Anti-hypertensive drugs
Physiological regulation of blood pressure

Baroreceptor dysfunction → ↓ Afferent inhibitory signals

↑ Sympathetic nervous system activity → ↓ Limb blood flow

Vasomotor center

↓ Renal blood flow
↑ Aldosterone secretion
↑ Sodium reabsorption
↑ Water reabsorption
Why treat hypertension?

To decrease:

a) Cerebrovascular accidents (35-40%)

b) Coronary events (20-25%)

c) Heart failure (50%)

d) Progression of renal disease

e) Progression to severe hypertension
Targets for anti-hypertensive drugs

**Alpha₂ agonists**
Decrease sympathetic impulses from the CNS to the heart and arterioles, causing vasodilation.

**Alpha₁ blockers**
Inhibit sympathetic activation in arterioles, causing vasodilation.

**Direct vasodilators**
Act on the smooth muscle of arterioles, causing vasodilation.

**Calcium channel blockers**
Block calcium ion channels in arterial smooth muscle, causing vasodilation.

**Angiotensin receptor blockers**
Prevent angiotensin II from reaching its receptors, causing vasodilation.

**Diuretics**
Increase urine output and decrease fluid volume.

**ACE inhibitors**
Block formation of angiotensin II, causing vasodilation and block aldosterone secretion, decreasing fluid volume.
Classes of anti-hypertensive drugs

- ACE inhibitors;
- Angiotensin II type 1 receptor antagonists;
- Ca++ channel blockers;
- β-blockers (hypertension with comorbidities);
- Diuretics;
- α1-antagonists.
- Miscellaneous drugs.
Autacoids, also known as local hormones, have several biological actions near the site of synthesis.

Autacoids can be classified basing on their chemical structure into:

- **Biogenic amines**
  - histamine
  - serotonin

- **Polypeptides**
  - angiotensin
  - kinins- bradykinin & kallikidin
  - vasopressin
  - vasoactive intestinal peptide
  - substance P
  - slow reacting substance of anaphylaxis

- **Eicosanoids**
  - leukotrienes
  - thromboxanes
  - prostaglandins
  - platelet activating factors
Synthesis of Bradykinin

Hageman factor
Trypsin
Kallikrein

Plasma prekallikrein → Plasma kallikrein

+ → HMW kininogen → Bradykinin

Aminopeptidases

LMW kininogen → Kallidin

+ → Tissue kallikreins

Kininases I and II

Inactive fragments

Angiotensin Converting Enzyme (ACE)
The role of bradykinin in hypertension has been established for more than three decades, with the observations that **urinary kallikrein excretion is significantly reduced in hypertensive patients and hypertensive rats.**

The physiological action of bradykinin in the regulation of systemic blood pressure involves:

1) **vasodilation** in most areas of the circulation,
2) reduction of total **peripheral vascular resistance**,
3) regulation of **Na\(^+\) excretion** from the kidney.

When bradykinin is injected into the renal artery, it causes **diuresis and natriuresis** by increasing renal blood flow. These actions of bradykinin have been attributed to prostaglandin release in the renal circulation. This led to the suggestion that reduced urinary kallikrein excretion might result from a defect in kinin generation in hypertensive situations.
Angiotensin II: Effects

Change in Peripheral Resistance
- Mechanisms
  - Direct Vasoconstriction
  - Sympathetic Discharge
  - Adrenal Medullary Catecholamine Release
  - Noradrenergic Enhancement
    1. decreased reuptake
    2. increased release
    3. increased vascular responsiveness

Change in Renal Function
- Mechanisms
  - Sodium Reabsorption (direct and aldosterone mediated)
  - Direct renal vasoconstriction
  - Noradrenergic transmission
  - Renal sympathetic tone

Structural Changes Remodeling
- Mechanisms
  - Proto-oncogene expression
  - Growth Factors
  - Afterload
  - Wall Tension

Rapid Pressor Response
Slow Pressor Response

Vascular and Cardiac Hypertrophy & Remodeling
ACE inhibitors

- Kininase II (ACE) inhibitors act:
  1) inhibiting the biodegradation of bradykinin;
  2) blocking the formation of angiotensin II.

- ACE inhibitors are currently used in the treatment of both clinical and experimental hypertension.

- ACE inhibitors pharmacological effects:
  
  1) **relaxation of blood vessels** as well as decrease in blood volume, which leads to lower blood pressure and decreased oxygen demand from the heart;

  2) **increasing blood flow**, which helps to decrease the heart work and can help to protect the kidney from the effects of hypertension and diabetes.
Mechanisms of ACE inhibitor-mediated anti-hypertensive effects
# ACE inhibitors: an overview

<table>
<thead>
<tr>
<th><strong>Angiotensin-converting enzyme inhibitors</strong></th>
<th>Captopril, enalapril, lisinopril, ramipril.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MECHANISM</strong></td>
<td>Inhibit ACE → ↓ AT II → ↓ GFR by preventing constriction of efferent arterioles. ↑ renin due to loss of negative feedback. Inhibition of ACE also prevents inactivation of bradykinin, a potent vasodilator.</td>
</tr>
<tr>
<td><strong>CLINICAL USE</strong></td>
<td>Hypertension, HF (↓ mortality), proteinuria, diabetic nephropathy. Prevent unfavorable heart remodeling as a result of chronic hypertension.</td>
</tr>
<tr>
<td><strong>ADVERSE EFFECTS</strong></td>
<td>Cough, Angioedema (due to ↑ bradykinin; contraindicated in Cl esterase inhibitor deficiency), Teratogen (fetal renal malformations), ↑ Creatinine (↓ GFR), Hyperkalemia, and Hypotension. Used with caution in bilateral renal artery stenosis because ACE inhibitors will further ↓ GFR → renal failure.</td>
</tr>
</tbody>
</table>

**Abbreviations:** AT II: angiotensin II; GFR: glomerular filtration rate; HF: heart failure
Chemical classification of ACE inhibitors

- Peptide structure:
  1) Direct-acting ACE inhibitors (Captopril, Lisinopril, Enalapril)
  2) Pro-drugs (de-esterified in the liver to active diacid forms).

- Three subgroups:
  1) Sulphydryl-containing (Captopril, Zofenopril, Alacepril, Pivalopril);
  2) Di-carboxyl-containing (Enalapril, Lisinopril, Quinapril, Ramipril, Perindopril);
  3) Phosphorus-containing (Fosinopril).
Captopril is the prototype of the sulfhydryl-containing ACE inhibitors. In vitro studies suggest that the presence of the sulfhydryl group may confer properties other than ACE inhibition to these drugs, such as free-radical scavenging and effects on prostaglandins.

Captopril is indicated in the initial therapy of hypertension, for patients with normal renal function or in patients with impaired renal function that do not respond to other drug therapy.

Side effects: dry cough, skin rash, angioedema, and dysgeusia (distortion of taste). Proteinuria (1 of 100 patients), neutropenia (less than 1000/mm3) and agranulocytosis may appear after 3-12 weeks of therapy, particularly in patients with autoimmune collagen vascular diseases.

Drug-drug interactions: drugs that increase the level of K+ in the blood (such as Angiotensin II type 1 receptor blockers, birth control pills containing drospirenone).
Enalapril is an orally administered prodrug, hydrolyzed to release enalaprilat.

Enalapril has been proven to protect the function of the kidneys in hypertension, heart failure, and diabetes, and may be used in the absence of hypertension for its kidney protective effects. Furthermore, enalapril is an emerging treatment for psychogenic polydipsia. A double-blind, placebo-controlled trial showed that when used for this purpose, enalapril led to decreased water consumption (determined by urine output and osmolality) in 60% of patients.

Side effects: dry cough, skin rash and dysgeusia (distortion of taste). Other adverse effects of enalapril are hypotension, hyperkalemia, angioedema, cholestatic jaundice, and hypersensitivity reaction. The most serious, although rare (0.68%), adverse event is angioedema. The incidence of angioedema is higher in African-American individuals. The involvement of the head and neck can potentially compromise the airway. Angioedema can occur at any point during treatment, but is most common after the first few doses.

Drug-drug interactions: drugs that may increase the level of K+ in the blood (such as angiotensin II type 1 receptor antagonists, birth control pills containing drospirenone).
Angiotensin II type 1 receptor antagonists
## Angiotensin II type 1 receptor antagonists: an overview

<table>
<thead>
<tr>
<th>Drug</th>
<th>Indications</th>
<th>Possible Side effects</th>
<th>Some Potential Interactions</th>
<th>Precautions and Contraindications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candesartan</td>
<td>• Hypertension</td>
<td>• Hypotension</td>
<td>• Digoxin</td>
<td><strong>Precautions:</strong></td>
</tr>
<tr>
<td></td>
<td>• Intolerance to ACE inhibitor</td>
<td>• Headache</td>
<td>• Lithium</td>
<td>• Impaired renal/ hepatic function</td>
</tr>
<tr>
<td></td>
<td>• Post- MI patients (secondary prevention of MI in patients with HF)</td>
<td>• Dizziness</td>
<td>• MAO inhibitors</td>
<td>• Unilateral renal artery stenosis</td>
</tr>
<tr>
<td>Eprosartan</td>
<td><strong>Additional</strong> Irbesartan / Losartan</td>
<td>• Lightheadedness</td>
<td>• NSAIDs</td>
<td><strong>Contraindications:</strong></td>
</tr>
<tr>
<td>Telmisartan</td>
<td>• HTN plus diabetic nephropathy</td>
<td>• Anemia</td>
<td>• Potassium-sparing diuretics</td>
<td>• Hypersensitivity</td>
</tr>
<tr>
<td>Irbesartan</td>
<td>• Hypertension</td>
<td>• Fatigue</td>
<td></td>
<td>• Pregnancy/ lactation</td>
</tr>
<tr>
<td>Losartan</td>
<td></td>
<td>• Hypoglycemia</td>
<td></td>
<td>• Bilateral renal artery stenosis</td>
</tr>
<tr>
<td>Valsartan</td>
<td></td>
<td>• Hyperkalemia</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Angioedema</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ↑ BUN</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• ↑ Serum creatinine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ACEI: Angiotensin-converting enzyme inhibitor; ARBs: Angiotensin II receptor blockers; BUN: Blood urea nitrogen; HF: Heart failure; HTN: Hypertension; MAO: Monoamine oxidase; MI: Myocardial infarction; NSAIDs: Nonsteroidal anti-inflammatory drugs
Candesartan cilexetil

- Candesartan is poorly absorbed after oral administration, therefore Candesartan was esterified.

- Candesartan cilexetil finds most significant clinical use in the treatment of **hypertension of all grades**. Candesartan is also approved to treat hypertension in children (1 year or older). Candesartan is also used in preventive treatment of migraine.

- Side effects: The most common adverse effects reported for candesartan are symptomatic hypotension (18.8%), impaired renal function (rise in creatinine, 12.5%), and hyperkalemia (6.3%).

- Drug-drug interactions: NSAIDs, lithium, ACE inhibitors, drugs that increase the K⁺ levels.
Valsartan is a diacid that does not require metabolic oxidation to achieve the maximum pharmacologic effect.

Valsartan is used to treat **hypertension of all grades**. Candesartan is also approved to treat hypertension in children (6 years or older).

Common side effects include headache, hyperkalemia and dizziness. Other serious side effects may include kidney problems, low blood pressure, and angioedema. Use in pregnancy may harm the baby and use when breastfeeding is not recommended.

Drug-drug interactions: Concomitant use of valsartan with other agents that block the renin-angiotensin system or K⁺-sparing diuretics may lead to increases in serum K⁺ and in heart failure patients to increases in serum creatinine. Other interactions: lithium, NSAIDs.
According to recommendations from the JNC8 members, Ca++ channel antagonists are a recommended choice for management of hypertension, either as monotherapy or as part of anti-hypertensive combination therapy.
Ca\textsuperscript{++} channel antagonists: an overview

 Calcium channel blockers are generally classified into three groups:

1) dihydropyridines (amlodipine, clevidipine, nicardipine, nifedipine, bepridil, felodipine, isradipine, and nisoldipine);

2) phenylalkylamines (verapamil);

3) benzothiazepines (diltiazem).

### Calcium channel blockers

<table>
<thead>
<tr>
<th>Calcium channel blockers</th>
<th>Amlodipine, clevidipine, nicardipine, nifedipine, nimodipine (dihydropyridines, act on vascular smooth muscle); diltiazem, verapamil (non-dihydropyridines, act on heart).</th>
</tr>
</thead>
</table>

### MECHANISM

Block voltage-dependent L-type calcium channels of cardiac and smooth muscle → ↓ muscle contractility.
Vascular smooth muscle — amlodipine = nifedipine > diltiazem > verapamil.
Heart — verapamil > diltiazem > amlodipine = nifedipine (verapamil = ventricle).

### CLINICAL USE

- Dihydropyridines (except nimodipine): hypertension, angina (including Prinzmetal), Raynaud phenomenon.
- Nimodipine: subarachnoid hemorrhage (prevents cerebral vasospasm).
- Nicardipine, clevidipine: hypertensive urgency or emergency.
- Non-dihydropyridines: hypertension, angina, atrial fibrillation/flutter.

### ADVERSE EFFECTS

- Non-dihydropyridine: cardiac depression, AV block, hyperprolactinemia, constipation.
- Dihydropyridine: peripheral edema, flushing, dizziness, gingival hyperplasia.
Therapeutical uses of Ca^{++} channel antagonists

- angina pectoris  
  (verapamil, diltiazem),
- cardiac failure  
  (verapamil, diltiazem,  
  amlodipine, nisoldipine),
- dysrrythmias (verapamil,  
  diltiazem),
- hypertensions  
  (dihydropyridines),
- migraine (verapamil),
- stroke  (nimodipine).
Side effects of Ca^{++} channel antagonists

- **ADVERSE EVENTS**
  - Most common
    - Constipation
  - Other significant effects
    - Myocardial ischemia or infarction due to "coronary steal" hypotension

<table>
<thead>
<tr>
<th>CALCIUM CHANNEL BLOCKERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constipation</td>
</tr>
<tr>
<td>Dizziness</td>
</tr>
<tr>
<td>Leg edema</td>
</tr>
<tr>
<td>Flushing</td>
</tr>
<tr>
<td>Headache</td>
</tr>
<tr>
<td>Hypotension</td>
</tr>
<tr>
<td>Palpitation</td>
</tr>
<tr>
<td>Weakness</td>
</tr>
</tbody>
</table>

- **ADVERSE EVENTS**
  - Constipation
  - Vertigo
  - Headache
  - Fatigue
  - Hypotension

- **CALCIUM CHANNEL BLOCKERS**
  - Constipation
  - Dizziness
  - Leg edema
  - Flushing
  - Headache
  - Hypotension
  - Palpitation
  - Weakness
Nifedipine is the prototype of the dihydropyridines.

Nifedipine is approved for the **long-term treatment of hypertension**. Off-label uses of nifedipine include severe hypertension during pregnancy and post-partum hypertension, high pulmonary edema, pulmonary arterial hypertension.

Adverse effects are present in about **20 to 30% of patients** administered with nifedipine. The most common adverse effects include flushing, peripheral edema, dizziness, headache. These problems are much less frequent in the sustained-release preparations of nifedipine. Abrupt discontinuance of the drug after prolonged use may lead to rebound hypertension or angina.

Nifedipine can inhibit the metabolism of drugs that are substrates of CYP3A, thereby increasing the exposure to other drugs. CYP3A inhibitors that increase the levels of nifedipine when co-administered are: fluconazole, clarithromycin, grapefruit, fluoxetine, saquinavir. Strong CYP3A inducers, such as rifampin, rifabutin, phenobarbital, phenytoin, carbamazepine reduce the bioavailability and efficacy of nifedipine.
β-blockers

- Two of the major guide-line committees (JNC8 and NICE UK) have dropped β-blockers as first-line therapy in the treatment of hypertension.

- Moreover, a recent meta-analyses have concluded that β-blockers are inappropriate first-line agents in the treatment of hypertension (Wiysonge CS et al. 2017. "Beta-blockers for hypertension". The Cochrane Database of Systematic Reviews. 1: CD002003).
Selected studies on β–blockers in hypertension.

<table>
<thead>
<tr>
<th>Study</th>
<th>Study design</th>
<th>Number of patients</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Srivastava et al¹</td>
<td>Double-blind prospective trial</td>
<td>20</td>
<td>Treatment benefits versus placebo did not reach statistical significance</td>
</tr>
<tr>
<td>Prichard and Gillam²</td>
<td>Prospective trial</td>
<td>109</td>
<td>92 of the patients in propranolol group achieved a supine, or standing BP of 100 mm Hg or less</td>
</tr>
<tr>
<td>MRC Working Party¹⁴</td>
<td>Randomized, placebo-controlled, single-blind trial in elderly</td>
<td>4,396 (aged 65-74 years)</td>
<td>Atenolol-treated patients showed no significant reduction in stroke, coronary events, and all CV events</td>
</tr>
<tr>
<td>Gupta et al (ASCOT)¹⁷</td>
<td>Randomized, comparator trial</td>
<td>19,257</td>
<td>Patients assigned to atenolol +/- thiazide developed more NOD</td>
</tr>
<tr>
<td>Lindholm et al²²</td>
<td>Meta-analysis of 7 randomized trials</td>
<td>27,433</td>
<td>β-blockers raised the risk of stroke</td>
</tr>
<tr>
<td>Law et al²⁷</td>
<td>Meta-analysis of 108 randomized trials</td>
<td>464,000</td>
<td>No significant difference among major antihypertensives</td>
</tr>
<tr>
<td>Fretheim et al²⁸</td>
<td>Meta-analysis of 25 randomized trials</td>
<td>164,671</td>
<td>β-blockers not superior to other antihypertensives</td>
</tr>
<tr>
<td>Mahmud and Feeley⁴¹</td>
<td>Comparator trial of atenolol and nebivolol</td>
<td>40</td>
<td>Nebivolol, but not atenolol, reduced aortic stiffness</td>
</tr>
<tr>
<td>Bangalore et al³⁹</td>
<td>Comparative meta-analysis of 22 clinical trials</td>
<td>68,222</td>
<td>β-blockers-induced decreased HR increased risk of cardio-vascular events and death</td>
</tr>
<tr>
<td>Phillips et al (GEMINI)⁴⁵</td>
<td>Comparative trial of carvedilol and metoprolol</td>
<td>1,235</td>
<td>Carvedilol is better in hypertensive patients with diabetes</td>
</tr>
<tr>
<td>Lewin et al³³</td>
<td>Nebivolol monotherapy in stage II hypertension</td>
<td>290</td>
<td>Nebivolol was significantly effective even in patients with BMI ≥30 Kg/m²</td>
</tr>
<tr>
<td>Zeltner et al⁶⁹</td>
<td>Comparative trial of ramipril vs metoprolol in PCKD</td>
<td>46</td>
<td>No significant difference in proteinuria, renal function, and LVM in 3 years follow-up</td>
</tr>
<tr>
<td>Caglar and Dincer (PROBE)⁷²</td>
<td>Comparative trial of nebivolol and ramipril in hypertensive patients with LV hypertrophy</td>
<td>106</td>
<td>Nebivolol significantly reduced LVMi, and at a lower dose</td>
</tr>
<tr>
<td>Collier et al (ASCOT-BPLA)⁸⁰</td>
<td>Comparative trial of atenolol and amlodipine in younger and older hypertensive patients</td>
<td>19,257</td>
<td>Amlodipine reduced relative risk of CV events more effectively than atenolol in both older and younger patients</td>
</tr>
<tr>
<td>Pareek et al⁷²</td>
<td>Comparative trial of metoprolol XL/amlodipine combination vs losartan/amlodipine combination</td>
<td>148</td>
<td>Both combinations were equally effective in lowering SBP and DBP</td>
</tr>
</tbody>
</table>

CV - cardiovascular, NOD - new onset diabetes, HR - heart rate, BMI - body mass index, LVMi - left ventricular mass index, PCKD - polycystic kidney disease, SBP - systolic blood pressure, DBP - diastolic blood pressure
β–blockers used in hypertension with comorbidities

- β-blockers are still administered to hypertensive patients who have suffered from myocardial infarction, or other forms of ischemic heart diseases, and heart failure due to systolic dysfunction, **but not in hypertensive patients without comorbidities**.
- β-blockers are usually avoided in patients suffering from bronchial asthma, or with airway hyper-reactivity.

### β receptor antagonists

- **Non-selective (First Generation)**
  - Nadolol
  - Penbutolol
  - Pindolol
  - Propanolol
  - Timolol
  - Sotalol
  - Levobunolol
  - Metipranolol

- **β₁-selective (2nd Generation)**
  - Acebutolol
  - Atenolol
  - Bisoprolol
  - Esmolol
  - Metoprolol

- **Non-selective (3rd Generation)**
  - Carteolol
  - Carvedilol
  - Bucindolol
  - Labetalol

- **β₁-selective (3rd Generation)**
  - Betaxolol
  - Celiprolol
  - Nebivolol
Adverse effects of β–blockers

- Highly lipophilic β-blockers can easily cross the blood-brain barrier and may cause various CNS manifestations as insomnia, sleep changes, and nightmares. Water-soluble β-blockers, for example atenolol, may also cause tiredness and fatigue.

- Bradycardia and hypotension are two adverse effects that may commonly occur. Fatigue, dizziness, nausea, and constipation are also widely reported. Some patients report sexual dysfunction and erectile dysfunction.

- β-blockers, especially the non-cardioselective blockers, should not be used in patients with pathologies such as asthma, diabetes and severe bradycardia (block of the effect of adrenaline).

- β-blockers should not be withdrawn suddenly because sudden withdrawal may worsen angina and cause heart attacks, serious abnormal heart rhythms, or sudden death.
Interactions of β–blockers with other drugs

β-Blockers may interact with a large number of commonly prescribed drugs, including:

- anti-hypertensive and antianginal drugs,
- inotropic agents,
- anti-arrhythmics,
- NSAIDs,
- psychotropic drugs,
- anti-ulcer medications,
- anaesthetics,
- HMG-CoA reductase inhibitors,
- warfarin,
- oral hypoglycaemics and rifampicin.
Diuretics

Diuretic drugs are classified according to their predominant site of action:

1) **Loop diuretics** (furosemide, bumetanide, and torsemide) are organic anions acting in the short descending limbs of the loop of Henle.

2) **Thiazides and thiazide-like** drugs are also organic anions that bind the thiazide-sensitive NaCl cotransporter along the distal convoluted tubule.

3) **K⁺-sparing diuretics** include drugs that block apical Na⁺ channels (amiloride and triamterene) and those that antagonize mineralocorticoid receptors (spironolactone and eplerenone).
Loop Diuretics

Loop diuretics have a higher capacity for diuresis compared to other diuretics. Their mechanism of action is based on:

1) Inhibition of Na\(^+\) and Cl\(^-\) reabsorption at the level of the short descending limbs of the loop of Henle and collecting ducts.

2) Increase of the fractional excretion of Ca\(^{++}\) by up to 30%.

3) Increase fractional Mg\(^{++}\) excretion by more than 60%.

Although the FDA approved the use of loop diuretics alone or in combination with other anti-hypertensive medications as an alternative to thiazide diuretics to treat hypertension, JNC-8 published in 2014 and the American College of Cardiology/American Heart Association (ACC/AHA) Task Force Panel Guidelines on hypertension treatment published in 2017 a report that do not recommend the use of loop diuretic as a first-line medication to treat hypertension.
### Loop Diuretics: an overview

<table>
<thead>
<tr>
<th>Drug</th>
<th>Indications</th>
<th>Possible Side effects</th>
<th>Potential Interaction</th>
<th>Precautions and Contraindications</th>
</tr>
</thead>
</table>
| Furosemide | - Peripheral edema  
           | - Acute pulmonary edema  
           | - Hypokalemia  
       | - ACE inhibitors  
 | - Hypertension  
           | - Hypercalcemia  
           | - Hypochloremia  
       | - Allopurinol  
 | - Hyperuricemia  
           | - Metabolic alkalosis  
           | - Beta 2-agonists  
       | - Corticosteroids  
 | - Hyperglycemia  
           |                                | - Ethacrynic acid  
       | - Lithium  
 |                                |                                | - MAO inhibitors  
       | - Methylphenidate  
 |                                |                                | - Phenytoin  
       | - Probenecid  
 |                                |                                | **Precautions:**  
       |                                    | - DM / SLE  
 |                                |                                | - Acute MI / arrhythmias  
       |                                    | - Prostatic hyperplasia/ urinary stricture  
 |                                |                                | - Elderly patients  
       |                                    | **Contraindications:**  
 |                                |                                | - Hypersensitivity to the drug  
       |                                    | - Hypersensitivity to sulfonamides  
 |                                |                                | - Anuria  
       |                                    | - Hepatic coma  

**ACE inhibitors**: Angiotensin-converting enzyme inhibitors; **DM**: Diabetes mellitus; **MAO inhibitors**: Monoamine oxidase inhibitors; **MI**: Myocardial infarction; **SLE**: Systemic lupus erythematosus
Furosemide is a sulfonamide derivative of aminobenzoic acid.

The Food and Drug Administration (FDA) has approved furosemide to treat conditions with volume overload and edema secondary to congestive heart failure exacerbation, liver failure, or renal failure, including nephrotic syndrome.

Furosemide can predispose to excessive loss of water, resulting in dehydration with electrolyte depletion (hyponatremia, hypokalemia and hypocalcemia). The magnitude of these effects can be greater than the effects produced by thiazides because of the more prominent natriuresis produced by loop diuretics. Furosemide may also cause hyperglycemia, glycosuria, hyperuricemia, hypertriglyceridemia, increased cholesterol levels.

Ototoxicity can occur with the use of furosemide, but the concomitant use of ethacrynic acid, aminoglycosides, or other ototoxic drugs increases the risk.
Thiazide and thiazide-like diuretics inhibit $\text{Na}^+\text{Cl}^-$ cotransport.

Their mechanism of action is based on:
1) increase in the excretion of NaCl and reduction of extracellular fluid volume.
2) increase the reabsorption of filtered Ca++. This action distinguishes these compounds from loop diuretics, which promote Ca++ excretion.
3) Mg++ initial reabsorption is also initially increased by thiazides, but subsequently loss.

The JNC8 and the World Health Organization recommend thiazide diuretics as a first-line treatment for **Stage 1 hypertension** because of their demonstrated efficacy and low cost.
Thiazide and thiazide-like diuretics: an overview

<table>
<thead>
<tr>
<th>Drug</th>
<th>Indications</th>
<th>Possible Side effects</th>
<th>Some Potential Interactions</th>
<th>Precautions and Contraindications</th>
</tr>
</thead>
</table>
| Hydrochlorothiazide | • Hypertension  
                  • Hypercalcemia  
                  • Edema            | • Hypokalemia  
                          • Hyponatremia  
                          • Hyperuricemia  
                          • Metabolic alkalosis  
                          • Hyperglycemia  
                          • Photosensitivity | • Lithium  
                              • NSAIDs  
                              • Hypoglycemic agents  
                              • Corticosteroids | **Precautions:**  
                                          • Electrolyte abnormalities  
                                          • Dehydration  
                                          • DM/ SLE  
                                          • Elderly patients  
                                          • Pregnancy/ lactation  
**Contraindications:**  
                                          • Hypersensitivity to drug and/or its components  
                                          • Anuria |
| Chlorthalidone | Additional Chlorthalidone  
                   • Renal tubular acidosis |                                 |                              |                                   |
| Indapamide    |                                                 |                                 |                              |                                   |

DM: Diabetes mellitus; MI: Myocardial infarction; NSAIDs: Nonsteroidal anti-Inflammatory drugs; SLE: Systemic lupus erythematosus
Hydrochlorothiazide is the most commonly prescribed thiazide diuretic.

The Food and drug administration (FDA) approved hydrochlorothiazide to treat hypertension as a sole agent or adjunct. Moreover, hydrochlorothiazide is recommended as adjunctive therapy to treat edema associated with congestive heart failure or renal dysfunction.

Hydrochlorothiazide can cause electrolyte imbalances, including hypokalemia, hyponatremia, hypercalcemia, and hypomagnesemia. Most prevalent among these is hypokalemia, which results from the combined effects of volume depletion–induced aldosterone release and increased delivery of Na\(^+\) and Cl\(^-\) to the collecting duct. Hyperglycemia can occur, and this drug has been known to unmask latent diabetes as well as cause an increase in cholesterol and triglycerides. There have been reports of exacerbation of systemic lupus erythematosus with the use of hydrochlorothiazide. Hydrochlorothiazide can cause acute transient myopia and acute angle-closure glaucoma, which can occur hours to weeks after beginning the drug. Risk factors for developing this reaction are a history of sulfonamide or penicillin allergy.

Hydrochlorothiazide interacts with antidiabetic drugs, corticosteroids (intensified electrolyte depletion), lithium, NSAIDs.
Hydrochlorothiazide combinations with other drugs

- K⁺-sparing diuretics.

- Another antihypertensive drug.
**K⁺-sparing diuretics ("Mineralocorticoid receptor antagonists")**

- K⁺-sparing agents can be divided into those that antagonize aldosterone (spironolactone and eplerenone) and those independent of aldosterone (amiloride and triamterene).

All of the drugs in this class:

1) inhibit Na⁺ absorption in the distal tubule and the collecting duct.

2) with the reduction in Na⁺/K⁺ ATPase, K⁺ secretion is reduced. This effect can lead to hyperkalemia and limit their use in patients with reduced renal function and in some with heart failure.

3) reduce the excretion of Ca⁺⁺ and Mg⁺⁺. K⁺-sparing agents are effective when added to triple hypertension medications regimen but should be used cautiously when added to ACE inhibitors or angiotensin II receptor 1 blockers due to higher incidence of hyperkalemia. They are effective in treating chronic heart failure as they are proven to decrease mortality rates.
# K+-sparing diuretics: an overview

<table>
<thead>
<tr>
<th>Potassium-sparing diuretics</th>
<th>Spironolactone and eplerenone; Triamterene, and Amiloride.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MECHANISM</strong></td>
<td>Spironolactone and eplerenone are competitive aldosterone receptor antagonists in cortical collecting tubule. Triamterene and amiloride act at the same part of the tubule by blocking Na⁺ channels in the cortical collecting tubule.</td>
</tr>
<tr>
<td><strong>CLINICAL USE</strong></td>
<td>Hyperaldosteronism, K⁺ depletion, HF, hepatic ascites (spironolactone), nephrogenic DI (amiloride), antiandrogen.</td>
</tr>
<tr>
<td><strong>ADVERSE EFFECTS</strong></td>
<td>Hyperkalemia (can lead to arrhythmias), endocrine effects with spironolactone (eg, gynecomastia, antiandrogen effects).</td>
</tr>
</tbody>
</table>

**Abbreviations:** HF: heart failure; nephrogenic DI: nephrogenic diabetes insipidus
Spironolactone

- Spironolactone is structurally similar to aldosterone and functions as an aldosterone antagonist.

- Spironolactone is FDA approved for the treatment of heart failure with reduced ejection fraction (HFrEF), resistant hypertension, primary hyperaldosteronism, edema secondary to cirrhosis, edema secondary to a nephrotic syndrome that is not adequately controlled using alternative therapies, and hypokalemia.

- Spironolactone, because of its steroid structure, mainly induce breast complaints and hyperkalemia. Men specifically may experience gynecomastia, loss of libido, and general feminization. Menstrual irregularities have been reported for women.

- Concomitant administration of ACE inhibitors with K⁺-sparing diuretics has been associated with severe hyperkalemia. Angiotensin II receptor 1 antagonists, aldosterone blockers, heparin may interact with spironolactone inducing excessive hyperkalemia.
α1-antagonists

- α1-antagonists are used as **second line drugs** in the therapy of hypertension.

- This blockade inhibits the smooth muscle contraction and lowers the blood pressure.

- Newer α-antagonists used in treating hypertension are relatively selective α1-adrenoceptor antagonists (e.g., prazosin, terazosin, doxazosin, trimazosin).
### α1-antagonists: an overview

<table>
<thead>
<tr>
<th>Drug</th>
<th>Indications</th>
<th>Possible Side effects</th>
<th>Some Potential Interactions</th>
<th>Precautions and Contraindications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selective Alpha-adrenoceptor antagonists</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prazosin</td>
<td>• Resistant hypertension</td>
<td>• Hypotension</td>
<td>• Amphetamines</td>
<td><strong>Precautions:</strong></td>
</tr>
<tr>
<td></td>
<td>• Pheochromocytoma</td>
<td>• Palpitation</td>
<td>• PDE-5 inhibitors</td>
<td>• Angina</td>
</tr>
<tr>
<td></td>
<td>• Benign prostatic hyperplasia</td>
<td>• Headache</td>
<td>• Prostacyclin analogues</td>
<td>• Cataract surgery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Dizziness</td>
<td></td>
<td>• Pregnancy/ lactation</td>
</tr>
<tr>
<td></td>
<td><strong>Additional Prazosin</strong></td>
<td>• Drowsiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PTSD</td>
<td>• Weakness</td>
<td></td>
<td><strong>Contraindications:</strong></td>
</tr>
<tr>
<td></td>
<td>• Raynaud’s syndrome</td>
<td></td>
<td></td>
<td>• Hypersensitivity</td>
</tr>
<tr>
<td>Terazosin</td>
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<tr>
<td>Doxazosin</td>
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<td></td>
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</tr>
<tr>
<td><strong>Non-selective Alpha-adrenoceptor antagonists</strong></td>
<td></td>
<td><strong>As Above</strong></td>
<td><strong>As Above</strong></td>
<td></td>
</tr>
<tr>
<td>Phentolamine</td>
<td>• Hypertensive crises due to catecholamine</td>
<td></td>
<td></td>
<td><strong>Precautions:</strong></td>
</tr>
<tr>
<td></td>
<td>• Diagnosis of pheochromocytoma</td>
<td></td>
<td></td>
<td>• Cardiac arrhythmias</td>
</tr>
<tr>
<td></td>
<td>• Hypertension due to</td>
<td></td>
<td></td>
<td>• Peptic ulcer disease</td>
</tr>
<tr>
<td></td>
<td>• Pheochromocytoma</td>
<td></td>
<td></td>
<td>• Gastritis</td>
</tr>
<tr>
<td></td>
<td>• Pralidoxime</td>
<td></td>
<td></td>
<td>• Pregnancy/ lactation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Contraindications:</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Hypersensitivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Renal impairment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Coronary or cerebral arteriosclerosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• MI (active or history)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Concurrent use with PDE-5 inhibitors</td>
</tr>
</tbody>
</table>

MI: Myocardial infarction; PDE-5 inhibitors: Phosphodiesterase 5 inhibitors; PTSD: Posttraumatic stress disorder
Doxazosin is a long-acting α1-antagonist structurally related to prazosin and terazosin.

The immediate-release formulation of doxazosin is a second-line agent for the management of hypertension in patients with concomitant benign prostatic hyperplasia. Doxazosin has also been used successfully in combination with β-blockers, diuretics, Ca++ channel antagonists, and ACE inhibitors in patients with hypertension that is uncontrolled with monotherapy.

The most commonly reported adverse effects are orthostatic hypotension/syncope, especially when combined with another anti-hypertensive, nitrates, or a PDE-5 inhibitor.

Doxazosin is a substrate of CYP3A4. Strong CYP3A inhibitors may increase exposure to doxazosin.
Other anti-hypertensive drugs: vasodilators

<table>
<thead>
<tr>
<th>Drug</th>
<th>Site of action</th>
<th>Mechanism of action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium nitroprusside</td>
<td>Arterioles and veins</td>
<td>Production of nitric oxide</td>
</tr>
<tr>
<td>Hydralazine</td>
<td>Arterioles</td>
<td>Stimulation of NO release, Inhibition of Ca++ release from SR</td>
</tr>
<tr>
<td>Minoxidil</td>
<td>Arterioles</td>
<td>K+ channel opening</td>
</tr>
<tr>
<td>Diazoxide</td>
<td>Arterioles</td>
<td>K+ channel opening</td>
</tr>
</tbody>
</table>
Other anti-hypertensive drugs: adrenergic drugs

Drugs
- Alpha-2 receptor agonists: **clonidine**
- Indirect acting adrenergic drugs: **methyldopa**

Mechanisms of antihypertensive action

a) **Alpha-2 receptor agonists:**
   - Activation of alpha-2 receptors in *Nucleus Tractus Solitarius* and in rostral ventrolateral medulla (**the main mechanism**).
   - Activation of peripheral alpha-2 receptors (after high doses).

b) **Indirect acting adrenergic drugs:**
   *Methyldopa* acts as a false neurotransmitter. It is taken up by the adrenergic neurons where it is transformed into methylnorepinephrine, the alpha-2 receptor agonist, which acts as described above.

The final effect common to all these drugs is a decreased firing of the reticulospinal tract, that is a decrease of central adrenergic tone.
Hypertensive emergencies

Hypertensive emergencies are diagnosed when there is a systolic blood pressure higher than 180 mm Hg or a diastolic blood pressure higher than 120 mm Hg

1) with the presence of acute target organ damage; 2) in an otherwise stable person without clinical or laboratory evidence of acute target organ damage.

Patients with hypertensive emergencies include:
- dissecting aortic aneurysm,
- acute pulmonary edema,
- acute myocardial infarction,
- unstable angina pectoris,
- acute renal failure,
- acute intracranial hemorrhage,
- acute ischemic stroke,
- hypertensive encephalopathy,
- peri-operative hypertension,
- sympathomimetic hypertensive crisis caused by use of cocaine, amphetamines, phencyclidine, or monoamine oxidase inhibitors or by abrupt cessation of clonidine or other sympatholytic drugs.

These patients need effective and rapid acting medications administered intravenously to lower the elevated blood pressure safely, protect target organ function, ameliorate symptoms, reduce complications, and improve clinical outcomes.
## Management of hypertensive emergencies

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dose</th>
<th>Onset of action</th>
<th>Adverse effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diuretics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furosemide</td>
<td>20–40 mg i.v. injection in 1–2 min, repeated and higher doses with renal insufficiency</td>
<td>5–15 min</td>
<td>Volume depletion, hypokalemia</td>
</tr>
<tr>
<td><strong>Vasodilators</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium nitroprusside</td>
<td>0.25–10 μg/kg/min as i.v. infusion</td>
<td>Within 30 sec</td>
<td>Nausea, vomiting, tachycardia, thiocyanate and cyanide intoxication</td>
</tr>
<tr>
<td>Nitroglycerin</td>
<td>5–100 μg/min as i.v. infusion</td>
<td>2–5 min</td>
<td>Headache, vomiting, methemoglobinemia, tolerance with prolonged use</td>
</tr>
<tr>
<td>Nicardipine</td>
<td>0.5–6 μg/kg/min as i.v. infusion</td>
<td>5–10 min</td>
<td>Headache, flushing, tachycardia, local phlebitis</td>
</tr>
<tr>
<td>Hydralazine</td>
<td>10–20 mg i.v. injection</td>
<td>10–20 min</td>
<td>Headache, flushing, tachycardia, worsening of angina</td>
</tr>
<tr>
<td><strong>Sympatholytics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labetalol</td>
<td>20–80 mg i.v. injection every 10 min; 2 mg/min as i.v. infusion</td>
<td>5–10 min</td>
<td>Nausea, vomiting, bronchospasm, heart block, orthostatic hypotension</td>
</tr>
<tr>
<td>Phentolamine</td>
<td>1–10 mg i.v. injection, then 0.5–2 mg/min as i.v. infusion</td>
<td>1–2 min</td>
<td>Headache, flushing, tachycardia</td>
</tr>
</tbody>
</table>
Hypertension and comorbidities

<table>
<thead>
<tr>
<th>Characteristic (Number and %)</th>
<th>Hypertension</th>
<th>Hypertension and Diabetes mellitus</th>
<th>Hypertension and Hyperlipidemia</th>
<th>Hypertension and Coronary heart disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1146218 (54.00)</td>
<td>209121 (54.44)</td>
<td>108929 (55.63)</td>
<td>163156 (54.44)</td>
</tr>
<tr>
<td>Female</td>
<td>976485 (46.00)</td>
<td>174984 (45.56)</td>
<td>86876 (44.37)</td>
<td>136538 (45.56)</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-44</td>
<td>265554 (12.51)</td>
<td>15222 (3.96)</td>
<td>20557 (10.50)</td>
<td>7444 (2.48)</td>
</tr>
<tr>
<td>45-59</td>
<td>653872 (30.80)</td>
<td>100263 (26.10)</td>
<td>62154 (31.74)</td>
<td>56712 (18.92)</td>
</tr>
<tr>
<td>60+</td>
<td>1203277 (56.69)</td>
<td>268620 (69.93)</td>
<td>113094 (57.76)</td>
<td>235538 (78.59)</td>
</tr>
</tbody>
</table>

Values in parentheses referred to the percentage of patients in the corresponding group.
Drugs used in hypertension with comorbidities

<table>
<thead>
<tr>
<th>HTN with:</th>
<th>Suitable Drug(s):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angina</td>
<td>Beta blockers, CCBs</td>
</tr>
<tr>
<td>Diabetes</td>
<td>ACE inhibitors, ARBs</td>
</tr>
<tr>
<td>Heart Failure</td>
<td>ACE inhibitors, ARBs, Beta blockers</td>
</tr>
<tr>
<td>Post-MI</td>
<td>Beta blockers</td>
</tr>
<tr>
<td>BPH</td>
<td>Alpha blockers</td>
</tr>
<tr>
<td>Dyslipidemias</td>
<td>Alpha blockers, CCBs, ACE inhibitors/ARBs</td>
</tr>
</tbody>
</table>

Abbreviations: HTN: hypertension; CCBs: Calcium channel blockers; BPH: Benign prostatic hyperplasia; ARBs: Angiotensin receptor blockers; MI: Myocardial infarction.
Moving from a less intensive to a more intensive therapeutic strategy should be done whenever BP target is not achieved.
Possible combinations of classes of anti-hypertensive drugs.

Green continuous lines: preferred combinations; green dashed line: useful combination (with some limitations); black dashed lines: possible but less well-tested combinations; red continuous line: not recommended combination.