

Emerging Antibiotherapeutic Strategies for Neonatal Sepsis: Trends and Challenges

^{*1}Abdullahi Samaila, ²Hafsat Almustapha Bindawa

¹Department of Clinical Pharmacology and therapeutics, College of Health Sciences, Umaru Musa Yaradua University, Katsina.

²Katsina State College of Health Sciences and Technology.

*Corresponding authors' email: abdullahi.samaila@umyu.edu.ng

¹ORCID ID: <https://orcid.org/0000-0001-5261-9305>

²ORCID ID: <https://orcid.org/0009-0006-2740-0399>

ABSTRACT

Neonatal sepsis remains a leading cause of mortality in Nigeria, accounting for 23-30% of neonatal deaths, with antimicrobial resistance (AMR) complicating treatment efficacy. The dominance of Multidrug resistant (MDR) pathogens particularly *K. pneumoniae* and *E. coli* has rendered the first line drugs such as ampicillin and gentamicin ineffective. This comprehensive review examines emerging antibiotic strategies, current trends, and persistent challenges in managing neonatal sepsis in Nigeria. The current review synthesizes findings from more than fifty (50) studies from 2016 to 2026 on pathogen profiles, resistance patterns, diagnostic advancements, and novel therapeutic approaches. Key challenges include limited healthcare infrastructure because only about 42% of hospitals perform blood cultures due to cost, antibiotic misuse mostly from antibiotics dispensed without prescriptions, and sustainability of interventions. Integrated solutions including antimicrobial stewardship, capacity building, and policy reforms should be adopted to mitigate AMR and improve neonatal sepsis treatment outcomes.

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INTRODUCTION

Nigeria faces a critical neonatal sepsis burden, with mortality rates of 46-63 per 1,000 live births in hospital settings among which neonatal sepsis contributes to 30-70% of neonatal deaths (Ogbara *et al.*, 2021). The rise of multidrug-resistant (MDR) pathogens, particularly Gram-negative bacteria (*Klebsiella pneumoniae*, *Escherichia coli*), has made the first-line antibiotics (ampicillin, gentamicin) ineffective in 60-84% of cases (Kirsty-Sands *et al.*, 2022).

Diagnosis and management of sepsis are great challenges facing clinical microbiologists and pediatricians due to the imprecise signs and symptoms. Moreover, there is variability of microbial patterns across hospitals, countries and clinical settings (Qaisar *et al.*, 2026). This however has contributed to the escalation of antibiotic resistance. Antibiotic resistance occurs when medications become less effective to infectious agents due to changes in the agents, steadily becoming one of the top public health concerns of the twenty-first century. Determining the precise burden of antibiotic resistance is a crucial challenge in the fight against it, especially in areas with inadequate surveillance and scant data (Ajekiigbe *et al.*, 2025).

Several studies attributed excessive use of antibiotics, poor sanitation and hygiene, and poor compliance with infection control practices, intra-partum exposure to ampicillin as one of the major contributors to newborns' infections by antibiotic-resistant Gram Negative Bacteria (Solomon *et al.*, 2021). This review Analyzes current epidemiological trends in Nigerian neonatal sepsis, evaluates emerging antibiotic therapies and diagnostic advancements, identifies health system challenges and policy gaps and proposes evidence-based solutions for sustainable management.

Literature Search Strategy

A literature search was conducted to identify relevant publications on neonatal sepsis. The databases and search platforms consulted included Scopus, PubMed, ScienceDirect, and Google Scholar. The search focused on peer-reviewed articles addressing neonatal sepsis, including its risk factors, incidence and prevalence, causative pathogens and antimicrobial resistance patterns, current antibiotic treatment practices, healthcare system challenges, emerging diagnostic technologies, and relevant policies and guidelines. Search terms included "neonatal sepsis," "risk factors for neonatal sepsis," "incidence and prevalence of neonatal sepsis," "bacterial pathogens," "antimicrobial resistance," "antibiotic treatment," "diagnostic advancements," and "healthcare challenges." Relevant keywords were combined using Boolean operators, including AND and OR, where appropriate.

The initial search yielded approximately 350 records. Following screening for relevance to the review objectives, publication type, and subject coverage, eligible peer-reviewed publications published between 2016-2026 were selected for further assessment. Studies that addressed one or more of the review's key themes were considered, while publications that did not directly relate to neonatal sepsis or the scope of the review were excluded. Following this process, approximately 50 publications were selected to inform the narrative synthesis. The findings were organized thematically to discuss the burden of neonatal sepsis, associated risk factors, causative pathogens, antimicrobial resistance, treatment practices, diagnostic advances, healthcare challenges, and relevant policy considerations

MATERIALS AND METHODS

Epidemiology and Pathogen Profile

Incidence of Neonatal Sepsis

A recent meta-analysis estimated the global incidence of neonatal sepsis to be 2824 per 100,000 live births and 2018 showing significantly higher than estimates at 2202 per 100,000 live births in the previous years (Kirsty-Sands *et al.*, 2022). Of the 2.3million global under- 5 neonatal deaths that occurred in 2021, 47% was as a result of neonatal sepsis, highlighting neonatal health as a critical global health issue. A report of 18.2/1000 live births (range: 7-55/1000) was reported in Nigerian hospitals (Medugu *et al.*, 2018). A critical review of the decline in Nigeria's neonatal mortality was compared with the global trend and it reveals that as the extent or level of global decline has been quite consistent, whereas that of Nigeria was much at a slower pace until 2018 (Ogbara *et al.*, 2021). High prevalence of neonatal sepsis has been reported in Nigeria, with incidence of positive blood culture ranging from 25% to 55% across various studies (Olorukooba *et al.*, 2020; Pius *et al.*, 2016; Rosa-Mangeret *et al.*, 2024). A three-year retrospective study in UAE found the incidence of neonatal sepsis to be 11.7% per 1000 live births (Almilhem *et al.*, 2026). In Nigeria, the incidence was reported as 25.2% in Lagos (Uwe *et al.*, 2022) and 22.4% in Abeokuta (Patritia *et al.*, 2022). Other studies in North eastern Nigeria reported the incidence of 37% (Ogbara *et al.*, 2021) in Katsina 51.7% (Obaro *et al.*, 2021), Ogun 34% (Shobowale *et al.*, 2017), Ibadan 12.5% (Akindolire *et al.*, 2016) and Osun 42.7% (Obadare *et al.*, 2022). A remarkable progress was made in the developed countries to reduce the incidence rate basically as a result of measures put in place such as providing access to hygienic skilled delivery for all women, risk based intrapartum antibiotic prophylaxis, and high-quality intensive care for newborns, this is not so in the developing countries (Patritia *et al.*, 2022).

Mortality Rate

Globally in 2019, 5.2 million children below the age of five died, and it was found that 2.5 million (47%) of these deaths happened in the first 28 days of life (Fajolu *et al.*, 2022). According to the World Health Organization (WHO), about five million neonatal deaths occur each year and 98% of this occurs in the developing countries (Roble *et al.*, 2022). Another data reveals that globally, as much as 40% of under-five deaths rate in the neonatal period, resulting in 3 million newborn deaths each year majority of these deaths occur in low-income countries, and about 1 million of the deaths are attributed to infectious causes, including neonatal sepsis. Deaths recorded from neonatal sepsis vary from 5% in the developed world and up to 60% in the developing world (Pillay *et al.*, 2024). The survivors of neonatal sepsis are vulnerable to both short- and long-term neurodevelopmental morbidity. A study in Northeastern Nigeria, reported an overall mortality rate of 28.3% among cases of neonatal sepsis despite being managed with antibiotics (Ajekiigbe *et al.*, 2025).

Risk Factors

Early Onset Neonatal Sepsis (Eons)

Neonatal sepsis can be classified based on the onset of symptoms into early onset if the symptoms manifest at 72 h or less after birth and late onset sepsis by onset of symptoms 72 hours after birth. Early onset is the sepsis that occurs 72 h or less after birth which is usually caused by organisms associated with female genital tract (Olorukooba *et al.*, 2020). According to Niyoyita *et al.*, (2021), early-onset sepsis is caused as a result of the pathogens acquired during

peripartum period, before or during childbirth (Niyoyita *et al.*, 2021). This definition differs from Mustefa *et al.* (2020) where EONS was defined as infection and sepsis occurring within the first 24 hours to first week of life. For maternal risk factors, study by An *et al.* (2022) describes chorioamnionitis, premature rupture of membranes (>18 hours), intrapartum maternal fever (>38 °C), delivery earlier than 37 weeks of gestation, maternal group B streptococcal (GBS) colonization to increase the risk of GBS infection in newborn. Olorukooba *et al.* (2020) revealed prematurity, low birth weight, chorioamnionitis, maternal febrile illnesses, and prolonged rupture of membranes (PROM) as the risk factors. A previous study suggests that EOS has a direct relation with the colonization of the microbiome associated to the maternal gut that transcends vertically from the mother to the neonate (Kirsty -Sands *et al.*, 2022). Bacteria vertically ascend from intra-uterine infections, mainly from the vaginal environment and enter into amniotic fluid during passage through the birth canal in vaginal delivery (Kariniotaki *et al.*, 2025).

Late Onset Neonatal Sepsis (Lons)

Late onset sepsis refers to neonatal infection after birth mainly as a result of hospital acquired infections and unenforced infection prevention and control in the Hospital settings (Niyoyita *et al.*, 2021). Olorokuba *et al.* (2020) describes late-onset neonatal sepsis as that caused by the organisms associated with the environment and may be nosocomial in origin. Another study describes LONS as onset of symptoms after 24 hours, after the first week of life, up to 28 days or 1 month (Niyoyita *et al.*, 2024). The risk factors for late-onset neonatal sepsis are invasive procedures such as resuscitation in the delivery room, intubation, mechanical ventilation, central venous catheters, surgical procedures, and staying in neonatal intensive care unit for prolonged period of time. Conversely, LONS results from exposure to environmental factors after birth. Pathogens get transmitted through transmission via healthcare workers, healthcare environments and other caregivers (Roble *et al.*, 2022). Immaturity of the neonatal immune system, central venous catheter and intravenous line insertion present additional pathogen entry mechanisms serving as risk factors for LOS (Raturi & Chandran 2024).

Pathogens and Resistance Patterns

In low and middle-income countries, Gram-negative bacteria such as *Klebsiella pneumoniae*, *Acinetobacter baumannii* and *Escherichia coli* in addition to *Staphylococcus aureus* are the most frequently reported cause of bacterial neonatal sepsis (Kirsty-Sands *et al.*, 2022). A meta-analysis across 24 studies on bacteriologic profiles comprising a total of 2,280 isolates found the *K. pneumoniae*, *Escherichia coli*, Coagulase negative Staphylococci (CoNS) and *Pseudomonas spp.* as the most commonly isolated pathogens. However, in the developed countries, Gram-positive organisms such as *Staphylococcus aureus* and *Streptococcus agalactiae* have been identified as the most common causative agents (Shobowale *et al.*, 2017). The organisms most implicated in EOS are *Streptococcus agalactiae* and *Escherichia coli* that account for nearly 70% of babies born prematurely and full-term neonates (Rallis *et al.*, 2023). The most implicated pathogens to LOS are coagulase-negative staphylococci (CoNS), which are responsible for 53-78% of episodes, *Staphylococcus aureus*, and Gram-negative bacteria which mainly include *Escherichia coli*, *Klebsiella spp.*, *Enterobacter spp.*, *Pseudomonas spp.*, *Citrobacter spp.*, and *Serratia spp* (Korang *et al.*, 2021). With respect to the etiology of neonatal sepsis, some studies have shown

Klebsiella species to be the predominant microorganism causing neonatal septicemia, especially late-onset sepsis (Pui-Ying *et al.*, 2023; Shobowole *et al.*, 2017). A study by Rallis *et al.* (2023) isolated the aetiological agents of neonatal sepsis from Gram positive bacteria *S. epidermidis*, *S. haemolyticus*, *S. hominis*, *S. aureus* and *Listeria*, *Enterococcus*, *faecalis*, *Klebsiella pneumoniae*, *E. coli*, *Enterobacter cloacae* for Gram Negative (Hashmi *et al.*, 2022). A study by Uwe *et al.* (2022) isolated the aetiological agents from the Gram positive group such as *S. aureus* and Coagulase Negative Staphylococci and from the Gram Negative *K. pneumoniae*, *P. auriginosa*, *E. coli*, *A. baumannii*, *P. fluorescens*, *C. freudii*, and *A. faecalis*. Another study by Qaisar *et al.* (2026) found *E. coli*, *Klebsiella* spp., *S. aureus*, *Acinetobacter* spp., *S. epidermidis*, *Enterobacter cloacae* and *Moxarella* spp. as the causative pathogens. Report by Zou *et al.* (2021) shows that most AMR pathogens exhibit high resistance to first-line drugs recommended by WHO, such as ampicillin, gentamicin, and cefotaxime, showing a multidrug-resistant (MDR) nature. A bacteriological profile of neonatal sepsis study conducted by Oboodi *et al.* (2021) found Gram positive and gram-negative organisms, of which *K. pneumonia* was more frequent among the Gram negative and *S. epidermidis* among the gram-positive organisms.

Resistance Rates

The rate of multidrug resistant organisms in neonatal intensive care unit over the last decades have been exacerbating, particularly the extended-spectrum beta-lactamase (ESBL)-producing Enterobacteriaceae, methicillin-resistant *S. aureus* (MRSA), and MDR *Acinetobacter baumannii* (Rallis *et al.*, 2023). Resistance to glycopeptides of Gram-positive strains was reported in 13% of neonatal sepsis in India and 45% in Nigeria (Poggi *et al.*, 2023). This resulted to the increase in mortality rates in infants, especially among the preterms (Rouhi *et al.*, 2022). A study in NICU by Dawood *et al.* (2017) found out that most *K. pneumoniae* and almost all *E. coli* strains were ESBL producers. *A. baumannii* and KPC-producing bacteria Enterobacteriaceae strains were much more resistant to gentamicin than amikacin (resistance rate of 76% vs. 38%) possibly because of the frequent use of gentamicin as part of empiric treatment regimens for early-onset sepsis in the facility. The study also reported that 63% of Gram-negative organisms were resistant to gentamicin.

In another study conducted in China, Panpan *et al.* (2023), Methicillin resistance was observed in 76.21% of CONS and 33.33% of *Staphylococcus aureus* strain, about 90% Coagulase negative staphylococci of the strains were resistant to penicillin, over 80% to erythromycin, 65.73% to clindamycin, and 50.81% to trimethoprim. Two Linezolid-resistant CoNS strains were detected. *Staphylococcus aureus* was found to have the highest resistance for penicillin (up to 96.67%), erythromycin (over 70%), and clindamycin (around 60%).

In another study by Sherif *et al.* (2023), Coagulase negative staphylococci (CoNS) was found to be highly resistant to ampicillin, trimethoprim, sulfamethoxazole and cloxacillin. *Klebsiella* spp were extremely resistant to gentamicin and cefotaxime. Similarly, *Acinetobacter* spp showed the highest resistance to gentamicin and trimethoprim. The predominant GNB species identified were *Klebsiella pneumoniae*, *Escherichia coli*. *E. coli* was found to be resistant to ceftazidime and cefotaxime.

Majigo *et al.* (2023) in their study found the pathogens implicated to neonatal sepsis exhibited a high resistance rate to commonly used antibiotics, and about two-thirds of the

pathogens were MDR strains. There was a high prevalence of resistance to all third and fourth-generation cephalosporins tested. Resistance to ceftriaxone was found to be 88%, cefotaxime 87%, ceftazidime 87% and cefepime was found to be 85%. Resistance to ciprofloxacin and fluoroquinolone, was observed in 42% of the organisms (Solomon *et al.*, 2021). In a cross-sectional study conducted in Nigeria by (Obadare *et al.* (2022), the resulted organisms from the Gram-negative bacteria were found to be *Acinetobacter baumannii*, *Enterobacter agglomerans*, *Klebsiella* Spp, *Providencia stuartii* and the Gram-positive Organisms *Staphylococcus aureus* CoNS and *Enterococcus*. The resistance profile reported show that 88.9% of the organisms were resistant to Ampicillin, cefuroxime 75.0%, ceftriaxone 75.0%, ciprofloxacin 52.6%, gentamicin 40.0% and 31.3% to meropenem. Four of the Gram-negative bacilli were confirmed as ESBL-and AmpC beta-lactamase producers respectively. Among Gram-positive cocci (97.6%) *Staphylococcus aureus* isolates were resistant to penicillin and 76.2 % resistant to both gentamicin and ciprofloxacin. The resistance to ceftaroline was 42.9%. *S. aureus* was susceptible to linezolid and vancomycin. Coagulase-negative *Staphylococcus* spp. showed considerable resistances to penicillin (100%), gentamicin (47.1%) and ciprofloxacin (70.6%), 85.7% *Staphylococcus aureus* and 52.9% CoNS were methicillin-resistant. A report by Hashmi *et al.* (2020) found the causative agents of neonatal sepsis to be highly resistant to common antibiotics like cefotaxime, gentamicin, ciprofloxacin and chloramphenicol and susceptibility was observed with carbapenems and colomycin for gram negative organisms and vancomycin for Gram positive organisms (Hashmi *et al.*, 2020).

Current Antibiotic Practices and Challenges

The World Health Organization (WHO) recommends the use of gentamicin with either ampicillin or benzylpenicillin as first-line treatment for neonatal and paediatric sepsis in resource-limited settings, with ceftriaxone as recommended second-line therapy (Wen *et al.*, 2021). The UNICEF handbook of neonatal infection (2018) published first time in 2005 highlighted the treatment for the young infants 0–59 days old with clinical severe infection with two recommended regimens: Oral amoxicillin twice daily for 7 days plus injectable gentamicin once daily for 7 days and Oral amoxicillin twice daily for 7 days plus injectable gentamicin once daily for 2 days. The World Health Organization (WHO) recommends a combination of gentamicin and benzylpenicillin or ampicillin as first line antibiotic therapy to treat neonatal sepsis in infants younger than two months. Solomon *et al.* (2021) highlighted this regimen, which can be administered intravenously or intramuscularly as a commonly recommended treatment approach in infants under two months. Third-generation cephalosporins, such as cefotaxime, ceftriaxone, and ceftazidime, are frequently used alternatives when resistance to first-line antibiotics is suspected.

Aline *et al.* (2018) reported that the recommendations for preventing neonatal infection and for the management of possible serious bacterial infection remain the same in WHO second edition. It recommends providing prophylactic intramuscular (IM) or intravenous (IV) ampicillin and gentamicin in neonates with documented risk factors for infection for at least 2 days and then to reassess and third-generation cephalosporin monotherapy.

Alternatives

Some studies have attributed high resistance to commonly used antibiotics for the empirical treatment of neonatal sepsis to the widespread use of third-generation cephalosporins, lack of reliability on blood culture and inappropriate therapeutic regimens (Shobowale *et al.*, 2017). Maternal intrapartum intravenous antibiotic administration with penicillin (or clindamycin for those with serious penicillin allergy) should ideally be given for at least 4 hours prior to time of delivery to target GBS in mothers with established GBS infection or those with relevant EOS risk factors. In those with suspected EOS, before confirmatory tests, broad-spectrum antimicrobials should be used. A combination of intravenous aminoglycoside and either ampicillin (Raturi & Chandran 2024). In the last two decades, colistin is the main antimicrobial used for the treatment of sepsis caused by *P. aeruginosa*, *A. baumannii*, and Clindamycin Resistant-Enterococci in newborns in the last two decades, with 75–100% of clinical success (Poggi *et al.*, 2023).

RESULTS AND DISCUSSION

Drivers of AMR

Beyond the existing burden of neonatal sepsis, the continued emergence and re-emergence of antimicrobial resistance among causative pathogens poses a serious threat to effective treatment and neonatal survival. (Geyesus *et al.*, 2017). The pathogens that because neonatal sepsis have in the last decade shown increasing resistance to the commonly used empirical antibiotherapeutic agents. The improper use of antibiotics for sepsis treatment has led to the escalation of antimicrobial resistance (AMR), and that has contributed to an increased neonatal mortality by 30% (Russell *et al.*, 2023), and in some sub-Saharan African countries there are records of increased rates of resistance to first-line and alternative therapies (Solomon *et al.*, 2021). The recurrent administration of antibiotics in the absence of bacteriological and susceptibility data has been shown to be a driver of AMR in neonatal sepsis (Fajolu *et al.*, 2022).

In a report by the representatives of the African Neonatal Association towards the possible reasons for the exacerbation of AMR in sub-Saharan Africa, three major issues were highlighted: the inability to periodically update the WHO-recommended first-line antibiotic regimen for neonatal sepsis, the limited microbiological diagnostic capacity in low-resource settings especially outside of central hospital and the lack of resources for the implementation of infection prevention and control guidelines. Other highlighted setbacks included were the limited capacity to conduct infection surveillance, and evaluate the effect of infection prevention and control interventions (Pui-Ying *et al.*, 2023). A study conducted by Thaulow *et al.* (2019) found that 77% of antibiotic courses administered to suspected cases of EOS were given to infants without confirmed infections, which further drives resistance. Another study highlighted the microbial factor such as mobile genetic elements which can easily transfer new resistance genes amongst GNB (An *et al.*, 2022). For instance, the plasmid-mediated transfer of resistance genes for extended-spectrum beta-lactamases has been documented between *Escherichia coli* and *Klebsiella pneumoniae*, as well as among other organisms within the Enterobacteriaceae family (Solomon *et al.*, 2021). The increased rate of antimicrobial resistance (AMR) has been associated with frequent antibiotic use, insufficient sanitation and hygiene and poor compliance with infection control methods. (Panpan *et al.*, 2023; Founou *et al.*, 2026). In the Nigeria, factors like lack of hygienic water and sanitation, high poverty rate and inadequate infection control, have

contributed to the spread of microorganisms and resistant strains (Ajekiigbe *et al.*, 2025). Other factors include inadequate healthcare infrastructures, poor policies and regulations (Fajolu *et al.*, 2022).

Emerging Antibiotic Treatment Strategies

The resistance mechanisms against newer antibiotics, such as B-lactamases, frequently transmit resistance to earlier antibiotics in the same class. In terms of B-lactams, recently developed antibiotics comprise either novel cephalosporins or novel B-lactam inhibitors paired with existing B-lactams. Cephalosporins that have recently been developed include ceftobiprole, ceftaroline, cefiderocol, and ceftolozane, which is available in conjunction with tazobactam. Ceftobiprole is a fifth generation cephalosporin and the first B-lactam to show antimicrobial efficacy against MRSA and VRSA *in vitro* (Sharma *et al.*, 2024). The treatment for LOS infections should normally be from incidence-data from local hospital boards. Recently there has been reports of high efficacy in the use of cephalosporins and vancomycin against the beta-lactamase-producing *Staphylococcus* bacteria more frequently encountered in EOS (Fajolu *et al.*, 2022).

Adjunctive Therapies

Adjuvant therapies are crucial strategies in reducing incidence rate of neonatal sepsis. Steroids have been shown to improve outcome in preterm infants (Shobowale *et al.*, 2017). Stewardship of antibiotics and use with caution steroids (pre- and postnatal administration) and proton pump inhibitors (PPIs) are of great import efforts to reduce prematurity rates, such as by improving maternal nutritional status and broader prenatal care. The use of probiotics and enzymes to promote animal growth and health as healthier alternative to antibiotic has been found to be a healthier alternative (Lloyd *et al.*, 2024). Probiotics, prebiotics, and lactoferrin are being researched for their possible use in preventing LOS and necrotizing enterocolitis (Kariniotaki *et al.*, 2025). Maternal vaccination during pregnancy against diseases that can cause sepsis (such as influenza, Bordetella pertussis, and RSV) can also offer protection via placental transfer of maternally derived antibodies as well as prenatal counseling of the mothers have proved helpful (Kariniotaki *et al.*, 2025). Efforts to reduce prematurity rates, such as by improving maternal nutritional status and broader prenatal care, may also reduce neonatal sepsis incidence (Raturi *et al.*, 2024).

Diagnostic Advancements and Barriers

Emerging Technologies

One of the major contributors to the death of neonates has been found to be late or missed diagnosis. This has led to recent research into the discovery of novel biomarkers that will help in the diagnosis of neonatal sepsis. A member of the transforming growth factor- β (TGF- β) cytokine family, and serum amyloid A, have shown higher sensitivity compared to more widely used markers (Raturi & Chandran 2024). Compared to blood culture, molecular testing with polymerase chain reaction (PCR) and deoxyribonucleic acid microarray can detect sepsis with improved sensitivity and specificity. Another study shows that microarray methods have been reported to deliver 100% sensitivity and 97.9% specificity, showing promise in terms of rapid detection of even lower concentrations (Glaser *et al.*, 2020). Recent advancements in automated blood culture systems, which continuously monitor cultures for signals indicative microbial growth, have improved the speed of pathogens detection and enabled earlier identification of bloodstream infections

(Glaser *et al.*, 2020). Matrix-assisted laser desorption ionization time-of-flight (MALDI-TOF) mass spectroscopy can identify organisms in blood cultures much earlier, allowing antibiotic therapy specific to the organism(s) involved (Ershad *et al.*, 2019). Another automated technology for diagnosis of neonatal sepsis is the use of T2MR, a direct molecular assay that utilizes magnetic resonance technology to identify the presence of pathogens in the bloodstream. A study by Lucignano *et al.* (2022) diagnosed 754 children and 27 neonates with neonatal sepsis in a pediatric ward with T2Bacteria and T2Candida panels and reported as 84.2% and 100%, with 85.9% and 94.1%, sensitivities respectively. The advancements of technology led to the use of internet of things (IoT) platform with wearable technology, cloud computing, and other innovations to reduce workload on medical personnels, to improve the coordination of antenatal care, facilitate timely sharing of clinical information, and enhance obstetrical treatment and follow-up to mitigate neonatal sepsis risks (Khan *et al.*, 2022).

Implementation Challenges

Microbiological testing is an essential diagnostic tool for bacterial infections and for getting AMR data. The scarcity of affordable diagnostic tools and facilities is one of the key elements that leads to inadequate surveillance in low-resource settings (Shobowale *et al.*, 2017; Ajekiigbe *et al.*, 2025)). Whilst the use of molecular techniques offers the ability to improve timely diagnosis of neonatal sepsis, sustainability in many LMICs hospitals will be difficult considering the cold-chain transport logistics, reagent shelf life, constant provision of electricity and cold storage at site (Kirsty-Sands *et al.*, 2022). In low and middle-income populations, microbiological testing is an essential diagnostic tool for bacterial infections and a means of getting AMR data. Improving current diagnostic tools for identifying bacterial infections and generating accurate data on the spot is the bedrock of a robust AMR surveillance system (Ajekiigbe *et al.*, 2025; Him *et al.*, 2026). Nigeria continues to face a critical shortage of healthcare workers, with a doctor-to-patient ratio of approximately 1:5000, far below the WHO's recommendation of 1:600 (Akpulu *et al.*, 2025).

Systemic Challenges

Healthcare Infrastructure

Healthcare infrastructure deficiencies pose significant challenges to the effective prevention, diagnosis, and management of neonatal sepsis in resource-limited settings (Bech *et al.*, 2021). At the facility level, inadequate bed capacity can restrict access to neonatal care, with one hospital-based study reporting that limited bed space had previously forced healthcare workers to turn away neonates (Hashmi *et al.*, 2020). Beyond physical capacity, unreliable and intermittent electricity supply remains a major infrastructural constraint across many African countries, disrupting the operation of essential diagnostic equipment and other critical medical devices (Akpulu *et al.*, 2025). These infrastructural limitations can further complicate antimicrobial treatment decisions. Where laboratory capacity for antimicrobial susceptibility testing is inadequate or unavailable, clinicians may be unable to identify the causative organisms and determine their susceptibility profiles (Coetzee *et al.*, 2017). Consequently, broad-spectrum antibiotics may be prescribed empirically, even when narrower-spectrum agents would be more appropriate, potentially increasing selective pressure for antimicrobial resistance (Ajekiigbe *et al.*, 2025). Furthermore, deficiencies in infection prevention and control can compound these

challenges. Folgori and Bielicki (2019) reported suboptimal hygiene practices and identified understaffing among the factors associated with infection outbreaks. Such conditions may undermine the consistent implementation of infection prevention protocols, increase the risk of healthcare-associated infections, and further strain already limited neonatal care resources.

Policy and Stewardship Gaps

In Nigeria, inadequate regulation and oversight of antibiotic distribution and utilization contribute to inappropriate antibiotic use, which is a major driver of resistance (Olagunju *et al.*, 2025). While that of the public can be hinged on self-medication as a result of the availability of over-the-counter antibiotics, the misuse by healthcare providers could be traced to weak regulatory mechanisms and limited knowledge in the face of unequally distributed resources (Mustefa *et al.*, 2020). Other drivers of antimicrobial resistance include inadequate "one health" integration of animal and human local disease surveillance systems, absence of a local antimicrobial resistance laboratory surveillance system, and absence of focused funding for antimicrobial resistance control tasks (Fajolu *et al.*, 2022). The lack of local infection prevention and control (IPC) integration guidelines and inadequate budgetary aid for IPC tasks in health facilities, the inadequacy of antimicrobial stewardship in both the public and private sectors, and weak integration of further research on antibiotic use contribute to the dilemma of resistance to locally available antibiotic agents (Ajekiigbe *et al.*, 2025).

RECOMMENDATIONS

Short-Term Solutions

- i. Sustaining diagnostic capacity in resource-limited settings requires dependable access to infrastructure, equipment, reagents, trained laboratory personnel and uninterrupted diagnostic services.
- ii. Installation of solar-powered devices to enhance sustainability, and strengthening local research and sustainable clinical services becomes necessary in resource-constrained settings
- iii. There is need to improve current diagnostic tools for identifying bacterial infections while generating accurate data on the spot is the bedrock of a robust AMR surveillance system.
- iv. There is need to put in strategies to address broader Infection prevention and control implementation.
- v. Straightening maternal screening, aseptic practices of delivery and providing early neonatal infection-prevention measures

Long-Term Strategies

- vi. Vaccination of pregnant women against GBS could result in reduction in pre-term deliveries and stillbirths
- vii. Improved knowledge, awareness and understanding of healthcare workers through education and training to mitigate the spread and delay of further development of antibiotic resistance.
- viii. Antimicrobial stewardship programmes should include nurses and community health extension workers to further deepen their understanding of prescription guidelines and antibiotic resistance
- ix. Educational programmes through community outreaches and the media to increase awareness of antibiotic resistance is needed to portray AMR as a public health issue.

- x. Regulatory frameworks can be reinforced by enhancing the public's knowledge of antibiotics and antimicrobial resistance and supporting antibiotic stewardship.
- xi. The government can assist in alleviating this national burden by constructing laboratory infrastructure and promoting diagnostic stewardship, enacting one health plan.
- xii. Sufficient funding should be provided to medical regulatory bodies and pharmaceutical companies as well and

CONCLUSION

Neonatal sepsis in Nigeria demands urgent action against AMR through multidisciplinary strategies. The misuse and overuse of antibiotics are leading drivers of resistance in neonatal sepsis. While emerging antibiotics and diagnostics offer hope, sustained investment in healthcare infrastructure, stewardship, and research is critical to reducing mortality. The current reliance on outdated empirical therapies in the face of widespread resistance highlights the urgent need for evidence-based antibiotic policies and innovative treatment strategies. Emerging therapeutics, probiotics, and molecular diagnostic tools demonstrate significant promise, yet their impact will remain limited without investments in healthcare infrastructure, workforce training, and sustainable funding strategies. Tackling neonatal sepsis requires more than clinical interventions but involves coordinated, multisectoral approach that integrates antimicrobial stewardship, surveillance of AMR, maternal preventive strategies, and the political will to strengthen neonatal intensive care systems. If Nigeria can align these strategies with global best practices and foster long-term research and innovation, the disastrous burden of neonatal sepsis can be significantly reduced. Addressing this challenge is not only a medical necessity but also a public health priority, essential for safeguarding the survival and well-being of the nation's most vulnerable population.

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REFERENCES

- Akindolire, A. E., Tongo, O., Dada-Adegbola, H., & Akinyinka, O. (2016). Etiology of early onset septicemia among neonates at the University College Hospital, Ibadan, Nigeria. *Journal of Infection in Developing Countries*, 10(12), 1338–1344. <https://doi.org/10.3855/jidc.7830>
- Akpulu, C., Yakubu, R., Tukur, F., Yusuf, A. H., Kassim, A., Mukaddas, A., Adeleye, A., Alkali, F., Maduekwe, A. O., Nsude, Q., Asunugwo, V., Okenu, M.-J., Yakubu, S., Audu, L., Amsa, M., Modibbo, F. I., Thomson, K., Achi, C. R., Iregbu, K. C., ... Sands, K. (2025). Beyond the samples: Nigerian research staff perspectives on a multicentre neonatal sepsis study's impact. *Nature Communications*, 16(6745). <https://doi.org/10.1038/s41467-025-62102-4>
- Fuchs, A., Bielicki, J., Mathur, S., Sharland, M., & Van Den Anker, J. N. (2018). Reviewing the WHO guidelines for antibiotic use for sepsis in neonates and children. *Paediatrics*

and *International Child Health*, 38(1), S3–S15. <https://doi.org/10.1080/20469047.2017.1408738>

Almilhem, A., Moustafa, D. M., Nached, I., Ali, Y., Khalaf, M., Ismail, H., Azzam, A., & Alkhaaldi, A. (2026). Predictors of time to positive blood culture in neonatal sepsis and its utility as a guide for optimizing antibiotic duration. *Journal of Pediatric Infectious Diseases*, 21(3), 172–181. <https://doi.org/10.53391/1305-7707.1058>

An, H., Zheng, W., Zhu, Q., & Chai, Y. (2022). A retrospective study of risk factors for early-onset neonatal sepsis with intrapartum maternal fever. *PeerJ*, 10(3834). <https://doi.org/10.7717/peerj.13834>

Bech, C. M., Stensgaard, C. N., Lund, S., Holm-Hansen, C., Brok, J. S., Nygaard, U., & Poulsen, A. (2022). Risk factors for neonatal sepsis in Sub-Saharan Africa: A systematic review with meta-analysis. *BMJ Open*, 12(9), 54–56. <https://doi.org/10.1136/bmjopen-2021-054491>

Coetzee, M., Mbowane, N., & de Witt, T. (2017). Neonatal sepsis: Highlighting the principles of diagnosis and management. *South African Journal of Child Health*, 11(2), 99–103. <https://doi.org/10.7196/SAJCH.2017.v11i2.1244>

Dawood, Y., Shalakhti, T., Awad, S., Algharaibeh, H., & Khasawneh, W. (2018). Characteristics and epidemiology of sepsis in the special care baby unit in the era of multidrug-resistant organisms: A retrospective review. *Pediatrics & Neonatology*, 59(1), 35–41. <https://doi.org/10.1016/j.pedneo.2017.06.001>

Ershad, M., Mostafa, A., Dela Cruz, M., & Vearrier, D. (2019). Neonatal sepsis. *Current Emergency and Hospital Medicine Reports*, 7(3), 83–90. <https://doi.org/10.1007/s40138-019-00188-z>

Fajolu, I. B., Satrom, K. M., Ezenwa, B. N., Kein, A. C., Slusher, T. M., & Ezeaka, V. C. (2022). Current trends in neonatal morbidity and mortality: Experiences from a tertiary center in Lagos, Nigeria. *The American Journal of Tropical Medicine and Hygiene*, 107(3), 617–623. <https://doi.org/10.4269/ajtmh.22-0009>

Folgori, L., & Bielicki, J. (2019). Future challenges in pediatric and neonatal sepsis: Emerging pathogens and antimicrobial resistance. *Journal of Pediatric Intensive Care*, 8(1), 17–24. <https://doi.org/10.1055/s-0038-1677535>

Founou, L. L., Founou, R. C., Charani, E., Gwanyama, N., Dramowski, A., & Feasey, N. (2026). Neonatal sepsis in Africa: What are we missing? *The Lancet Microbe*, 7(7), Article 101374. <https://doi.org/10.1016/j.lanmic.2026.101374>

Geyesus, T., Feleke, M., Setegn, E., Biruk, Y., & Ebba, A. (2017). Bacterial etiologic agents causing neonatal sepsis and associated risk factors in Gondar, Northwest Ethiopia. *BMC Pediatrics*, 17 Article 137. <https://doi.org/10.1186/s12887-017-0892-y>

Glaser, M. A., Hughes, L. M., Jnah, A., & Newberry, D. (2021). Neonatal sepsis: A review of pathophysiology and current management strategies. *Advances in Neonatal Care*, 21(1), 49–60. <https://doi.org/10.1097/ANC.0000000000000769>

- Hashmi, M. A., Lodhi, M. A., Toor, K. M., Tahir, A., Khan, H. S., & Aziz, R. (2020). Emerging antimicrobial resistance in neonatal sepsis. *Journal of the College of Physicians and Surgeons Pakistan*, 30(12), 1312–1315. <https://doi.org/10.29271/jcpsp.2020.12.1312>
- Him, R. L., Sihota, D., Harrison, L., Dramowski, A., Coffin, S. E., Hamer, D. H., & Bhutta, Z. A. (2026). Strategies to reduce antimicrobial resistance in newborns in low-income and middle-income countries: A systematic review and meta-analysis. *The Lancet Global Health*, 14(4), e524–e538. [https://doi.org/10.1016/S2214-109X\(25\)00533-9](https://doi.org/10.1016/S2214-109X(25)00533-9)
- Kariniotaki, C., Thomou, C., Gkentzi, D., Panteris, E., Dimitriou, G., & Hatzidaki, E. (2025). Neonatal sepsis: A comprehensive review. *Antibiotics*, 14(1), Article 6. <https://doi.org/10.3390/antibiotics14010006>
- Khan, M., Khurshid, M., Vatsa, M., Singh, R., Duggal, M., & Singh, K. (2022). On AI approaches for promoting maternal and neonatal health in low resource settings: A review. *Frontiers in Public Health*, 10, Article 880034. <https://doi.org/10.3389/fpubh.2022.880034>
- Sands, K., Spiller, O. B., Thomson, K., Portal, E. A. R., Iregbu, K. C., & Walsh, T. R. (2022). Early-onset neonatal sepsis in low- and middle-income countries: Current challenges and future opportunities. *Infection and Drug Resistance*, 933–946. <https://doi.org/10.2147/IDR.S294156>
- Lloyd, L. G., Dramowski, A., Bekker, A., Ballot, D. E., Ferreyra, C., Gleeson, B., Nana, T., Sharland, M., Velaphi, S. C., Wadula, J., Whitelaw, A., & van Weissenbruch, M. M. (2024). Multicentre external validation of the Neonatal Healthcare-associated infectiOn Prediction (NeoHoP) score: A retrospective case-control study. *BMJ Paediatrics Open*, 8(1), e002748. <https://doi.org/10.1136/bmjpo-2024-002748>
- Lucignano, B., Cento, V., Agosta, M., Ambrogio, F., Albitar-Nehme, S., Mancinelli, L., Mattana, G., Onori, M., Galaverna, F., Di Chiara, L., Fragasso, T., Bianchi, R., Tortora, F., Auriti, C., Dotta, A., Cecchetti, C., Perdicchizzi, S., Raponi, M., Onetti Muda, A., ... Bernaschi, P. (2022). Effective rapid diagnosis of bacterial and fungal bloodstream infections by T2 magnetic resonance technology in the pediatric population. *Journal of Clinical Microbiology*, 60(10), Article e00292-22. <https://doi.org/10.1128/jcm.00292-22>
- Majigo, M., Makupa, J., Mwazyunga, Z., Luoga, A., Kisinga, J., Mwamko, B., Kim, S., & Joachim, A. (2023). Bacterial aetiology of neonatal sepsis and antimicrobial resistance pattern at the regional referral hospital, Dar es Salaam, Tanzania: A call to strengthening antibiotic stewardship program. *Antibiotics*, 12(4), Article 767.
- Medugu, N., Iregbu, K., Iroh Tam, P.-Y., & Obaro, S. (2018). Aetiology of neonatal sepsis in Nigeria, and relevance of Group B streptococcus: A systematic review. *PLOS ONE*, 13(7), Article e0200350. <https://doi.org/10.1371/journal.pone.0200350>
- Mustefa, A., Abera, A., Aseffa, A., Abathun, T., Degefa, N., Tadesse, H., & Yeheyis, T. (2020). Prevalence of neonatal sepsis and associated factors amongst neonates admitted in Arbaminch General Hospital, Arbaminch, Southern Ethiopia, 2019. *Journal of Pediatrics & Neonatal Care*, 10(1), 1–7. <https://doi.org/10.15406/jpnc.2020.10.00404>
- Niyoyita, J. C., Ndayisenga, J., Omolo, J., Niyompano, H., Bimenyimana, P. C., Dzinamarira, T., Nsekuye, O., Chavez, I., & Hakizayezu, F. (2024). Factors associated with neonatal sepsis among neonates admitted in Kibungo Referral Hospital, Rwanda. *Scientific Reports*, 14, Article 15961. <https://doi.org/10.1038/s41598-024-66818-z>
- Obadare, T. O., Adejuyigbe, E. A., Adeyemo, A. T., Amupitan, A. A., Ugowe, O. J., Anyabolu, C. H., & Aboderin, A. O. (2023). Clinical and bacteriological profiles of neonatal sepsis in a tertiary hospital, south-western Nigeria. *Germs*, 13(2), 137–150. <https://doi.org/10.18683/germs.2023.1377>
- Obaro, H. K., Abdulkadir, B., & Samaila, A. (2022). In vitro antibiotic susceptibility of bacterial pathogens and risk factors associated with culture-positive neonatal sepsis in two hospitals, Katsina metropolis, Nigeria. *African Journal of Clinical and Experimental Microbiology*, 23(4), 378–388. <https://doi.org/10.4314/ajcem.v23i4.6>
- Oboodi, R., Hashemi, Z., Jaafarzadeh, E., Yazdani, N., & Barzegar, H. (2024). Bacterial etiology and antibiotic susceptibility profile in neonatal sepsis. *Archives of Pediatric Infectious Diseases*, 12(1), e136487. <https://doi.org/10.5812/apid-136487>
- Ogbara, C. N., Chime, H. E., & Nwose, E. U. (2021). Neonatal sepsis in Nigeria 2: Narrative review of epidemiology and socioeconomic factors. *Biomedical Journal of Scientific & Technical Research*, 36(2). <https://doi.org/10.26717/BJSTR.2021.36.005815>
- Olorukooba, A. A., Ifusemu, W. R., Ibrahim, M. S., Jibril, M. B., Amadu, L., & Lawal, B. B. (2020). Prevalence and factors associated with neonatal sepsis in a tertiary hospital, North West Nigeria. *Nigerian Medical Journal*, 61(2), 60–66. https://doi.org/10.4103/nmj.NMJ_31_19
- Fang, P., Gao, K., Yang, J., Li, T., Gong, W., Sun, Q., & Wang, Y. (2023). Prevalence of multidrug-resistant pathogens causing neonatal early and late onset sepsis, a retrospective study from the tertiary referral children's hospital. *Infection and Drug Resistance*, 16(1), 4213–4225. <https://doi.org/10.2147/IDR.S416020>
- Patritia, E. I., Abiodun, J. K., Akinbowale, R. E., & Ebunoluwa, A. A. (2022). Bacteriology of neonatal sepsis in a hospital in southwest Nigeria. *Microbes and Infectious Diseases*, 4(3), 943–953. <https://doi.org/10.21608/MID.2022.129005.1262>
- Pillay, K., Ray-Chaudhuri, A., O'Brien, S., Heath, P., & Sharland, M. (2024). *Acinetobacter* spp. in neonatal sepsis: An urgent global threat. *Frontiers in Antibiotics*, 3(2), Article 1448071. <https://doi.org/10.3389/frabi.2024.1448071>
- Iroh Tam, P.-Y., Bekker, A., Bolaji, O. B., Chimhini, G., Dramowski, A., Fitzgerald, F., Gezmu, A. M., Nkuranga, J. B., Okomo, U., Stevenson, A., & Stryko, J. P. (2023). Neonatal sepsis and antimicrobial resistance in Africa. *The Lancet Child & Adolescent Health*, 7(10), 677–679. [https://doi.org/10.1016/S2352-4642\(23\)00167-0](https://doi.org/10.1016/S2352-4642(23)00167-0)

- Qaisar, I., Ahmed, I., Hussain, A., Ullah, I., Rafique, A., & Sheikh, S. A. (2026). Microbial profiles and antibiotic resistance patterns in neonatal sepsis: A frequency analysis. *Pakistan Journal of Health Sciences*, 7(7), 98–102. <https://doi.org/10.54393/pjhs.v7i7.2663>
- Rallis, D., Giapros, V., Serbis, A., Kosmeri, C., & Baltogianni, M. (2023). Fighting antimicrobial resistance in neonatal intensive care units: Rational use of antibiotics in neonatal sepsis. *Antibiotics*, 12(3), Article 508. <https://doi.org/10.3390/antibiotics12030508>
- Raturi, R., & Chandran, S. (2024). Neonatal sepsis: Aetiology, pathophysiology, diagnostic advances and management strategies. *Clinical Medicine Insights: Pediatrics*, 18, 1–11. <https://doi.org/10.1177/11795565241281337>
- Roble, A. K., Ayehubizu, L. M., & Olad, H. M. (2022). Neonatal sepsis and associated factors among neonates admitted to special care baby unit in general hospitals, Eastern Ethiopia, 2020. *Clinical Medicine Insights: Pediatrics*, 16, Article 11795565221098346. <https://doi.org/10.1177/11795565221098346>
- Rosa-Mangeret, F., Dupuis, M., Dewez, J. E., Muhe, L. M., Wagner, N., & Pfister, R. E. (2024). Challenges and opportunities in neonatal sepsis management: Insights from a survey among clinicians in 25 Sub-Saharan African countries. *BMJ Paediatrics Open*, 8(1), Article e002398. <https://doi.org/10.1136/bmjpo-2023-002398>
- Rouhi, S., Nachate, S., Lamrani Hanchi, A., Bennaoui, F., Slitine, N., Maouainine, F. M. R., & Soraa, N. (2022). Neonatal septicemia: Clinical and epidemiological features. *Saudi Journal of Pathology and Microbiology*, 7(4), 180–185. <https://doi.org/10.36348/sjpm.2022.v07i04.005>
- Sharma, S., Chauhan, A., Ranjan, A., Mathkor, D. M., Haque, S., Ramniwas, S., Tuli, H. S., Jindal, T., & Yadav, V. (2024). Emerging challenges in antimicrobial resistance: Implications for pathogenic microorganisms, novel antibiotics, and their impact on sustainability. *Frontiers in Microbiology*, 15, Article 1403168. <https://doi.org/10.3389/fmicb.2024.1403168>
- Sherif, M., Abera, M., & Desta, K. (2023). Prevalence and antibiotic resistance pattern of bacteria from sepsis-suspected neonates at St. Paul's Hospital Millennium Medical College, Addis Ababa, Ethiopia. *BMC Pediatrics*, 23, Article 575. <https://doi.org/10.1186/s12887-023-04399-y>
- Shobowale, E. O., Solarin, A. U., Elikwu, C. J., Onyedibe, K. I., Akinola, I. J., & Faniran, A. A. (2017). Neonatal sepsis in a Nigerian private tertiary hospital: Bacterial isolates, risk factors, and antibiotic susceptibility patterns. *Annals of African Medicine*, 16(2), 52–58. https://doi.org/10.4103/aam.aam_34_16
- Solomon, S., Akeju, O., Odumade, O. A., Ambachew, R., Gebreyohannes, Z., Van Wickle, K., et al. (2021). Prevalence and risk factors for antimicrobial resistance among newborns with Gram-negative sepsis. *PLOS ONE*, 16(8), Article e0255410. <https://doi.org/10.1371/journal.pone.0255410>
- Thaulow, C. M., Berild, D., Blix, H. S., Brigtsen, A. K., Myklebust, T. Å., & Eriksen, B. H. (2019). Can we optimize antibiotic use in Norwegian neonates? A prospective comparison between a university hospital and a district hospital. *Frontiers in Pediatrics*, 7, Article 440. <https://doi.org/10.3389/fped.2019.00440>
- Uwe, N. O., Ezenwa, B. N., Fajolu, I. B., Oshun, P., Chukwuma, S. T., & Ezeaka, V. C. (2022). Antimicrobial susceptibility and neonatal sepsis in a tertiary care facility in Nigeria: A changing trend? *JAC-Antimicrobial Resistance*, 4(5), Article dlac100. <https://doi.org/10.1093/jacamr/dlac100>
- Wen, S. C. H., Ezure, Y., Rolley, L., Spurling, G., Lau, C. L., Riaz, S., Paterson, D. L., & Irwin, A. D. (2021). Gram-negative neonatal sepsis in low- and lower-middle-income countries and WHO empirical antibiotic recommendations: A systematic review and meta-analysis. *PLOS Medicine*, 18(9), Article e1003787. <https://doi.org/10.1371/journal.pmed.1003787>
- Agnche, Z., Yeshita, H. Y., & Gonete, K. A. (2020). Neonatal sepsis and its associated factors among neonates admitted to neonatal intensive care units in primary hospitals in Central Gondar Zone, Northwest Ethiopia, 2019. *Infection and Drug Resistance*, 3957–3967. <https://doi.org/10.2147/IDR.S276678>
- Zou, H., Jia, X., He, X., Su, Y., Zhou, L., Shen, Y., Sheng, C., Liao, A., Li, C., & Li, Q. (2021). Emerging threat of multidrug-resistant pathogens from neonatal sepsis. *Frontiers in Cellular and Infection Microbiology*, 11, Article 694093. <https://doi.org/10.3389/fcimb.2021.694093>
- Pius, S., Bello, M., Mava, Y., Ibrahim, B. A., Faruk, A. G., & Ambe, J. P. (2016). Factors influencing neonatal septicaemia in Maiduguri, North-Eastern Nigeria. *African Journal of Clinical and Experimental Microbiology*, 17(2), 110–115. <https://doi.org/10.4314/ajcem.v17i2.6>
- Korang, S. K., Safi, S., Nava, C., Greisen, G., Gupta, M., Lausten-Thomsen, U., & Jakobsen, J. C. (2021). Antibiotic regimens for late-onset neonatal sepsis. *Cochrane Database of Systematic Reviews*, 2021(5), Article CD013836. <https://doi.org/10.1002/14651858.CD013836>
- Russell, N. J., Stöhr, W., Plakkal, N., Cook, A., Berkley, J. A., Adhisivam, B., Agarwal, R., Ahmed, N. U., Balasegaram, M., Ballot, D., Bekker, A., Berezin, E. N., Bilardi, D., Boonkasidecha, S., Carvalho, C. G., Chami, N., Chaurasia, S., Chiurchiu, S., Colas, V. R. F., ... Sharland, M. (2023). Patterns of antibiotic use, pathogens, and prediction of mortality in hospitalized neonates and young infants with sepsis: A global neonatal sepsis observational cohort study (NeoOBS). *PLOS Medicine*, 20(6), Article e1004179. <https://doi.org/10.1371/journal.pmed.1004179>
- Olagunju, O. J., Ben, E., Olagunju, O., Majolagbe, O. G., Osanyinlusi, O. O., Adewoye, T., Atoyebi, O. F., Ojo, I. O., & Dawha, S. D. (2025). Poorly regulated antibiotic use in Nigeria: A critical public health concern and its impact on medical practice. *Cureus*, 17(6), Article e85212. <https://doi.org/10.7759/8521>

