**COMPARATIVE ANALYSIS OF THE STRENGTH OF THE THREE MOST COMMONLY USED ANTIBIOTICS IN IBADAN: CIPROFLOXACIN, CEFTRIAXONE, AND AMOXICILLIN**

**ABSTRACT**

This study investigates the comparative strength and efficacy of three commonly used antibiotics—Ciprofloxacin, Ceftriaxone, and Amoxicillin—against prevalent bacterial pathogens in Ibadan, Nigeria. Given the alarming rise of antibiotic resistance, which threatens the effectiveness of these critical treatments, this research employs a multifaceted approach, integrating microbiological principles, pharmacokinetics, and clinical outcomes to evaluate antibiotic strength comprehensively. The study utilized a cross-sectional design, involving the collection and analysis of clinical isolates from patients presenting with bacterial infections. Minimum inhibitory concentrations (MICs) were determined using standardized broth microdilution techniques to assess the effectiveness of each antibiotic. Additionally, sensitivity testing was conducted to evaluate the resistance patterns of isolated strains, providing insight into the clinical implications of antibiotic use in the region. Results indicated significant variations in the efficacy of the antibiotics studied. Ciprofloxacin exhibited robust activity against Gram-negative bacteria, although resistance rates were concerning, particularly among uropathogenic strains. Ceftriaxone demonstrated broad-spectrum efficacy but showed susceptibility to ESBL-producing organisms, limiting its utility in certain cases. Amoxicillin remained effective against common pathogens; however, rising beta-lactamase production posed challenges to its use. The findings underscore the urgent need for effective antimicrobial stewardship programs to combat the rising threat of antibiotic resistance. By understanding the pharmacodynamics and clinical effectiveness of these antibiotics, healthcare providers can make informed decisions regarding treatment options. This study contributes to the growing body of literature on antibiotic efficacy in local contexts, highlighting the importance of ongoing surveillance and research to inform public health strategies.

**Keywords:** *Antibiotic resistance, Ciprofloxacin, Ceftriaxone, Amoxicillin, Efficacy, Microbial sensitivity, Public health.*

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# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of the Study

Antibiotics, especially Ciprofloxacin, Ceftriaxone, and Amoxicillin, play a vital role in managing bacterial infections, particularly in areas with limited healthcare resources. The development and assessment of these antibiotics are crucial, as they show varying levels of effectiveness against common pathogens, including Staphylococcus aureus and Escherichia coli—both prevalent in clinical settings (Oleghe et al., 2020). Antibiotic efficacy is often measured by its "zone of inhibition" in in vitro studies, showing the extent of bacteria suppression (ResearchGate, 2020). Studies reveal that while Ciprofloxacin is highly effective against a broad spectrum of Gram-positive and Gram-negative bacteria, its efficacy varies based on bacterial resistance patterns and the environment in which it’s deployed (Oleghe et al., 2020; Mathews Open Access, 2020).

Ceftriaxone, a third-generation cephalosporin, has demonstrated reliable results against Gram-negative bacteria, while Amoxicillin, a penicillin-class antibiotic, remains a standard treatment for respiratory and urinary infections, though its use is sometimes limited by bacterial resistance (Mathews Open Access, 2020). This study seeks to identify the comparative strength of these antibiotics by evaluating their minimum inhibitory concentrations (MIC) and zones of inhibition on targeted bacteria, following standards set by the Clinical and Laboratory Standards Institute (CLSI).

## 1.2 Statement of the Problem

With rising antibiotic resistance, particularly in sub-Saharan Africa, determining the efficacy of widely prescribed antibiotics is essential. This study addresses the urgent need to assess Ciprofloxacin, Ceftriaxone, and Amoxicillin, which are commonly administered in Ibadan, to ensure optimal treatment outcomes and reduce resistance risks. Resistance can complicate infection control and lead to prolonged hospitalizations and healthcare costs, posing a significant problem in medical practice and policy (ResearchGate, 2020).

## 1.3 Research Questions

1. What is the comparative efficacy of Ciprofloxacin, Ceftriaxone, and Amoxicillin against common pathogenic bacteria in Ibadan?
2. Which of these antibiotics demonstrates the highest zone of inhibition against targeted bacteria?
3. How does the resistance profile of bacteria influence the effectiveness of these antibiotics?

## 1.4 Objectives of the Study

1. To assess the comparative effectiveness of Ciprofloxacin, Ceftriaxone, and Amoxicillin against selected bacterial strains.
2. To identify which antibiotic has the highest inhibitory effect on pathogenic bacteria common in Ibadan.
3. To analyze the resistance patterns and susceptibility of bacteria to these antibiotics.

## 1.5 Hypotheses

**Ha1:** Ciprofloxacin has a significantly larger zone of inhibition against targeted bacteria than Ceftriaxone and Amoxicillin.

**Ha2:** There is no significant difference in the effectiveness of Ciprofloxacin and Ceftriaxone against Gram-negative bacteria.

**Ha3:** Amoxicillin will have a lower inhibitory effect compared to Ciprofloxacin and Ceftriaxone against Staphylococcus aureus.

## 1.6 Significance of the Study

This research is valuable for healthcare practitioners, providing data on the most effective antibiotic for common bacterial infections. Furthermore, it assists in formulating treatment protocols to combat resistance, promoting evidence-based prescription practices. By understanding which antibiotics are more effective locally, practitioners can make informed choices, which ultimately supports public health efforts against antibiotic resistance.

## 1.7 Scope and Limitations of the Study

This study focuses on the antibacterial strength of Ciprofloxacin, Ceftriaxone, and Amoxicillin using samples from bacterial cultures in Ibadan. It does not include other commonly used antibiotics and is limited to laboratory conditions, which may not fully replicate in vivo environments. Additional limitations include the study’s reliance on selected bacterial strains, excluding other potential pathogens.

## 1.8 Definition of Key Terms

**Zone of Inhibition:** The area around an antibiotic disc where bacterial growth is prevented, measured in millimeters to indicate antibiotic efficacy.

**Minimum Inhibitory Concentration (MIC):** The lowest concentration of an antibiotic that inhibits visible bacterial growth, used to assess potency.

**Antibiotic Resistance**: The ability of bacteria to survive and proliferate despite the presence of antibiotic agents intended to inhibit or kill them.

# CHAPTER TWO

# LITERATURE REVIEW

## **2.1. Introduction**

The term antibiotic was coined from the word ‘antibiosis’ which literally means ‘against life’. In the past, antibiotics were considered to be organic compounds produced by one microorganism which are toxic to other microorganisms (Russell, 2004). As a result of this notion, an antibiotic was originally, broadly defined as a substance, produced by one microorganism (Denyer et al., 2004), or of biological origin (Schlegel, 2003) which at low concentrations can inhibit the growth of, or are lethal to other microorganisms (Russell, 2004). However, this definition has been modified in modern times, to include antimicrobials that are also produced partly or wholly through synthetic means.

Whilst some antibiotics are able to completely kill other bacteria, some are only able to inhibit their growth. Those that kill bacteria are termed bactericidal while those that inhibit bacterial growth are termed bacteriostatic (Walsh, 2003). Although antibiotic generally refers to antibacterial, antibiotic compounds are differentiated as antibacterials, antifungals and antivirals to reflect the group of microorganisms they antagonize (Brooks et al., 2004; Russell, 2004).

Penicillin was the first antibiotic discovered in September 1928 by an English Bacteriologist, late Sir Alexander Fleming who accidentally obtained the antibiotic from a soil inhabiting fungus Penicillium notatum but its discovery was first reported in 1929 (Aminov, 2010), and clinical trials first conducted on humans in 1940 (Russell, 2004; Schlegel, 2003).



Figure 1. Chemical structure of beta-lactam ring (Tidwell, 2008).

Figure 2. Chemical structure of beta-lactam structure. Core structure of penicillins (top) and cephalosporins (bottom) (Holten and Onusko, 2000).

The discovery and development of the first significant antibiotic “penicillin” in 1920‟s, and subsequent introduction into man‟s health care system in the 1940‟s has continued to transform the management and fight against bacterial infections (White and Cox, 2013). However, antibiotics are not totally selective in their antibacterial activity. Whilst antagonizing disease causing bacteria, they also antagonize the normal and useful microbiota that we all have and need in our systems as those in the gastrointestinal tract (Walsh, 2003). Prescription and administration of any given antibiotics is therefore predicated on the overall intended benefit, taking into consideration the attendant side effects. For this reason, it is pertinent to understand the mechanism of action of every identified antibiotic before introduction into our health care delivery system, and recent molecular biological approaches have played very significant roles to elucidate our understanding in this regard.

## 2.2. Classification of Antibiotics

There are several ways of classifying antibiotics but the most common classification schemes are based on their molecular structures, mode of action and spectrum of activity (Calderon and Sabundayo, 2007). Others include route of administration (injectable, oral and topical). Antibiotics within the same structural class will generally show similar pattern of effectiveness, toxicity and allergic-potential side effects. Some common classes of antibiotics based on chemical or molecular structures include Beta-lactams, Macrolides, Tetracyclines, Quinolones, Aminoglycosides, Sulphonamides, Glycopeptides and Oxazolidinones (van Hoek et al., 2011; Frank and Tacconelli, 2012; Adzitey, 2015).

**Beta-lactams**

Members of this class of antibiotics contain a 3-carbon and 1-nitrogen ring that is highly reactive (Figures 1 and 2). They interfere with proteins essential for synthesis of bacterial cell wall, and in the process either kills or inhibits their growth. More succinctly, certain bacterial enzymes termed penicillin-binding protein (PBP) are responsible for cross linking peptide units during synthesis of peptidoglycan. Members of beta-lactam antibiotics are able to bind themselves to these PBP enzymes, and in the process, they interfere with the synthesis of peptidoglycan resulting to lysis and cell death (Heesemann, 1993). The most prominent representatives of the beta-lactam class include Penicillins, Cephalosporins, Monobactams and Carbapenems.

**Penicillins**

The first antibiotic, penicillin, which was first discovered and reported in 1929 by Alexander Fleming was later found to be among several other antibiotic compounds called the penicillins. (McGeer et al., 2001). Penicillins are involved in a class of diverse group of compounds, most of which end in the suffix -cillin. They are beta-lactam compounds containing a nucleus of 6-animopenicillanic acid (lactam plus thiazolidine) ring and other ring side chains (Zahner and Maas, 1972).



Figure 3. Structure of Cephalosporins (Pegler and Healy, 2007).

Members of Penicillin class include Penicillin G, Penicillin V, Oxacillin (dicloxacillin), Methicillin, Nafcillin, Ampicillin, Amoxicillin, Carbenicilin, Piperacillin, Mezlocillin and Ticarcillin (Boundless, 2016). Penicillin G was the first to be produced amongst this group of antibiotics, and in fact of all antibiotics. Although penicillin G was discovered by Alexander Fleming in the 1920’s, it took the efforts of several other workers such as Ernst Chain, Edward Abraham, Norman Heatley and Howard Florey in 1945 to understand the cultural requirements of the fungus and its clinical effectiveness. Furthermore, although Penicillin G was originally discovered and isolated from the fungus P. notatum by Alexander Flemming, a close relative Penicilliun chrysogenum is the preferred choice of source. Also, producing the antibiotics through biochemical microbial fermentation more cost effective as compared to synthesizing it from raw materials (Talaro and Chess, 2008). There is no gainsaying that the discovery of this drug heralded the introduction of antibiotics into our health care delivery system. Sadly, however, Penicillin G has a narrow spectrum; only Gram positive bacteria (streptococci) and some Gram-negative bacteria such as Treponema pallidum causative agent for syphilis, and meningococci are sensitive to it (Talaro and Chess, 2008).

As with every biological interaction systems where living systems seek to protect itself from attack, certain bacteria are able to counter the activity of antibiotics by encoding enzymes. In view of this, some antibiotics such as ampicillin, carbenicillin and amoxicillin have been developed semi-synthetically with different side-chains. These side chains confer on the antibiotics the ability to evade the degradative capacity of certain enzymes produced by certain bacterial strains as well as facilitating the movement of antibiotics across the outer membrane of such bacterial cell walls. This double-pronged capability increases their spectrum of activity against Gram-negative bacteria. In particular, some penicillins such as Augmentin are produced in combination with non-antibiotic compound that are able to inhibit the activity of bacterial penicillinase enzyme. Augmentin is actually a drug comprising amoxicillin (antibiotic) and clavulanic acid a non-antibiotic compound. Clavulanic acid is able to inhibit beta-lactamase enzyme thereby prolonging the antibacterial activity of the amoxicillin component of Augmentin even amongst penicillinase producing bacteria (Poirel et al., 2005).

**Cephalosporin**

Members of this group of antibiotics are similar to penicillin in their structure and mode of action. They form part of the most commonly prescribed and administered antibiotics; more succinctly, they account for one-third of all antibiotics prescribed and administered by the National Health Scheme in the United Kingdom (Talaro and Chess, 2008). The first known member of this group of antibiotics was first isolated by Guiseppe Brotzu in 1945 from the fungus Cephalosporium acremonium. Although the drug was first isolated by Guiseppe Brotzu, it was Edward Abraham who got the credit to patent it having been able to extract the compound. Cephalosporins contain 7-aminocephalosporanic acid nucleus and side chain containing 3,6-dihydro-2 H-1,3-thiazane rings (Figure 3). Cephalosporins are used in the treatment of bacterial infections and diseases arising from Penicillinase-producing, Methicillin-susceptible Staphylococci and Streptococci, Proteus mirabilis, some Escherichia coli, Klebsiella pneumonia, Haemophilus influenza, Enterobacter aerogenes and some Neisseria (Pegler and Healy, 2007).

They are subdivided into generations (1st-5th) in accordance to their target organism but later versions are increasingly more effective against Gram-negative pathogens. Cephalosporins have a variety of side chains that enable them get attach to different penicillin-binding proteins (PBPs), to circumvent blood brain barrier, resist breakdown by penicillinase producing bacterial strains and ionize to facilitate entry into Gram-negative bacterial cells (Abraham, 1987).

**Monobactams**

The discovery of this class of antibiotics was first reported by Skyes and co-workers. The antibiotic was obtained from the bacterium Chromobacterium violaceum. They are part of beta-lactam compounds but unlike most other beta-lactams, the beta-lactam ring of monobactams stand alone and is not fused to another ring (Figure 4) (Bonner and Sykes, 1984; Sykes and Bonner, 1985). Aztreonam is the only commercially available monobactam antibiotic, with a narrow spectrum of activity. Aztreonam is active only against aerobic Gram-negative bacteria such as Neisseria and Pseudomonas; used for treating pneumonia, septicemia and urinary tract infections caused by these groups of bacteria. The monobactams are not effective against Gram-positive bacteria or anaerobes. They are used as injectables and inhalers (Sykes et al., 1981).

Figure 4. Structure of Monobactam (Bonner and Sykes, 1984).



Figure 5. Structure of Carbapenem (Papp-Wallace et al., 2011).

**Carbapenems**

This class of antibiotics, represented in Figure 5, was discovered out of necessity in 1976. Prior to this time in the late 1960‟s the effectiveness of penicillin was greatly threatened owing to the emergence of beta-lactamase in bacteria. Bacterial beta-lactamases conferred resistance on bacteria against penicillin (Papp-Wallace et al., 2011). This seemingly ugly scenario led scientists to embark on massive search for beta-lactamase inhibitors. Their efforts yielded result in 1976 when olivanic acids, produced by a Gram-positive bacterium Streptomyces clavuligerus, was noted to inhibit beta-lactamase (Brown et al., 1976; Butterworth et al., 1979). Unfortunately, these acids were chemically unstable and could not easily penetrate the bacterial cell. These setbacks slowed down further works on the olivanic acids (Reading and Farmer, 1984), but interestingly, shortly afterwards, two superior beta-lactamase inhibitors were discovered. These were clavulanic acid obtained also from S. clavuligerus (Brown et al., 1976), and thienamycin isolated from Streptomyces cattleya (Kropp et al., 1976). Thienamycin is reportedly considered to be the first “carbapenem” and serves as a standard for every other carbapenem (Papp-Wallace et al., 2011). A good number of other carbapenems have also been identified (Cassidy et al, 1981; Kobayashi et al., 1982).

Carbapenems occupy a very important place in our fight against bacterial infections. This is because they are able to resist the hydrolytic action of beta-lactamase enzyme. Among the several hundreds of known beta-lactams, carbapenems possess the broadest spectrum of activity and greatest potency against Gram-positive and Gram-negative bacteria. As a result, they are often called “antibiotics of last resort” and are administered when patients with infections become gravely ill or are suspected of harboring resistant bacteria (Torres et al., 2007). Examples of carbapenem are:

**i. Imipenem** – a broad spectrum effective against aerobic and anaerobic pathogens, usually taken orally and active in low concentrations, with minimal allergy side effects;

**Meropenem** – a broad spectrum effective against non-fermentative Gram-negative bacilli particularly against acquired infections;

Ertapenem – a broad spectrum with limited activity against non-fermentative Gram-negative bacilli (Brink et al., 2004).

Sadly, emergence of bacterial pathogens resistant to this life saving class of antibiotics has been reported. More worrisome is the fact that bacterial resistance to carbapenems is on the increase globally (Livermore et al., 2011; Patel and Bonomo, 2011) and is fast becoming an international concern (Papp-Wallace et al., 2011).

**Macrolides**

The first antibiotic belonging to this class was first discovered and isolated in 1952 by J. M. McGuire as a metabolic product of a soil inhabiting fungus Saccharopolyspora erythraea. This fungus was formerly known as Streptomyces erythraeus belonging to the genus Saccharopolyspora of actinomycete bacteria (Moore, 2015).

Macrolides are characterized by 14-, 15-, or 16-membered macrocyclic lactose rings with unusual deoxy sugars L-cladinose and D-desosamine attached (Figure 6). They have a wider spectrum of antibiotic activity than Penicillins and are often administered to patients allergic to penicillin (Moore, 2015). Macrolides either kill or inhibit microorganisms by effectively inhibiting bacterial protein synthesis. They do so by binding to bacterial ribosome, and in the process, prevent the addition of amino acid to polypeptide chains during protein synthesis. Macrolides tend to build up in the body because the liver is able to recycle it into the bile. They also have the capacity to cause inflammation.

Figure 6. Structure of Macrolide (Hamilton-Miller, 1973).

Figure 7. Structure of Tetracycline (Chopra and Roberts, 2001).

As a result, clinicians usually recommend administering low doses. Although, Macrolides are generally broad spectrum, some bacterial species such as Streptococcus pneumoniae have resistance against the antibiotics. Example of members includes Erythromycin, Azithromycin and Clarithromycin (Hamilton-Miller, 1973).

**Tetracyclines**

Tetracycline was discovered in 1945 from a soil bacterium of the genus Streptomyces by Benjamin Duggar (Sanchez et al., 2004). The first member of this class was chlorotetracycline (Aureomycin). Members of this class have four (4) hydrocarbon rings (Figure 7) and they are known by name with the suffix – ‘cycline’.

Historically, members of this class of antibiotics are grouped into different generations based on the method of synthesis. Those obtained by biosynthesis are said to be First generation. Members include Tetracycline, Chlortetecycline, Oxytetracycline and Demeclocycline. Members such as Doxycycline, Lymecycline, Meclo cycline, Methacycline, Minocycline, and Rolitetracycline are considered Second generation because they are derivatives of semi-synthesis. Those obtained from total synthesis such as Tigecycline are considered to be Third generation (Fuoco, 2012).

Their target of antimicrobial activity in bacteria is the ribosome. They disrupt the addition of amino acids to polypeptide chains during protein synthesis in this bacterial organelle (Medical News Today, 2015). Patients are advised to take tetracyclines at least two hours before or after meals for better absorption. All tetracyclines are recommended for patients above eight (8) years because the drugs have shown to cause teeth discoloration among patients below this age can be used in treating malaria, elephantiasis, amoebic parasites and rickettisia (Sanchez et al., 2004).

In the past, antibiotics belonging to this class were very much the envy of numerous Clinicians owing to their wide antimicrobial spectrum but this is no longer the case because numerous bacteria are now able to resist them (Chopra and Roberts, 2001).

**Quinolones**

This class of antibiotics was first discovered as nalidixic acid by Scientists involved in search of antimalarial drugs. Nalidixic acid was discovered as an impurity during the development of quinine in the early sixties. They are able to interfere with DNA replication and transcription in bacteria. Two major groups of compounds have been developed from the basic molecule: quinolones and naphthyridones which include cinoxacin, norfloxacin, ofloxacin, ciproxacin, temafloxacin, sparfloxacin, nalidixic acid, enoxacin etc. (Domagala, 1994). Their structure generally consists of two rings but recent generations of quinolones possess an added ring structure which enables them to extend their spectrum of antimicrobial activity to some bacteria, particularly anaerobic bacteria that were hitherto resistant to quinolone.



Figure 8. Structure of Aminoglycoside (Streptomycin) (Mingeot-Leclercq et al., 1999).

Since its discovery in the early 1960‟s, several modifications have been made to its parent structure and this has led to the development and synthesis of many derivatives with tested antibiotic potency. The nomenclature of members of this class of antibiotics is complex (Domagala, 1994) but members are often known by the suffix–oxacin, such as floxacin, ciprofloxacin and levofloxacin.

Modifications in the basic structure of quinolones are reported to have improved their bioavailability and increased both their spectrum of activity and potency; enhancing their performance in the treatment of various forms of illnesses such as urinary, systemic and respiratory tract infections. Notwithstanding these notable feats, there still exist safety concerns with some members of this class of antibiotics which has led to the withdrawal of grepafloxacin, sparfloxacin, temafloxacin, trovafloxacin etc., all belonging to the class quinolones, from the market (Domagala, 1994). Although a good deal of progress is being made in terms of in vitro studies and pharmacodynamics, knowledge of the dynamics of toxicity amongst some of this class of antibiotics is yet inconclusive.

**Aminoglycosides**

The first drug to be discovered among members of this class of antibiotics was streptomycin, first isolated in 1943 (Mahajan and Balachandran, 2012). Streptomycin has been greatly used against Mycobacterium tuberculosis, the causal agent of tuberculosis among humans. The aminoglycosides are compounds of usually 3-amino sugars connected by glycosidic bonds (Figure 8). They are obtained from soil Actimomycetes. Aminoglycoside have a broad spectrum of antibacterial activity. They are able to inhibit the protein synthesis in bacteria by binding to one of the ribosomal subunits (Peterson, 2008), and are effective against aerobic Gram-negative rods and certain Gram-positive bacteria. The oldest known aminoglycoside, as earlier inferred is Streptomycin which has been used severally in treating bubonic plague, tularemia and tuberculosis (Talaro and Chess, 2008). Notwithstanding its effectiveness against a wide array of infections, streptomycin was found to be highly toxic. This unfortunate feature of the drug necessitated the need to search for new members of aminoglycosides that would still be effective against bacteria but less toxic to humans. The search was fruitful with the discoveries of antibiotics such as Gentamicin, Neomycin, Tobramycin and Amikacin. Gentamicin is less toxic and is widely used for infections caused by Gram-negative rods (Escherichia, Pseudomonas, Shigella and Salmonella). Tobramycin, in particular, is used in treating Pseudomonas infections in cystic fibrosis patients (Gilbert, 2000).

**Sulphonamides**

Sulphonamides are reportedly, the first group of antibiotics used in therapeutic medicine, and they still play very important role in medicine and veterinary practice (Eyssen et al., 1971). Sulphonamides inhibit both Gram-positive and Gram-negative bacteria such as Nocardia, E. coli, Klebsiella, Salmonella, Shigella and Enterobacter, Chlamydia trachomatis and some Protozoa, and are widely used in the treatment of various infections including tonsillitis, septicemia, meningococcal meningitis, bacillary dysentery and some urinary tract infections (Eyssen et al., 1971). Studies have shown that Sulphonamides are also able to impede cancerous cell agents (Stawinski et al., 2013; Xu et al., 2014). The original antibacterial sulphonamide (also spelt sulfonamide by some Workers), are synthetic antimicrobial agents that contain the sulphonamide group (Figure 9) (Henry, 1943).

Sulphonamides are generally thought to be bacteriostatic rather than bactericidal. However, Henry (1943) in his thorough early work opined that sulphonamides may become bactericidal if their concentration is sufficiently high or if the presence of any sulfonamide concentration is accompanied by other environmental conditions unfavourable to bacteria. Such unfavourable conditions would include poor cultural conditions, adverse temperature, antibodies, toxic proteolytic product etc.

Although sulphonamides are adjudged good and effective in treating various diseases and infections, they are recommended and administered with caution because of their toxicity and side effects, some of which include urinary tract disorders, haemolytic anaemia, porphyria, and hypersensitivity reactions (Slatore and Tilles, 2004; Choquet-Kastylevsky et al., 2002).



Figure 9. General structure of Sulphano mides (Henry,1943).



Figure 10. Structure of Linezolid (Leach et. al., 2007).

**Glycopeptides**

Glycopeptide antibiotics generally abbreviated as GPAs were originally obtained as natural products, but the last 20 years witnessed the emergence of semi-synthetic derivatives with improved activity and pharmacokinetic properties (Kahne et al., 2005; Van Bambeke et al., 2004; Van Bambeke, 2004). Naturally, glycopeptides are made of a cyclic peptide of 7 amino acids, to which are bound 2 sugars, hence the name glycopeptides (Kang and Park, 2015). Structures of various forms of glycopeptides are well presented by Yim and Associates (2014). Binding of the antibiotic to its target occurs via the formation of 5 hydrogen bonds with the peptidic backbone of the drug. Sometimes, an additional chlorine and/or sugar is/are attached to the backbone of the drug (as is the case in oritavancin) during synthesis. Drugs with such additional attachments are known to bind more efficiency to the target (Allen and Nikas, 2003; Beauregard et al., 1995). Similarly, a lipophilic side chain antibacterial potency and prolongs half-life of glycopeptides.

**Oxazolidinones**

Oxazolidinones are a group of synthetic antibiotics approved only recently for use. Linezolid (Figure 10) which represents the first member to be synthesized was approved for clinical application only in the year 2000. Although the mechanism of action of oxazolidinone is not yet fully understood, they are reported to interfere with protein synthesis. Oxazolidinones inhibit protein synthesis by binding to the P site of the ribosomal 50S subunit (Shinabarger et al., 1997; Bozdogan and Appelbaum, 2004). They have a broad spectrum of activity against Gram-positive bacteria including methicillin- and vancomycin-resistant staphylococci, vancomycin-resistant enterococci, penicillin-resistant pneumococci and anaerobes (Bozdogan and Appelbaum, 2004).

Linezolid is used for treatment of respiratory tract and skin infections caused by Gram-positive bacterial pathogens (Moellering, 2003). Oxazolidinones constitute the choice drug in dealing with surgical infections because they easily penetrate and accumulate in the tissue including bone, lung, vegetations (plant-like growth in tissues), haematoma and cerebrospinal fluid (Bozdogan and Appelbaum, 2004). Although adhering to normal standard routines of linezolid administration are usually safe, side effects such as myelosuppression, resulting to anemia and thrombocytopenia are often encountered in cases when treatment is prolonged (Kuter and Tillotson, 2001).

**ANTIBIOTICS MODE OF ACTION**

The antimicrobial potency of most classes of antibiotic are directed at some unique feature of the bacterial structure or their metabolic processes. The most common targets of antibiotics are illustrated in Figure 11. The mechanism of antibiotic actions are as follows:

* Inhibition of cell wall synthesis
* Breakdown of cell membrane structure or function
* Inhibition of the structure and function of nucleic acids
* Inhibition of protein synthesis
* Blockage of key metabolic pathways
* Inhibition of cell wall synthesis

(Talaro and Chess, 2008; Madigan and Martinko, 2006; Wright, 2010)

Most bacterial cells are encased by a rigid layer of peptidoglycan (PG), also called murein in older sources) which both protect the cells in the face of prevailing osmotic pressure consistent with the often-harsh environment and conditions under which they exist. Peptidoglycan has a degree of cross-linking peptide bonds called β-(1-4) –N– acetyl Hexosamine (Bugg and Walsh, 1992; Holtje, 1998). To stay alive, bacteria must of necessity synthesize peptidoglycan; they do this by the activity of PBPs which are transglycosylases and transpeptidases. These two enzymes play very pivotal roles by adding disaccharide pentapeptides to extend the glycan strands of existing peptidoglycan molecule and also cross-link strands of immature peptidoglycan units (Park and Uehara, 2008). Drugs like penicillins, carbapenems and cephalosporins are able to block the cross-linking of peptidoglycan units by inhibiting the peptide bond formation catalyzed by PBPs (Josephine et al., 2004).



Figure 11. Antibiotic target sites (Madigan and Martinko, 2006).

Most antibiotics belonging to the glycopeptide class of antibiotics (for example, vancomycin) are able to inhibit bacterial growth by inhibiting the synthesis of PG. They inhibit the synthesis of PG by binding themselves to PG units, as well as blocking transglycosylase and transpeptidase activity (Kahne et al., 2005).

**Breakdown of the cell membrane structure or function**

The classes of antibiotics that damage cell membranes of bacteria are specific in each microbial group based on the differences in the types of lipids in their cell membranes. For example, Daptomycin depolarizes calcium-dependent membrane, and that leads to the cessation of macromolecular synthesis and disruption of the cellular membrane in bacteria (Alborn et al., 1991). The polymyxins cause disintegration of bacterial cell membrane by effectively binding to the lipid moiety of the lipopolysaccharide in the bacterial cell (Falagas et al., 2010).

**Inhibition of nuclei acid synthesis**

The metabolic pathways that result in synthesis of nucleic acids are very essential; disruption of nucleic acid synthesis is inimical to both the survival and posterity of bacterial cells. Antibiotics interfere with nuclei acid synthesis by blocking replication or stopping transcription. DNA replication involves the unwinding of the traditional double helix structure, a process facilitated by the helicase enzymes (Gale et al., 1981). The quinolones group of antibiotics, for example, do interfere with the functionality of the helicase enzyme thereby disrupts the enzyme from playing its function of unwinding DNA. This antibiotic action of the quinolones ultimately truncates the process of DNA replication and repair amongst susceptible bacteria (Chen et al., 1996). Antibiotics whose mode of action is inhibition of nucleic acid synthesis also target topoisomerase II and topoisomerase IV of bacteria. Disrupting the activities of these enzymes in bacteria adversely affects RNA polymerase which in turn prevents RNA synthesis. Quinolones that inhibit bacterial nucleic acid synthesis in this way do not interact with mammalian RNA polymerase, making them specifically antagonistic to Gram-positive bacteria and some Gram-negative bacteria.

**Inhibition of protein synthesis**

Living things including bacteria are defined by the amount and type of proteins they are composed of, and continually produce. Proteins are responsible for the structural composition, metabolic and physiological processes, and response to adverse conditions, amongst other roles. However, the type and amount of proteins produced by a bacterium at any given time is dependent on information contained in yet another very important biomolecule – Deoxyribonucleic acid (DNA). DNA determines the type of protein a bacterial cell produces through certain information it harbors within itself. The information is a set of genetic codes called codons, handed down to an identical biomolecule – Ribonucleic acid (RNA), specifically messenger RNA (mRNA). Transfer RNA (tRNA), a similar biomolecule is also formed under the directive of DNA. This biomolecule together with mRNA travels to the ribosomes – the factory for protein synthesis in a living cell. The tRNA then deciphers the codons contained in the mRNA and facilitates the translation of the sequence of codons to a sequence of amino acids which are the building blocks of proteins (Etebu, 2013).

The translation of mRNA into proteins occurs over three sequential phases (initiation, elongation and termination) involving the ribosome and a host of cytoplasmic accessory factors (Gualerzi et al., 2000). Ribosomes are made up of RNA and proteins, and are generally called RIBONUCLEOPROTEINS. The RNA component is what is referred to as Ribosomal RNA (rRNA), and comprises two subunits, one small subunit (SSU) and the other large subunit (LSU). These two subunits are usually described in terms of their sedimentation coefficients (that is, their rate of sedimentation is an ultracentrifuge), and are measured in Svedberg units (symbols) termed the 30S and 50S, respectively (Nissen et al., 2000). Bacterial possess 5S, 16S and 23S genes on their rRNA (Moore, 2001). The 16S rRNA gene resides as a single RNA gene in their SSU (16S) whilst the other two rRNA genes (23S and 5S) occur on the LSU of the bacterial ribosome (Lafontaine and Tollervey, 2001). There is huge difference between prokaryotic and eukaryotic rRNA, and this feat has greatly enabled Scientists to develop antibiotics that would target rRNA of a wide spectrum of pathogenic bacteria (Hong et al., 2014).

Given the importance of proteins in the metabolic and life processes of all living organisms, whatever disrupts the process of its synthesis in a bacterial cell would ultimately incapacitate the cell; inhibit its growth or even kill it completely. Drugs that inhibit protein synthesis are among the broadest classes of antibiotics and can be divided into two subclasses: the 50S inhibitors and 30S inhibitors.

Antibiotics such as erythromycin, clindamycin, lincomycin, chloramphenicol, linezolid etc. have been shown to be among the 50S ribosome inhibitors (Douthwaite, 1992; Katz and Ashley, 2005). In general terms, antibiotics that inhibit 50S ribosome do so by physically blocking either the initiation phase of protein translation or the elongation phase of protein synthesis where the incoming amino acid is linked up with the growing nascent peptide chain (Patel et al., 2001; Vannuffel and Cocito, 1996; Menninger and Otto, 1982). Examples of antibiotic that block initiation of protein translation are members of Oxazolidinones (Patel et al., 2001) whilst macrolides such as lincosamide and streptogramin block protein synthesis by inhibiting the elongation phase of mRNA translation (Vannuffel and Cocito, 1996; Menninger and Otto, 1982). These latter groups of antibiotics are therefore reportedly ineffective when elongation has progressed beyond a critical length (Tenson et al., 2003).

The 30S ribosome-inhibitors principally work by blocking the access of aminoacyl-tRNAs to the ribosome. Examples of antibiotics that function in this manner include the tetracycline, streptomycin, spectinomycin, etc. (Hong et al., 2014; Chopra and Roberts, 2001). It is worthy to note that some earlier works have shown that tetracycline also inhibits some proteins at the 50S ribosomes (Epe and Woolley, 1984).

Among ribosome inhibitors, the naturally-derived aminoglycoside subclass is the only one that is broadly bactericidal. Macrolides, streptogramins, spectinomycin, tetracyclines and chloramphenicol are typically bacteriostatic. However, some of these ribosome inhibitory antibiotics that are typically bacteriostatic in action could be bactericidal under certain conditions relating to species- or treatment-specific fashion. For example, chloramphenicol known typically to be bacteriostatic has been shown to effectively kill S. pneumoniae and Neisseria meningitidis (Rahal and Simberkoff, 1979), as well as H. influenza (Rahal and Simberkoff, 1979; Goldstein et al., 1990). This species-specific variability in ribosome inhibition or mediated cell death is potentially linked to sequence differences among bacterial species in the variable regions of the highly conserved ribosomal proteins and RNAs (Roberts et al., 2008).

**Blockage of key metabolic pathways**

Some antibiotics like sulphonamides and trimethoprim have been shown to mimic a substrate needed for cellular metabolism of bacteria. This deception cause bacterial enzymes to attach themselves to the antibiotic rather than the normal substrate. In particular, sulphonamides act like tetrahydrofolate which is required for the synthesis of folic acid in bacterial cells (Talaro and Chess, 2008). Folic acid is vital in the metabolism of nucleic acid and amino acids; for this reason, sulphonamides ultimately disrupt the production of nucleic acids (DNA and RNA) and amino acids, as they mimic substrates required for folic acid metabolism (Talaro and chess, 2008).

## 2.3. Overview of Antibiotics and Their Mechanisms of Action

Antibiotics have played a critical role in medical advancements by combating bacterial infections and significantly reducing mortality rates worldwide. These drugs are classified based on their mechanisms of action, which target various essential bacterial processes, disrupting cell structures or metabolic pathways. The mechanisms of antibiotics generally include inhibiting cell wall synthesis, protein synthesis, nucleic acid synthesis, or interfering with bacterial metabolic pathways, rendering bacterial cells incapable of survival or replication (Kohanski et al., 2010; Walsh, 2003).

### 2.3.1. Cell Wall Synthesis Inhibitors

Antibiotics that inhibit bacterial cell wall synthesis are primarily effective against Gram-positive bacteria due to the structural composition of their cell walls. Penicillin and other β-lactam antibiotics, such as Amoxicillin, work by binding to and inactivating penicillin-binding proteins (PBPs) located on the bacterial cell wall. PBPs are crucial for the synthesis and cross-linking of peptidoglycan layers that provide structural strength to the bacterial cell wall (Tipper & Strominger, 1965; Bush & Bradford, 2016). Without functional PBPs, bacterial cells cannot maintain their cell walls, leading to lysis due to osmotic pressure imbalances. This mechanism renders β-lactam antibiotics bactericidal, as the disruption of cell wall integrity is incompatible with bacterial viability (Bush & Bradford, 2016). Amoxicillin, a β-lactam antibiotic, is often used against non-resistant strains of Escherichia coli and Staphylococcus aureus. However, with increasing resistance from β-lactamase-producing bacteria, which can hydrolyze the β-lactam ring, the efficacy of β-lactams has become limited in treating certain infections (Livermore, 2008; Bush & Bradford, 2016).

### 2.3.2. Protein Synthesis Inhibitors

Protein synthesis inhibitors target bacterial ribosomes, which differ structurally from human ribosomes, allowing these drugs to selectively inhibit bacterial protein synthesis without harming human cells. Antibiotics in this category, such as tetracyclines, macrolides, and aminoglycosides, interfere with the 30S or 50S subunits of the bacterial ribosome. For instance, tetracyclines bind to the 30S ribosomal subunit, preventing the attachment of aminoacyl-tRNA to the ribosomal complex and thus halting protein elongation (Chopra & Roberts, 2001). Aminoglycosides, such as streptomycin, also target the 30S subunit but cause misreading of mRNA, leading to faulty proteins that compromise bacterial function (Davis, 1987).

Macrolides, including erythromycin, inhibit protein synthesis by binding to the 50S ribosomal subunit, obstructing the translocation of the ribosome along the mRNA strand, which stalls protein synthesis (Vazquez, 2007). These mechanisms are particularly effective against certain Gram-positive and atypical bacterial pathogens. Although protein synthesis inhibitors are valuable for treating many infections, the rise of resistance, such as efflux pumps and mutations in ribosomal subunits, poses challenges (Chopra & Roberts, 2001; Davies & Davies, 2010).

### 2.3.3. Nucleic Acid Synthesis Inhibitors

Another important class of antibiotics targets nucleic acid synthesis, particularly DNA and RNA replication processes. Fluoroquinolones, such as Ciprofloxacin, inhibit bacterial DNA gyrase and topoisomerase IV, enzymes critical for supercoiling and uncoiling DNA during replication and transcription (Hooper, 1998). By disrupting these enzymes, fluoroquinolones induce breaks in the bacterial DNA, leading to cell death. Ciprofloxacin, with its strong activity against Gram-negative bacteria and some Gram-positive organisms, is often used for urinary and respiratory infections (Hooper, 2001; Redgrave et al., 2014). Rifamycins, another group in this category, inhibit bacterial RNA synthesis by binding to RNA polymerase, thereby preventing the transcription of DNA into mRNA (Campbell et al., 2001). Due to the specificity of RNA polymerase in bacterial cells, rifamycins are effective against a narrow range of bacteria, including Mycobacterium tuberculosis, though resistance due to mutation in the RNA polymerase gene has been widely documented (Campbell et al., 2001; Davies & Davies, 2010).

### 2.3.4. Metabolic Pathway Inhibitors

Some antibiotics inhibit bacterial growth by interfering with essential metabolic pathways. Sulfonamides, for example, target the synthesis of folic acid, a precursor for nucleotides required in DNA synthesis. By acting as competitive inhibitors of dihydropteroate synthase, sulfonamides block the conversion of para-aminobenzoic acid (PABA) into dihydrofolic acid, thus preventing bacterial DNA replication and leading to bacteriostatic effects (Wang et al., 1996). Trimethoprim, often combined with sulfonamides, inhibits a downstream enzyme, dihydrofolate reductase, enhancing the bacteriostatic effect and reducing the likelihood of resistance (Sköld, 2001).

This combination, widely used for urinary tract infections and specific respiratory infections, exemplifies the synergistic action of drugs that interfere with consecutive steps in a metabolic pathway. However, the emergence of resistance due to alternate pathways or mutations in targeted enzymes presents ongoing challenges in clinical practice (Wang et al., 1996; Sköld, 2001).

### 2.3.5. Implications of Mechanisms for Resistance and Clinical Use

The specific mechanisms of antibiotic action contribute to the selection pressures that drive bacterial resistance. For example, the widespread use of β-lactams has led to the evolution of β-lactamase enzymes in bacteria that deactivate these antibiotics by hydrolyzing the β-lactam ring (Bush & Bradford, 2016). Similarly, the use of protein synthesis inhibitors has led to resistance mechanisms such as ribosomal protection proteins and efflux pumps, which reduce intracellular antibiotic concentration (Chopra & Roberts, 2001; Davies & Davies, 2010).

Given these evolving resistance patterns, the understanding of antibiotic mechanisms of action is crucial for optimizing their clinical use. Rational prescription practices, based on bacterial susceptibility profiles, have become essential for combating infections effectively. As new antibiotics are developed, understanding their mechanisms will also guide the preservation of their efficacy, addressing both current and emerging resistance threats. These considerations have prompted research into combination therapies and novel antibiotics that can evade existing resistance mechanisms, ensuring continued effectiveness against both common and resistant infections (Livermore, 2008; Walsh, 2003).

## 2.4. Ciprofloxacin, Ceftriaxone, and Amoxicillin: Properties, Uses, and Effectiveness

Ciprofloxacin, Ceftriaxone, and Amoxicillin are three widely used antibiotics with varying properties, mechanisms of action, and levels of effectiveness against different bacterial infections. These antibiotics are essential in clinical practice for treating infections caused by both Gram-positive and Gram-negative bacteria. Understanding their individual properties, common uses, and effectiveness is critical to ensuring appropriate clinical applications, particularly given rising bacterial resistance.

### 2.4.1. Ciprofloxacin

**Properties and Mechanism of Action**

Ciprofloxacin belongs to the fluoroquinolone class, a group of broad-spectrum antibiotics that target both Gram-negative and Gram-positive bacteria (Hooper, 2001). Its mechanism of action involves inhibiting bacterial DNA gyrase and topoisomerase IV, enzymes responsible for supercoiling and uncoiling DNA during replication and transcription (Hooper, 1998). By preventing these enzymes from functioning, Ciprofloxacin disrupts bacterial DNA replication, leading to bacterial cell death. This bactericidal effect makes it highly effective against a range of pathogens, particularly Escherichia coli, Salmonella spp., and Pseudomonas aeruginosa (Redgrave et al., 2014).

**Uses:**

Ciprofloxacin is widely used to treat infections of the urinary tract, respiratory tract, skin, and gastrointestinal system. Its effectiveness in treating urinary tract infections (UTIs) is notable due to its activity against common uropathogens, including E. coli and Klebsiella pneumoniae (Gupta et al., 2011). Additionally, its broad-spectrum activity and high tissue penetration make it suitable for respiratory infections, including those caused by atypical pathogens like Legionella pneumophila (Mandell, 2010). It is also a preferred choice in treating travel-related gastrointestinal infections and is often prescribed as a prophylactic for travelers to regions with high incidences of bacterial infections (Reller et al., 2019).

**Effectiveness and Resistance Concerns:**

Ciprofloxacin’s efficacy is well-established, but resistance is becoming an increasing concern, especially in Gram-negative bacteria. Mechanisms of resistance include mutations in genes encoding DNA gyrase and topoisomerase IV, and the production of efflux pumps that expel the drug from bacterial cells (Hooper & Jacoby, 2016). Studies indicate that resistance to fluoroquinolones like Ciprofloxacin has led to decreased effectiveness in treating UTIs, with some countries observing resistance rates of over 30% in E. coli (Tängdén & Giske, 2015). This growing resistance highlights the importance of targeted use and susceptibility testing before prescribing Ciprofloxacin.

### 2.4.2. Ceftriaxone

**Properties and Mechanism of Action:**

Ceftriaxone is a third-generation cephalosporin with a broad spectrum of activity, particularly against Gram-negative bacteria. Its mechanism of action involves binding to penicillin-binding proteins (PBPs) in bacterial cell walls, which are essential for cell wall synthesis. By inhibiting PBPs, Ceftriaxone prevents the formation of peptidoglycan cross-links, leading to cell wall rupture and bacterial death (Page et al., 2005). Ceftriaxone’s long half-life allows for once-daily dosing, which enhances patient adherence and makes it suitable for outpatient care (Pollack, 2000).

**Uses:**

Ceftriaxone is frequently used to treat serious infections, including bacterial meningitis, pneumonia, and sepsis. Its ability to penetrate the blood-brain barrier makes it particularly effective in treating bacterial meningitis caused by Neisseria meningitidis and Streptococcus pneumoniae (Peltola, 2000). Additionally, Ceftriaxone is widely used to treat community-acquired pneumonia and other lower respiratory tract infections. Its use in sexually transmitted infections, specifically gonorrhea, is also common, as it is effective against Neisseria gonorrhoeae, especially strains that are resistant to other antibiotics (Unemo & Shafer, 2014).

**Effectiveness and Resistance Concerns:**

Ceftriaxone remains highly effective against many Gram-negative organisms, but resistance is increasing, especially due to the emergence of extended-spectrum beta-lactamases (ESBLs) that hydrolyze cephalosporins (Bradford, 2001). ESBL-producing E. coli and Klebsiella species have shown substantial resistance, compromising Ceftriaxone's efficacy in treating UTIs and other infections (Paterson & Bonomo, 2005). Resistance rates vary globally, with higher rates observed in hospitals and regions with extensive antibiotic use. Clinical guidelines now recommend performing susceptibility testing to ensure that Ceftriaxone is suitable for treating specific infections (Pitout & Laupland, 2008).

### 2.4.3. Amoxicillin

**Properties and Mechanism of Action:**

Amoxicillin, a β-lactam antibiotic, is part of the penicillin class and is structurally similar to penicillin but with an added hydroxyl group that enhances its absorption. Its mechanism of action involves inhibiting cell wall synthesis by binding to PBPs, disrupting the formation of peptidoglycan cross-links. This action leads to cell lysis and bacterial death, making Amoxicillin a bactericidal agent (Tipper & Strominger, 1965). However, its activity is limited primarily to Gram-positive organisms and a narrower range of Gram-negative bacteria due to its susceptibility to β-lactamase enzymes produced by resistant bacteria (Livermore, 2008).

**Uses:**

Amoxicillin is commonly prescribed for mild to moderate infections, particularly respiratory tract infections, such as sinusitis, pharyngitis, and otitis media, as well as in some cases of UTIs (Mandell et al., 2010). In combination with clavulanic acid (a β-lactamase inhibitor), it is often used to treat more resistant infections, including those caused by Staphylococcus aureus and H. influenzae (Bush & Bradford, 2016). Due to its safety profile and broad availability, Amoxicillin is frequently used in outpatient settings and pediatric care.

**Effectiveness and Resistance Concerns:**

The effectiveness of Amoxicillin has been increasingly compromised by resistance, particularly among Gram-negative bacteria. Resistance arises primarily from β-lactamase production, which deactivates the antibiotic by breaking the β-lactam ring (Livermore, 2008). To counteract this resistance, Amoxicillin is often paired with β-lactamase inhibitors like clavulanic acid, which protect the antibiotic from enzymatic degradation. Even with this combination, certain bacterial strains, such as ESBL-producing E. coli, remain resistant, limiting the use of Amoxicillin in treating serious infections (Pitout & Laupland, 2008). Furthermore, resistance patterns vary widely, emphasizing the importance of local susceptibility data to guide Amoxicillin use effectively.

### 2.4.4. Comparative Effectiveness and Clinical Considerations

Each of these antibiotics—Ciprofloxacin, Ceftriaxone, and Amoxicillin—has strengths and limitations in clinical applications. Ciprofloxacin’s broad-spectrum activity makes it a valuable option for treating diverse infections; however, its use is limited by growing resistance, particularly in Gram-negative organisms (Tängdén & Giske, 2015). Ceftriaxone is effective for severe infections, including meningitis and gonorrhea, and has retained broad-spectrum activity, although resistance from ESBL-producing organisms presents challenges (Paterson & Bonomo, 2005). Amoxicillin is generally effective for mild to moderate infections but faces significant resistance challenges, especially from Gram-negative bacteria that produce β-lactamase (Livermore, 2008).

In choosing among these antibiotics, it is essential to consider resistance patterns, infection severity, patient-specific factors, and potential adverse effects. For instance, while Ciprofloxacin may be preferred for UTIs due to its efficacy against E. coli, its use in pediatrics is often limited due to potential adverse effects on developing cartilage (Levison & Levison, 2009). Ceftriaxone offers strong efficacy in serious infections but requires careful use to mitigate resistance risk in hospital settings (Bradford, 2001). Amoxicillin remains widely used in community settings, particularly with clavulanic acid, but should be prescribed with caution where resistance data suggests limitations.

## 2.5. Antibiotic Resistance and Its Implications

Antibiotic resistance is one of the most pressing public health challenges worldwide, with major implications for the treatment of bacterial infections. The phenomenon occurs when bacteria evolve mechanisms to withstand the effects of drugs that once killed them or inhibited their growth. This resistance often develops due to misuse and overuse of antibiotics in human medicine, veterinary practices, and agriculture, creating environments in which bacteria are exposed to sub-lethal doses of drugs, accelerating mutation and resistance (Ventola, 2015). This section explores the mechanisms of antibiotic resistance, its societal and clinical implications, and the importance of stewardship programs to combat this growing threat.

### 2.5.1. Mechanisms of Resistance

Bacteria can acquire resistance through various mechanisms, including mutation and horizontal gene transfer (HGT). Mutation, especially in the presence of selective pressure from antibiotics, allows bacteria to adapt quickly. For instance, mutations in the genes encoding bacterial enzymes like DNA gyrase and penicillin-binding proteins can prevent antibiotics from binding, rendering drugs like ciprofloxacin and beta-lactams ineffective (Hooper & Jacoby, 2016; Munita & Arias, 2016). Horizontal gene transfer, including conjugation, transformation, and transduction, enables bacteria to exchange genetic material, even across different species. Through this process, bacteria acquire plasmids, which often contain multiple resistance genes. These plasmids can spread resistance traits rapidly within bacterial populations, contributing to the global rise of multidrug-resistant organisms (Davies & Davies, 2010). For instance, the emergence of extended-spectrum beta-lactamase (ESBL)-producing bacteria has made it difficult to treat infections with drugs like ceftriaxone and amoxicillin (Paterson & Bonomo, 2005).

### 2.5.2. Clinical Implications

Antibiotic resistance has far-reaching clinical implications. Resistant infections are associated with higher morbidity, mortality, and healthcare costs. When first-line antibiotics are ineffective, physicians must rely on more toxic, costly, and sometimes less effective alternatives (Laxminarayan et al., 2013). Multidrug-resistant (MDR) bacteria, including methicillin-resistant Staphylococcus aureus (MRSA) and carbapenem-resistant Enterobacteriaceae (CRE), have become common in hospitals, leading to prolonged hospital stays, increased medical costs, and higher death rates (Centers for Disease Control and Prevention, 2019).

The efficacy of antibiotics like ciprofloxacin, ceftriaxone, and amoxicillin is compromised as resistance grows. For instance, fluoroquinolone-resistant E. coli, one of the main causes of urinary tract infections, has limited the effectiveness of ciprofloxacin in many regions (Tängdén & Giske, 2015). Ceftriaxone’s efficacy against certain Gram-negative bacteria is threatened by the spread of ESBL-producing organisms, which render many beta-lactams ineffective. The result is a need for combination therapy or last-resort drugs like carbapenems, which have their own resistance issues (Bush & Bradford, 2016).

### 2.5.3. Societal Implications and Stewardship Programs

Beyond healthcare, antibiotic resistance poses societal risks, affecting food security and global economies. Resistant bacteria in agricultural settings can transfer to humans through the food chain, environmental contamination, and direct contact with animals. In low- and middle-income countries, where antibiotic use may be less regulated, the burden of resistance is even more significant (Founou et al., 2017).

In response, antimicrobial stewardship programs (ASPs) have been implemented in healthcare and community settings to reduce unnecessary antibiotic use. These programs promote responsible prescription practices, encourage infection control, and emphasize the importance of accurate diagnostics to limit the indiscriminate use of antibiotics (Dyar et al., 2017). However, the success of stewardship programs depends on global cooperation and compliance with guidelines, as resistance knows no borders.

### 2.5.4. Comparative Studies on Antibiotic Strength and Efficacy

Comparing the strength and efficacy of antibiotics such as ciprofloxacin, ceftriaxone, and amoxicillin provides insights into their suitability for various infections and helps identify alternative treatments in cases of resistance. Studies commonly assess antibiotics through methods like minimum inhibitory concentration (MIC) tests, which determine the lowest concentration of an antibiotic that inhibits visible bacterial growth.

**Ciprofloxacin Studies**

Ciprofloxacin is widely studied for its effectiveness against Gram-negative bacteria, particularly in urinary tract infections (UTIs). Studies have found ciprofloxacin’s MIC values to be low for common uropathogens like E. coli and Proteus mirabilis, which makes it highly effective in standard dosages. However, due to resistance, its MIC values have gradually increased in some cases, requiring higher dosages or alternative treatments (Reller et al., 2019). Clinical trials have shown that fluoroquinolone-resistant E. coli infections have become more prevalent, suggesting a need to limit ciprofloxacin’s use to specific infections with confirmed sensitivity (Gupta et al., 2011).

**Ceftriaxone Studies**

Ceftriaxone, a third-generation cephalosporin, is highly effective against various Gram-negative pathogens, including Neisseria gonorrhoeae and Streptococcus pneumoniae. Comparative studies show its low MIC values for these pathogens, making it effective in treating severe infections, such as bacterial meningitis and pneumonia. However, the rise of ESBL-producing bacteria has reduced ceftriaxone’s effectiveness in treating UTIs and bloodstream infections (Paterson & Bonomo, 2005). In settings where ESBL prevalence is high, ceftriaxone’s effectiveness is significantly reduced, and carbapenems are often required as alternative treatments (Tamma et al., 2011).

**Amoxicillin Studies**

Amoxicillin is a broad-spectrum penicillin antibiotic commonly used for respiratory and urinary infections. While it remains effective against many Gram-positive bacteria, it shows limited efficacy against beta-lactamase-producing Gram-negative organisms. Comparative studies have shown that amoxicillin’s MIC values for susceptible organisms are low, but they are significantly higher for resistant strains, such as Haemophilus influenzae and Moraxella catarrhalis, due to beta-lactamase production (Livermore, 2008). This limitation has led to the combination of amoxicillin with clavulanic acid, a beta-lactamase inhibitor, to broaden its spectrum.

### 2.5.5. Implications of Comparative Findings

The comparative efficacy of ciprofloxacin, ceftriaxone, and amoxicillin highlights the importance of sensitivity testing and local resistance patterns in clinical decision-making. While ciprofloxacin and ceftriaxone remain effective for many Gram-negative infections, resistance rates indicate the need for prudent usage to prevent further resistance development. The data suggest that amoxicillin’s efficacy is limited by beta-lactamase-producing bacteria, emphasizing the value of combination therapy in overcoming resistance. These comparative findings underscore the need for regular surveillance of resistance trends and the potential development of newer antibiotics that can bypass existing resistance mechanisms.

## 2.6. Theoretical Framework for Evaluating Antibiotic Strength

The evaluation of antibiotic strength, particularly in the context of Ciprofloxacin, Ceftriaxone, and Amoxicillin, is crucial for clinical decision-making and understanding treatment efficacy against various bacterial pathogens. A theoretical framework that encompasses microbiological principles, pharmacokinetics, pharmacodynamics, and clinical effectiveness can provide a comprehensive approach to this evaluation. This framework will facilitate a systematic analysis of the antibiotics in question, considering both laboratory-based and clinical findings.

**Microbiological Principles**

The foundation of evaluating antibiotic strength lies in microbiology, particularly the understanding of bacterial pathogens and their interactions with antibiotics. Bacterial classification into Gram-positive and Gram-negative groups is essential because these classifications affect the choice and effectiveness of antibiotics. For instance, Ciprofloxacin is generally more effective against Gram-negative bacteria due to its ability to penetrate the outer membrane, while Amoxicillin is primarily effective against Gram-positive organisms (Murray et al., 2020).

The mechanisms by which bacteria develop resistance to antibiotics are critical to consider. Resistance mechanisms include the production of beta-lactamases, alterations in drug targets, and the efflux of antibiotics. Understanding these mechanisms helps in predicting the potential efficacy of Ciprofloxacin, Ceftriaxone, and Amoxicillin in clinical settings (Bush & Bradford, 2016). Furthermore, the significance of minimum inhibitory concentration (MIC) testing is paramount, as it quantifies the lowest concentration of an antibiotic needed to inhibit bacterial growth, providing a direct measure of antibiotic strength.

**Pharmacokinetics**

Pharmacokinetics, which examines how drugs move through the body, plays a vital role in evaluating antibiotic strength. Key pharmacokinetic parameters include absorption, distribution, metabolism, and excretion (ADME).

**Absorption**: The effectiveness of an antibiotic often depends on its absorption in the gastrointestinal tract. For example, Amoxicillin has excellent oral bioavailability, making it highly effective for outpatient treatment (Li et al., 2015). In contrast, Ceftriaxone is usually administered parenterally, which provides immediate systemic availability, making it suitable for serious infections requiring rapid therapeutic effects.

**Distribution:** The distribution of antibiotics within body tissues influences their efficacy. Ciprofloxacin exhibits high tissue penetration, particularly in the lungs and urinary tract, which enhances its effectiveness against respiratory and urinary infections (Lepak et al., 2014). In contrast, Ceftriaxone’s ability to cross the blood-brain barrier makes it the preferred choice for treating central nervous system infections.

**Metabolism and Excretion:** Understanding how antibiotics are metabolized and eliminated from the body is crucial in evaluating their dosing regimens. Ciprofloxacin and Amoxicillin are primarily excreted unchanged via the kidneys, which means that renal function can significantly influence their effectiveness (Mouton et al., 2012). Dosage adjustments may be necessary in patients with impaired renal function to prevent toxicity and ensure adequate therapeutic levels.

**Pharmacodynamics**

Pharmacodynamics describes the relationship between antibiotic concentrations and their antibacterial effects. This relationship can be represented by various models, including the time-dependent killing model and concentration-dependent killing model.

**Time-Dependent Killing:** For antibiotics like Amoxicillin, the duration that the drug concentration remains above the MIC is crucial for its effectiveness. Studies have shown that maintaining serum concentrations above the MIC for a significant portion of the dosing interval is essential for optimal therapeutic outcomes (Friedman et al., 2017).

**Concentration-Dependent Killing:** In contrast, Ciprofloxacin exhibits concentration-dependent killing, where higher concentrations lead to a more significant bactericidal effect (Cohen et al., 2013). This characteristic is critical for understanding dosing strategies, as higher doses may lead to increased efficacy in treating severe infections.

**Clinical Effectiveness**

Clinical effectiveness is a critical aspect of evaluating antibiotic strength and involves assessing the outcomes of antibiotic treatment in real-world scenarios. This evaluation can be conducted through randomized controlled trials (RCTs), observational studies, and meta-analyses.

**Randomized Controlled Trials:** RCTs provide robust evidence regarding the comparative effectiveness of antibiotics. For instance, studies comparing Ciprofloxacin to other antibiotics for the treatment of UTIs demonstrate its effectiveness, particularly in cases caused by susceptible strains (Gupta et al., 2011).

**Observational Studies:** These studies allow researchers to assess the outcomes of antibiotic use in diverse populations, providing insight into factors affecting treatment success, such as patient comorbidities and resistance patterns (Klein et al., 2019).

**Meta-Analyses:** By synthesizing data from multiple studies, meta-analyses can provide a comprehensive overview of the relative effectiveness of different antibiotics. This is particularly valuable for understanding the nuances of antibiotic strength across various bacterial strains and resistance profiles (Laxminarayan et al., 2013).

## 2.7. Summary of Reviewed Literature

The literature on antibiotic strength and effectiveness reveals a complex landscape influenced by microbial resistance, pharmacokinetics, and clinical outcomes. A primary focus is on the increasing prevalence of antibiotic resistance, which has emerged as a significant global health concern. Resistance mechanisms, such as the production of beta-lactamases and alterations in antibiotic targets, pose challenges in effectively treating infections (Paterson & Bonomo, 2005; Hooper & Jacoby, 2016). Understanding these mechanisms is critical for predicting the efficacy of commonly used antibiotics like Ciprofloxacin, Ceftriaxone, and Amoxicillin.

Studies have demonstrated that Ciprofloxacin, a fluoroquinolone antibiotic, exhibits strong efficacy against a range of Gram-negative bacteria, particularly Escherichia coli and Klebsiella pneumoniae (Gupta et al., 2011). Its mechanism of action, which involves the inhibition of DNA gyrase and topoisomerase IV, facilitates rapid bacterial cell death (Hooper, 1998). However, the rising rates of resistance, particularly due to mutations in target genes and efflux pump mechanisms, have been noted, necessitating cautious use of this antibiotic (Redgrave et al., 2014).

Ceftriaxone, a broad-spectrum cephalosporin, is often employed for serious infections due to its excellent activity against Gram-positive and Gram-negative organisms. Its ability to penetrate well into tissues and the central nervous system makes it particularly valuable in treating conditions like meningitis (Mandell, 2010). However, the emergence of extended-spectrum beta-lactamases (ESBLs) has significantly reduced its efficacy against certain pathogens, highlighting the need for ongoing surveillance of resistance patterns (Paterson & Bonomo, 2005).

Amoxicillin, a widely used beta-lactam antibiotic, is favored for its high oral bioavailability and effectiveness against many common infections, including respiratory tract infections and otitis media. Studies indicate that maintaining appropriate dosing regimens is crucial, as its effectiveness is heavily reliant on the time above the minimum inhibitory concentration (MIC) (Friedman et al., 2017). Nonetheless, resistance to Amoxicillin, often mediated by the production of beta-lactamases, has increased, particularly in pediatric populations (Nguyen et al., 2020).

Comparative studies underscore the importance of evaluating the relative strength of these antibiotics. For instance, RCTs have demonstrated the effectiveness of Ciprofloxacin in treating uncomplicated urinary tract infections, but resistance rates challenge its continued use (Gupta et al., 2011). Similarly, observational studies indicate that while Ceftriaxone remains a preferred option for serious infections, its effectiveness is compromised by rising resistance, especially in hospital settings (Klein et al., 2019).

Overall, the literature suggests that antibiotic stewardship programs are essential in managing antibiotic use and mitigating resistance. Such programs aim to promote the appropriate use of antibiotics, ensuring that their strength and effectiveness are preserved for future generations. This includes optimizing dosing regimens, monitoring resistance patterns, and encouraging the development of new antibiotics to address the challenges posed by resistant bacteria (Laxminarayan et al., 2013).

# CHAPTER THREE

# METHODOLOGY

## 3.1. Research Design

This study adopted an experimental research design aimed at comparing the antibacterial efficacy of Ciprofloxacin, Ceftriaxone, and Amoxicillin against selected bacterial strains commonly associated with infections in Ibadan. This design was appropriate as it allowed the controlled testing of each antibiotic’s effectiveness, establishing a clear causal relationship between the antibiotics and their inhibitory effects on the bacterial isolates (Smith et al., 2021). Laboratory-based experiments under standardized conditions facilitated a reliable comparison of antibiotic strength based on measurable data like zone of inhibition and minimum inhibitory concentration (MIC) (Gao & Hu, 2019).

## 3.2.Study Population and Sampling Technique

The study population included bacterial isolates obtained from clinical samples collected from hospitals within Ibadan. The target bacteria—Staphylococcus aureus, Escherichia coli, and Klebsiella pneumoniae—were selected based on their high prevalence and resistance patterns in the region, as reported in recent surveillance data (Oluwasegun et al., 2020). A purposive sampling technique was used to ensure the inclusion of representative isolates of these bacteria, each confirmed through biochemical tests to align with the study's objectives.

## 3.3. Data Collection Methods

Clinical isolates were obtained following standard procedures for bacterial sample collection from patients diagnosed with infections where antibiotics are typically prescribed. The collection adhered to ethical guidelines, with informed consent obtained from patients for the use of anonymized samples (World Health Organization [WHO], 2021). Laboratory records provided demographic data about the strains and detailed medical histories, enabling the characterization of bacteria based on resistance patterns and infection types (WHO, 2021; Adeyemi et al., 2019).

## 3.4. Laboratory Analysis of Antibiotic Strength

The comparative strength of Ciprofloxacin, Ceftriaxone, and Amoxicillin was assessed using the Kirby-Bauer disk diffusion method, a widely accepted protocol for measuring antibiotic efficacy (CLSI, 2020). Antibiotic-impregnated disks containing the standard concentrations for each drug were placed on agar plates inoculated with each bacterial isolate. After 24 hours of incubation at 37°C, zones of inhibition were measured in millimeters to evaluate bacterial susceptibility or resistance (Adeyemi et al., 2019).

**3.4.1. Sensitivity Testing**

Sensitivity testing was conducted using the MIC method, identifying the lowest concentration of each antibiotic capable of inhibiting visible bacterial growth. MIC testing was performed through serial dilution in Mueller-Hinton broth, aligning with Clinical and Laboratory Standards Institute (CLSI) guidelines (CLSI, 2020). The results were interpreted using breakpoint concentrations for each antibiotic, classifying each strain as susceptible, intermediate, or resistant (Oluwasegun et al., 2020).

## 3.5. Instrumentation and Procedures

Agar plates and antibiotic disks for Ciprofloxacin, Ceftriaxone, and Amoxicillin were prepared in sterile conditions, following standard microbiological procedures. Sterile forceps and calibrated incubators were used to maintain controlled test environments, and measurements were taken with digital calipers for precision (Smith et al., 2021). The agar diffusion method for zone measurement and MIC testing for concentration efficacy followed standardized operating procedures (SOPs) as outlined in contemporary microbiological testing protocols (WHO, 2021).

## 3.6. Data Analysis Techniques

Data analysis involved quantitative comparison of zones of inhibition and MIC values for each antibiotic against each bacterial strain. Statistical tests, including ANOVA and t-tests, were performed to assess significant differences in antibiotic strength across the strains. Data was analyzed using SPSS software to determine which antibiotic demonstrated superior efficacy in terms of inhibition zones and MIC values, with significance set at p < 0.05 (Gao & Hu, 2019).

## 3.7. Ethical Considerations

This study was conducted in alignment with ethical principles outlined in the Declaration of Helsinki, ensuring that all bacterial isolates were used with patient consent and anonymized to protect privacy (WHO, 2021). The ethical review board of the institution approved the study protocol. Precautions were taken to ensure biosafety, including proper disposal of bacterial cultures and sterilization of all equipment to prevent contamination and exposure (Adeyemi et al., 2019).

# CHAPTER FOUR

# DATA ANALYSIS AND RESULTS

## 4.1. Description of Sample Characteristics

The study analyzed 120 bacterial isolates, which included three primary bacterial strains: Escherichia coli, Staphylococcus aureus, and Klebsiella pneumoniae. These strains were collected from different infection sites and represented a diverse cross-section of pathogenic bacteria treated with antibiotics in clinical settings in Ibadan.

**Table 4.1: Characteristics of Bacterial Isolates**

|  |  |  |  |
| --- | --- | --- | --- |
| **Bacterial Strain** | **No. of Isolates** | **Infection Site** | **Frequency (%)** |
| Escherichia coli | 40 | Urinary Tract | 33.3% |
| Staphylococcus aureus | 50 | Skin and Soft Tissue | 41.7% |
| Klebsiella pneumoniae | 30 | Respiratory Tract | 25.0% |
| Total | 120 |  | 100% |

The majority of isolates were Staphylococcus aureus (41.7%), followed by Escherichia coli (33.3%) and Klebsiella pneumoniae (25.0%). The infection sites varied, with the urinary tract being the most common site for E. coli, skin and soft tissue infections for S. aureus, and respiratory tract infections for K. pneumoniae. This distribution aligns with patterns observed in studies that associate these pathogens with respective infection sites (Adeyemi et al., 2019; Smith et al., 2021).

## 4.2. Comparative Analysis of Antibiotic Efficacy

The efficacy of Ciprofloxacin, Ceftriaxone, and Amoxicillin was tested on each bacterial strain. The outcome was measured by the diameter of inhibition zones (in millimeters) around antibiotic disks, with larger zones indicating higher antibiotic efficacy.

**Table 4.2: Average Zone of Inhibition (mm) for Each Antibiotic by Bacterial Strain**

|  |  |  |  |
| --- | --- | --- | --- |
| **Bacterial Strain** | **Ciprofloxacin (mm)** | **Ceftriaxone (mm)** | **Amoxicillin (mm)** |
| Escherichia coli | 22.4 | 18.7 | 10.5 |
| Staphylococcus aureus | 20.3 | 15.6 | 8.9 |
| Klebsiella pneumoniae | 25.1 | 21.0 | 11.2 |

Ciprofloxacin demonstrated the highest average zone of inhibition across all bacterial strains, suggesting a superior efficacy relative to Ceftriaxone and Amoxicillin. The highest efficacy was observed against Klebsiella pneumoniae (25.1 mm), while Amoxicillin had the smallest zones of inhibition across all strains, with the least effect against Staphylococcus aureus (8.9 mm). These findings support similar research indicating that Ciprofloxacin is effective against a broad range of Gram-negative and some Gram-positive bacteria (Gao & Hu, 2019; Oluwasegun et al., 2020).

## 4.3. Findings on Ciprofloxacin

**Table 4.3: Zone of Inhibition for Ciprofloxacin by Bacterial Strain**

|  |  |
| --- | --- |
| **Bacterial Strain** | **Zone of Inhibition (mm)** |
| Escherichia coli | 22.4 |
| Staphylococcus aureus | 20.3 |
| Klebsiella pneumoniae | 25.1 |

Ciprofloxacin showed consistent high efficacy, with the largest inhibitory effect against Klebsiella pneumoniae (25.1 mm). The substantial zones of inhibition indicate that Ciprofloxacin can be effectively used against infections caused by these pathogens. Its broad-spectrum action aligns with prior findings on its efficacy against both Gram-negative and Gram-positive bacteria (Adeyemi et al., 2019).

## 4.4. Findings on Ceftriaxone

**Table 4.4: Zone of Inhibition for Ceftriaxone by Bacterial Strain**

|  |  |
| --- | --- |
| **Bacterial Strain** | **Zone of Inhibition (mm)** |
| Escherichia coli | 18.7 |
| Staphylococcus aureus | 15.6 |
| Klebsiella pneumoniae | 21.0 |

Ceftriaxone displayed moderate efficacy, with the highest inhibition zone against Klebsiella pneumoniae (21.0 mm) and the lowest against Staphylococcus aureus (15.6 mm). These findings support Ceftriaxone's effectiveness against Gram-negative infections but suggest it may be less effective against Gram-positive bacteria like S. aureus (Gao & Hu, 2019).

## 4.5. Findings on Amoxicillin

**Table 4.5: Zone of Inhibition for Amoxicillin by Bacterial Strain**

|  |  |
| --- | --- |
| **Bacterial Strain** | **Zone of Inhibition (mm)** |
| Escherichia coli | 10.5 |
| Staphylococcus aureus | 8.9 |
| Klebsiella pneumoniae | 11.2 |

Amoxicillin had the smallest zones of inhibition across all strains, indicating comparatively lower efficacy. Klebsiella pneumoniae displayed a slightly larger inhibition zone (11.2 mm) than Escherichia coli and Staphylococcus aureus. This outcome is consistent with prior research that points to growing resistance against penicillin-class antibiotics, especially for Gram-positive bacteria like S. aureus (Smith et al., 2021; CLSI, 2020).

## 4.6. Discussion of Results

The results indicated a marked difference in the efficacy of Ciprofloxacin, Ceftriaxone, and Amoxicillin against the tested bacterial strains. Ciprofloxacin consistently showed the highest efficacy across all strains, with inhibition zones indicating a broad-spectrum capability effective against both Gram-positive and Gram-negative bacteria. This supports previous findings that Ciprofloxacin is a potent antibiotic for treating urinary and respiratory infections caused by E. coli and Klebsiella pneumoniae (Oluwasegun et al., 2020; Adeyemi et al., 2019). Ceftriaxone, while effective, displayed lower efficacy than Ciprofloxacin, particularly against Staphylococcus aureus, suggesting that its utility may be optimized in infections involving Gram-negative bacteria. Its moderate effect against E. coli aligns with studies that highlight its role in treating certain Gram-negative bacterial infections but underscore its limitations with Gram-positive pathogens (Gao & Hu, 2019).

Amoxicillin showed the lowest efficacy, with small inhibition zones against all strains tested. These findings align with reports on rising resistance against penicillin-class antibiotics, especially for Staphylococcus aureus infections, due to β-lactamase production by resistant strains. The study’s data reinforces the necessity for careful antibiotic selection in clinical practice to address resistance concerns and optimize patient outcomes (Smith et al., 2021; CLSI, 2020). In summary, Ciprofloxacin's superior efficacy suggests it may be preferable for treating infections involving E. coli and Klebsiella pneumoniae in the Ibadan area. Ceftriaxone remains a viable option for specific Gram-negative infections, though it may be less effective against Staphylococcus aureus. Amoxicillin’s limited efficacy highlights the need for caution in its use against these strains, aligning with global trends in antibiotic resistance. These findings underscore the need for ongoing surveillance of antibiotic efficacy to inform local antibiotic stewardship programs and guide prescribing practices effectively.

# CHAPTER FIVE

# DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

## 5.1. Summary of Findings

The analysis of Ciprofloxacin, Ceftriaxone, and Amoxicillin efficacy against Escherichia coli, Staphylococcus aureus, and Klebsiella pneumoniae offers essential insights into the strength and suitability of these antibiotics for treating common infections in Ibadan. Ciprofloxacin demonstrated the highest efficacy across the three bacterial strains, with the largest zones of inhibition. This efficacy was especially pronounced against Klebsiella pneumoniae, supporting its utility as a potent choice against Gram-negative bacteria, aligning with global research findings that underline its broad-spectrum effectiveness (Adeyemi et al., 2019; Oluwasegun et al., 2020). Ceftriaxone followed Ciprofloxacin in effectiveness, showing moderate inhibition zones, particularly for E. coli and K. pneumoniae, although its efficacy was comparatively lower for S. aureus. Amoxicillin exhibited the least inhibitory effect across all tested strains, aligning with observations that penicillin-class antibiotics face significant resistance, especially from Gram-negative bacteria like E. coli.

These findings have implications for clinical decision-making, particularly in Ibadan, where bacterial resistance to commonly used antibiotics is a growing concern. The high efficacy of Ciprofloxacin suggests its strong potential for first-line treatment, especially in cases where Gram-negative infections are prevalent. However, the moderate efficacy of Ceftriaxone highlights its role as a suitable alternative, particularly in Gram-negative and certain Gram-positive infections, given its effectiveness against strains like Klebsiella pneumoniae. On the other hand, the limited efficacy of Amoxicillin suggests that its role may be more restricted to infections where resistance patterns indicate susceptibility, necessitating a more targeted approach for its prescription. This evidence underscores the need for localized antibiotic stewardship practices to optimize treatment efficacy and reduce resistance risk, aligning treatment practices with region-specific resistance patterns.

The findings reinforce the importance of monitoring and updating empirical antibiotic use, especially as bacterial resistance continues to evolve. The study further suggests that continuous evaluation of antibiotic effectiveness within specific geographic and demographic contexts is crucial. Variations in resistance patterns and antibiotic efficacy stress the need for local hospitals and health policymakers to adopt updated treatment guidelines. With bacteria such as E. coli and Klebsiella pneumoniae showing notable resistance to certain antibiotics, it is essential that health professionals have access to recent data on antibiotic resistance to inform their prescriptions.

## 5.2. Conclusions

Antibiotic resistance has become a significant global health challenge, with implications for both individual patient outcomes and broader public health goals. The proliferation of resistant bacterial strains can lead to more prolonged infections, increased healthcare costs, and higher morbidity and mortality rates. Consequently, the need for effective antibiotics that maintain strong efficacy against resistant strains is more crucial than ever. Studies that compare the effectiveness of commonly used antibiotics, like Ciprofloxacin, Ceftriaxone, and Amoxicillin, provide valuable data to help guide antibiotic stewardship and improve patient outcomes.

In line with this study’s objectives, Ciprofloxacin was found to exhibit the strongest inhibitory effect across all three bacterial strains, underscoring its role as a powerful broad-spectrum antibiotic. Its superior performance, especially against Klebsiella pneumoniae, suggests that it can be prioritized for treating infections caused by Gram-negative bacteria. These findings are consistent with broader evidence that Ciprofloxacin remains highly effective against diverse pathogens despite growing concerns about resistance. In contrast, Ceftriaxone demonstrated moderate efficacy, making it a suitable alternative, especially where Gram-negative infections are suspected. Although its efficacy was somewhat lower than that of Ciprofloxacin, it still holds substantial therapeutic value.

Amoxicillin’s comparatively limited effect underscores the challenges associated with using penicillin-class antibiotics in areas with established resistance patterns. This limited efficacy calls for judicious use of Amoxicillin, particularly in cases where culture and sensitivity tests indicate susceptibility. Given these outcomes, it is evident that empirical use of antibiotics in Ibadan should prioritize Ciprofloxacin and Ceftriaxone while considering Amoxicillin in more restricted circumstances. The study further reinforces the broader imperative for healthcare systems to support routine sensitivity testing before antibiotic prescription, as resistance levels can vary significantly between geographic locations and within specific bacterial strains.

These results indicate a need to integrate regular reviews of antibiotic efficacy and resistance patterns into healthcare practices. The findings serve as a reminder that antibiotic use should not solely rely on historical efficacy but must adapt to evolving resistance patterns. The broader implication is that health systems worldwide, not just in Ibadan, must adopt antibiotic stewardship policies that involve regular surveillance and adaptive treatment guidelines. Such strategies are critical in preserving antibiotic effectiveness and protecting public health.

## 5.3. Recommendations

**Encourage Routine Sensitivity Testing:** Hospitals and clinics in Ibadan and similar regions should adopt routine bacterial sensitivity testing as part of the diagnostic process for infections. This approach will guide antibiotic prescriptions based on current resistance patterns, optimizing treatment efficacy.

**Prioritize Ciprofloxacin for Gram-negative Infections:** Given Ciprofloxacin’s high efficacy, it should be prioritized for empirical treatment of Gram-negative infections. This recommendation could reduce treatment duration and minimize complications associated with resistant bacterial infections.

Limit Use of Amoxicillin to Susceptible Strains: Amoxicillin should be reserved for cases where sensitivity tests confirm its effectiveness. This targeted use can help avoid contributing to resistance development and maintain Amoxicillin’s efficacy where it remains potent.

**Implement Regular Resistance Surveillance Programs:** Health authorities should establish periodic surveillance programs to monitor local bacterial resistance trends. This initiative would provide essential data for updating treatment guidelines and adapting antibiotic use to changing resistance patterns.

**Promote Antibiotic Stewardship Education:** Healthcare providers should receive regular training in antibiotic stewardship to reinforce the importance of prudent antibiotic use and resistance prevention. This training can empower practitioners to make evidence-based decisions that align with resistance data, thereby supporting public health initiatives to combat antibiotic resistance.

## REFERENCES

Abraham E. (1987). Cephalosporins. Drugs. 4(2):1-4.

Adeyemi, O. A., Shoyombo, O. S., & Ajayi, K. (2019). Comparative effectiveness of antibiotics on pathogenic bacteria isolated from patients in a tertiary hospital. African Journal of Clinical Microbiology, 15(2), 113-122.

Adzitey F. (2015). Antibiotic classes and antibiotic susceptibility of bacterial isolates from selected poultry; a mini review. World Vet. J. 5 (3):36-41.

Alborn W., Allen N. & Preston D. (1991). Deptomycin disrupts membrane potential in growing Staphylococcus aureus. Antimicrob. Agents Chemother. 31(7):1093-1099.

Allen N. E. & Nicas T. I. (2003). Mechanism of action of oritavancin and related glycopeptide antibiotics. FEMS Microbiol. Rev. 26(5):511-532.

Aminov R. I. (2010). A brief history of the antibiotic era: Lessons learned and challenges for the future. Front Microbiol. 1(134):1-7.

Beauregard D. A., Williams D. H., Gwynn M. N. & Knowles D. J. C. (1995). Dimerization and membrane anchors in extracellular targeting of vancomycin group antibiotics. Antimicrob. Agents Chemother. 39(3):781-785.

Bonner D. P. & Sykes R. B. (1984). Structure activity relationships among the monobactams. J. Antimicrob. Chemother. 14:313-327.

Boundless (2016). Antibiotic Classifications. Boundless microbiology. https://www.boundless.com/microbiology/textbooks/boundless-microbiology-textbook/antimicrobial-drugs-13/overview-of-antimicrobial-therapy-153/antibiotic-classifications-775-4905/. Accessed September 13, 2016.

Bozdogan B. & Appelbaum P. C. (2004). Oxazolidinones: activity, mode of action, and mechanism of resistance. Int. J. Antimicrob. Agents. 23(2):113-119.

Bradford, P. A. (2001). Extended-spectrum β-lactamases in the 21st century: Characterization, epidemiology, and detection of this important resistance threat. Clinical Microbiology Reviews, 14(4), 933-951. https://doi.org/10.1128/CMR.14.4.933-951.2001

Brink A. J., Feldman C., Grolman D. C., Muckart D., Pretorius J., Richards G. A., Senekal M. & Sieling W. (2004). Appropriate use of the carbapenems. SAMJ. 94(10):857-861.

Brooks G. F., Butel J. S. & Morse S. A. (2004). Jawetz, Melnick and Adelberg‟s Medical Microbiology, 23rd Edition. McGraw Hill Companies, Singapore.

Brown A. G., Butterworth D., Cole M., Hanscomb G., Hood J. D., Reading C. & Rolinson G. N. (1976). Naturally-occurring beta-lactamase inhibitors with antibacterial activity. J. Antibiot. (Tokyo). 29(6):668-669.

Bugg T. D. H. & Walsh C. T. (1992). Intracellular steps of bacterial cell wall peptidoglycan biosynthesis: Enzymology, antibiotics, and antibiotic resistance. Nat. Prod. Rep. 9:199-215.

Bush, K., & Bradford, P. A. (2016). Extended-spectrum beta-lactamases in the 21st century: Characterization, epidemiology, and detection of this important resistance threat. Clinical Microbiology Reviews, 29(3), 535-563. https://doi.org/10.1128/CMR.00012-16

Bush, K., & Bradford, P. A. (2016). β-Lactams and β-Lactamase Inhibitors: An Overview. Cold Spring Harbor Perspectives in Medicine, 6(8), a025247. https://doi.org/10.1101/cshperspect.a025247

Butterworth D., Cole M., Hanscomb G. & Rolinson G. N. (1979). Olivanic acids, a family of beta-lactam antibiotics with beta-lactamase inhibitory properties produced by Streptomyces species. Detection, properties and fermentation studies. J. Antibiot. (Tokyo). 32:287-294.

Calderon C. B. & Sabundayo B. P. (2007). Antimicrobial classifications: Drugs for bugs. In: Schwalbe R, Steele-Moore L & Goodwin AC (eds). Antimicrobial susceptibility testing protocols. CRC Press, Taylor and Frances group. ISBN 978-0-8247-4100-6.

Campbell, E. A., Korzheva, N., Mustaev, A., Murakami, K., Nair, S., Goldfarb, A., & Darst, S. A. (2001). Structural mechanism for rifampicin inhibition of bacterial RNA polymerase. Cell, 104(6), 901-912.

Cassidy P. J., Albers-Schonberg G., Goegelman R. T., Miller T., Arison B., Stapley E. O. & Birnbaum J. (1981). Epithienamycins. II. Isolation and structure assignment. J. Antibiot. (Tokyo). 34:637-648.

Centers for Disease Control and Prevention. (2019). Antibiotic Resistance Threats in the United States, 2019.

Chen C. R., Malik M., Snyder M. & Drlica K. (1996). DNA gyrase and topoisomerase IV on the bacterial chromosome: quinolone – induced DNA cleavage. J. Mol. Biol. 258:627-637.

Chopra I. & Roberts M. (2001). Tetracycline antibiotics: Mode of action, applications, molecular biology, and epidemiology of bacterial resistance. Microbiol. Mol. Biol. Rev. 65(2):232-260.

Chopra, I., & Roberts, M. (2001). Tetracycline antibiotics: Mode of action, applications, molecular biology, and epidemiology of bacterial resistance. Microbiology and Molecular Biology Reviews, 65(2), 232-260.

Choquet-Kastylevsky G., Vial T. & Descotes J. (2002). Allergic adverse reactions to sulfonamides. Curr. Allergy Asthma Rep. 2(1):16-25.

Clinical and Laboratory Standards Institute (CLSI). (2020). Performance standards for antimicrobial susceptibility testing (30th ed.).

Cohen, S. H., et al. (2013). Pharmacodynamics of Ciprofloxacin in vitro: a population pharmacokinetic-pharmacodynamic model. Journal of Antimicrobial Chemotherapy, 68(3), 600-608. https://doi.org/10.1093/jac/dks468

Davies, J., & Davies, D. (2010). Origins and evolution of antibiotic resistance. Microbiology and Molecular Biology Reviews, 74(3), 417-433. https://doi.org/10.1128/MMBR.00016-10

Davis, B. D. (1987). Mechanism of bactericidal action of aminoglycosides. Microbiological Reviews, 51(3), 341-350.

Denyer S. P., Hodges N. A. & German S. P. (2004). Introduction to pharmaceutical microbiology. In: Denyer SP, Hodges NA & German SP (eds.) Hugo and Russell‟s Pharmaceutical Microbiology. 7th Ed. Blackwell Science, UK. Pp. 3-8.

Domagala J. M. (1994). Structure-activity and structure-side-effect relationships for the quinolone antibacterials. J. Antimicrob. Chemother. 33:685-706.

Douthwaite S. (1992). Interaction of the antibiotics clindamycin and lincomycin with Escherichia coli 23S ribosomal RNA. Nucleic Acids Res. 20:4717-4720.

Dyar, O. J., Huttner, B., Schouten, J., & Pulcini, C. (2017). What is antimicrobial stewardship? Clinical Microbiology and Infection, 23(11), 793-798.

Epe B. & Woolley P. (1984). The binding of 6-demethylchlortetracycline to 70S, 50S and 30S ribosomal particles: A quantitative study by fluorescence anisotropy. EMBO J. 3:121-126.

Etebu E. (2013). Potential panacea to the complexities of polymerase chain reaction (PCR). Adv. Life. Sci. Tech. 13:1-8.

Eyssen H. J., Van den Bosch J. F., Janssen G. A. & Vanderhaeghe H. (1971). Specific inhibition of cholesterol absorption by sulfaguanidine. Atherosclerosis. 14 (2):181-192.

Falagas M. E., Rafailidis P. I. & Matthaiou D. K. (2010). Resistance to polymyxins: Mechanisms, frequency and treatment options. Drug Resist. Update. 13:132-138.

FDA Consumer health Information. www.fda.gov/downloads/.../UCM350090.pdf. Accessed September, 4, 2016.

Founou, L. L., Founou, R. C., & Essack, S. Y. (2017). Antibiotic resistance in the food chain: A developing country-perspective. Frontiers in Microbiology, 8, 2140. https://doi.org/10.3389/fmicb.2017.02140

Frank U. & Tacconelli E. (2012). The Daschner Guide to In-Hopsital Antibiotic Therapy. European standards. Available online at: http://www.springer.com/978-3-642-18401-7. 300p.

Friedman, N. D., et al. (2017). The importance of time above the minimum inhibitory concentration for antibiotic therapy in the ICU: A review of the evidence. Critical Care Medicine, 45(3), 493-500. https://doi.org/10.1097/CCM.0000000000002227

Fuoco D. (2012). Classification framework and chemical biology of tetracycline-structure-based drugs. Antibiotics. 1:1-13.

Gale E., Cundliffe E., Reynolds P. E., Richmond M. H. & Waring M. J. (1981). The molecular basis of antibiotic action. 2nd Ed. John Wiley & Sons, New York. 670p.

Gao, X., & Hu, H. (2019). Evaluation of antimicrobial resistance patterns among clinical isolates. Journal of Microbial Resistance, 21(3), 249-255.

Gilbert D. (2000). Aminoglycosides. In: Mandell G. L., Bennett J. E. & Dolin R, (eds.) Mandell, Douglas, and Bennett's principles and practice of infectious diseases. 5th ed. Philadelphia: Churchill Livingstone. Pp. 307-336.

Goldstein F. W., Emirian M. F., Coutrot A. & Acar J. F. (1990). Bacteriostatic and bactericidal activity of azithromycin against Haemophilus influenzae. J. Antimicrob. Chemother. 25:25-28.

Gualerzi C. O., Brandi L. B., Caserta E., La Teana A., Spurio R., Tomsic J. & Pon C. L. (2000). Translation initiation in bacteria. In: Garrett R. A., Douthwaite S. R., Liljas A., Matheson A. T., Moore P. B. & Noller H. F. (eds.). The ribosome: Structure, function, antibiotics, and cellular interactions. ASM Press, Washington, DC. Pp. 477-494.

Gupta, K., et al. (2011). The effectiveness of ciprofloxacin in treating uncomplicated urinary tract infections. Clinical Infectious Diseases, 52(5), e103-e120. https://doi.org/10.1093/cid/ciq257

Gupta, K., Hooton, T. M., & Naber, K. G. (2011). International clinical practice guidelines for the treatment of acute uncomplicated cystitis and pyelonephritis in women: A 2010 update by the Infectious Diseases Society of America and the European Society for Microbiology and Infectious Diseases. Clinical Infectious Diseases, 52(5), e103-e120. https://doi.org/10.1093/cid/ciq257

Hamilton-Miller J. M. (1973). Chemistry and biology of the polyene macrolide antibiotics. Am. Soc. Microbiol. 37(2):166-196.

Heesemann J. (1993). Mechanisms of resistance to beta-lactam antibiotics. Infection. 21(1):S4-9.

Henry R. J. (1943). The mode of action of sulfonamides. Bacteriol. Rev. 7(4):175-262.

Holten K. B. & Onusko E. M. (2000). Appropriate prescribing of oral beta-lactam antibiotics. Am. Fam. Physician. 62(3): 611-620.

Holtje J. V. (1998). Growth of the stress bearing and shape maintaining murein sacculus of Escherichia coli. Microbiol. Mol. Biol. Rev. 62:181-189.

Hong W., Zeng J. & Xie J. (2014). Antibiotic drugs targeting bacterial RNAs. Acta Pharm. Sin B. 4(4):258-265.

Hooper, D. C. (1998). Mechanisms of action of antimicrobials: Focus on fluoroquinolones. Clinical Infectious Diseases, 27(Supplement\_1), S18-S22. https://doi.org/10.1086/514909

Hooper, D. C. (2001). Mechanisms of action of antimicrobials: Focus on fluoroquinolones. Clinical Infectious Diseases, 32(S1), S9-S15.

Hooper, D. C., & Jacoby, G. A. (2016). Mechanisms of drug resistance: quinolone resistance. Annals of the New York Academy of Sciences, 1354(1), 12-31. <https://doi.org/10.1111/nyas.12830>

Josephine H. R., Kumar I. & Pratt R. F. (2004). The Perfect Pencillin? Inhibition of a bacterial DD-peptidase by peptidoglycan-mimetic beta-lactams. J. Am. Chem. Soc. 126:81222-81223.

Kahne D., Leimkuhler C., Lu W. & Walsh C. (2005). Glycopeptide and lipoglycopeptide antibiotics. Chem. Rev. 105(2):425-448.

Kang H-K. & Park Y. (2015). Glycopeptide antibiotics: Structure and mechanism of action. J. Bacteriol. Virol. 45(2):67-78.

Katz L. & Ashley G. W. (2005). Translation and protein synthesis: macrolides. Chem. Rev. 105:499-528.

Klein, E. Y., et al. (2019). Resistance to ceftriaxone in common pathogens: A global perspective. The Lancet Infectious Diseases, 19(7), 693-706. https://doi.org/10.1016/S1473-3099(19)30071-1

Kobayashi F., Sainyo Y., Koshi T., Hattori Y., Nakayama M., Iwasaki A., Mori T. & Mitsuhashi S. (1982). Antimicrobial and Beta-lactamase inhibitory activities of carpetimycins A and B, new carbapenem antibiotics. Antimicrob. Agents Chemother. 21:536-544.

Kohanski, M. A., Dwyer, D. J., & Collins, J. J. (2010). How antibiotics kill bacteria: From targets to networks. Nature Reviews Microbiology, 8(6), 423-435.

Kropp H., Kahan J. S., Kahan F. M., Sandolf J., Darland G. & Birnbaum J. (1976). Abstract on 16th Interscientific conference on antimicrobial agents and chemotherapy. Am. Soc. Microbiol. Abstract 228.

Kuter, D. J. & Tillotson, G. S. (2001). Hematologic effects of antimicrobials: focus on the oxazolidinone linezolid. Pharmacotherapy. 21:1010-1013.

Lafontaine D. L. & Tollervey D. (2001). The function and synthesis of ribosomes. Nat. Rev. Mol. Cell Biol. 2(7):514-520.

Laxminarayan, R., Duse, A., Wattal, C., & Zaidi, A. K. (2013). Antibiotic resistance—the need for global solutions. The Lancet Infectious Diseases, 13(12), 1057-1098.

Leach K. L., Swaney S. M., Colca J. R., McDonald W. G., Blinn J. R., Thomasco L. M., Gadwood R. C., Shinabarger D., Xiong L. & Mankin A. S. (2007). The site of action of Oxazolidinone antibiotics in living bacteria and in human mitochondria. Mol. Cell. 26:393-402.

Lepak, A. J., et al. (2014). Pharmacokinetics and pharmacodynamics of Ciprofloxacin against gram-negative pathogens in a murine model of pneumonia. Antimicrobial Agents and Chemotherapy, 58(4), 2027-2036. https://doi.org/10.1128/AAC.02230-13

Li, Y., et al. (2015). Pharmacokinetics of Amoxicillin in patients with varying degrees of renal function. Clinical Pharmacokinetics, 54(7), 691-706. https://doi.org/10.1007/s40262-015-0231-3

Livermore D. M., Warner M., Mushtaq S., Doumith M., Zhang J. & Woodford N. (2011). What remains against carbapenem-resistant Enterobacteriaceae? Evaluation of chloramphenicol, ciprofloxacin, colistin, fosfomycin, minocycline, nitrofurantoin, temocillin and tigecycline. Int. J. Antimicrob. Agents. 37:415-419.

Livermore, D. M. (2008). Defining an extended-spectrum β-lactamase. Clinical Microbiology and Infection, 14(S1), 3-10.

Madigan M. T. & Martinko J. M. (2006). Brock biology of microorganisms. 11th edition. Pearson Prentice Hall Inc.

Mahajan G. B. & Balachandran L. (2012). Antibacterial agents from actinomycetes - a review. Front Biosci. (Elite Ed). 4:240-253.

Mandell, L. A. (2010). Infectious Diseases Society of America/American Thoracic Society Consensus Guidelines on the Management of Community-Acquired Pneumonia in Adults. Clinical Infectious Diseases, 44(Supplement\_2), S27-S72. https://doi.org/10.1086/511159

Mandell, L. A. (2010). Infectious Diseases Society of America/American Thoracic Society Consensus Guidelines on the Management of Community-Acquired Pneumonia in Adults. Clinical Infectious Diseases, 44(Supplement\_2), S27-S72. <https://doi.org/10.1086/511159>

Mathews Open Access. (2020). Ceftriaxone, an empirical goldmine: A systematic review of randomized controlled trials. Mathews Journal of Microbiology, 3(2), 1-10. Available at: Mathews Open Access.

McGeer A., Fleming C. A., Gree K. & Low D. E. (2001). Antimicrobial resistance in Ontario: Are we making progress? Laboratory Proficiency Testing Program Newsletter. 293:1-2.

Medical News Today (2015). Antibiotics: How do antibiotics work? MediLexicon International Ltd. Bexhill-on-sea UK.

Menninger J. R. & Otto D. P. (1982). Erythromycin, carbomycin, and spiramycin inhibit protein synthesis by stimulating the dissociation of peptidyl-tRNA from ribosomes. Antimicrob. Agents Chemother. 21:811-818.

Mingeot-Leclercq M. P., Glupczynski Y. & Tulkens P. M. (1999).Aminoglycosides: Activity and resistance. Antimicrob. Agents Chemother. 43(4):727-737.

Moellering R. C. (2003). Linezolid: The first oxazolidinone antimicrobial. Ann. Intern. Med. 138:135-142.

Moore D. (2015). Antibiotic Classification and Mechanism. <http://www.orthobullets.com/basic-science/9059/antibiotic> classification-and-mechanism. Accessed on September, 1 2016.

Moore P. B. (2001). The ribosome at atomic resolution. Biochemistry 40:3243-3250.

Mouton, J. W., et al. (2012). Pharmacokinetics and pharmacodynamics of antibiotics: The search for the holy grail. Current Opinion in Pharmacology, 12(5), 618-623. https://doi.org/10.1016/j.coph.2012.07.002

Munita, J. M., & Arias, C. A. (2016). Mechanisms of antibiotic resistance. Microbiology Spectrum, 4(2), 1-22. https://doi.org/10.1128/microbiolspec.VMBF-0016-2015

Murray, C. J. L., et al. (2020). Global burden of bacterial antimicrobial resistance in 2019: A systematic analysis. The Lancet, 399(10325), 629-655. https://doi.org/10.1016/S0140-6736(20)22051-6

Nguyen, A. T., et al. (2020). Increasing resistance to amoxicillin in pediatric populations. Pediatrics, 145(4), e20193511. https://doi.org/10.1542/peds.2019-3511

Nissen P., Hansen J., Ban N., Moore P. B. & Steitz T. A. (2000). The structural basis of ribosome activity in peptide bond synthesis. Sci. 289:920-930.

Oleghe, P. O., Ajayi, M. O., Adeoti, S. O., & Osho, P. O. (2020). Comparative evaluation of antimicrobial efficacy of commonly used antibiotics against Staphylococcus aureus and Escherichia coli in clinical isolates. International Journal of Biomedical Research, 4(3), 45-49. Retrieved from ResearchGate.

Oluwasegun, A. T., Eniola, A. S., & Akinola, R. D. (2020). Prevalence and resistance patterns of E. coli and S. aureus in Nigeria. Journal of Medical Microbiology, 17(4), 221-230.

Oluwasegun, T., Ajiboye, M., & Adeoti, O. (2020). Patterns of antibiotic resistance in common pathogenic bacteria in Ibadan. West African Journal of Microbiology, 25(1), 65-74.

Page, M. G., & Bush, K. (2005). Discovery and development of new antibacterial agents targeting Gram-negative bacteria in the twenty-first century. International Journal of Antimicrobial Agents, 16(1), 23-31. https://doi.org/10.1016/S0924-8579(00)00217-9

Papp-Wallace K., Endimiani A., Taracila M. & Bonomo R. (2011). Carbapenems: past, present, and future. Antimicrob. Agents Chemother. 55(11):4943-4960.

Park J. T. & Uehara T. (2008). How bacteria consume their own exoskeleton (turnover and recycling of cell wall-peptidoglycan). Microbiol. Mol. Biol. 72:211-227.

Patel G. & Bonomo R. A. (2011). Status report on carbapenemases: challenges and prospects. Expert Rev. Anti. Infect. Ther. 9:555-570.

Patel U., Yan Y. P., Hobbs F. W. Jr., Kaczmarczyk J., Slee A. M., Pompliano D. L., Kurilla M. G. & Bobkova E. V. (2001). Oxazolidinones mechanism of action: Inhibition of the first peptide bond formation. J. Biol. Chem. 276(40):37199-37205.

Paterson, D. L., & Bonomo, R. A. (2005). Extended-spectrum β-lactamases: a clinical update. Clinical Microbiology Reviews, 18(4), 657-686.

Pegler S. & Healy B. (2007). In patients allergic to penicillin, consider second and third generation cephalosporins for life threatening infections. BMJ. 335(7627): 991.

Peltola, H. (2000). Meningococcal disease: Still with us. Scandinavian Journal of Infectious Diseases, 32(1), 7-10. https://doi.org/10.1080/00365540050162791

Peterson L. R. (2008). Currently available antimicrobial agents and their potential for use as monotherapy. Clin Microbial. Infect. 14(6):30-45.

Poirel L., Brinas L., Verlinde A., Ide L. & Nordmann P. (2005). BEL-1, a novel clavulanic acid-inhibited extended-spectrum beta-lactamase, and the class 1 integron In120 in Pseudomonas aeruginosa. Antimicrob Agents Chemother. 49(9):3743-3748.

Rahal J. J. & Simberkoff M. S. (1979). Bactericidal and bacteriostatic action of chloramphenicol against meningeal pathogens. Antimicrob Agents Chemother. 16:13-18.

Reading C. & Farmer T. (1984). The inhibition of periplasmic β-lactamase in Escherichia coli by clavulanic acid and other -lactamase inhibitors. McGraw-Hill, New York.

Redgrave, L. S., Sutton, S. B., Webber, M. A., & Piddock, L. J. V. (2014). Fluoroquinolone resistance: Mechanisms, impact on bacteria, and role in evolutionary success. Trends in Microbiology, 22(8), 438-445. https://doi.org/10.1016/j.tim.2014.04.007

Reller, L. B., Weinstein, M., & Barrett, S. (2019). A review of antibiotic treatment of traveler’s diarrhea. Antimicrobial Agents and Chemotherapy, 49(7), 3011-3016.

Reller, L. B., Weinstein, M., & Barrett, S. (2019). A review of antibiotic treatment of traveler’s diarrhea. Antimicrobial Agents and Chemotherapy, 49(7), 3011-3016. https://doi.org/10.1128/AAC.49.7.3011-3016.2005

Roberts E., Sethi A., Montoya J., Woese C. & Luthey-Schulten Z. (2008). Molecular signatures of ribosomal evolution. Proc. Natl. Acad. 105:13953–13958.

Russell A. D. (2004). Types of antibiotics and synthetic antimicrobial agents. In: Denyer S. P., Hodges N. A. & German S. P. (eds.) Hugo and Russell‟s pharmaceutical microbiology. 7th Ed. Blackwell Science, UK. Pp. 152-186.

Sanchez A. R., Rogers R. S. & Sheridan P. J. (2004). Tetracycline and other tetracycline-derivative staining of the teeth and oral cavity. Int. J. Dermatol. 43(10):709-715.

Schlegel H. G. (2003). General microbiology. 7th Ed. Cambridge University Press, Cambridge.

Shinabarger D. L., Marotti K. R., Murray R. W., Lin A. H., Melchior E. P., Swaney S. M., Dunyak D. S., Demyan W. F. & Buysse J. M. (1997). Mechanism of action of oxazolidinones: effects of linezolid and eperezolid on translation reactions. Antimicrob. Agents Chemother. 41:2132-2136.

Sköld, O. (2001). Resistance to trimethoprim and sulfonamides. Veterinary Research, 32(3-4), 261-273.

Slatore, C. G. & Tilles, S. A. (2004). Sulfonamide hypersensitivity. Immunol. Allergy Clin. North Am. 24(3):477-490.

Smith, R. J., Zhang, Y., & Long, J. (2021). Methodologies in antimicrobial testing: A comparative approach. International Journal of Biomedical Research, 28(3), 319-328.

Stawinski J., Szafranski K., Vullo D. & Supuran C. T. (2013). Carbonic anhydrase inhibitors. Synthesis of heterocyclic 4-substituted pyridine-3-sulfonamide derivatives and their inhibition of the human cytosolic isozymes I and II and transmembrane tumor-associated isozymes IX and XII. Eur. J. Med. Chem. 69:701-710.

Sykes R. B. & Bonner D. P. (1985). Discovery and development of the monobactams. Clin. Infect. Dis. 7(4):S579-S593.

Sykes R. B., Cimarusti C. M., Bonner D. P., Bush K., Floyd D. M., Georgopapadakou N. H., Koster W. H., Liu W. C., Parker W. L., Principe P. A., Rathnum M. L., Slusarchyk W. A., Trejo W. H. & Wells J. S. (1981). Monocyclic β-lactam antibiotics produced by bacteria. Nature. 291:489-491.

Talaro K. P. & Chess B. (2008). Foundations in microbiology. 8th Ed. McGraw Hill, New York.

Tamma, P. D., Cosgrove, S. E., & Maragakis, L. L. (2011). Combination therapy for treatment of infections with Gram-negative bacteria

Tängdén, T., & Giske, C. G. (2015). Global dissemination of extensively drug-resistant carbapenemase-producing Enterobacteriaceae: Clinical perspectives on detection, treatment and infection control. Journal of Internal Medicine, 277(5), 501-512. https://doi.org/10.1111/joim.12342

Tenson T., Lovmar M. & Ehrenberg M. (2003). The mechanism of action of macrolides, lincosamides and streptogramin B reveals the nascent peptide exit path in the ribosome. J. Mol. Biol. 330(5):1005-1014.

Tidwell T. T. (2008). Hugo (Ugo) Schiff, Schiff bases, and a century of β-Lactam synthesis. Angew. Chem. Int. Ed. Engl. 47(6):1016-1020.

Tipper, D. J., & Strominger, J. L. (1965). Mechanism of action of penicillins: A proposal based on their structural similarity to acyl-D-alanyl-D-alanine. Proceedings of the National Academy of Sciences, 54(4), 1133-1141.

Torres J. A., Villegas M. V. & Quinn J. P. (2007). Current concepts in antibiotic-resistant gram-negative bacteria. Expert Rev. Anti. Infect. Ther. 5:833-843.

Unemo, M., & Shafer, W. M. (2014). Antimicrobial resistance in Neisseria gonorrhoeae in the 21st century: Past, evolution, and future. Clinical Microbiology Reviews, 27(3), 587-613. https://doi.org/10.1128/CMR.00010-14

van Bambeke F. (2004). Glycopeptides in clinical development: pharmacological profile and clinical perspectives. Curr. Opin. Pharmacol. 4(5):471-478.

van Bambeke F., Van Laethem Y., Courvalin P. & Tulkens P. (2004). Glycopeptide antibiotics: From conventional molecules to new derivatives. Drugs. 64(9):913-936.

van Hoek A. H. A. M., Mevius D., Guerra B., Mullany P., Roberts A. P. & Aarts H. J. M. (2011). Acquired antibiotic resistance genes: An overview. Front. Microbiol. 2:203 doi: 10.3389/fmicb.2011.00203.

Vannuffel P. & Cocito C. (1996). Mechanism of action of streptogramins and macrolides. Drugs. 51(1):20-30.

Vazquez, J. A. (2007). Optimizing antimicrobial therapy of respiratory infections. Infectious Diseases and Therapy, 11(4), 333-342.

Walsh C. (2003). Antibiotics: actions, origins, resistance. 1st Ed. ASM Press, Washington, DC. 345p.

White D. & Cox E. (2013). Fighting the impact of antibiotic-resistance.

World Health Organization (WHO). (2021). Guidelines on ethical standards in clinical microbiology research.

Wright G. D. (2010). Q & A: Antibiotic resistance: Where does it come from and what can we do about it? BMC Biol. 8:123. http://doi.org/10.1186/1741-7007-8-123.

Xu F., Xu H., Wang X., Zhang L., Wen Q., Zhang Y. & Xu W. (2014). Discovery of N-(3-(7H-purin-6-yl)thio)-4-hydroxynaphthalen-1-yl) sulfonamide derivatives as novel protein kinase and angiogenesis inhibitors for the treatment of cancer: synthesis and biological evaluation. Part III. Bioorg. Med. Chem. 22(4):1487-1495.

Yim G., Thaker M. N., Koteva K. & Wright G. (2014). Glycopeptide antibiotic biosynthesis. The Journal of Antibiotics. 67:31-41.

Zahner H. & Maas W. (1972). Biology of Antibiotics. Springer-Verlag, New York.