities. Prior antibiotic use is a well-established risk factor, consistent with broader antimicrobial resistance (AMR) literature.[4,12] Age less than six months and malnutrition should be considered markers of vulnerability and increased healthcare exposure, rather than direct causes of resistance. Larger prospective studies are required to clarify causal relationships.

Implications

Clinicians prescribed antibiotics to nearly all patients, most often as combination therapies involving intravenous broad-spectrum agents. These prescribing patterns highlight the urgent need for structured antimicrobial stewardship in Pakistani hospitals, where empirical antibiotic use remains prevalent; stewardship interventions have proven effective, including prompt implementation of local guidelines to eliminate early empirical regimens and transition from intravenous to oral therapy. Adopting these measures is expected to optimize antibiotic use and improve patient outcomes.

Table 7. Factors Associated with Antimicrobial Resistance Among Culture-Positive Pediatric Pneumonia Patients

Factor	Category	Resistant n (%)	Susceptible n (%)	Total	Crude OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Previous antibiotic exposure	Yes	68 (82.9)	14 (17.1)	82	5.01 (2.34–10.73)	<0.001	4.21 (1.89–9.38)	<0.001
	No	31 (49.2)	32 (50.8)	63	Reference	—	Reference	—
Malnutrition	Yes	26 (86.7)	4 (13.3)	30	3.46 (1.11–10.78)	0.032	2.41 (0.71–8.18)	0.158
	No	73 (63.5)	42 (36.5)	115	Reference	—	Reference	—
Hospitalization in previous 3 months	Yes	22 (84.6)	4 (15.4)	26	3.04 (1.06–8.72)	0.038	2.12 (0.68–6.61)	0.194
	No	77 (64.7)	42 (35.3)	119	Reference	—	Reference	—
Age <6 months	Yes	64 (77.1)	19 (22.9)	83	2.57 (1.25–5.30)	0.010	2.18 (1.01–4.71)	0.047
	No	35 (56.5)	27 (43.5)	62	Reference	—	Reference	—
Comorbid conditions	Yes	17 (85.0)	3 (15.0)	20	2.97 (0.95–9.28)	0.061	1.84 (0.52–6.48)	0.343
	No	82 (65.6)	43 (34.4)	125	Reference	—	Reference	—
Total	—	99 (68.3)	46 (31.7)	145	—	—	—	—

Strengths

A key strength of this study is its prospective design, which enabled systematic documentation of antibiotic prescribing, specimen collection, microbiological findings, treatment modifications, and clinical outcomes throughout patient care. Additionally, the inclusion of laboratory-confirmed antimicrobial susceptibility testing, rather than reliance on clinical treatment failure as a surrogate for resistance, enhances the robustness of the results. The relatively large cohort of 423 pediatric pneumonia patients and the integration of prescribing and microbiological data further increase the clinical relevance of the findings.

Limitations

This study's single-center design limits its generalizability to other settings in Pakistan. Prior antibiotic exposure may have reduced culture positivity rates. Microbiological results, particularly from endotracheal aspirates, may reflect colonization rather than true infection and therefore require careful clinical interpretation. While phenotypic susceptibility was assessed, underlying resistance mechanisms were not investigated. Additionally, the small number of isolates for certain organisms reduces the precision of the findings. As an observational study, it cannot establish causal relationships between prescribing practices, antimicrobial resistance, and clinical outcomes.

Conclusion

This prospective study shows high antibiotic exposure and significant laboratory-confirmed antimicrobial resistance among children with pneumonia in a tertiary care hospital in Faisalabad. Streptococcus pneumoniae was the most frequently isolated pathogen. This study also detected notable resistance among both Gram-positive and Gram-negative organisms, including methicillin-resistant Staphylococcus aureus (MRSA) and extended-spectrum beta-lactamase (ESBL)-producing isolates. Inappropriate initial empirical therapy occurred in more than half of microbiologically confirmed cases and was associated with more antibiotic switching and longer hospital stays. These results underscore the need to strengthen microbiological surveillance and pediatric antimicrobial stewardship, emphasizing evidence-based

Table 8. WHO/INRUD Core Prescribing Indicators in Pediatric Pneumonia Patients

Variable	Category	n (%)/Mean ± SD	p-value
Appropriateness of initial therapy (n = 145)	Appropriate	62 (42.8)	
	Inappropriate	83 (57.2)	
Antibiotic switching	Appropriate therapy	22 (26.5)	<0.001*
	Inappropriate therapy	61 (73.5)	
Hospital stay (days)	Appropriate therapy	4.2 ± 1.8	<0.001**
	Inappropriate therapy	6.8 ± 3.1	

empirical treatment, proper specimen collection, timely susceptibility testing, antibiotic de-escalation, and regular review of local resistance patterns.

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