In this article, we will study the details about various antifungal drugs, their mechanism of action, adverse effects/toxicity, contraindications, drug interactions and drugs of choice. Other important pharmacological and therapeutic aspects of individual drugs will also be discussed.

Definition of Antifungal Drugs

Antifungals are the drugs that treat fungal infections by acting on the synthesis of the fungal cell membrane, cell wall components, membrane permeability, synthesis of nucleic acids and on the mitotic spindle function of the fungi during cell division.

Overview of Fungal Infections

Fungi are non-motile eukaryotic single-celled or multinucleate organisms formerly classified as plants that lack chlorophyll and cannot perform photosynthesis, hence parasitic in nature. Thousands of species have been identified, out of which some are the cause for local or systemic fungal infection (mycoses) in patients with AIDS, or humans whose immune systems are compromised by drug therapy or other means. This may cause serious, sometimes life-threatening infections.

Introduction into the host’s body is mainly through wounds or inhalation into the lungs and nasal passages. Diseases caused by fungi are mainly due to the Microsporum, Trichophyton or Epidermophyton genera.
Various Types of Fungal Infections

Athlete’s Foot

*Tinea pedis (Athlete’s foot)*: The infection is caused by *Trichophyton mentagrophytes* and *Trichophyton rubrum*. It is often located between the toes, with the space between the fourth and fifth digits most commonly afflicted; however, it can spread if not treated in time.

Image: “A severe case of athlete’s foot.” by James Heilman, MD. License: [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)

Ringworm Infection

*Tinea corporis (ringworm)*: The infection is caused by *Microsporum canis*, *Trichophyton mentagrophytes* via direct skin contact with an infected individual, or by using the personal care products of the affected individual.
Brazilian Blastomycosis

It is caused by *Paracoccidioides brasiliensis* and is a systemic infection involving mucous membranes, lymph nodes, bone and lungs and prevalent in South America. Amphotericin B, Itraconazole or ketoconazole are effective in treating the infection.

Candidiasis

Candidiasis is caused by yeast *Candida Albicans*. It is commonly present as a saprophyte in the GI tract and *genitourinary system* of human beings. However, it can infect locally or systemically and cause serious systemic infections with multi-system organ failure.
Mucormycosis

The infection is caused by the genera Mucor, Rhizopus, Absidia, and Cunninghamella with the affected areas being sinuses, eyes, blood, and brain.

Image: "Mucormycosis" by Ran Yuping et al. License: CC BY-SA 3.0

Classification of Anti Fungal Drugs

These agents are categorized as:

- Topical vs systemic (acting in the bloodstream)

Naturally occurring:

- Antifungal Antibiotics (mostly produced by Actinomycetes, classified as ‘higher bacteria’). **Examples:** Amphotericin B (AMB), a polyene antimycotic, Nystatin
- Antifungals of fungal origin. **Example:** Griseofulvin, a Heterocyclic Benzofuran discovered in 1939 from a type of *Penicillium* mold

Synthetic Agents:

- Azoles
  - Imidazoles: Clotrimazole, Econazole, Miconazole, Oxiconazole, Ketoconazole
  - Triazoles: Fluconazole, Itraconazole, Voriconazole
- Anti-metabolites: Flucytosine (5-FC)
- Allylamine: Terbinafine (Lamisil)

Newest antifungals:

- Echinocandins

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Antifungal Drugs
Below you can find different kinds of antifungal drugs.

**Amphotericin B (AMB)**

It is derived from cultures of *Streptomyces Nodosus* and is a very large (‘macrolide’) molecule belonging to the polyene group of antifungal agents.

**Mechanism of Action**

The molecule has a high affinity for ergosterol present in the fungal cell membrane and combines with it in such a way to make a ‘micropore.’ The basic mechanism of the drug is to disrupt the cell membrane. It is fungicidal at high and fungistatic at low concentrations.

**Important:** Amphotericin is not active against human and bacterial sterols as the predominant sterol found in bacteria and humans are cholesterol.

**Indication**

Amphotericin B is active against a wide range of yeasts and fungi: Candida Albicans, *Histoplasma capsulatum*, *Cryptococcus neoformans*, *Blastomyces dermatitidis*, *Coccidioides immitis*, *Torulopsis*, *Rhodotorula*, *Aspergillus*, and *Sporothrix*, etc. It does not have any anti-bacterial property. It is the most effective drug for resistant cases of kala-azar and mucocutaneous leishmaniasis.

**Pharmacokinetics**

Amphotericin B is not absorbed orally; that is why it is administered intravenously and rarely intrathecally (for fungal meningitis). Amphotericin B has a half-life of 15 days. The excretion through urine requires a long time, although excretion occurs slowly both in the urine and bile. Penetration into the CNS is poor; about 60% of AMB is metabolized by the liver.

**Side Effects**

Nephrotoxicity is the most important side effect. Acute reactions may be triggered by symptoms consisting of chills, fever, aches, and pain, nausea, vomiting, and dyspnea lasting for one hour, probably due to the release of cytokines. To reduce the side effects
and improve the tolerability of infusion, formulations of lipid complex, colloidal dispersion, and small unilamellar vesicles have been introduced.

**Important: Irreversible renal toxicity** can result in prolonged administration (more than 4g cumulative dose).

**AmBisome (liposome-based), Amphotec** (a complex of amphotericin B and cholesteryl sulfate), Abelcet (consists of amphotericin B complexed with two phospholipids) are the lipidic formulations available to reduce the renal toxicity of the conventional amphotericin B; however, these are very costly.

**Nystatin**

It is also called fungicidin with a similar structure to that of Amphotericin B. It is derived from *Streptomyces noursei* and has high systemic toxicity, hence, it is commonly used as a topical agent.

**Mechanism of Action**

The molecule also has a high affinity for ergosterol present in fungal cell membranes and it disrupts the cell membrane.

**Indication**

It is used against monilial vaginitis, corneal, conjunctival and cutaneous candidiasis in the form of an ointment but is ineffective in dermatophytosis. Nystatin can be added to tetracycline to prevent monilial overgrowth caused by the destruction of the bacterial microflora of the intestine during tetracycline therapy.

**Pharmacokinetics**

It is given in the form of vaginal tablets and pastilles for local application only. Nystatin will treat gut candidiasis and is used in a ‘swish and swallow’ routine for oral candidiasis.

**Side Effects**

The common side effects associated are itching, irritation and burning. Rarely, nystatin can cause diarrhea and nausea.
Griseofulvin

Griseofulvin is a narrow-spectrum antifungal agent isolated from cultures of *Penicillium griseofulvum*, and is active against dermatophytes, including Epidermophyton, Trichophyton, Microsporum, but not against fungi causing deep mycosis.

**Mechanism of Action**

The mechanism of action of griseofulvin is not clear. It is thought to interfere with mitosis during the fungal hyphae formation. It also causes abnormal metaphase in the division of cells by acting in a way that the daughter nuclei fail to move apart, or move only a short distance during division. It does not inhibit polymerization of tubulin, but binds to polymerized microtubules and disorients them.

**Pharmacokinetics**

The absorption of the drug is improved by taking it with a fatty meal and by microfining the drug particles. Griseofulvin gets deposited in keratin forming cells of skin, hair, and nails; concentrating in tinea infected cells because it is fungistatic and not cidal. The newly formed keratin is not affected by the fungus.

**Side Effects**

Effects with griseofulvin use are infrequent, but the drug causes gastrointestinal upsets, headache, and photosensitivity. Allergic reactions (rashes and fever) may occur. The drug is contraindicated in pregnant women.

**Azoles and Triazole Agents**

These are synthetically derived antifungal agents, both used orally and topically. They are used for treating a large number of infections caused by dermatophytes, Candida, other fungi involved in deep mycosis, Nocardia, some gram-positive and anaerobic bacteria, e.g., *Staphylococcus aureus, Enterococcus faecalis, Bacteroides fragilis* and *Leishmania*.

**Mechanism of Action**

The azoles constitute imidazoles and triazoles subgroups and act by inhibiting CYP P450 14 α-demethylase enzyme in fungi which causes the conversion of lanosterol to
ergosterol. Other P450s in sterol biosynthesis may also be affected. The nitrogen of the azole ring forms a bond with the heme iron of the fungal P450 preventing substrate and oxygen binding, leading to changes in shape and physical properties of the fungi membrane, leading to permeability and fluidity changes. They also inhibit the transformation of yeast cells into hyphae, the invasive and the pathogenic form of the parasite.

**Ketoconazole (KTZ)**

It is available in the form of a cream or in shampoos at a strength of 1 or 2 % for treating tinea pedis, tinea corporis, tinea cruris, and cutaneous candidiasis. It can also be administered orally.

**Pharmacokinetics**

The oral absorption of KTZ is improved by gastric acidity because it is more soluble at lower pH. Hepatic metabolism is extensive for the drug; metabolites are excreted through urine and feces. The half-life is short and varies from 1.5—6 hours.

**Side Effects**

The drug causes inhibition of adrenocortical steroid and testosterone synthesis with high doses, leading to gynecomastia, loss of hair and libido in male patients. In females, menstrual irregularities may occur. Hepatotoxicity is also a side effect but is rarely fatal.

**Clotrimazole**

The topical application of the drug is useful in treating tinea pedis, ringworms, otomycosis, and oral/cutaneous vaginal candidiasis. It is the preferred drug for treating vaginitis because of a long residual effect after a once-daily application. The drug is also combined sometimes with glucocorticoids, which are anti-inflammatory in nature.

**Side Effects**

The drug is well tolerated; however, causes a local irritation with a stinging and burning sensation occurring in some. No systemic toxicity is seen after topical use.

**Fluconazole**

It is marketed in the form of a tablet or suspension to treat yeast infections of the vagina, mouth, throat, esophagus, abdomen, and lungs.

**Important:** it is a drug of choice for esophageal and invasive candidiasis and coccidioidomycoses.

**Pharmacokinetics**

Fluconazole is 94 % absorbed; oral bioavailability is unaffected by food or gastric pH. It is primarily excreted unchanged in the urine with a t1/2 of 25—30 hours.

**Side Effects**

Prominent side effects are nausea, vomiting, abdominal pain, rash, and headache. Elevation of hepatic transaminase has been noted in AIDS patients. As compared to
other azoles, it has the least effect on liver microsomal enzymes.

**Voriconazole**

The drug is present in the form of oral suspension, tablets or parenteral injection. It is used to treat serious fungal infections and may be used in patients who have not responded to other antifungal agents.

Rashes, visual disturbances, QT prolongation and an acute reaction on the IV injection are the significant adverse effects.

**Flucytosine (5-FC)**

It is an antifungal drug, which acts by blocking the pyrimidine and DNA synthesis in fungi. It is converted to its active metabolite (5-FU) by fungal cells.

The pathway of conversion is below:

\[
\text{Flucytosine} \rightarrow (5-\text{FC}) \rightarrow 5\text{-Fluorouracil (5-FU)} \rightarrow 5\text{-fluorodeoxyuridine monophosphate}
\]

No toxicity in humans due to 5-FC as human cells can’t convert 5-FC to 5-FU.

It is not used as a single agent for fungal infections but is used with other antifungal agents such as amphotericin B (cryptococcal meningitis) and itraconazole (chromoblastomycosis).

Side-effects are reversible bone marrow depression, liver dysfunction, and alopecia.

**Terbinafine**

It is fungicidal and is given in shorter course therapy and the relapse rates are low. It is particularly useful against Dermatophytes, especially nail infections, along with the treatment of candida infection. It is available for oral, as well as topical use.

**Mechanism of Action**

It acts as a non-competitive inhibitor of ‘squalene epoxidase’, an enzyme in ergosterol biosynthesis by fungi. Accumulation of toxic squalene within fungal cells leads to the fungicidal action.

**Pharmacokinetics**

Approximately 75 % of oral terbinafine is absorbed. The drug is lipophilic and is widely distributed in the body, strongly plasma protein bound and concentrated in sebum, stratum corneum and nail plates. Elimination t1/2 of 11—16 hours is prolonged to 10 days after the repeated dosing schedule.

**Side Effects**

The common side effects are gastric upset, rash and taste disturbance. Some cases of hepatic dysfunction, hematological disorder, and severe cutaneous reaction also occur.

**Echinocandins**

These are recently discovered antifungal drugs. Examples of drugs in this class are caspofungin and dulafungin.
They act by blocking the synthesis of $\beta(1\rightarrow3)$-glucan in fungus.

They are active against Candida spp., Aspergillus spp., pneumocystis carinii; however, they are not active against Cryptococcus neoformans.

They are poorly absorbed from the GI tract, thus they are only available as intravenous formation.

They are well tolerated and have only minor gastrointestinal side-effects such as nausea and vomiting. Other side-effects are headache and flushing.

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