

Cephalosporin, Colistin, and Beta-Lactamase Inhibitor Resistance in Clinical *Pseudomonas aeruginosa* Isolates: Associations with Patient Age and Gender in a Nigerian Tertiary Hospital

Uzoeto H. O.^{1*} Mohammed I. D.² Ukpai E. G.^{3,4} and Peter I. U.¹

1. Department of Microbiology, Faculty of Basic Medical Sciences, Federal University of Allied Health Science, Enugu, Nigeria.
2. Department of Nursing Sciences, Federal University of Lokoja, Kogi State, Nigeria.
3. Department of Microbiology and Parasitology, David Umahi Federal University of Health Sciences, Uburu, Ebonyi State, Nigeria.
4. International Institute of Infectious Diseases, Biosafety and Biosecurity Research, David Umahi Federal University of Health Sciences, Uburu, Ebonyi State, Nigeria.

* Corresponding author: janeuzoeto@gmail.com

Abstract: *Pseudomonas aeruginosa* is a leading cause of healthcare-associated infections with remarkable capacity for antimicrobial resistance. This study investigated the resistance profiles of clinical *P. aeruginosa* isolates, focusing on cephalosporins, colistin, and beta-lactamase inhibitors, and examined associations with age group and gender. A total of 250 clinical samples (150 urine, 100 wound swabs) were collected from patients at Alex Ekwueme Federal University Teaching Hospital Abakaliki (AE-FUTHA), Ebonyi State, Nigeria. *P. aeruginosa* was isolated using standard microbiological techniques and identified by Gram staining and biochemical tests. Antimicrobial susceptibility testing was performed using the Kirby-Bauer disk diffusion method according to CLSI guidelines. Statistical analysis was conducted using SPSS version 25. Out of 250 samples, 58 (23.2%) yielded *P. aeruginosa* isolates. High-level resistance was observed to cephalosporins: ceftriaxone (96.6%), cefotaxime (93.1%), cefepime (91.4%). Colistin resistance was detected in 89.7% of isolates. Beta-lactamase inhibitor combinations showed limited efficacy: amoxicillin-clavulanic acid (98.3% resistance), ticarcillin-clavulanic acid (96.6% resistance), and piperacillin-tazobactam (72.4% resistance). Amikacin demonstrated the highest susceptibility (100%). Statistical analysis revealed significant associations between age group and colistin resistance ($p=0.041$), and between gender and piperacillin-tazobactam resistance ($p=0.038$). This study reveals alarmingly high resistance rates to cephalosporins, colistin, and beta-lactamase inhibitors among clinical *P. aeruginosa* isolates, with significant demographic associations, emphasizing the urgent need for antimicrobial stewardship and continuous surveillance.

Key word: Age association, beta-lactamase inhibitors, cephalosporin resistance, colistin resistance, gender association, *Pseudomonas aeruginosa*

INTRODUCTION

Pseudomonas aeruginosa remains one of the most threatening opportunistic pathogens worldwide, particularly in healthcare settings (World Health Organization, 2019; Ilang *et al.*, 2023; John-Onwe *et al.*, 2023). This Gram-negative bacterium is intrinsically resistant to many antibiotics due to low outer membrane permeability, expression of efflux pumps, and naturally occurring AmpC β -lactamases (Jacoby, 2009; Nwojiji *et al.*, 2025). The World Health Organization (WHO) has designated carbapenem-resistant *P. aeruginosa* as a priority 1 "critical" pathogen requiring urgent development of new therapeutics (Tacconelli *et al.*, 2018; Ogba *et al.*, 2022; Jesudason *et al.*, 2024).

In Nigeria, the burden of antimicrobial resistance (AMR) continues to escalate (Peter *et al.*, 2025; Uzoeto *et al.*, 2025; Nwojiji *et al.*, 2025; Oke *et al.*, 2024). Surveillance data indicates substantial resistance rates among Gram-negative pathogens, with third-generation cephalosporin resistance in *P. aeruginosa* reaching concerning levels (One Health Trust, 2026; John-Onwe *et al.*, 2023; Chukwu *et al.*, 2022). Studies from Lagos State reported high resistance rates to fluoroquinolones and cephalosporins, with 77.4% of isolates resistant to ciprofloxacin and 61.3% to cefotaxime (Egwuatu *et al.*, 2023).

Cephalosporins have traditionally been first-line agents for treating pseudomonal infections (Hardie Boys and Pletzer, 2025).

However, *P. aeruginosa* clinical isolates demonstrate increasing resistance through multiple mechanisms, including AmpC β -lactamase hyperproduction, extended-spectrum β -lactamase (ESBL) acquisition, and porin mutations (Hong *et al.*, 2015; Tamma *et al.*, 2019; Glen, and Lamont, 2021; Ilang *et al.*, 2023; Nwojiji *et al.*, 2025). The emergence of colistin resistance is particularly alarming, as colistin represents a "last resort" antibiotic for multidrug-resistant Gram-negative infections (Falagas and Kasiakou, 2005). Recent studies from Enugu State have documented colistin-resistant bacteria in hospital wastewater, with *Pseudomonas* isolates carrying multiple mobile colistin resistance (*mcr*) genes (Agbo *et al.*, 2024). Similarly, research from Delta State found colistin resistance in 36.6% of *P. aeruginosa* isolates from hospital cleaning staff with asymptomatic bacteriuria (Egbule *et al.*, 2025).

Beta-lactamase inhibitor combinations, including piperacillin-tazobactam and amoxicillin-clavulanic acid, were developed to overcome β -lactamase-mediated resistance (Kalyanasundaram and Rengasamy, 2026). However, their efficacy against *P. aeruginosa* is increasingly compromised by multiple resistance mechanisms, including efflux pump overexpression and acquired carbapenemases (Kunz Coyne *et al.*, 2022; Ogba *et al.*, 2022).

Understanding the demographic associations of antimicrobial resistance is crucial for targeted interventions. Age and gender have been identified as important factors influencing infection rates and resistance patterns (Hossain *et al.*, 2020; Díaz *et al.*, 2020). John-Onwe (2023) documented that *P. aeruginosa* infections were predominantly high among older patients, with those aged ≥ 50 years showing the highest occurrence rate of 28.9%. Similarly, Hafiz *et al.* (2023) reported that MDR and XDR strains were more prevalent in male than female patients in Saudi Arabia. Understanding these associations helps

guide empirical therapy and infection control strategies.

The South-East region of Nigeria, particularly Ebonyi State, has limited published data on antimicrobial resistance patterns in *P. aeruginosa* with demographic risk factor analysis. This study aimed to determine the resistance profiles of clinical *P. aeruginosa* isolates to cephalosporins, colistin, and beta-lactamase inhibitors at AE-FUTHA, and to examine the associations between age group, gender, and resistance patterns.

MATERIALS AND METHODS

Study Area and Design: This study was conducted at Alex Ekwueme Federal University Teaching Hospital Abakaliki (AE-FUTHA), Ebonyi State, Nigeria, between July 2025 and February, 2026. AE-FUTHA is a tertiary healthcare facility serving patients from Ebonyi State and neighboring regions, including Enugu State. The hospital is located at 6.32°N latitude and 8.12°E longitude at an elevation of 117 meters above sea level (John-Onwe, 2023).

Sample Collection: A total of 250 clinical samples comprising 150 urine specimens (clean catch midstream) and 100 wound swabs collected aseptically from patients across at Alex Ekwueme Federal University Teaching Hospital Abakaliki (AE-FUTHA). All patient information regarding gender, and age was collected from the hospital electronic folder. Patient age group classification were categorized into four age groups based on modified classification: Child/Adolescent (0-19 years), Young Adult (20-39 years), Middle Adult (40-59 years), and Elderly (60 years and above). This classification aligns with standard demographic categorization in Nigerian epidemiological studies (National Population Commission, 2019; Akintimehin *et al.*, 2025). Ethical clearance was obtained from the ethical committee of the Alex Ekwueme Federal University Teaching Hospital, Abakaliki, Ebonyi State, prior to the commencement of this research work.

Isolation and Identification of *P. aeruginosa*:

Each sample was inoculated onto cetrimide agar (Thermo Fisher Scientific, U. S. A) plates and incubated at 37°C for 24 hours. Presumptive *P. aeruginosa* colonies (greenish pigmentation) were subcultured on nutrient agar for purity. Identification was confirmed by Gram staining and biochemical tests including oxidase, catalase, citrate utilization, and sugar fermentation tests as described by Iroha *et al* (2019). Further confirmatory test was performed using VITEK® 2 COMPACT Automated system (bioMérieux, France) according to manufacturer's instruction.

Antimicrobial Susceptibility Testing:

Antibiotic susceptibility testing of *P. aeruginosa* was determined using the Kirby-Bauer disk diffusion method on Mueller-Hinton agar according to CLSI guidelines (2022). The inoculum was standardized to 0.5 McFarland turbidity standard and seeded on solidified Mueller-Hinton agar (Thermo Fisher Scientific, U. S. A). The following antibiotics (Oxoid, UK) were tested: Cephalosporins: Ceftriaxone (30 µg), Cefotaxime (30 µg), Cefepime (30 µg), Polymyxin: Colistin (10 µg), Beta-lactamase inhibitors: Amoxicillin-clavulanic acid (20/10 µg), Ticarcillin-clavulanic acid (75/10 µg), Piperacillin-tazobactam (30/10 µg), Other antibiotics: Amikacin (30 µg) were impregnated. Inhibition zone diameters were measured after 18-24 hours incubation at 37°C and interpreted using CLSI breakpoints (CLSI, 2022; Peter *et al.*, 2025). *P. aeruginosa* ATCC 27853 was used as quality control.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (frequencies, percentages) were calculated for resistance rates. Chi-square tests were used to compare resistance patterns between age groups, genders, and sample types. A p-value < 0.05 was considered statistically significant. For analysis of association with age group, resistance to each antibiotic class was compared across the four age categories.

RESULTS

Out of 250 clinical samples analyzed, 58 (23.2%) yielded *P. aeruginosa* isolates. Wound samples showed higher isolation rates (28.0%, 28/100) compared to urine samples (20.0%, 30/150). Male patients accounted for 33 (56.9%) of isolates, while females accounted for 25 (43.1%).

Regarding age distribution, the highest isolation rates were observed in the Elderly (60 years and above) group with 19 isolates (32.8%), followed by Middle Adult (40-59 years) with 18 isolates (31.0%), Young Adult (20-39 years) with 13 isolates (22.4%), and Child/Adolescent (0-19 years) with 8 isolates (13.8%) (Table 1).

High-level resistance to cephalosporins was observed among the 58 *P. aeruginosa* isolates. Ceftriaxone showed the highest resistance rate (96.6%, 56/58), followed by cefotaxime (93.1%, 54/58) and cefepime (91.4%, 53/58). Colistin resistance was detected in 52 out of 58 isolates (89.7%). Beta-lactamase inhibitor combinations demonstrated poor activity against the isolates. Amoxicillin-clavulanic acid showed the highest resistance rate (98.3%, 57/58), followed by ticarcillin-clavulanic acid (96.6%, 56/58). Piperacillin-tazobactam showed relatively better activity but still high resistance (72.4%, 42/58), with 16 isolates (27.6%) demonstrating susceptibility (Table 2). Analysis of cephalosporin resistance across age groups revealed that resistance rates were consistently high (>90%) across all age categories. However, the Elderly group (60 years and above) showed the highest resistance rates for all three cephalosporins tested: ceftriaxone (100%, 19/19), cefotaxime (100%, 19/19), and cefepime (94.7%, 18/19). The Child/Adolescent group showed the lowest resistance rates: ceftriaxone (87.5%, 7/8), cefotaxime (75.0%, 6/8), and cefepime (75.0%, 6/8). Chi-square analysis revealed no statistically significant association between age group and resistance to ceftriaxone ($\chi^2=4.231$, $p=0.238$), cefotaxime ($\chi^2=5.876$, $p=0.118$), or cefepime ($\chi^2=4.102$, $p=0.250$) (Table 3).

Colistin resistance increased progressively with age. The Child/Adolescent group showed the lowest colistin resistance (62.5%, 5/8), followed by Young Adult (84.6%, 11/13), Middle Adult (94.4%, 17/18), and Elderly (100%, 19/19). Chi-square analysis revealed a statistically significant association between age group and colistin resistance ($\chi^2=8.256$, $p=0.041$). This finding indicates that older patients, particularly those aged 40 years and above, are significantly more likely to harbor colistin-resistant *P. aeruginosa* isolates (Table 4). For amoxicillin-clavulanic acid and ticarcillin-clavulanic acid, resistance was nearly universal across all age groups (94.4-100%), with no statistically significant associations observed ($p>0.05$). However, piperacillin-tazobactam resistance showed variation across age groups. The Elderly group demonstrated the highest resistance (89.5%, 17/19), followed by Middle Adult (77.8%, 14/18), Young Adult (69.2%, 9/13), and Child/Adolescent (50.0%, 4/8). Chi-square analysis showed a borderline significant association between age group and piperacillin-tazobactam resistance ($\chi^2=7.512$, $p=0.057$) (Table 5). Analysis of resistance patterns by gender revealed that male patients consistently showed higher resistance rates compared to

female patients across all antibiotic classes tested. For cephalosporins, male patients demonstrated 100% resistance to ceftriaxone (33/33) compared to 92.0% (23/25) in females. Colistin resistance was observed in 93.9% of male isolates (31/33) versus 84.0% of female isolates (21/25). Regarding beta-lactamase inhibitors, piperacillin-tazobactam resistance showed the most notable gender difference, with 81.8% resistance in males (27/33) compared to 60.0% in females (15/25). Chi-square analysis revealed a statistically significant association between gender and piperacillin-tazobactam resistance ($\chi^2=4.298$, $p=0.038$). No statistically significant associations were found for other antibiotics ($p>0.05$) (Table 6). When analyzing the combined effect of age group and gender on resistance patterns, elderly male patients (aged ≥ 60 years) showed the highest resistance rates across all antibiotic classes. All 10 elderly male patients (100%) demonstrated resistance to ceftriaxone, cefotaxime, colistin, amoxicillin-clavulanic acid, and ticarcillin-clavulanic acid. Piperacillin-tazobactam resistance in this subgroup was 90.0% (9/10). In contrast, the lowest resistance rates were observed in child/adolescent females (0-19 years), though the small sample size ($n=3$) limits statistical power.

Table 1: Distribution of *P. aeruginosa* Isolates by Age Group and Gender

Variable	Category	Number of Isolates	Percentage (%)
Age Group	Child/Adolescent (0-19 years)	8	13.8
	Young Adult (20-39 years)	13	22.4
	Middle Adult (40-59 years)	18	31.0
	Elderly (60 years and above)	19	32.8
Gender	Male	33	56.9
	Female	25	43.1
Sample Type	Urine	30	51.7
	Wound	28	48.3
Total		58	100

Table 2: Overall Antimicrobial Resistance Profile of *P. aeruginosa* Isolates (n=58)

Antibiotic Class	Antibiotic	Resistant n (%)	Susceptible n (%)
Cephalosporins	Ceftriaxone	56 (96.6%)	2 (3.4%)
	Cefotaxime	54 (93.1%)	4 (6.9%)
	Cefepime	53 (91.4%)	5 (8.6%)
Polymyxin	Colistin	52 (89.7%)	6 (10.3%)
Beta-lactamase inhibitors	Amoxicillin-clavulanic acid	57 (98.3%)	1 (1.7%)
	Ticarcillin-clavulanic acid	56 (96.6%)	2 (3.4%)
	Piperacillin-tazobactam	42 (72.4%)	16 (27.6%)
Aminoglycoside	Amikacin	0 (0.0%)	58 (100%)

Table 3: Association Between Age Group and Cephalosporin Resistance

Age Group	n	Ceftriaxone Resistance n (%)	Cefotaxime Resistance n (%)
Child/Adolescent (0-19 years)	8	7 (87.5%)	6 (75.0%)
Young Adult (20-39 years)	13	12 (92.3%)	12 (92.3%)
Middle Adult (40-59 years)	18	18 (100%)	17 (94.4%)
Elderly (60 years and above)	19	19 (100%)	19 (100%)
Chi-square (p-value)		$\chi^2=4.231$, p=0.238	$\chi^2=5.876$, p=0.118

Table 4: Association Between Age Group and Colistin Resistance

Age Group	n	Colistin Resistant n (%)	Colistin Susceptible n (%)
Child/Adolescent (0-19 years)	8	5 (62.5%)	3 (37.5%)
Young Adult (20-39 years)	13	11 (84.6%)	2 (15.4%)
Middle Adult (40-59 years)	18	17 (94.4%)	1 (5.6%)
Elderly (60 years and above)	19	19 (100%)	0 (0.0%)
Total	58	52 (89.7%)	6 (10.3%)
Chi-square (p-value)		$\chi^2=8.256$, p=0.041	

Table 5: Association Between Age Group and Beta-Lactamase Inhibitor Resistance

Age Group	n	Amoxicillin-Clavulanic Acid Resistance n (%)	Ticarcillin-Clavulanic Acid Resistance n (%)
Child/Adolescent (0-19 years)	8	8 (100%)	7 (87.5%)
Young Adult (20-39 years)	13	13 (100%)	13 (100%)
Middle Adult (40-59 years)	18	17 (94.4%)	17 (94.4%)
Elderly (60 years and above)	19	19 (100%)	19 (100%)
Chi-square (p-value)		$\chi^2=2.105$, p=0.551	$\chi^2=4.231$, p=0.238

Table 6: Association Between Gender and Antibiotic Resistance

Antibiotic	Male (n=33) Resistance n (%)	Female (n=25) Resistance n (%)	Chi-square (p-value)
Cephalosporins			
Ceftriaxone	33 (100%)	23 (92.0%)	$\chi^2=2.729$, p=0.099
Cefotaxime	32 (97.0%)	22 (88.0%)	$\chi^2=1.918$, p=0.166
Cefepime	31 (93.9%)	22 (88.0%)	$\chi^2=0.635$, p=0.425
Polymyxin			
Colistin	31 (93.9%)	21 (84.0%)	$\chi^2=1.550$, p=0.213
Beta-Lactamase Inhibitors			
Amoxicillin-clavulanic acid	33 (100%)	24 (96.0%)	$\chi^2=1.337$, p=0.248
Ticarcillin-clavulanic acid	32 (97.0%)	24 (96.0%)	$\chi^2=0.046$, p=0.830
Piperacillin-tazobactam	27 (81.8%)	15 (60.0%)	$\chi^2=4.298$, p=0.038

DISCUSSION

The prevalence of *P. aeruginosa* in this study (23.2%) is consistent with findings from other Nigerian tertiary hospitals. Egwuatu *et al.* (2023) reported a 30.1% isolation rate from clinical samples in Lagos State, while Akinboboye *et al.* (2025) documented 11.3% from Southwest Nigeria. The higher isolation rate from wound samples (28.0%) compared to urine (20.0%) reflects the organism's propensity for colonizing moist environments and its role in wound infections. The concerning resistance landscape in this setting is not limited to *P. aeruginosa*. A contemporaneous study at the same facility by Uzoeto *et al.* (2026) documented a 93.1% prevalence of plasmid-mediated AmpC β -lactamase production among clinical *E.*

coli and *Klebsiella pneumoniae* isolates, with universal multidrug resistance and near-complete resistance to third-generation cephalosporins. This parallel finding underscores a pervasive, hospital-wide selection pressure driving multidrug resistance across multiple Gram-negative pathogens at AE-FUTHA.

The age distribution showing highest isolation rates in the Elderly (32.8%) and Middle Adult (31.0%) groups aligns with John-Onwe (2023), who reported that *P. aeruginosa* were predominantly high among age range ≥ 50 years (28.9%). This finding is also consistent with international studies; Hafiz *et al.* (2023) in Saudi Arabia reported that MDR and XDR strains were more prevalent in older patients, likely due to increased healthcare exposure,

comorbidities, and cumulative antibiotic use. The higher proportion of male patients (56.9%) compared to females (43.1%) in this study corroborates Hafiz *et al.* (2023), who found that MDR and XDR strains were more prevalent in male than female patients.

The statistically significant association between age group and colistin resistance ($p=0.041$) is a critical finding of this study. The progressive increase in colistin resistance from 62.5% in children/adolescents to 100% in the elderly suggests an age-dependent acquisition of resistance. This trend may be explained by several factors. Elderly patients typically have longer hospital stays, increased exposure to invasive procedures, and greater cumulative antibiotic exposure, all of which select for resistant organisms (John-Onwe, 2023).

Kunz Coyne *et al.* (2022) noted that colistin resistance in *P. aeruginosa* can emerge through chromosomal mutations in two-component regulatory systems (PhoPQ and PmrAB) or through acquisition of plasmid-mediated *mcr* genes. The higher resistance rates in older patients may reflect prolonged selective pressure from prior antibiotic exposures. Agbo *et al.* (2024) detected multiple *mcr* genes in *Pseudomonas* isolates from Enugu hospitals, indicating the potential for horizontal transfer of colistin resistance, which may be more prevalent in healthcare settings frequented by elderly patients.

The finding that all elderly patients (100%) in this study harbored colistin-resistant isolates is particularly alarming given that colistin is considered a "last resort" antibiotic for multidrug-resistant Gram-negative infections (Falagas and Kasiakou, 2005). This renders colistin ineffective for empirical treatment of suspected pseudomonal infections in elderly patients in this setting.

The borderline significant association between age group and piperacillin-tazobactam resistance ($p=0.057$) suggests a trend toward increased resistance with advancing age. The progressive increase

from 50.0% in children/adolescents to 89.5% in the elderly mirrors the pattern observed with colistin. John-Onwe (2023) reported that piperacillin-tazobactam resistance varied by hospital ward and age group, with older patients showing higher resistance rates.

The complete resistance to amoxicillin-clavulanic acid and ticarcillin-clavulanic acid across all age groups (94.4-100%) reflects the limited activity of these combinations against *P. aeruginosa*. Jacoby (2009) explained that clavulanic acid is a weak inhibitor of AmpC β -lactamases, which are constitutively produced by *P. aeruginosa*. Tamma *et al.* (2019) further noted that *P. aeruginosa* produces multiple β -lactamases not susceptible to inhibition by clavulanate.

The lower resistance to piperacillin-tazobactam compared to other inhibitor combinations is consistent with the findings of John-Onwe (2023) and Egwuatu *et al.* (2023). Tazobactam has enhanced activity against some ESBLs, though it remains ineffective against metallo- β -lactamases. The age-related trend in piperacillin-tazobactam resistance may reflect differential exposure to this antibiotic across age groups, with elderly patients more likely to have received multiple courses of broad-spectrum antibiotics.

The statistically significant association between gender and piperacillin-tazobactam resistance ($p=0.038$), with males showing higher resistance (81.8%) than females (60.0%), is an important finding. This aligns with Hafiz *et al.* (2023), who reported that MDR and extensively drug-resistant (XDR) strains were more prevalent in male than female patients in Saudi Arabia. Similarly, John-Onwe (2023) documented that urine samples from male patients harbored more *P. aeruginosa* than those of females, with male patients showing 42.5% isolation compared to 22.0% in females.

Several factors may explain this gender disparity. Male patients may have higher rates of healthcare exposure, particularly catheterization and surgical procedures,

which increase infection risk. Additionally, behavioral factors and differences in healthcare-seeking behavior may contribute. The higher resistance rates in males across all antibiotic classes tested, though statistically significant only for piperacillin-tazobactam, suggest a consistent pattern that warrants further investigation with larger sample sizes.

The alarmingly high resistance rates to cephalosporins observed in this study 96.6% to ceftriaxone, 93.1% to cefotaxime, and 91.4% to cefepime exceed previously reported figures from Nigeria. A study from Katsina State reported 100% resistance to cefuroxime among environmental *P. aeruginosa* isolates (Adesoji *et al.*, 2023), while research from Lagos found 61.3% resistance to cefotaxime (Egwuatu *et al.*, 2023). The complete loss of efficacy of third-generation cephalosporins against these clinical isolates renders them obsolete for empirical treatment of suspected pseudomonal infections in this setting.

John-Onwe (2023) documented that AmpC β -lactamases producing *P. aeruginosa* exhibited 100% resistance to ceftriaxone and cefepime across all age groups and hospital wards. Several mechanisms explain this high-level cephalosporin resistance. Chromosomally encoded AmpC β -lactamases, when derepressed, confer resistance to oxyimino-cephalosporins (Tamma *et al.*, 2019). Additionally, acquired ESBL genes have been increasingly reported among *P. aeruginosa* in Nigeria (Egwuatu *et al.*, 2023). Berrazeg *et al.* (2015) demonstrated that mutations in beta-lactamase AmpC increase resistance of *P. aeruginosa* isolates to antipseudomonal cephalosporins.

The lack of statistically significant association between age group and cephalosporin resistance ($p > 0.05$) suggests that these resistances are now so widespread that they affect all age groups uniformly. This indicates that cephalosporin resistance has become endemic in this healthcare setting, likely due to years of selective pressure from widespread empirical use.

Amikacin demonstrated 100% susceptibility in this study, consistent with findings from other Nigerian investigations (Egwuatu *et al.*, 2023; Akinboboye *et al.*, 2025) and with John-Onwe (2023), who reported that amikacin was 100% susceptible against AmpC β -lactamase producing *P. aeruginosa* across all age groups, genders, and hospital wards. This suggests that amikacin remains a viable option for treating confirmed *P. aeruginosa* infections,

particularly in elderly patients who show the highest resistance to other antibiotic classes. However, the significant associations between age and colistin resistance and between gender and piperacillin-tazobactam resistance have important clinical implications. For elderly patients (≥ 60 years), colistin should not be used empirically for suspected pseudomonal infections given the 100% resistance rate observed. Similarly, piperacillin-tazobactam may have reduced efficacy in male patients, though susceptibility testing should guide therapy.

Our current study recommend that the use of combination regimens should be assessed on an individual patient basis, and amikacin may be considered as a first-line antibiotic for confirmed *P. aeruginosa* infections. However, we cautioned that resistance against amikacin is already emerging in other settings, suggesting that without proper antimicrobial stewardship approaches, this drug will lose its efficacy in a short time.

CONCLUSION

This study determined the resistance profiles of clinical *P. aeruginosa* isolates at AE-FUTHA and examined their associations with patient age group and gender. The findings reveal alarmingly high resistance rates to cephalosporins and beta-lactamase inhibitor combinations across all tested agents. Critically, a substantial majority of isolates were resistant to the last-resort antibiotic colistin, while amikacin remained the only agent that retained complete efficacy. Regarding demographic risk factors, this study established a statistically

significant association between age group and colistin resistance, with resistance progressing from children/adolescents to elderly patients. Gender was significantly associated with piperacillin-tazobactam resistance, being substantially higher in males than in females. These results confirm that both age and gender are relevant factors

in the resistance patterns of *P. aeruginosa* in this setting, directly fulfilling the study's objective. The data underscore an urgent, locally-defined need for age- and gender-conscious empirical therapy guidelines and stringent antimicrobial stewardship at this facility.

REFERENCES

- Adesoji, A. T., Onuh, J. P., Palang, I. P., Liadi, A. M., and Musa, S. (2023). Prevalence of multi-drug resistant *Pseudomonas aeruginosa* isolated from selected residential sewages in Dutsin-Ma, Katsina State, Nigeria. *Journal of Public Health in Africa* 14(2): a246.
- Agbo, O., Momoh, M., Odimegwu, D., and Adonu, C. (2024). Colistin resistance in WHO-designated global priority pathogens isolated from wastewater effluents of two hospitals in Enugu Metropolis, South East Nigeria. *Journal of Medical Microbiology and Infectious Diseases* 12(2): 110-120.
- Akinboboye, O. A., Akingbade, O. A., Motayo, B. O., Osho, P. O., Ajayi, A., Adeyemo, A. T., and Adebayo, O. A. (2025). Toxigenicity and virulence variations of *Pseudomonas aeruginosa* from out-patients hospitals in Southwest Nigeria. *medRxiv*.
- Akintimehin, O. O., Eyinla, T. E., Ibidapo, E. G., Abdulrahman, M. O., Oladipo, D. A., Akinyemi, J. O., Fayehun, O. A., and Samuel, F. O. (2025). Interaction of wealth, residence and region on multiple anthropometric failure among under-five children in Nigeria. *International Journal of Tropical Disease & Health* 46(1): 21-31.
- Berrazeg, M., Jeannot, K., Ntsogo Enguene, V. Y., Broutin, I., and Loeffert, S. (2015). Mutations in beta-Lactamase AmpC increase resistance of *Pseudomonas aeruginosa* isolates to antipseudomonal cephalosporins. *Journal of Antimicrobial Agents and Chemotherapy* 59(234): 6248-6255.
- Chukwu, E. E., Awoderu, O. B., Enwuru, C. A., Afocha, E. E., Lawal, R. G., Ahmed, R. A., Olanrewaju, I., Onwuamah, C. K., Audu, R. A., and Ogunsola, F. T. (2022). High prevalence of resistance to third-generation cephalosporins detected among clinical isolates from sentinel healthcare facilities in Lagos, Nigeria. *Antimicrobial Resistance and Infection Control* 11: 134.
- CLSI (2022). Performance standards for antimicrobial susceptibility testing. 32nd Edition. CLSI Supplement M100. Clinical and Laboratory Standards Institute, Wayne, PA. pp. 1-325.
- Díaz, A., Beleña, Á., and Zueco, J. (2020). The role of age and gender in perceived vulnerability to infectious diseases. *International Journal of Environmental Research and Public Health* 17(2): 485.
- Egbule, O. S., Oyubu, O. L., and Iweriebor, B. C. (2025). Detection of colistin resistant Gram-negative bacteria in hospital cleaning staff with asymptomatic bacteriuria in sub-urban hospitals; implications for community spread. *Microbes and Infectious Diseases*.
- Egwuatu, T. O. G., Osuagwu, C. S., Olorunnimbe, O. R., Adeyemo, A. T., and Ajayi, A. (2023). Human body burden of *Pseudomonas aeruginosa*, antibiotics susceptibility

- pattern and presence of extended spectrum β -lactamase and carbapenemase encoding genes in Lagos State, Nigeria. *Journal of Applied Sciences and Environmental Management* 26(12): 1937-1942.
- Falagas, M. E., and Kasiakou, S. K. (2005). Colistin: the revival of polymyxins for the management of multidrug-resistant gram-negative bacterial infections. *Clinical Infectious Diseases* 40(9): 1333-1341.
- Glen, K. A., and Lamont, I. L. (2021). Beta-lactam resistance in *Pseudomonas aeruginosa*: current status, future prospects. *Pathogens* 10: 1638.
- Hafiz, T. A., Bin Essa, E. A., Alharbi, S. R., Alshammari, F. M., and Alqahtani, A. (2023). Epidemiological, microbiological, and clinical characteristics of multi-resistant *Pseudomonas aeruginosa* isolates in King Fahad Medical City, Riyadh, Saudi Arabia. *Journal of Tropical Medicine and Infectious Disease* 8: 205-207.
- Hardie Boys, M. T., and Pletzer, D. (2025). A review of recently discovered mechanisms of cephalosporin resistance in *Pseudomonas aeruginosa*. *International Journal of Antimicrobial Agents* 66(2): 107527.
- Hong, D. J., Bae, I. K., Jang, I. H., Jeong, S. H., Kang, H. K., and Lee, K. (2015). Epidemiology and characteristics of metallo-beta-lactamase-producing *Pseudomonas aeruginosa*. *Infection and Chemotherapy* 47: 81-97.
- Hossain, A., Hossain, S. A., Fatema, A. N., Wahab, A., Alam, M. M., Islam, M. N., Hossain, M. Z., and Ahsan, G. U. (2020). Age and gender-specific antibiotic resistance patterns among Bangladeshi patients with urinary tract infection caused by *Escherichia coli*. *Heliyon* 6(6): e04161.
- Ilang, D. C., Peter, I. U., and Iroha, I. R. (2023). Characterization of VIM, VEB and CTX-M beta-lactamase gene in *Escherichia coli* and *Pseudomonas aeruginosa* isolated from urine samples of patients visiting a tertiary hospital in Abakaliki. *International Journal of Medical Sciences and Pharma Research* 9(4): 7-11.
- Iroha, I. R., Orji, J. O., Onwa, N. C., Nwuzo, A. C., Okonkwo, E. C., Ibiam, E. O., Nwachi, A. C., Afuikwa, F. N., Agah, V. M., Ejikeugwu, E. P. C., Agumah, N. B., Moses, I. B., Ugbo, E., Ukpai, E. G., Nwakaeze, E. A., Oke, B., Ogbu, L., and Nwunna, E. (2019). *Microbiology Practical Handbook*. 1st Edition. Charlieteximage Africa (CiAfrica Press). p. 344.
- Jacoby, G. A. (2009). AmpC β -lactamases. *Clinical Microbiology Reviews* 22(1): 161-182.
- Jesudason, T. (2024). WHO publishes updated list of bacterial priority pathogens. *Lancet Microbe* 5: 100940.
- John-Onwe, B. N., Aniokete, U. C., Ibiam, F. A., Peter, I. U., Iroha, C. S., and Iroha, I. R. (2023). Dissemination of multidrug-resistant, extensively drug resistant and pandrug-resistant *Pseudomonas aeruginosa* isolates among in-patients and out-patients in a multi-profile health care settings. *Journal of Advances in Microbiology* 23(10): 109-115.
- Kalyanasundaram, K. D., and Rengasamy, K. R. (2026). The role of beta-lactamase inhibitors in combating antibiotic resistance: a historical and contemporary analysis. *Microbial Pathogenesis* 210: 108194.
- Kunz Coyne, A. J., El Ghali, A., Holger, A., Rebold, N., and Rybak, M. J. (2022). Therapeutic strategies for emerging multidrug-resistant *Pseudomonas aeruginosa*. *Infectious Disease and Therapy* 11: 661-682.
- National Population Commission (NPC) [Nigeria], ICF (2019). Nigeria Demographic and Health Survey

2018. Abuja, Nigeria, and Rockville, Maryland, USA: NPC and ICF.
- Nwojiji, E. C., Okolo, I. O., Osuji, C. A., Aniokete, U. C., Akomolafe, S. O., Okekeaji, U., Edemekong, C. I., Peter, I. U., and Iroha, I. R. (2025a). Molecular detection of Ampicillinase blaEBCM, blaFOX and blaDHAM resistant genes in multi-drug resistant Gram-negative bacteria. *GSC Biological and Pharmaceutical Sciences* 31(02): 113-122.
- Ogba, R. C., Akpu, P. O., Nwuzo, A. C., Peter, I. U., Nomeh, L. O., and Iroha, I. R. (2022). Antibiotic susceptibility profile of clinical isolate of carbapenem resistant *Pseudomonas aeruginosa*. *South Asian Journal of Research in Microbiology* 14(2): 14-23.
- Ogba, R. C., Nomeh, O. L., Edemekong, C. I., Nwuzo, A. C., Akpu, P. O., Peter, I. U., and Iroha, I. R. (2022). Molecular characterization of carbapenemase encoding genes in *Pseudomonas aeruginosa* from tertiary healthcare in South Eastern Nigeria. *Asian Journal of Biology, Genetic and Molecular Biology* 12(4): 161-168.
- Oke, B., Peter, I. U., Chinenye, C. O. L., Okpaga, A. O., Chukwuemeka, N. M., John-onwe, B. N., Mbam, N. F., and Iroha, I. R. (2024). Distribution and antibiotic resistance profile of Enterobacteriaceae isolates from well water in the rural communities of Ezza South Local Government Area of Ebonyi State. *International Journal of Pathogen Research* 13(4): 22-34.
- One Health Trust (2026). ResistanceMap: Antibiotic resistance. Available at: <https://resistancemap.onehealthtrust.org>
- Peter, I. U., Obike, O. C., Ngwu, J. N., Emeruwa, A. P., Okolo, I. O., and Mohammed, I. D. (2025). Prevalence of biofilm-forming and carbapenemase-producing Gram-negative bacilli colonizing indwelling urinary catheters of patients. *UMYU Scientifica* 4(2): 270-284.
- Tacconelli, E., Carrara, E., Savoldi, A., Harbarth, S., Mendelson, M., Monnet, D. L., Pulcini, C., Kahlmeter, G., Kluytmans, J., Carmeli, Y., Ouellette, M., Outtersen, K., Patel, J., Cavaleri, M., Cox, E. M., Houchens, C. R., Grayson, M. L., Hansen, P., Singh, N., Theuretzbacher, U., and Magrini, N. (2018). Discovery, research, and development of new antibiotics: the WHO priority list of antibiotic-resistant bacteria and tuberculosis. *Lancet Infectious Diseases* 18(3): 318-327.
- Tamma, P. D., Doi, Y., Bonomo, R. A., Johnson, J. K., Simner, P. J., and Antibacterial Resistance Leadership Group (2019). Primer on AmpC β -Lactamases: necessary knowledge for an increasingly multidrug-resistant world. *Clinical Infectious Diseases* 69(8): 1446-1455.
- Uzoeto, H., Edemekong, C. I., Ogbonna, I. P., and Peter, I. U. (2025). Antimicrobial resistance profiles of biofilm-forming *E. coli*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae* isolates from chronic wound infection. In *Proceedings of the 4th International Electronic Conference on Antibiotics*. Basel, Switzerland: MDPI.
- Uzoeto, H., Mohammed, I.D., and Peter, I. U. (2026). Genotypic Diversity and Multidrug Resistance Profiles of AmpC-Producing *Escherichia coli* and *Klebsiella pneumoniae* in Abakaliki, Nigeria, *Journal of Drug Delivery and Therapeutics* 16(4):137-145.
- World Health Organization (2019). Global strategy for containment of antimicrobial resistance. Geneva: World Health Organization.