



# Protein Synthesis Inhibitors

Pharmacology and Toxicology

General Pharmacology

Second Year Medical Students

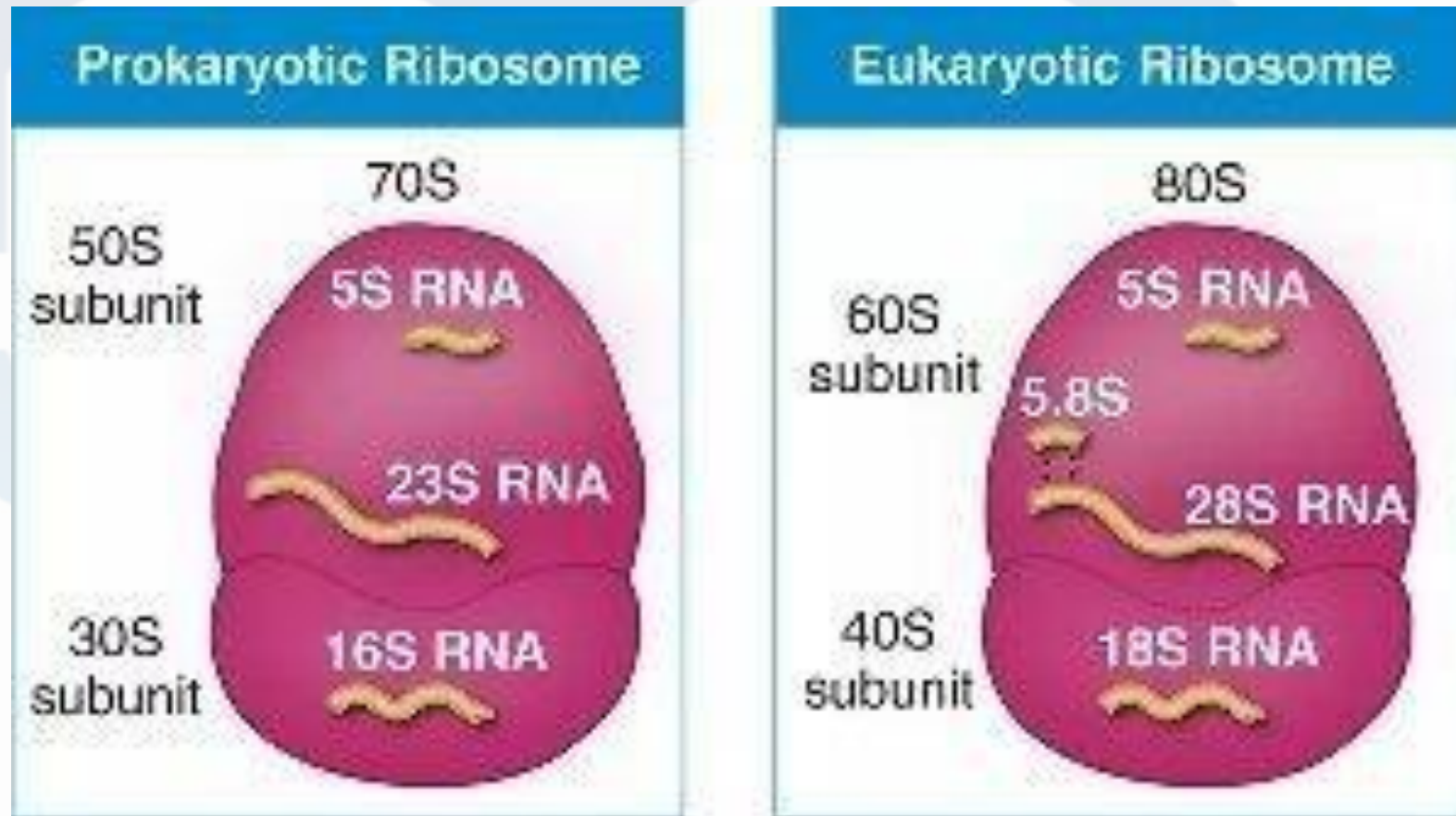
Tareq Saleh

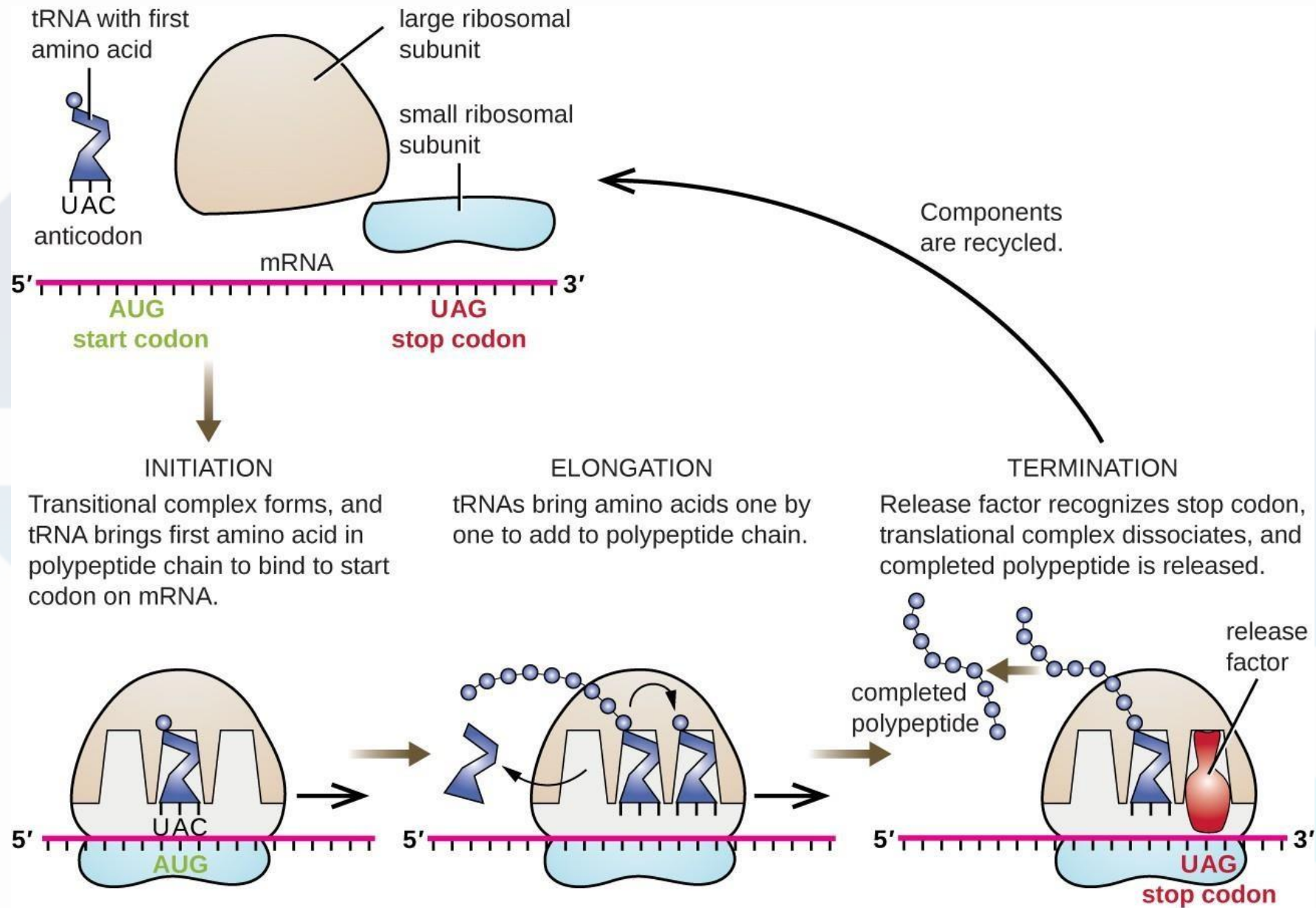
Faculty of Medicine

The Hashemite University

**Textbook:** Chapter 30 pp: 384-399

# Bacterial Protein Synthesis



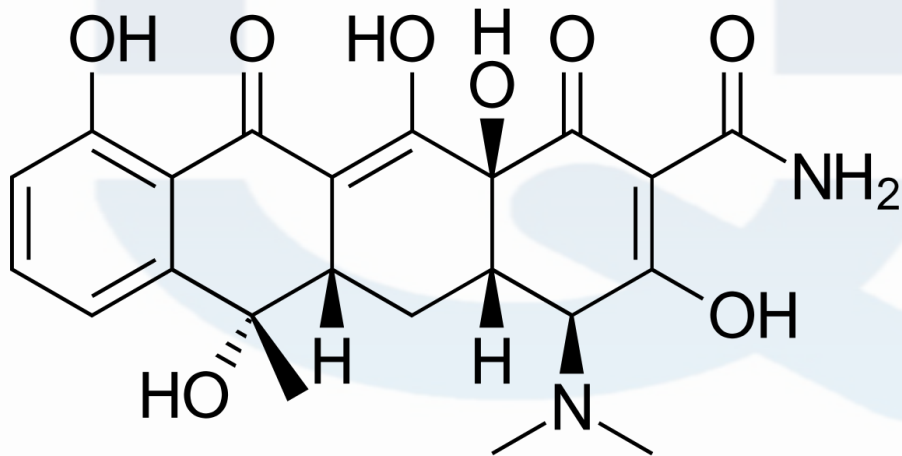




# Tetracyclines

Sheet prepared by:-  
Dr Ahmad Almohtaseb

# Tetracyclines



Tetracycline

consist of **four aromatic fused rings**, substitutions on these rings alter the individual pharmacokinetics and spectrum of antimicrobial activity.

## TETRACYCLINES

*Demeclocycline* **DECLOMYCIN**

*Doxycycline* **VIBRAMYCIN**

*Minocycline* **MINOCIN**

*Tetracycline*

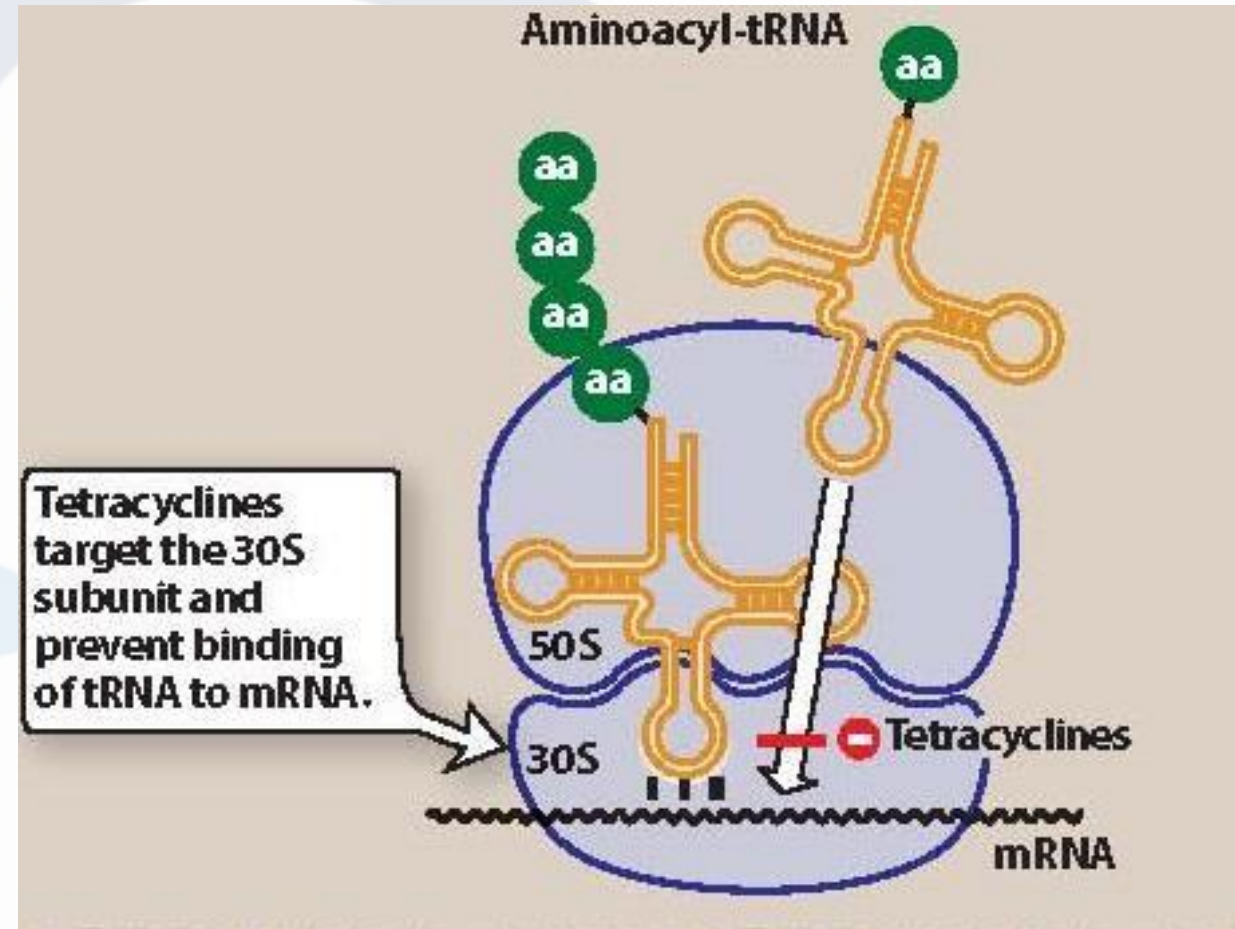




# Tetracyclines

## Mechanism of action

- bind **reversibly** to the **30S** subunit of bacterial ribosomes
- prevent the binding of tRNA to the mRNA ribosome complex** -





For Tetracyclines and other protein synthesis inhibitors to work , they have to cross bacterial plasma membrane and concentrate within the cytoplasm (site of protein synthesis in bacteria ) ,it can cross plasma membrane via passive diffusion or shunted through special energy dependent transporter in susceptible organisms then it binds with its target (30s subunit) resulting in prevent binding of new tRNA with mRNA ribosome complex .



# Tetracyclines

## Antibacterial spectrum

- Bacteriostatic
- Effective against gram-positive, gram-negative, protozoa, spirochetes, atypical, etc

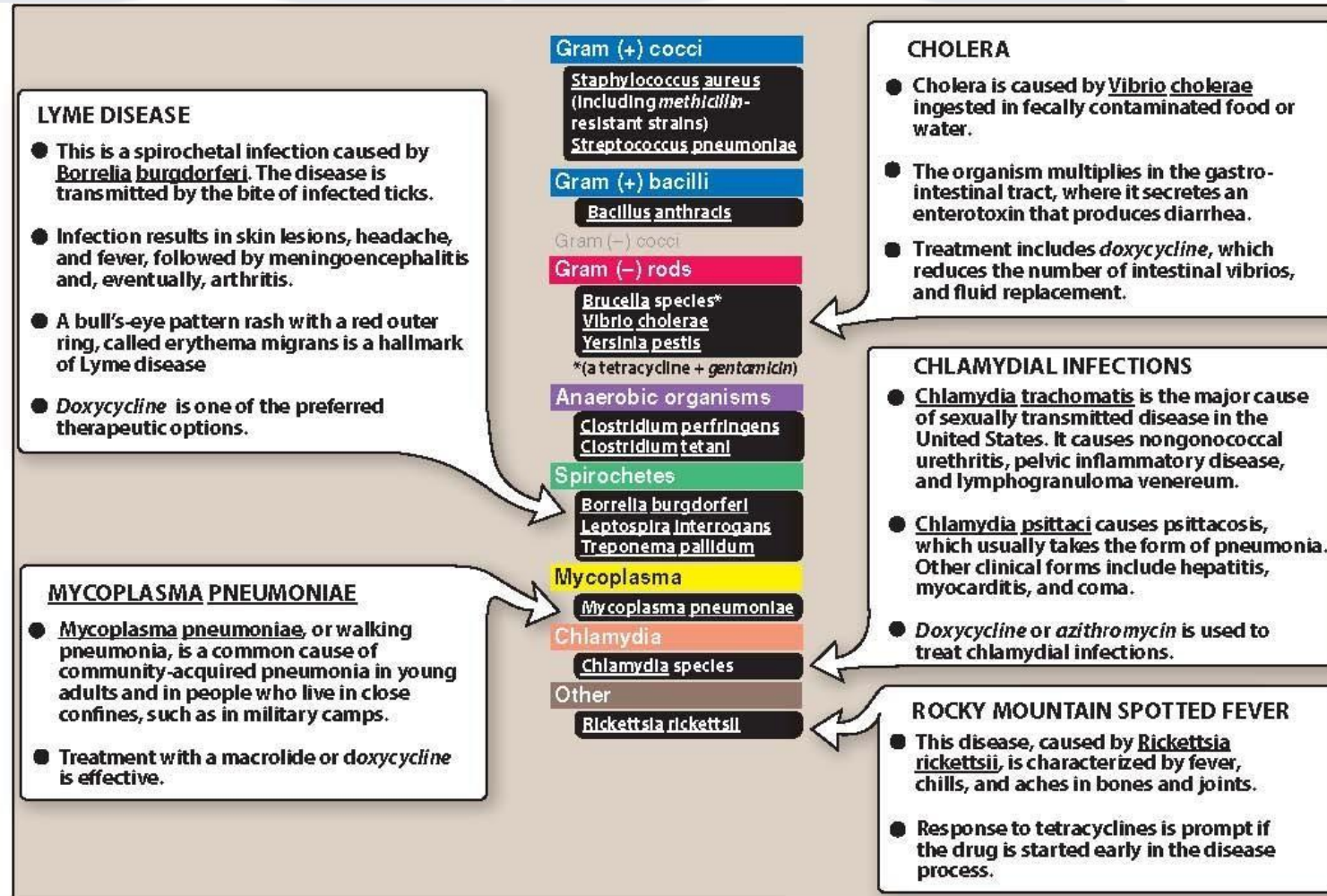
## Commonly used for the treatment of:

1. Acne (doxycycline)
2. Chlamydia: **sexually transmitted, usually accompanied by gonorrhea. in certain cases can cause eye infection or mucus membrane infection** (doxycycline)
3. Peptic ulcer disease (tetracycline)
4. Lyme Disease **common in northern America** (doxycycline)
5. Mycoplasma Pneumonia (doxycycline)





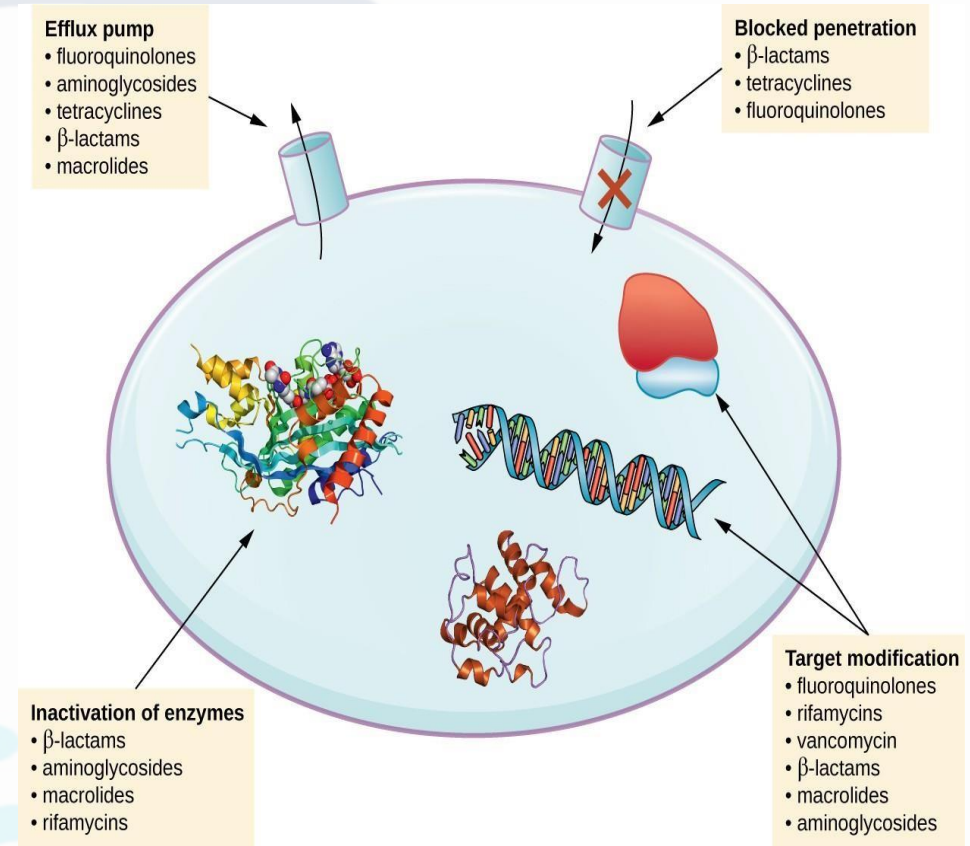
# Therapeutic Spectrum of Doxycycline



# Tetracyclines

## Mechanisms of resistance

- **Efflux pump (most common)**
- Enzymatic inactivation of the drug
- Interfering with binding to ribosomes
- Cross-resistance is *not* Common (that means resistance to one tetracycline doesn't confer universal resistance to all tetracyclines, and development of cross resistance may be dependent on the mechanism of resistance.)



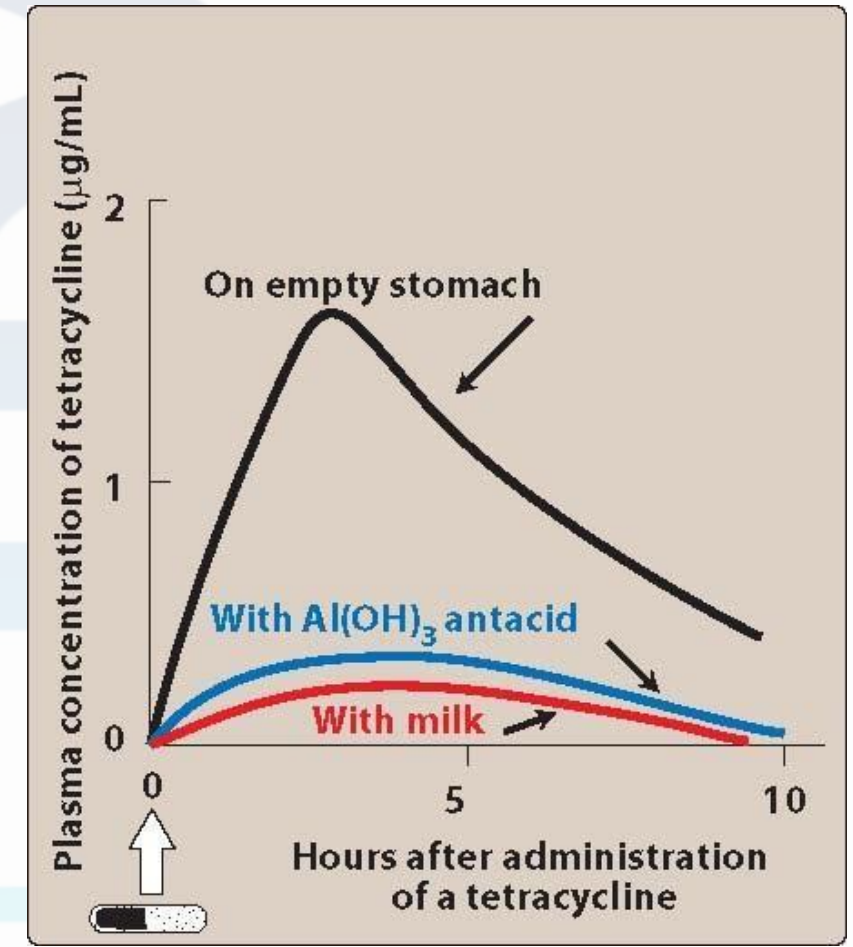


# Tetracyclines

## Pharmacokinetics

### Absorption

- Oral
- Adequately absorbed
- ↓ **absorption** when administered **with dairy (high cations)** → **formation of nonabsorbable chelates**



# Tetracyclines

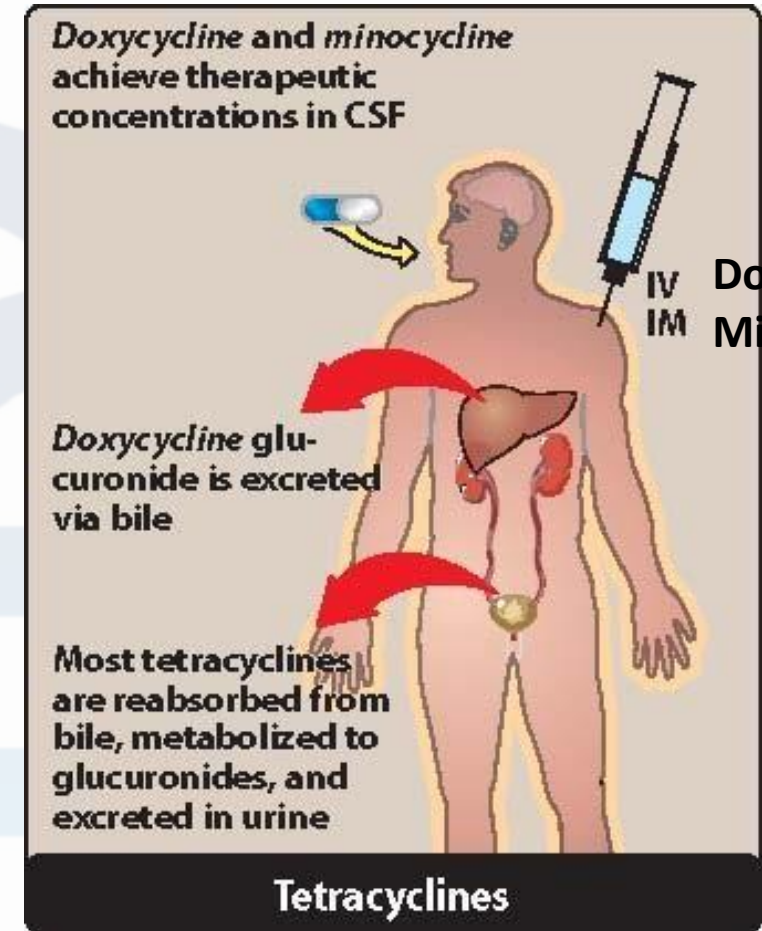
## Pharmacokinetics

### Distribution

- Distribute well in body fluids, including CSF
- Bind to tissues undergoing calcification e.g., bones, teeth.
- Cross placenta and deposit in fetal bones (**teratogenic**)

### Elimination

- Tetracycline eliminated unchanged in urine
- Doxycycline eliminated in bile/feces (no need to adjust dose in renal failure)



**Minocycline** also achieves high concentrations in saliva and tears, rendering it useful in **eradicating the meningococcal carrier**





## Adverse effects

- **Gastric discomfort:**

- irritation of gastric mucosa(epithelium)→ epigastric distress→non-compliance!

- esophagitis

(if irritation is severe) Irritation is minimized through coadministration

With food or with fluids (other than dairy products!!)

You can also use dosage forms of enteric coating or capsules instead of tablets .

Tetracycline should be taken on an empty stomach always.

- **Effects on calcified tissues**

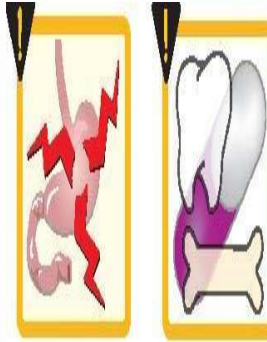
- deposited in tissues undergoing calcification, e.g., bones in children.

- dental hypoplasia

- growth problems

- pediatric use is limited

10/28/2022





# Tetracyclines

## Adverse effects

- **Hepatotoxicity**(particularly in pregnant women and those with preexisting hepatic dysfunction)
- **Phototoxicity:**
  - severe sunburns (recommended to wear sun protection)→more commonly with tetra and demeclo
- **Vestibular dysfunction:**
  - dizziness, vertigo, tinnitus→ more commonly with minocycline
- **Pseudotumor cerebri**(**increased intracranial pressure**→**headache and blurred vision**)



Liver failure



Phototoxicity



Vertigo



Avoid in pregnancy



# Tetracyclines

## Contraindications

1. Pregnant women
2. Breast-feeding women
3. Pediatric age group <8 years



Sports drink → GI  
upset and  
hepatotoxicity

# Tetracycline mnemonic

Pseudotumor  
cerebri, vertigo

Phototoxicity



Cycle can't  
get across  
colored  
mountains →  
Not effective  
against  
pseudomonas

Bicycle: broad spectrum  
including MRSA

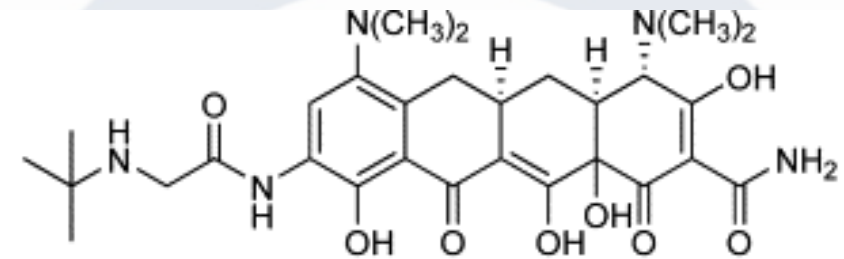
Pregnant lady can't  
ride bicycle



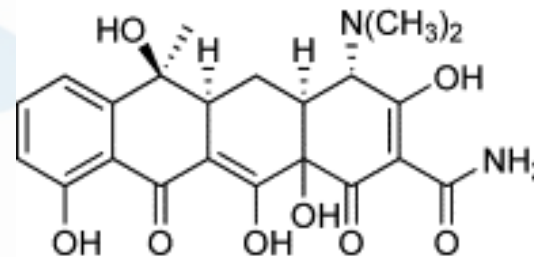
# Glycylcyclines

# Tigecycline

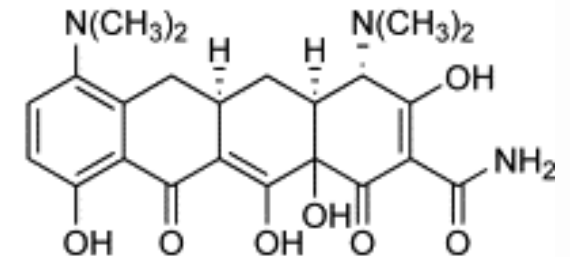
- Derivative of minocycline
- Same mechanism of action as tetracyclines
- Similar mechanisms of resistance



Tigecycline (58)



Tetracycline (59)



Minocycline (60)





# Tigecycline

## Antibacterial spectrum

- Effective against **MRSA**
- Effective against multi-drug resistant streptococci
- Effective against vancomycin-resistant enterococci (VRE)
- Effective against ESBL gram-negative bacteria
- Effective against **Acinetobacter spp**
- NOT effective against Pseudomonas



Tigecycline is indicated for the treatment of complicated skin and soft tissue infections, complicated intra-abdominal infections, and community-acquired pneumonia.



Resistance:-

Tigecycline was developed to overcome the emergence of tetracycline class-resistant organisms that utilize efflux pumps and ribosomal protection to confer resistance.

Resistance to tigecycline has been observed and is primarily **attributed to overexpression of efflux pumps**



## D. Tigecycline Pharmacokinetics:-

Following IV infusion, tigecycline exhibits a **large volume of distribution**(due to its lipophilicity)→It penetrates tissues well but achieves low plasma concentrations. Consequently, tigecycline is a poor option for bloodstream infections(septicemia)

The primary route of elimination is biliary/fecal. No dosage adjustments are necessary for patients with renal impairment;  
however, a dose reduction is recommended in severe hepatic dysfunction



Adverse effects of Tigecycline:

**Significant nausea and vomiting, Acute pancreatitis.**

All-cause mortality in patients treated with tigecycline is higher than with other agents.

Due to its adverse effects it's not used as first line.

A boxed warning states that tigecycline should be reserved for use in situations when alternative treatments are not suitable

Other adverse effects are similar to those of the tetracyclines

Tigecycline may decrease the **clearance of warfarin**. Therefore, the international normalized ratio should be monitored closely when tigecycline is coadministered with warfarin.

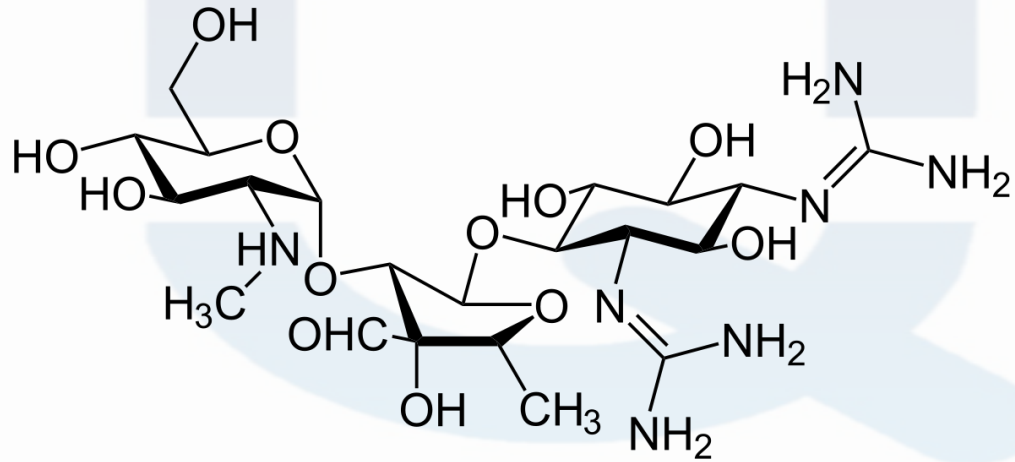




# Aminoglycosides



# Aminoglycosides



## AMINOGLYCOSIDES

*Amikacin*

*Gentamicin* GARAMYCIN

*Neomycin* NEO-FRADIN

*Streptomycin*

*Tobramycin* TOBREX



# Clinical applications of aminoglycosides

Amikacin : IV

❑ Gentamicin

❑ Neomycin :is given topically in skin

❑ Tobramycin : in respiratory infection (cystic fibrosis, which favors pseudomonal infections)

❑ Streptomycin: antiTb drug قديما

قل استخدامه انه يوجد ادوية احسن منه وبسبب سميته

Vancomycin,daptomycin  
and Fosfomycin are not  
aminoglycosides

They are non-beta lactam  
cell wall inhibitors



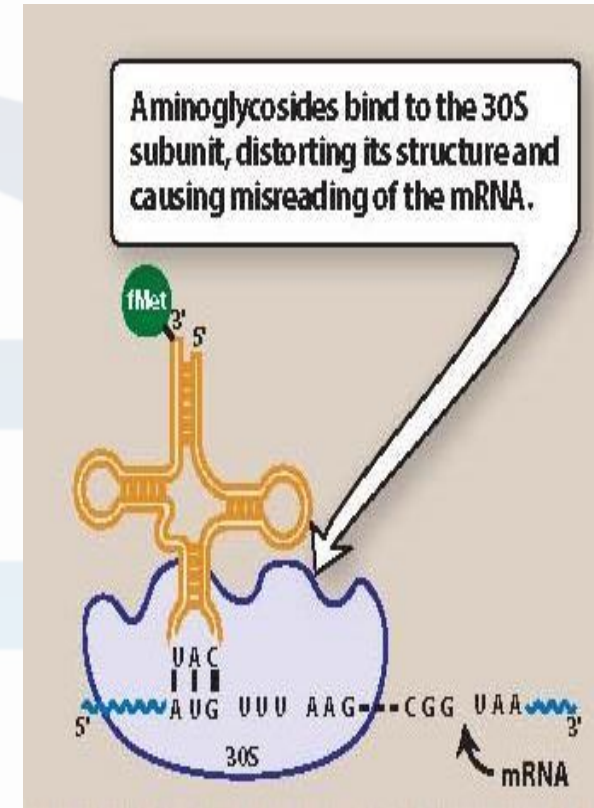
# Aminoglycosides

## Mechanism of action:-

Aminoglycosides diffuse through **porin channels** in the outer membrane of **susceptible gram(-ve) organisms**.

These organisms also have an **oxygen-dependent system** that transports the drug across the cytoplasmic membrane

- Bind to **30S ribosomal subunit**
- Interfere with assembly of the **functional ribosomal apparatus**
- Cause the 30S subunit of the completed ribosome to **misread the genetic code**





# Aminoglycosides

## Antibacterial spectrum

- **Bactericidal**(my note:because of misread toxic protein production!!)
- Concentration-dependent(their efficacy is dependent on the maximum concentration (C<sub>max</sub>) of drug above the minimum inhibitory concentration (MIC) of the organism. For aminoglycosides, the target C<sub>max</sub> is eight to ten times the MIC)
- **Exhibit PAE**(. The larger the dose, the longer the PAE, so high-dose extended-interval dosing is commonly utilized. This strategy also reduces the risk of nephrotoxicity and increases convenience)
- Effective against **aerobic gram-negative bacilli** (INCLUDING **multi- DRUG resistant *P. aeruginosa*, klebsiella etc...**)
- **Used in combination with  $\beta$ -lactams for synergism**





- Tularemia is acquired during rabbit-hunting season by hunters skinning infected animals.
- Pneumonic tularemia results from infection by the respiratory route or by bacteremic seeding of lungs.
- *Gentamicin* is effective in treating this rare lymphoid disease.

- Aminoglycosides may be added to  $\beta$ -lactams for synergy for select serious gram-positive infections.

**Enterococcus species**  
(ampicillin + gentamicin)

**Streptococcus agalactiae**  
(ampicillin + gentamicin)

Gram (+) bacilli

Gram (-) cocci

**Acinetobacter baumannii**  
**Brucella species**  
(gentamicin + doxycycline)

**Acinetobacter baumannii**

**Brucella species**  
(gentamicin + doxycycline)

**Francisella tularensis**  
(gentamicin)

### Klebsiella species

**Pseudomonas aeruginosa**

**Yersinia pestis**  
(streptomycin)

### Anaerobic organisms

Spirochetes

Mycoplasma

Chlamydia

Other

## **INFECTIONS DUE TO PSEUDOMONAS AERUGINOSA**

- ***Pseudomonas aeruginosa*** rarely attacks healthy individuals, but can cause infections in patients with specific risk factors (e.g., recent antibiotic exposure, prolonged hospitalization, bronchiectasis).
- Treatment includes *tobramycin* alone (e.g., for UTI) or in combination with an antipseudomonal  $\beta$ -lactam (e.g., for pneumonia).

## Some clinical uses of aminoglycosides



**11. An 18-day-old neonate has been brought to the pediatric unit by her parents. She has been crying inconsolably, irritable, and poorly breast-feeding. Her vitals show high temperature and elevated heart rate. You are worried that she might have meningitis and want to initiate empirical antimicrobial therapy. Knowing that *L. monocytogenes* is a common pathogen in this age group, your treatment regimen must include which of the following synergistic drug combinations?**

- A. Piperacillin + tazobactam
- B. Ticarcillin + amikacin
- C. Nafcillin + ciprofloxacin
- D. Ampicillin + gentamicin
- E. trimethoprim + sulfamethoxazole

**Answer: D**



# Aminoglycosides

## Mechanisms of resistance

- 1) **efflux pumps**
- 2) decreased uptake
- 3) modification and inactivation by **plasmid-associated** synthesis of enzymes that hydrolyze aminoglycosides

Cross-resistance is unlikely

-Amikacin is less vulnerable to these enzymes



# Aminoglycosides

## Pharmacokinetics Absorption

-Aminoglycosides are very bulky and charged.

all are given IV (except neomycin)

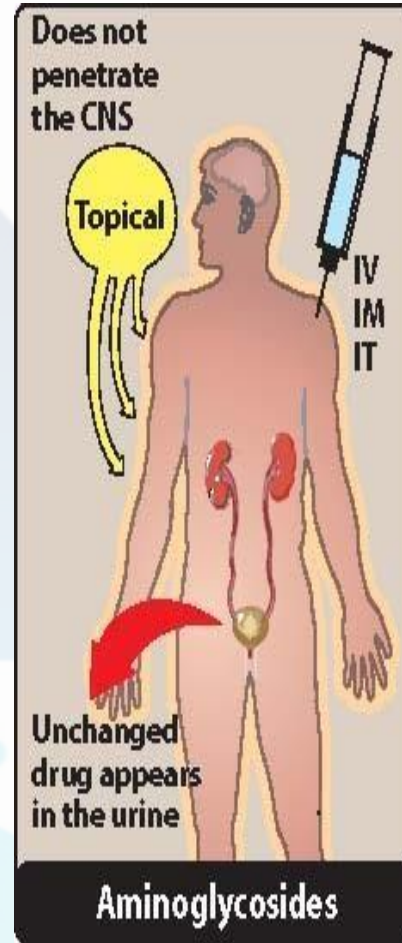
. [Note: Neomycin is not given parenterally due to severe nephrotoxicity. It is administered topically for skin infections or orally to decontaminate the gastrointestinal tract prior to colorectal surgery.]

## Distribution

-variable distribution in body fluids

-inadequate distribution in CSF (For central nervous system infections, the intrathecal or intraventricular routes may be utilized.)

-cross the placenta and affects fetuses



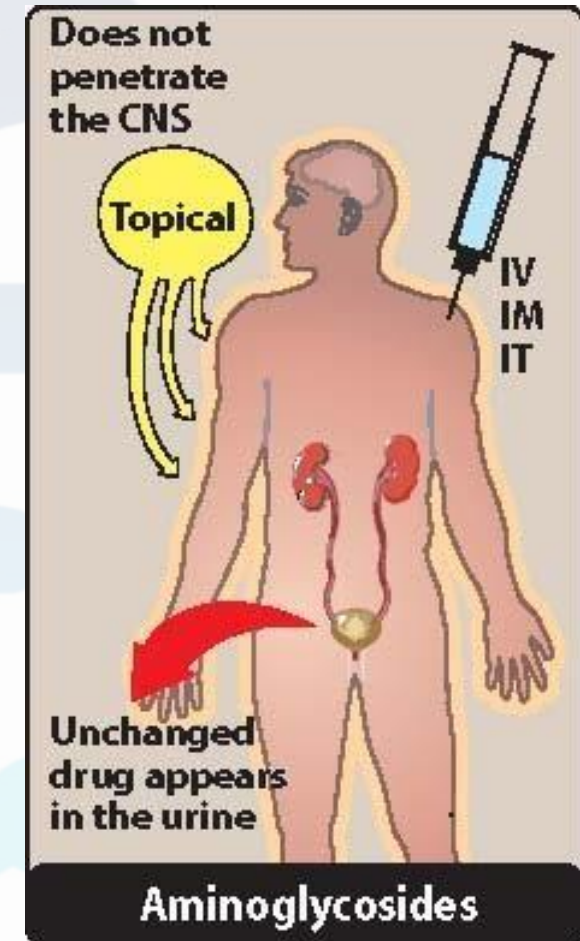


# Aminoglycosides

## Pharmacokinetics

### Elimination

- 90% are excreted unchanged in the urine
- accumulation occurs in cases of renal dysfunction
- Neomycin is excreted unchanged in feces.





Therapeutic drug monitoring of gentamicin, tobramycin, and amikacin plasma concentrations is imperative to ensure appropriateness of dosing and to minimize dose-related toxicities

.





# Aminoglycosides

## Adverse effects

- **Ototoxicity (both vestibular and auditory)**

directly related to **high peak plasma concentrations** and the **duration of treatment**.

-might cause **irreversible** deafness, even to fetuses when it crosses placenta!!

-**Vertigo** (especially with streptomycin)

- **Nephrotoxicity**

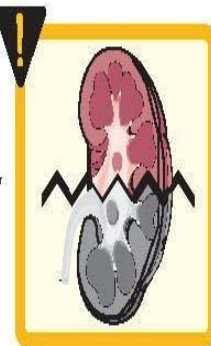
-disrupt  $\text{Ca}^{++}$ -mediated transport processes

-from mild reversible renal impairment to irreversible acute tubular necrosis

Ototoxicity



Nephrotoxicity





# Aminoglycosides

## Adverse effects

- Neuromuscular paralysis
  - patient with myasthenia gravis are at risk
- associated with a rapid increase in concentration (for example, high doses infused over a short period) or concurrent administration with neuromuscular blockers
- Allergic reaction
  - Mostly **contact dermatitis** with **topical neomycin**

Paralysis



Skin rash



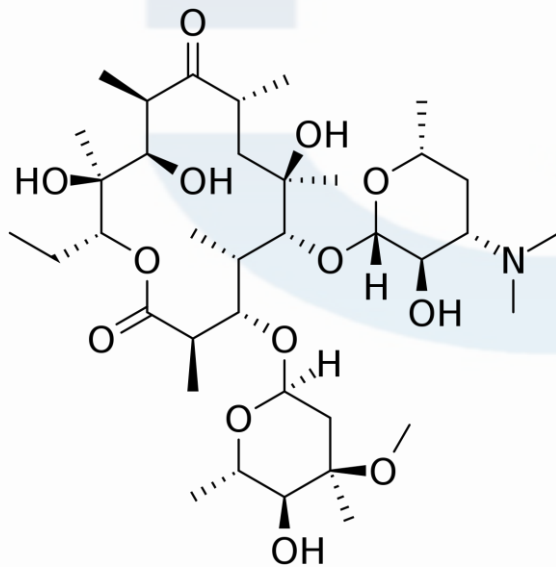


# Macrolides and Ketolides

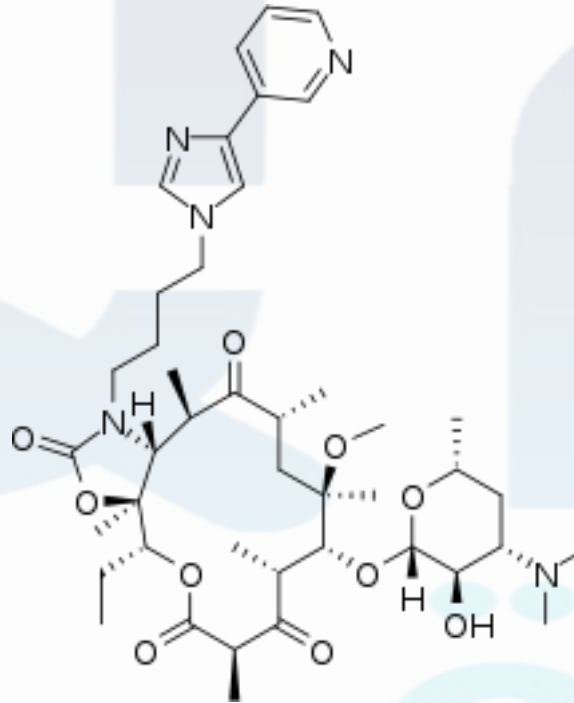


# Macrolides and Ketolides

Macrolides have a macrocyclic polylactonic structure attached to one or more deoxy sugars. The lactone ring is the primary structure in macrolides, and they are bulky compounds.



Erythromycin



Telithromycin  
(a ketolide)

MACROLIDES/KETOLIDES	
Azithromycin	ZITHROMAX
Clarithromycin	BIAXIN
Erythromycin	VARIOUS
Telithromycin	KETEK

Clarithromycin has a methyl group

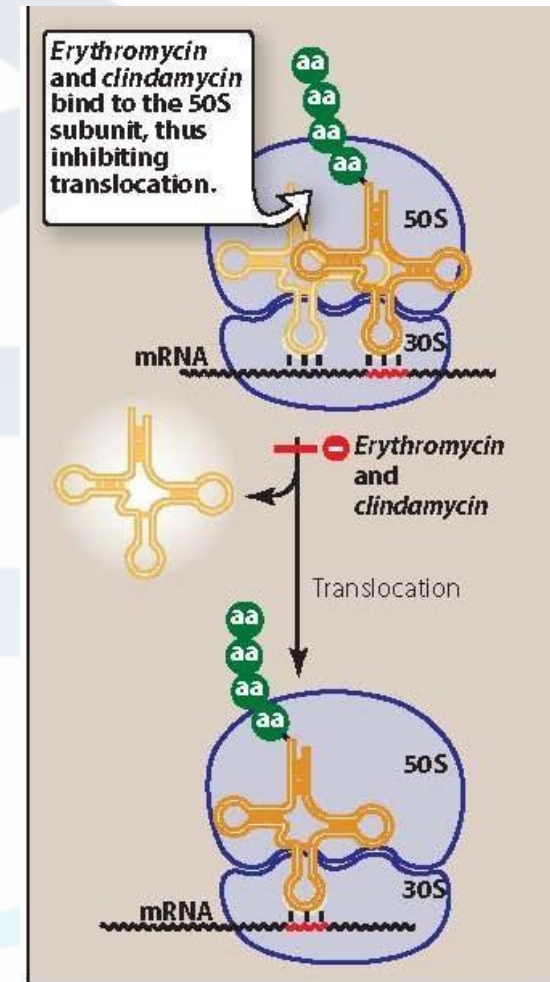
the use of erythromycin has been largely replaced by azithromycin & clarithromycin because they have slightly better antibacterial coverage & better adverse effect profile, Zomac "azithromycin" has a larger lactone ring



# Macrolides and Ketolides

## Mechanism of action

- bind **irreversibly** to a site on the **50S subunit** of the bacterial ribosome (mnemonic: macrolides bind to the macro"big" lid"ribosome part)
- Inhibit translocation (leading) step
- Interfere with transpeptidation (the movement of polypeptide from the P-site to be linked with the amino acid on the A-site)
- Binding site identical/near that of clindamycin or chloramphenicol







# Macrolides and Ketolides

## Antibacterial spectrum

-bacteriostatic (can be –cidal at high doses)

- **Erythromycin**

-similar spectrum to penicillin G(used in syphilis ,gas gangrene, and strep pyogenes prophylaxis)

-used in cases of penicillin allergy

- **Clarithromycin**

-similar to erythromycin but extended to include some gram negatives like **H.influenza**

-effective against **intracellular pathogens**, e.g. Chlamydia, Legionella, H. Pylori etc... (Mnemonic :Cells are cleared from pathogens by clarithromycin)



# Macrolides and Ketolides

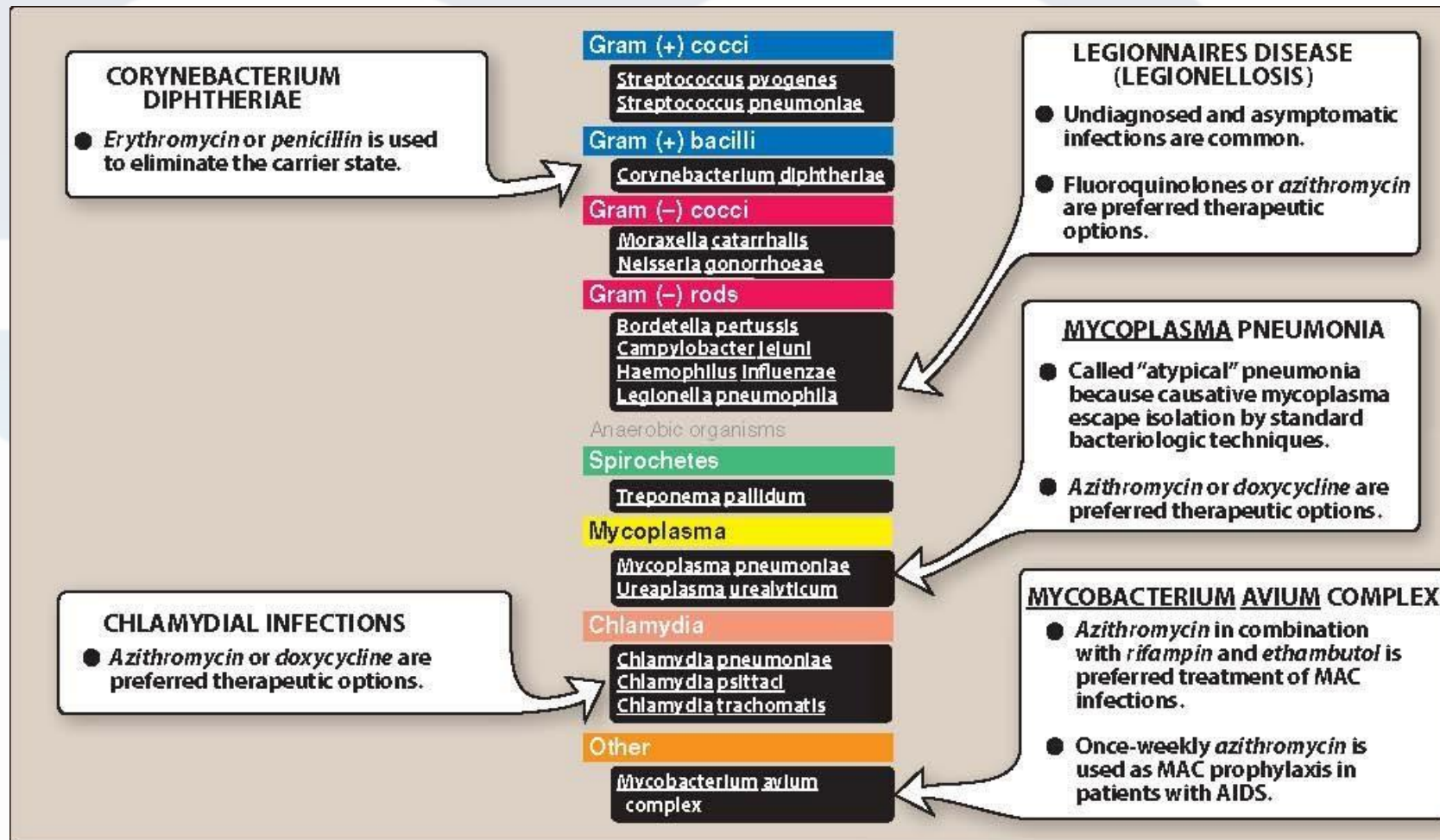
## Antibacterial spectrum

- **Azithromycin**

- less active against staph and strep species
- more active against RTI due to *H. influenzae* or *M. catarrhalis*
- increasing *S. pneumonia* resistance



# Clinical Spectrum of Macrolides





# Macrolides and Ketolides

## **Mechanisms of resistance**

- 1) the inability of the organism to take up the antibiotic
- 2) the presence of efflux pumps
- 3) a decreased affinity of the 50S ribosomal subunit for the antibiotic
- 4) the presence of plasmid- associated erythromycin esterases in gram-negative organisms

**Telithromycin may be effective against macrolide-resistant organisms**

# Macrolides and Ketolides

## Pharmacokinetics

- **Administration**

- oral (enteric-coated tablets for erythro)
- Erythro and azithro are available IV

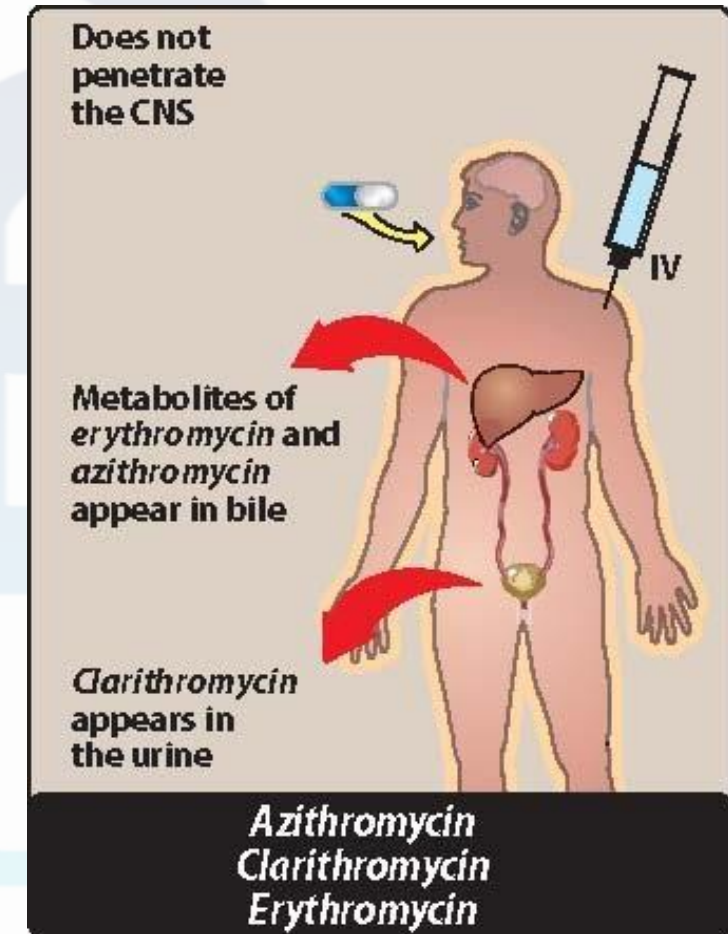
- **Distribution**

- distribute well in body fluids except CSF

- **Elimination**

- hepatic metabolism

-Inhibit CYP450 system (drug-drug interactions)







# Dr sheriff slide reminder

## Examples of Enzyme Inhibitors

Cimetidine- chloramphenicol - ciprofloxacin- erythromycin - ketocenazol -  
♀ (F) estrogen, progesterone, contraceptive pills.

2. **Pathological factors which affect hepatic activity** e.g. liver failure  
starvation, cancer → ↓ activity of HME → need to adjust dose.
3. **Pharmacogenetic variations in metabolizing enzymes** e.g. slow &  
fast acetylators (see pharmacogenetics).
4. **Hepatic blood flow:** drugs ↓ hepatic blood flow → ↓drug metabolism
5. **Age:** ↓ enzymatic activity in extremes of age
  - Premature babies have ↓ conjugate of chloramphenicol → fatal gray baby syndrome.
6. **Sex:** female sex hormones are HME inhibitors → receive lower doses than male.



# Macrolides and Ketolides

## Pharmacokinetics

- **Administration**

- oral (enteric-coated tablets for erythro)
- Erythro and azithro are available IV

- **Distribution**

- distribute well in body fluids except CSF

- **Elimination**

- hepatic metabolism

-Inhibit CYP450 system (drug-drug interactions)

	<i>Erythro- mycin</i>	<i>Clarithro- mycin</i>	<i>Azithro- mycin</i>	<i>Telithro- mycin</i>
Oral absorption	Yes	Yes	Yes	Yes
Half-life (hours)	2	3.5	>40	10
Conversion to an active metabolite	No	Yes	No	Yes
Percent excretion in urine	15	50	12	13

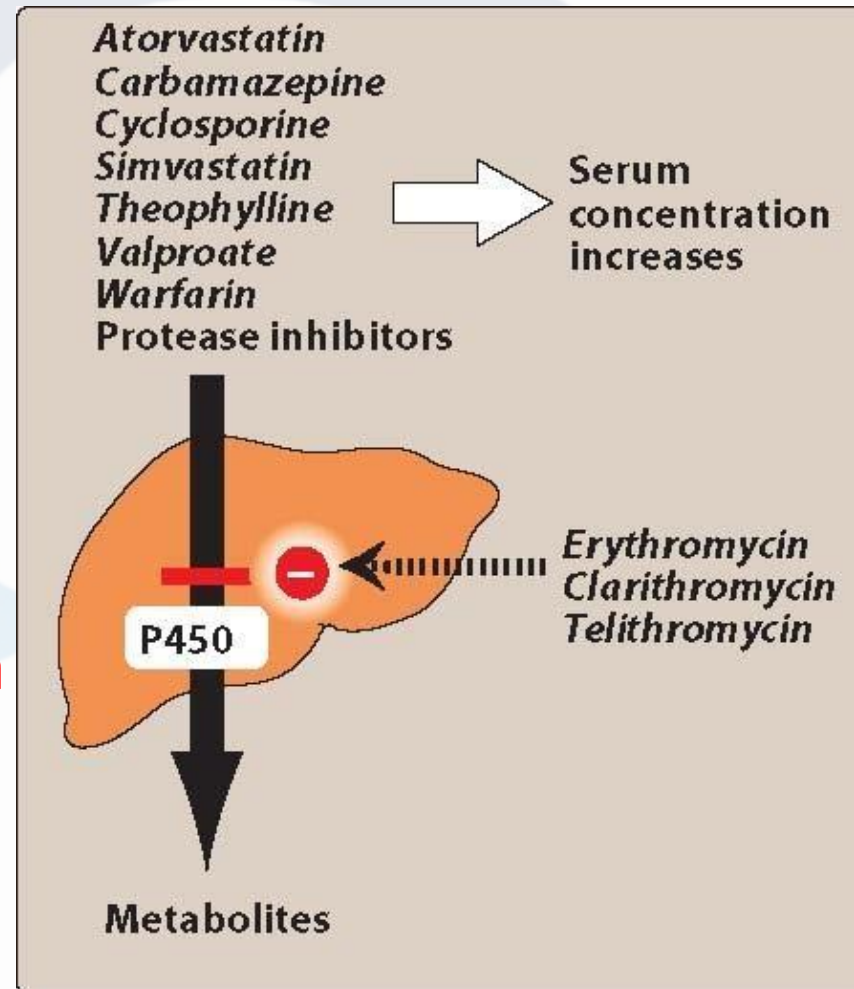


# Macrolides and Ketolides

## Drug-drug interactions

- Inhibit hepatic metabolism of a number of drugs, increasing their serum levels → toxicity.

This is especially of concern with warfarin which might cause bleeding





# Adverse effects      Macrolides and Ketolides

- **Gastric distress and motility**

-high doses of erythromycin cause smooth muscle contraction and bowel movement. **Could this be helpful?** yes , this adverse effect can be used for the treatment of gastroparesis or postoperative ileus. Gastroparesis paralysis in the nerve supply of the stomach , seen in patients with diabetes which result in delayed emptying

- **Jaundice**

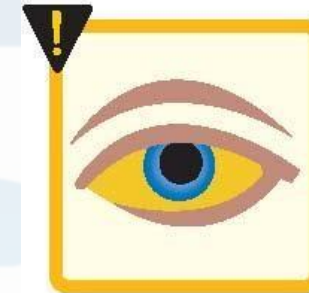
- **Ototoxicity**

- **Hepatotoxicity**

-contraindicated in patients with hepatic dysfunction



GI disturbance



Jaundice



Ototoxicity




# Fidaxomicin

قائمة





# Fidaxomicin

- **Structure:** macrocyclic, similar to macrolides with a **lactone ring**
- **MOA:** acts on the  $\sigma$  subunit of RNA polymerase → disruption of bacterial transcription →  protein synthesis
- Very narrow-spectrum: gram-positive aerobes/anaerobes
- Poorly absorbed (remains in GI tract), primarily used for C. difficile infections (**but not the first line drug, first line drug is vancomycin**)
- Cross-resistance with other antibiotics is rare. **Why? because of the unique target site**
- Cross-allergy with macrolides
- Adverse effects: nausea, vomiting, abdominal pain



# Chloramphenicol



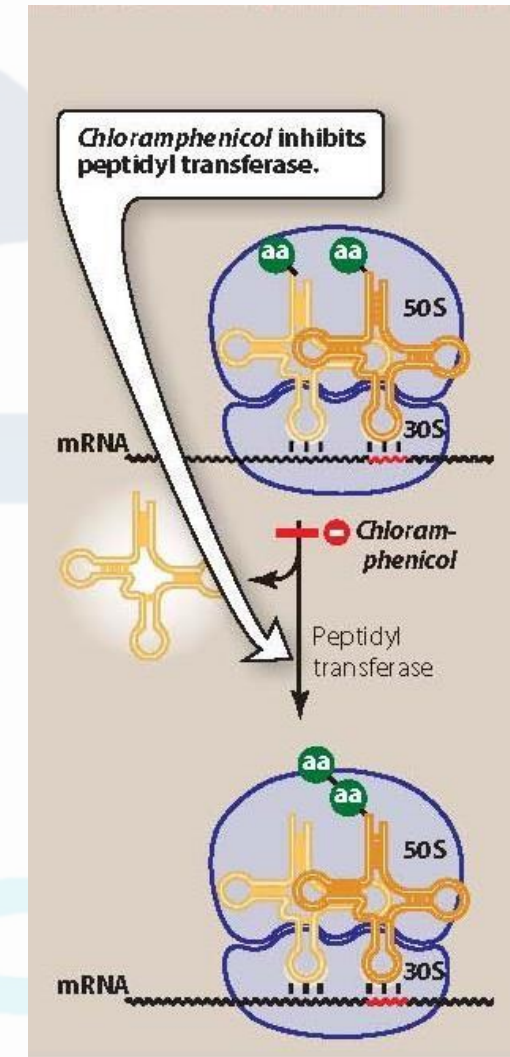
# Chloramphenicol

- Broad-spectrum
- Mainly –static (but can be –cidal)
- Limited use due to high toxicity
- **MOA:** *reversibly* to the bacterial 50S ribosomal subunit and inhibits peptidyl transferase reaction
- Given IV: can be secreted in breast milk

**Contraindicated in breastfeeding mothers**

- \* it can cross the placental barrier , so

**it's contraindicated in pregnant women**





# Chloramphenicol

## Adverse effects

- **Aplastic anemia, hemolytic anemia**  
in case of G6PD deficiency
- **Gray baby syndrome**
  - accumulation of the drug due to underdeveloped liver and kidney functions
  - can cause death by respiratory and cardiovascular failure

Gray body syndrome may occur in adults if given in high dose

- **Drug-drug interactions**

-inhibits liver enzymes





# Critical Thinking Question

?

Since chloramphenicol is toxic due to its targeting of the mammalian protein synthesis ... which type of ribosomes in mammalian cells will be most susceptible to inhibition by chloramphenicol? And why?

Mitochondrial mammalian ribosomes , because the structure of mitochondrial ribosomes more closely resembles bacterial ribosomes





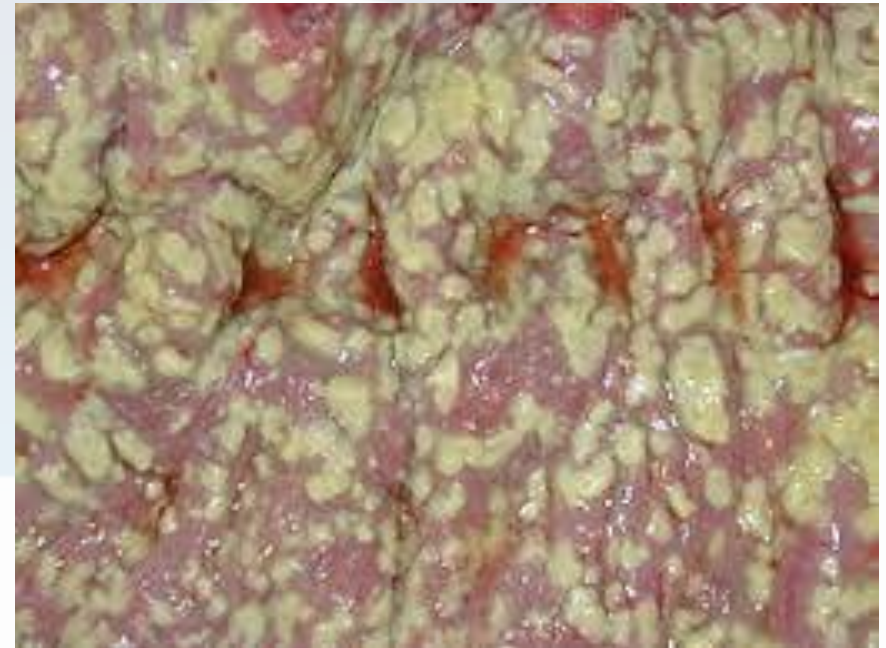
# Clindamycin

قائمة



# Clindamycin

- **MOA:** same as erythromycin
- Effective against gram-positive bacteria: staph INCLUDING MRSA (**broad spectrum antibiotic**)
- Oral and IV, **and topical (for acne)**
- **Adverse effects:** skin rash, diarrhea : associated with pseudomembranous colitis caused by overgrowth of *C. difficile*
  - Treated with vancomycin or metronidazole





# Oxazolidinones

قائمة



# Linezolid

- Developed to treat resistant gram- positive organisms, such as MRSA (**not bacteremia**. **Why? Because linezolid is a bacteriostatic agent**), VRE, resistant mycobacterium and penicillin-resistant streptococci
- **MOA:** binds to the bacterial 23S ribosomal RNA of the 50S sub-unit, thereby inhibiting the formation of the 70S initiation complex
- Bacteriostatic (-cidal against strep)

## Gram (+) cocci

Enterococcus faecalis  
(including vancomycin-resistant strains)

Enterococcus faecium  
(including vancomycin-resistant strains)

Staphylococcus epidermidis  
(including methicillin-resistant strains)

Staphylococcus aureus  
(including methicillin-resistant strains)

Staphylococcus haemolyticus

Streptococcus pneumoniae  
(including penicillin-resistant strains)

Viridans group streptococci

## Gram (+) bacilli

Corynebacterium species

Listeria monocytogenes

Gram (-) cocci

Gram (-) rods

## Anaerobic organisms

Clostridium perfringens

Spirochetes

Mycoplasma

Chlamydia

## Other

Mycobacterium tuberculosis



# Linezolid

- **Main clinical uses:** Treatment of drug-resistant gram-positive organisms  
e.g., alternative to daptomycin for VRE
- **Pharmacokinetics:** oxidized in the liver into two inactive metabolites → excreted in urine
- **Adverse effects:** GI upset, thrombocytopenia, serotonin syndrome, peripheral neuropathy (with prolonged use)

## Gram (+) cocci

Enterococcus faecalis  
(including vancomycin-resistant strains)

Enterococcus faecium  
(including vancomycin-resistant strains)

Staphylococcus epidermidis  
(including methicillin-resistant strains)

Staphylococcus aureus  
(including methicillin-resistant strains)

Staphylococcus haemolyticus

Streptococcus pneumoniae  
(including penicillin-resistant strains)

Viridans group streptococci

## Gram (+) bacilli

Corynebacterium species

Listeria monocytogenes

Gram (-) cocci

Gram (-) rods

## Anaerobic organisms

Clostridium perfringens

Spirochetes

Mycoplasma

Chlamydia

## Other

Mycobacterium tuberculosis





# Thrmobocytopenia

