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Classification of Anti-Bacterial Agents and Their Functions

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Abstract

Bacteria that cause bacterial infections and disease are called pathogenic bacteria. They cause diseases and infections when they get into the body and begin to reproduce and crowd out healthy bacteria or to grow into tissues that are normally sterile. To cure infectious diseases, researchers discovered antibacterial agents, which are considered to be the most promising chemotherapeutic agents. Keeping in mind the resistance phenomenon developing against antibacterial agents, new drugs are frequently entering into the market along with the existing drugs. In this chapter, we discussed a revised classification and function of the antibacterial agent based on a literature survey. The antibacterial agents can be classified into five major groups, i.e. type of action, source, spectrum of activity, chemical structure, and function.

Keywords: anti-bacterial agents, classification, functions

1. Introduction

Bacteria are simple one-celled organism, which were first identified in the 1670s by van Leeuwenhoek. Latter in the nineteenth century, concepts have been developed that there is the strongest correlation between bacteria and diseases. Such considerations attracted interest of the researchers not only to answer some mysterious questions about infectious diseases, but also to find a substance that could kill, inhibit, or at least slow down the growth of such disease-causing bacteria. These efforts led to the revolutionary discovery of the antibacterial agent “penicillin” in 1928 from *Penicillium notatum* by Sir Alexander Fleming. The discovery unlocked the field of microbial natural products and so new agents were continually added, such as newly introduced daptomycin, tigecycline, linezolid, and so on. Gradually, due to various issues arising during the use of antibacterial agents, such as the resistance phenomenon,

an enormous increase in the number and types (e.g., structurally different and agent with a slightly different pattern of activity) of the newly added antibacterial agents has been observed, which made it necessary to review and compile the existing classification and functions of almost all the antibacterial agents. It is aimed that this approach will be equally helpful for researchers, clinicians, and academicians.

2. Classification

Infectious diseases are the major causes of human sickness and death. To overcome such health care issues, antibiotics proved to be promising agents ever since they were introduced in the 1940s. Antibacterials, which are a subclass of antibiotics, have been classified earlier in several ways; however, to make it more easily understandable, we can classify antibacterial agents into five groups: type of action, source, spectrum of activity, chemical structure, and function [1].

2.1. Classification based on type of action

Generally, antibacterials can be classified on the basis of type of action: bacteriostatic and bactericidal. Antibacterials, which destroy bacteria by targeting the cell wall or cell membrane of the bacteria, are termed bactericidal and those that slow or inhibit the growth of bacteria are referred to as bacteriostatic. Actually, the inhibition phenomenon of bacteriostatic agents involves inhibition of protein synthesis or some bacterial metabolic pathways. As bacteriostatic agents just prevent the growth of the pathogenic bacteria, sometimes it is difficult to mark a clear boundary between bacteriostatic and bactericidal, especially when high concentrations of some bacteriostatic agents are used then they may work as bactericidal [2]. Some prominent examples of bacteriostatic and bactericidal antibacterials along with their mode of action are presented in **Table 1**.

| A. Bacteriostatic antibacterials | Function |
|--|---|
| Sulphonamides | They act to inhibit folate synthesis at initial stages |
| Amphenicols, e.g. chloroamphenicol | Amphenicols work as protein synthesis inhibitors |
| Spectinomycin | It binds to the 30S ribosomal subunit, thereby interrupting protein synthesis |
| Trimethoprim | It disturbs the tetrahydrofolate synthesis pathway |
| Tigecycline; it belongs to the glycylicycline class | It is a protein synthesis inhibitor. It binds reversibly to the 30S bacterial ribosomal subunit, which blocks the binding of amino-acyl-tRNA to the acceptor site on the mRNA complex. This prohibits the incorporation of amino acids to the developing peptide chain, thereby inhibiting protein synthesis. |
| Erythromycin, clarithromycin and azithromycin are macrolides | They work as inhibitors of protein synthesis |
| Linezolid is a member of the oxazolidinone class | |
| Doxycycline, tetracycline, and minocycline belong to tetracyclines class | |

| B. Bactericidal antibacterials | Function |
|--|---|
| Penicillins, e.g. pen V, penicillin G, procaine penicillin G, benzathine penicillin G, methicillin, oxacillin, cloxacillin, dicloxacillin and flucloxacillin. They belong to β -lactams antibiotic class | |
| Carbapenems like imipenem, meropenem, aztreonam, ticarcillinclavulnate and piperacillin-tazobactam; these are β -lactam/ β -lactamase inhibitors. Some other β -lactam inhibitors are cephalosporin, e.g. cefotaxime, ceftriaxone, ceftazidime, and cefepime | They work by interfering the synthesis of the bacterial cell wall |
| Gentamicin, tobramycin, and amikacin are aminoglycosides | They inhibit protein synthesis |
| Quinolones and fluoroquinolones, such as levofloxacin, ciprofloxacin, and oxifloxacin | These block bacterial DNA replication |
| Vancomycin is a glycopeptide | These inhibit cell wall synthesis |
| Polymyxin B and colistin are polymyxins | These antibacterial disrupt cell membrane |

Table 1. List of some bacteriostatic and bactericidal antibacterials.

2.2. Classification based on source of antibacterial agents

Antibacterials are the subclass of antibiotics, which can be naturally obtained from fungal sources, semi-synthetic members which are chemically altered natural product and or synthetic. Cephalosporins, cefamycins, benzylpenicillin, and gentamicin are well-known examples of natural antibiotics/antibacterials. Natural antibiotics/antibacterials often exhibit high toxicity than synthetic antibacterials. Ampicillin and amikacin are semi-synthetic antibiotics, which were developed to show low toxicity and increase effectiveness. Synthetic antibiotics are also designed to have even greater effectiveness and less toxicity and, thus, have an advantage over the natural antibiotics that the bacteria are not exposed to the compounds until they are released. Moxifloxacin and norfloxacin are promising synthetic antibiotics [3].

2.3. Classification based on spectrum of activity

This is another way of classification of antibiotics or antibacterial agents, which is based on their target specification. In this category, the antibacterials may be either narrow or broad spectrum. The terms narrow spectrum and broad spectrum have been interpreted not specifically since their use in antibiotic history, but recently these acquired clear meanings in academic and industrial fields [4, 5]. The narrow spectrum antibacterials are considered to be those which can work on a narrow range of microorganisms, that is, they act against Gram-positive only or Gram-negative only bacteria. Unlike narrow spectrum antibacterial, the broad spectrum antibacterial affects a wide range of pathogenic bacteria, including both Gram-positive and Gram-negative bacteria. Usually, the narrow spectrum antibacterials are considered ideal antibacterials and are preferred over the broad-spectrum antibacterials. The reason is

that the narrow-spectrum antibiotics do not kill as many of the normal microorganisms in the body as the broad-spectrum antibiotics and thus has less ability to cause superinfection. Also, the narrow-spectrum antibiotic will cause less resistance of the bacteria as it will deal with only specific bacteria.

Based on the spectrum of activity, both of these groups have a large and diverse library of antibacterials. **Table 2** shows all the well-known examples of these categories.

2.4. Classification based on chemical structure

Different skeleton-containing antibiotics display different therapeutic behaviour; therefore, it is an ultimate need to classify antibacterials on the basis of their chemical structure. This classification is also very important as similar structural units have similar patterns of toxicity, effectiveness, and other related properties. Usually on a structural basis, antibacterials have

| Broad-spectrum antibacterials (examples) | Narrow-spectrum antibacterials (examples) |
|--|--|
| Ampicillin and its derivative amoxicillin are broad-spectrum antibacterials. Amoxicillin/clavulanic acid (common name co-amoxiclav) is an antibiotic useful for the treatment of a number of bacterial infections | β -Lactamase-sensitive, first generation include penicillin G, benzathine penicillin G, penicillin V, procaine penicillin, propicillin, pheneticillin, azidocillin, clometocillin, and penamecillin are considered in narrow-spectrum antibacterial category |
| Quinolones [6] such as Maxaquin (lomefloxacin), Floxin (ofloxacin), Noroxin (norfloxacin), Tequin (gatifloxacin), Cipro (ciprofloxacin), Avelox (moxifloxacin), Levaquin (levofloxacin), Factive (gemifloxacin), Cinobac (cinoxacin), NegGram (nalidixic acid), Trovan (trovafloxacin), and Zagam (sparfloxacin) are considered as broad-spectrum antibacterials | β -Lactamase-resistant, 1st generation include; Cloxacillin (dicloxacillin flucloxacillin), methicillin, nafcillin, oxacillin and temocillin are narrow-spectrum antibacterials |
| Aminoglycosides which are broad-spectrum antibacterials include kanamycin A, amikacin, tobramycin, dibekacin, gentamicin, sisomicin, netilmicin, neomycins B, C and neomycin E (paromomycin) [7] | Cephalosporins (first generation and second generation) antibacterials are relatively narrow spectrum |
| Cephalosporins (third, fourth, and fifth generations) are relatively extended to the broad spectrum of activity | Vancomycin, clindamycin, isoniazid, rifampin, ethambutol, pyrazinamide, bacitracin, polymyxins, sulfonamides, glycopeptide and nitroimidazoles are counted in this group |
| Carbapenems (e.g. imipenems) show a broad pattern of activity [8] | |
| Macrolides such as erythromycin, roxithromycin, clarithromycin, azithromycin, and dirithromycin are considered in this category [9] | |
| Tetracycline, chlortetracycline, oxytetracycline, demeclocycline, lymecycline, meclocycline, methacycline, minocycline, and tigecycline are considered as broad-spectrum antibacterials | |
| Chloramphenicol | |
| Ticarcillin, a carboxypenicillin, also has a broad spectrum of activity | |
| Rifamycins also exhibited broad coverage [10] | |

Table 2. List of broad- and narrow-spectrum antibacterials.

been classified into two groups: group A (β -lactams) and group B (aminoglycosides). However, in a more elaborated way, the antibacterials can be classified into β -lactams, β -lactam/ β -lactamase inhibitor combinations, aminoglycoside, macrolides, quinolones, and fluoroquinolones.

2.4.1. β -Lactams

Beta-lactams are a popular class of drugs, having a four-membered lactam ring (**Figure 1**), known as β -lactam ring; however, they vary by side chain attached or additional cycles. Penicillin derivatives, cephalosporins, monobactams, and carbapenems, e.g. imipenems, all belong to this class.

Usually, alterations were made to the basic penam and cephem structural units such that enhanced antimicrobial potential is achieved. Among such modified agents, some are clavulanate, latamoxef, loracarbef, etc. On the cephalosporins unit, most changes have been made at positions 7 and 3. Cephalothin, cephaloridine, and cephazolin are among some of the modified cephalosporins, which have shown good activity against Gram positive with the exception of enterococci- and methicillin-resistant staphylococci. Some other examples include preparation of microbiologically active oxacephems and carbacephems (**Figure 2**) by modification of the cephalosporin nucleus [11].

The aminopenicillins are also included in this class, which are structural analogues of ampicillin, which is a 2-amino derivative of benzylpenicillin [12].

2.4.2. Aminoglycoside

In compounds of this group, two aminosugars joined by glycosidic bond to an aminocyclitol. Commonly used aminoglycosides are streptomycin, gentamicin, sisomicin, netilmicin, kanamycin,

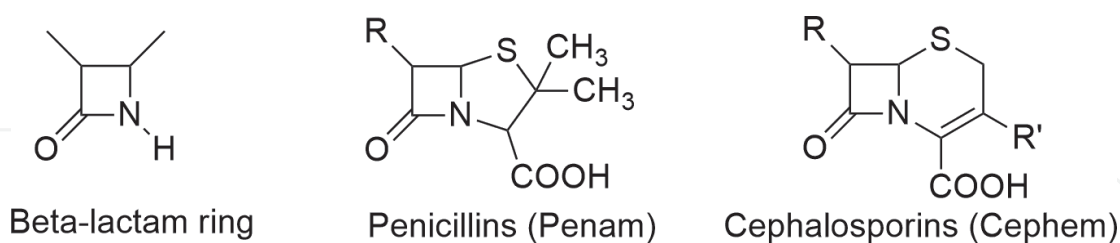


Figure 1. Basic structure of the β -lactam ring, penicillins (Penam skeleton) and cephalosporins (Cephem skeleton). R in Penam and Cephem nucleus represents the side chain that could be different for different penicillins and cephalosporins, while R' denotes another side chain in the Cephem nucleus.



Figure 2. Cephalosporin-modified structure of oxacephems and carbacephems.

amikacin, neomycin, tobramycin, toframycin, spectinomycin, and paromomycin. The structure of some of these is presented in **Figure 3**.

Changes in original structural units of aminoglycosides can be made either synthetically or enzymatically. Structural properties such as the number and location of various functional groups on a modified compound compared to their parent compounds usually exhibit great effect on the biological activities of these drugs. The literature [13] has shown that the number and location of amino groups on the hexoses and the site of attachment of the other rings to deoxystreptamine have a considerable effect on preventing inhibition of protein synthesis or, in other words, their biological activities. For example, among kanamycin A, B, and C, kanamycin B is a highly effective antibiotic than either kanamycin A or C. It is inferred that the presence of a diamino hexose results in a compound that has better efficiency for inhibition of protein synthesis than the one holding only one amino group.

2.4.3. Macrolides

Macrolides belong to the polyketide class of natural products. Structurally, macrolides are antibiotics that consist of a macrocyclic lactone ring, usually 14-, 15-, or 16-member to which one or more deoxy sugars, usually cladinose and desosamine, may be attached. Some well-known examples of macrolides are erythromycin and roxithromycin etc.

So far, the relationship of structural activity of various macrolides has been studied. Studies revealed that some existing 14-, 15-, and 16-member macrolide antibiotics were modified toward interesting targets. For example, specific substitution on the C-9, C-11, C-12, or C-6 sites in the macrolactone ring results in better in vitro activity against mycobacterium tuberculosis (**Figure 4**) [14].

2.4.4. Quinolones and fluoroquinolones

Quinolones are quinine-derived structural units and have been proved to be potent synthetic antibacterial agents. The basic skeleton of the quinolone molecule is presented in **Figure 5**. The addition of fluorine at position 6 is called fluoroquinolone. In the bicyclic ring, the variation

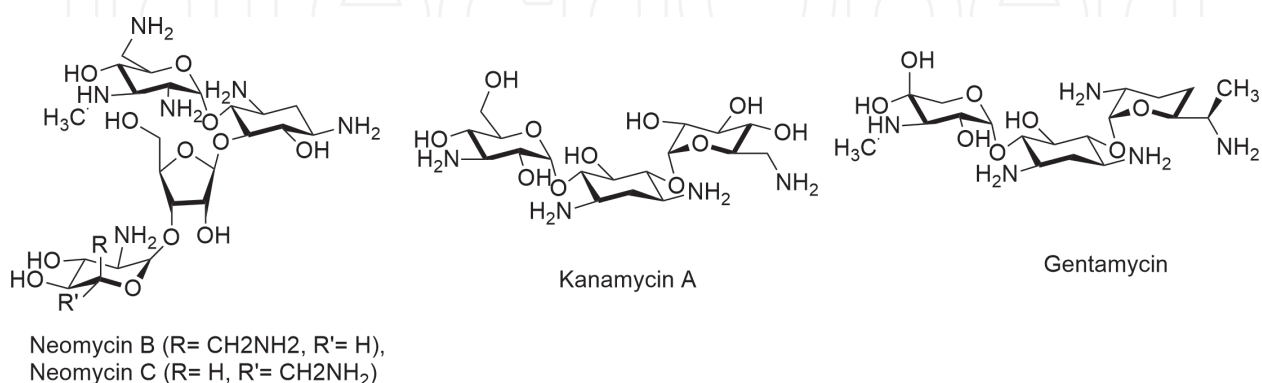


Figure 3. Structures of some well-known aminoglycosides antibacterials.

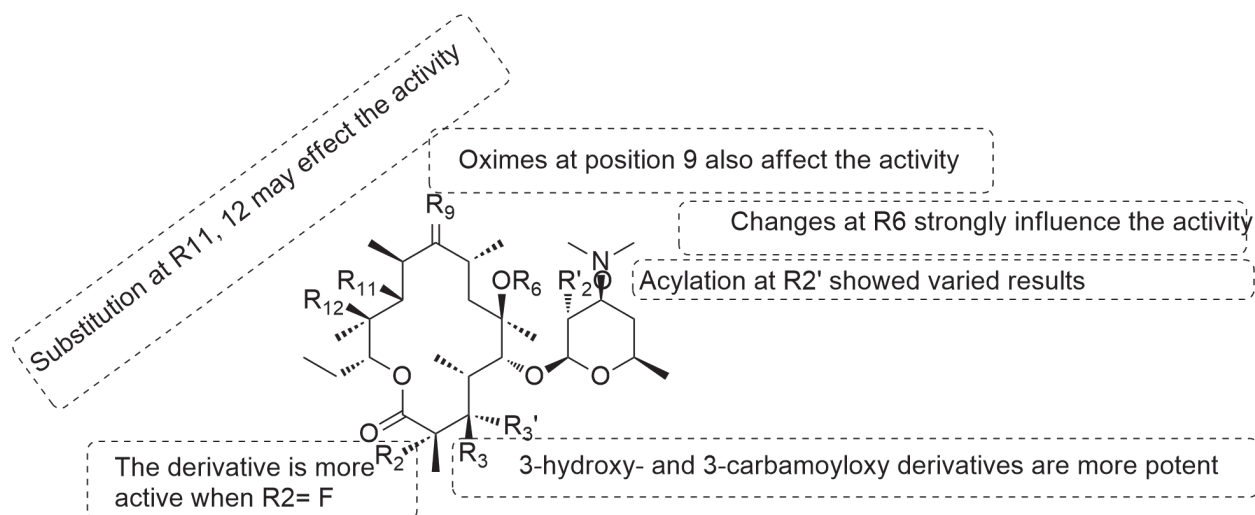
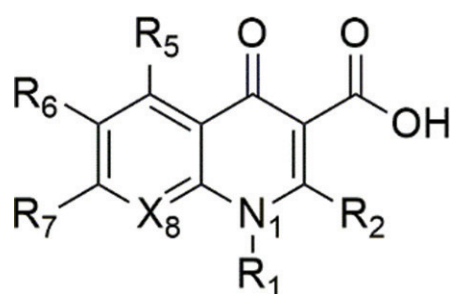


Figure 4. Substitution effect on activity of macrolides.



Flouroquinolone if R₆=F

Figure 5. Basic structure of quinolone.

at positions 1-, 5-, 6-, 7-, and 8- exerts key effect on the therapeutic behaviour of these drugs. Usually, such structural alteration has led to enhanced coverage and potency of antibacterial activity and pharmacokinetics, e.g. improved anti-Gram-positive activity of moxifloxacin and garenoxacin. However, some of these modifications are associated with definite adverse effects [15]. Some well-known examples of quinolone include nalidixic acid (first generation), ciprofloxacin (second generation), levofloxacin (third generation), and trovafloxacin (fourth generation).

2.4.5. Streptogramin antibiotics

Streptogramin antibiotics are a unique class of antibacterials consisting of two groups of structurally unrelated molecules: group A streptogramins (polyunsaturated macrolactones) and group B streptogramins (cyclic hexadepsipeptides) [16]. Dalfopristin and quinopristin

are representative example of the streptogramin A and streptogramin B groups, respectively. Alteration of the group B structural units has been mainly achieved on the 3-hydroxypicolinoyl, the 4-dimethylaminophenylalanine, and the 4-oxo pipercolinic residues. Modifications on this third part result in water-soluble derivative quinupristin. Water-soluble group A derivatives were obtained by some synthetic steps, e.g. dalbapristin, which is a sulfone derivative that can be obtained by Michael addition of aminothiols to the dehydroproline ring of pristinamycin IIA, followed by oxidation [17]. The group A molecules impede with the expansion of the polypeptide chain by avoiding the binding of aminoacyl-tRNA to the ribosome and the creation of peptide bonds, while the group B building blocks encourage the disconnection of the peptidyl-tRNA and can interfere with the removal of the completed polypeptide by blocking its access to the channel through which it usually leaves the ribosome.

2.4.6. Sulphonamides

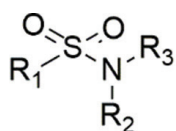
Sulphonamides are one of the important class of synthetic organic compounds with great medicinal importance having a sulphonamide functional group ($R_1-SO_2-NR_2R_3$) in their structures. Some compounds belonging to this group also show antibacterial properties such as sulfadiazine. The original antibacterial sulphonamides are synthetic antimicrobial agents that contain the sulphonamide group. Some others are sulfonylureas and thiazide diuretics which proved to be newer drug groups based on the antibacterial sulphonamides (**Figure 6**).

2.4.7. Tetracyclines

Tetracyclines are four rings hydrocarbon containing compounds, which can be defined also as “a subclass of polyketides having an octahydrotetracene-2-carboxamide skeleton.” These antimicrobial agents were originally derived from *Streptomyces* bacteria, but the newer derivatives are semi-synthetic. Some promising examples of this group are oxytetracycline and doxycycline.

2.4.8. Nitroimidazoles

Nitroimidazoles are a group of compounds that contain a basic imidazole ring. The most commonly used example is metronidazole (**Figure 7**). Nitroimidazoles vary by the location of the nitro functional group. Most of the drugs of this class have their nitro group at position 6, such as metronidazole, and/or at position 2, such as benznidazole.



R₁, R₂ and R₃ can be alkyl, aryl
and heteroaryl

Figure 6. Basic structural unit of sulphonamide.

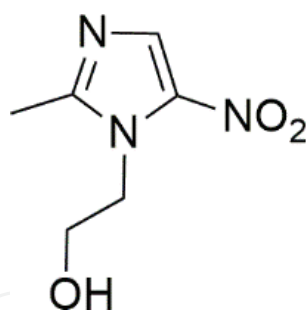


Figure 7. Structure of metronidazole.

2.5. Function-based classification of antibacterial drugs

Function means how a drug works or what is its mode of action. This is one of the most important factors related to each antibacterial. The major processes or functions, which are responsible for bacterial growth, are cell wall synthesis, cell membrane function, protein synthesis, nucleic acid synthesis, and so on. All such processes are targets for antibiotics; therefore, antibacterials, which interfere or disturb these processes in different ways, can be subdivided into four groups: such as cell wall synthesis inhibitors, inhibitors of membrane function, inhibitors of protein synthesis, and inhibitors of nucleic acid synthesis. All these groups are discussed briefly hereafter.

2.5.1. Cell wall synthesis inhibitors

Structurally, the bacterial cell wall is different from that of all other organisms by the presence of polysaccharide backbone, called peptidoglycan, which is composed of alternating *N*-acetylmuramic acid and *N*-acetylglucosamine residues in equal amounts and most of eubacteria have peptidoglycan-based cell walls except the mammalian cell. Like all other organisms, the bacterial cell wall offers structural completion to the cell; therefore, the most important process for avoiding bacterial growth is to stop cell wall synthesis by inhibiting the peptidoglycan layer of bacterial cell walls. The agents used to work against this function are called cell wall synthesis inhibitors and the cell wall of new bacteria growing in the presence of these agents is deprived of peptidoglycan.

β -Lactam drugs, including penicillin derivatives, cephalosporins, monobactams, and carbapenems, are the major antibiotics that inhibit bacterial cell wall synthesis. To understand the inhibition process, one must be aware of the fact that the last step in the synthesis of peptidoglycan is eased by penicillin-binding proteins; therefore, this initially occurs in the binding of drug to cell receptors, i.e. penicillin-binding proteins. Thus, β -lactam drugs work as a false molecule for D-alanyl-D-alanyl transpeptidases, which result in inhibition of transpeptidation reaction and peptidoglycan synthesis. Thereafter, autolytic enzyme inhibitors get inactivated, which activates the lytic enzyme, thereby resulting in division of bacteria provided that the environment is isotonic [18]. Some other antibiotics such as bacitracin, teicoplanin, vancomycin, ristocetin, and novobiocin must be subjected at early stages, which impede early phases of the peptidoglycan synthesis.

Gram-positive and Gram-negative bacteria vary in the susceptibility to the β -lactam drugs because of the structural differences in their cell wall, i.e. Gram-negative bacteria usually have

less susceptibility because these antibiotics fail to reach the cell wall as they are blocked by the outer membrane of the Gram-negative bacteria. Factors such as the amount of peptidoglycan, receptors, and lipids availability, nature of crosslinking, autolytic enzymes activity greatly influence the activity, permeation, and incorporation of the drugs.

Considering the resistance phenomenon, all β -lactam antibacterials can only be inactivated by bacterial produced enzymes called β -lactamases (e.g. penicillinases, cephalosporinases, cephamycinases, carbapenemases, and so on).

2.5.2. *Inhibitors of membrane function*

The cytoplasmic membrane, which covers the cytoplasm, serves as a selective barrier and controls the internal composition of the cell. Whenever these functional roles of the cytoplasmic membrane get disturbed, macromolecules and ions will outflow, which will result in cell destruction or death. Selectivity of the agents is necessary to carry out this chemotherapy as the agents are aimed to target the bacterial cell membrane. Polymyxins are active antibacterial agents, which are cyclic peptides, having a long hydrophobic tail. Polymyxins are found in the form of A, B, C, D, E, where B and E can be used therapeutically. Polymyxins show their specificity for polysaccharide molecules, which are present in the outer membrane of many Gram-negative bacteria; therefore, polymyxins are considered to be selectively toxic for Gram-negative bacteria. Mechanistically, after association with the lipopolysaccharide substrate in the outer membrane of Gram-negative bacteria, polymyxins change the membrane structure so that its permeability increases, which results in disruption of the osmotic balance. Additionally, changes like discharge of the molecules from interior of the cell, inhibition of respiration, and increased water uptake lead to the cell death. Since Gram-positive bacteria have a too thick cell wall, which denies the access of these molecules to the Gram-positive bacterial cell membrane, polymyxins have less or even no effect on Gram-positives [19].

2.5.3. *Protein synthesis inhibitors*

Protein synthesis is one of the most important functions in the bacterial cell and humans as well. Therefore, to cure infectious disease caused by pathogenic bacteria, it is the most important target for the drugs, which are called protein synthesis inhibitor antibiotics. Since both human and bacterial cells synthesize proteins, due to the slow synthesis of human proteins, it has remained a comfortable task for the development of the selective antibiotics. Only the side effects from toxicity and resistance phenomenon are taken seriously during antibiotic development.

Mechanistically, protein synthesis inhibitors act to disturb any stage of the protein synthesis such as initiation and elongation stages (aminoacyl tRNA entry, proofreading, peptidyl transfer, ribosomal translocation and termination). **Table 3** shows representative antibiotics, their sites and pathways, etc. [20].

2.5.4. *Inhibition of nucleic acid synthesis*

One of the most important targets for antibiotic to cure infectious diseases is nucleic acid synthesis, and the antibiotics used are called nucleic acid synthesis inhibitors. A sound

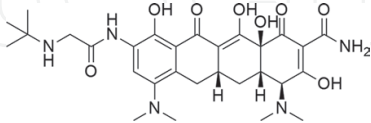
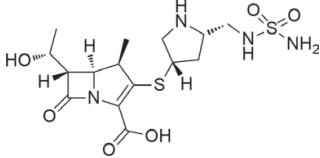
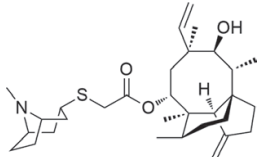
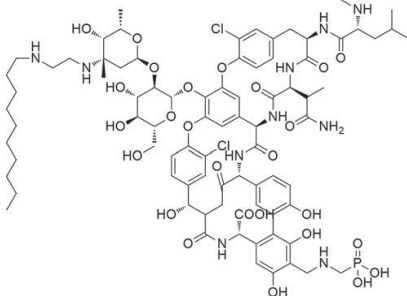
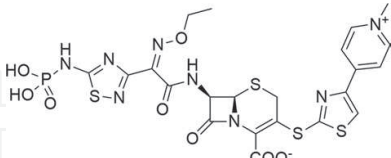
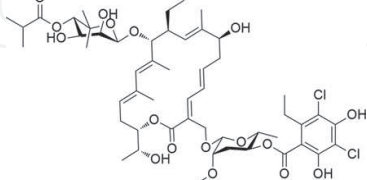
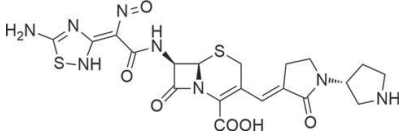
| Drug type | Binding site function and pathway disturbed |
|---|--|
| Aminoglycosides: Examples include gentamicin, tobramycin, streptomycin, and kanamycin | Aminoglycosides bind to the 30S ribosomal subunit which alter the ribosomal structure. This affects all normal steps of protein synthesis, such as initiation step of translation, blocking of elongation of peptide bond formation, discharge of incomplete, and toxic proteins. These disturbances ultimately stop protein synthesis and destroy the cytoplasmic membrane. |
| Macrolides | These are protein synthesis inhibitors, which bind to the 50S ribosomal subunits, impeding peptidyl transfer |
| Tetracyclines and glycyclines (tigecycline) | These inhibitors bind to the 30S ribosomal subunit. Protein translation (through inhibition of aminoacyl tRNA binding to ribosome) gets disturbed by these inhibitors |
| Strptogramines: Examples include pristinamycin, dalfopristin, and quinupristin | Their binding site is the 50S ribosomal subunit. They interfere in protein translation through prevention of initiation, elongation, and translocation stages and free tRNA depletion |
| Phenicol: For example, chloroamphenicol | These antibiotics, e.g. chloroamphenicols, bind to the 50S ribosomal subunit and inhibit protein synthesis by blocking the peptidyl transfer phase of elongation on the 50S ribosomal subunit in bacteria |
| Oxazolidinone: The most common example is linezolid | They bind to the 50S ribosomal subunit, which are thought to act at the initiation stage [21] |
| Ketolides: This is a novel class of protein synthesis inhibitors, which exhibit excellent activity against resistant organisms. | |
| Protein synthesis inhibitors with unknown pathway include retapamulin, mupirocin, and fusidic acid. | |

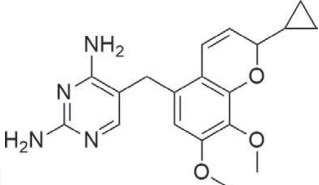
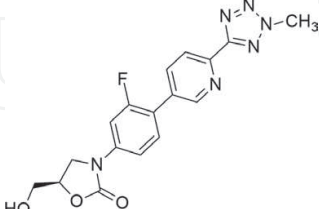
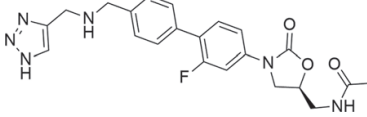
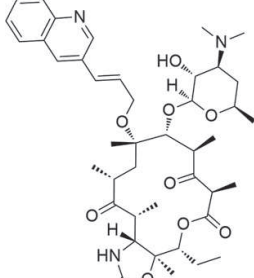
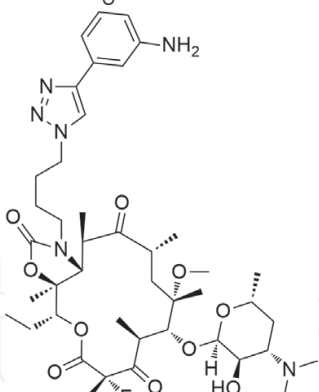
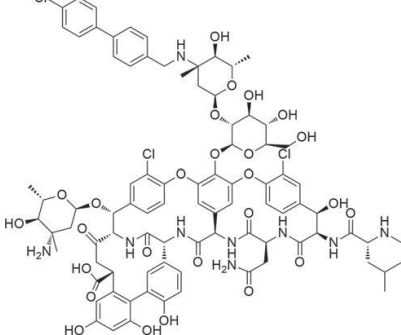
Table 3. Example of drugs, their binding sites and pathways which get affected.

difference in the enzymes that carry out DNA and RNA synthesis between eukaryotic and prokaryotic cells helps to achieve selective toxicity, which favours development of the antibiotic. The antibacterials of this class can be subdivided into DNA inhibitors and RNA inhibitors. RNA inhibitors interfere with the bacterial transcription process in which messenger RNA transcripts of genetic material are produced for later transformation into proteins. RNA inhibitors such as rifampin, a well-known example of the rifamycins family, bind to DNA-dependent RNA polymerase, thereby creating a wall that inhibits elongation of RNA. Such a situation prevents gene transcription which affects the normal function of bacteria that results in cell death. Like all other biological polymerization processes, DNA synthesis is also achieved by initiation, elongation, and termination stages; therefore, anti-bacterial drugs target any one of these processes to inhibit DNA synthesis. Quinolones, including nalidixic acid and ciprofloxacin, work as DNA inhibitors. DNA gyrase (a topoisomerase) is accountable for cutting one of the chromosomal DNA parts at the beginning of the supercoiling. The scratch is made provisionally and later on linked back together. Quinolones bind to DNA gyrase, inhibiting their function, which results in inhibition of the DNA replication that ultimately results in cell damage. There are some other antibacterial drugs, which act upon anaerobic bacteria by creating metabolites that are bind into DNA strands, which then are more likely to rupture. Examples of such drugs include nitrofurantoin and metronidazole.

3. Recent antimicrobial agents

Our discussion covered almost all the old and some new antimicrobial agents. However, to make these agents easily understandable, **Table 4** lists some recent antibacterial agents with their structure, class, and so on [22].

| FDA-approved antibacterial agent | Structure | Category | Approval year/ trial phase |
|--|---|----------------|----------------------------|
| Tigecycline |  | Glycylcycline | 2005 |
| Doripenem |  | Carbapenems | 2007 |
| Retapamulin |  | Pleuromutillin | 2007 |
| Telavancin |  | Glycopeptides | 2009 |
| Ceftaroline |  | Cephalosporins | 2010 |
| Fidaxomicin |  | Macrocyclic | 2011 |
| FDA approval awaiting antibacterial agents | Structure | Category | Approval year/ trial phase |
| Ceftobiprole |  | Cephalosporin | Awaited |

| FDA-approved antibacterial agent | Structure | Category | Approval year/ trial phase |
|----------------------------------|---|------------------------------------|----------------------------|
| Iclaprim |  | Dihydropholate reductase inhibitor | Awaited |
| Torizolid |  | Oxazolidinones | Phase II |
| Radezolid |  | Oxazolidinones | Phase II |
| Cethromycin |  | Ketolides | Phase III |
| Solithromycin |  | Ketolides | Phase II |
| Oritavancin |  | Glycopeptide | Phase III |

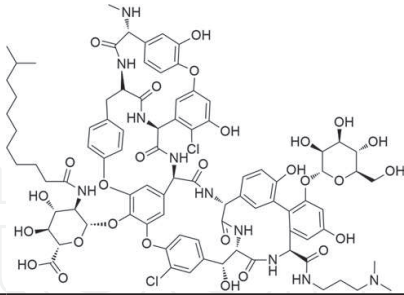
| FDA-approved antibacterial agent | Structure | Category | Approval year/ trial phase |
|----------------------------------|---|--------------|----------------------------|
| Dalbavancin |  | Glycopeptide | Phase III |

Table 4. List of newer antibacterial agent.

4. Conclusion and prospectives

Unlike antibiotics classification, little efforts have been made to classify antibacterials (a subclass of antibiotic) separately. Therefore, we tried to classify antibacterial into five principal categories, each of which has its own importance. However, classifications based on chemical structure and function of these agents are considered to be more important as these groups describe a lot about their therapeutic nature, while the rest of the classification is less important, e.g. sometimes, classification based on the spectrum of activity distinguishes these agents in an ambiguous way as the spectrum sometime depends on their concentration used. The classification mentioned could be a better guide for future classification, i.e. the agents that are in developing stages or those that are going to develop can be adjusted in any suitable group mentioned in the text. Further, this categorization could be helpful in academic and in health care fields at present and in the future as well.

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