A seizure is a brief episode of signs/symptoms resulting due to uncontrolled, abnormal electrical activity in the brain. In this article, we will study in detail the classification, mechanism of action, and adverse effects and interactions of antiseizure drugs. First and second-line drugs for various types of seizures will also be studied.

Definitions and Classification of Seizures

**Epilepsy** is a group of neurological disorders characterized by the recurrence of seizures. A seizure is a brief surge of uncontrolled, abnormal electrical activity in the brain which may produce a physical convulsion in some individuals or minor physical signs in others. Yet other people may suffer thought disturbances or a combination of symptoms. Many structures and processes are involved in the development of a seizure, including neurons, ion channels, receptors, glia, and inhibitory and excitatory synapses.

**Epilepsy is defined by any of the following:**

1. At least two unprovoked (or reflex) seizures occurring greater than 24 hours apart
2. One unprovoked (or reflex) seizure and a probability of further seizures similar to the general recurrence risk (at least 60 %) after two unprovoked seizures,
occurring over the next 10 years

3. Diagnosis of an epilepsy syndrome

**Anti-seizure or antiepileptic drugs**, therefore, are targeted to inhibit neurotransmission. This can be achieved via blocking sodium or calcium excitatory channels/currents, enhancing the inhibitory activity of **gamma-aminobutyric acid (GABA)**, or by blocking **glutamate receptors**.

Seizures can be primary (idiopathic) or secondary to a specific cause such as trauma or a **tumor**. Most antiseizure drugs require dose adjustment in patients with liver and/or **kidney failure**, and some have considerable drug-drug interactions.

Seizures are clinically classified as partial or generalized:

**Partial seizures**
- Simple partial seizures, in which consciousness is **not impaired**.
- Complex partial seizures, in which consciousness is **impaired**.
- Both types of partial seizures can spread, resulting in **secondarily generalized tonic-clonic seizures**.

**Generalized seizures**
Generalized seizures are those in which the first clinical changes indicate that both hemispheres are initially involved. Consciousness usually is impaired during generalized seizures, although some seizures, such as the myoclonic type, may be so brief that impairment of consciousness cannot be assessed.
- Generalized tonic-clonic seizures, aka **grand mal** or **GTC**
- Absence seizures, aka **petit mal seizures**
- Tonic seizures
- Atonic seizures
- Clonic seizures
- Myoclonic seizures
- Infantile spasms

The meanings of some of the terms involved are as follows:
- **Simple**: no loss of consciousness
- **Complex**: accompanied by loss of consciousness
- **Partial**: a part of the body is involved
- **Complete**: the whole body is involved, e.g., status epilepticus
- **Absence**: no epileptic movements, but there is impaired consciousness

**Relevant Pathophysiology of Seizure Types**

**Focal**
- **Decreased inhibition**—defective activation of GABA neurons, defective GABA-A/ -B inhibition, a defect in intracellular calcium regulation
- **Increased excitation**—increased activation of glutamate N-methyl-D-aspartate (NDMA) receptors, increased synchrony or activation of neurons

**Generalized**
Altered thalamocortical rhythms (regulated by the T-type calcium channels/currents)

Antiseizure Drugs (Anticonvulsants)

As already mentioned, the main effect of antiseizure drugs is to suppress the abnormal electrical activity at the epileptic foci in the brain. This is achieved by many different mechanisms.

Sodium channel blockade: phenytoin and phenobarbital and valproic acid at high doses

The block of voltage-gated sodium channels in neuronal membranes prevents Na$^+$ influx, which results in decreased axonal conductance by increasing the refractory period of the neuron.

Promotion of GABA-related inhibition:

- Increase the frequency of chloride ion channel opening—benzodiazepines
- Increase the duration of chloride ion channel opening—barbiturates, such as phenobarbital

Glutamate NMDA receptor blockade: decreased glutamic acid
Excitability—*felbamate*

**Calcium channel blockade:** inhibition of the T-type Ca$^{+}$ currents, especially in thalamic neurons, and decreased Ca$^{+}$ influx in presynaptic vesicles. E.g., *ethosuximide and valproic acid.*

### General pharmacokinetics

- Good absorption from the gut, with a bioavailability of 80–100%
- They usually do not have high plasma protein binding (exceptions: valproic acid, phenytoin, and tiagabine).
- Mainly metabolized by the liver
- Some are excreted unchanged in the urine, and these have minimal drug-drug interaction.
- Usually, medium-to-long acting because of relatively low plasma clearance; longer half-lives
- Phenytoin and gabapentin can exhibit nonlinear pharmacokinetics.

### Important Antiseizure Drugs

**Phenytoin**

- Most widely used antiepileptic drug
- **Fosphenytoin** is a water-soluble prodrug; it can be used parenterally (intravenous and intramuscular).
- Highly bound to plasma proteins

**Mechanism of action:** sodium channel blockade

**Use:**
- Status epilepticus
- GTC seizures (primary or secondary)
- Focal seizures

**Notable adverse effects:**

- Nystagmus and ataxia (because of cerebellar depression), gingival hyperplasia, hirsutism, diplopia, folic acid deficiency (manifested as depression, apathy, psychomotor retardation, and cognitive decline)
- Long-term use mild peripheral neuropathy, osteomalacia (due to vitamin D metabolism abnormalities)
- Fosphenytoin’s adverse effects (not found with phenytoin) include perineal paresthesias and rash/itching, and these are concentration-dependent.
- Stevens-Johnson syndrome and toxic epidermal necrolysis may occur.

**Important points:**

- Zero order (non-linear)
- Requires dose adjustment in patients with renal failure.
- Slow-/extended-release formulation available, which can be administered once daily.
- Calcium and vitamin D supplements required in long-term use to prevent osteomalacia.

**Drug-drug interactions of phenytoin:**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Effect</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamotrigine</td>
<td>Increased metabolism of lamotrigine (glucuronidation induction)</td>
<td>Adjust lamotrigine dose</td>
</tr>
<tr>
<td>Oxcarbazepine</td>
<td>Possible phenytoin toxicity with higher doses of oxcarbazepine</td>
<td>Reduce phenytoin dose</td>
</tr>
<tr>
<td>Tiagabine</td>
<td>Increased tiagabine metabolism (CYP3A4)</td>
<td>Monitor clinical status</td>
</tr>
<tr>
<td>Topiramate</td>
<td>Possible phenytoin toxicity with higher doses of topiramate</td>
<td>Monitor clinical status and phenytoin concentration</td>
</tr>
<tr>
<td>Valproic acid</td>
<td>Increased valproic acid metabolism à increased the formation of a toxic metabolite, Thus, decreased efficiency and increased toxicity</td>
<td>Monitor valproic acid concentration and adjust the dose</td>
</tr>
<tr>
<td>Zonisamide</td>
<td>Decreased zonisamide metabolism (CYP3A4)</td>
<td>Monitor zonisamide concentration and adjust the dose</td>
</tr>
</tbody>
</table>

**Carbamazepine**

**Mechanism of action:** sodium channel blockade

**Use:**

- Focal seizures
- GTC seizures
- Trigeminal neuralgia
- Bipolar disorder
- Not in absence seizures (may increase them)

**Notable adverse effects:** hyponatremia (partly due to increased responsiveness of collecting tubules in the kidney to ADH), dizziness, drowsiness, and nausea.

**Important points:**

- It induces its own metabolism.
- Inducer of CYP1A2, CYP2C, CYP3A, and UDP glucuronosyltransferase
- Severe, even fatal, dermatological reactions may rarely occur—**toxic**
epidermal necrolysis and Stevens-Johnson syndrome.
- Contraindicated in pregnancy due to the risk of fetal carbamazepine syndrome
- Contraindicated in patients with a history of bone marrow suppression and administration of monoamine oxidase (MAO) inhibitors in the past 14 days.

Oxcarbazepine

This is a prodrug and converted to active monohydroxy derivative (MHD) metabolite. It shows fewer drug interactions than carbamazepine because it is a less potent inducer of CYP3A and UDP glucuronosyltransferase.

Hyponatremia is a significant adverse effect (probably higher than that in carbamazepine).

Valproic acid

[Image: “2D structure of anticonvulsant valproic acid (Depakote)” by Harbin – Own work. License: Public Domain]

- Highly bound to plasma proteins

Mechanism of action: sodium channel and calcium T-type current blockade

Inhibits GABA transaminase

Use:
- Complex partial seizures as monotherapy and/or adjuvant
- Simple and complex absence seizures
- Myoclonic seizures
- Migraine prophylaxis
- Bipolar mania.

Notable adverse effects: weight gain, pancreatitis, tremor, thrombocytopenia, headache, azoospermia, hirsutism, hair color change

Important points:
- Being a teratogenic drug it can cause spina bifida if given during pregnancy.
- P450 inhibitor
- High drug-drug interactions:
  - Competes with phenytoin for protein binding.
  - Inhibits metabolism of carbamazepine, ethosuximide, phenytoin, phenobarbital, and lamotrigine.
### Other Anticonvulsants

<table>
<thead>
<tr>
<th>Drug</th>
<th>Mechanism of Action</th>
<th>Use</th>
<th>Significant Adverse Effects</th>
<th>Other remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethosuximide</td>
<td>T-type calcium channel blockade</td>
<td>Only in absence seizures (drug of choice with valproic acid)</td>
<td>Commonly, gastric effects: pain, nausea, and vomiting</td>
<td>More effective than lamotrigine for absence seizures; long half-life (~40 hours)</td>
</tr>
<tr>
<td>Felbamate</td>
<td>Glutamate NMDA receptor blockade and calcium and sodium channel blockade</td>
<td>Third-line drug for refractory partial seizures and for Lennox-Gastaut syndrome</td>
<td>Aplastic anemia (1:4000) and hepatic failure.</td>
<td>Increases plasma phenytoin and valproic acid levels but decreases levels of carbamazepine</td>
</tr>
<tr>
<td>Gabapentin</td>
<td>GABA analog</td>
<td>Adjunct for focal seizures and postherpetic neuralgia</td>
<td>Sedation</td>
<td>Excreted unchanged in kidneys; minimal drug interaction; preferable in the elderly because of milder side effects;</td>
</tr>
<tr>
<td>Lamotrigine</td>
<td>Sodium channel blockade, high voltage-dependent calcium channel blockade</td>
<td>Many seizures, Lennox-Gastaut syndrome, bipolar disorder</td>
<td>Skin rashes, life-threatening Stevens-Johnson syndrome</td>
<td>Dose reduction required with valproic acid</td>
</tr>
<tr>
<td>Levetiracetam</td>
<td>Facilitate GABA-mediated inhibition—although the exact mechanism is unclear (binds selectively to the synaptic vesicular protein SV2A)</td>
<td>Adjunct for focal, myoclonic, and primary GTC seizures</td>
<td>Behavior changes—may require dose reduction or change of drug altogether</td>
<td>Excreted unchanged in kidneys with minimal drug interaction</td>
</tr>
<tr>
<td>Phenobarbital</td>
<td>Promotion of GABA-related inhibition, glutamate blockade, Na and Ca current blockade at high concentrations</td>
<td>Status epilepticus, partial seizures, GTC, febrile seizures</td>
<td>Skin rash, Stevens-Johnson syndrome, toxic epidermal necrolysis, learning difficulties, ataxia</td>
<td>May worsen seizures in absence, tonic, and infantile spasms; Primidone (a prodrug) is metabolized to phenobarbital and phenylethylmalonamide (both have antiseizure activity)</td>
</tr>
<tr>
<td>Tiagabine</td>
<td>Block reuptake of GABA</td>
<td>Adjunct for partial-onset seizures</td>
<td>Dizziness, difficulty concentrating, abdominal pain, nausea</td>
<td>Both hepatic metabolism and renal elimination; should not be used in patients who do not have epilepsy (as it may precipitate seizures).</td>
</tr>
<tr>
<td>Topiramate</td>
<td>Sodium channel blockade, carbonic anhydrase inhibitor, glutamate NMDA receptor blockade, etc.</td>
<td>Partial and primary generalized epilepsy</td>
<td>Somnolence, weight loss, paresthesias</td>
<td>Both hepatic metabolism and renal elimination</td>
</tr>
<tr>
<td>Vigabatrin</td>
<td>Increases GABA levels by inhibiting GABA transaminase</td>
<td>Focal epilepsy (adjunct&gt; monotherapy)</td>
<td>Visual field loss (mild to severe) in about 1/3 of the patients</td>
<td>Excreted unchanged in kidneys with minimal drug interaction</td>
</tr>
<tr>
<td>Zonisamide</td>
<td>Sodium channel and T type calcium current blockade.</td>
<td>Focal epilepsy</td>
<td>Kidney stones, decreased sweating (oligohidrosis), severe skin reactions</td>
<td>Both hepatic metabolism and renal elimination; contraindicated when hypersensitivity to sulfonamides or carbonic anhydrase inhibitors present.</td>
</tr>
</tbody>
</table>

**Notes:**

Drug excreted unchanged through the kidneys requires **dose reduction in renal disease**.

Newer antiseizure drugs have somewhat fewer neurotoxic and systemic side effects than the older/standard ones.

**Other points on toxicity:**

- Most antiseizure drugs are **CNS depressants**. Therefore, overdosage can depress the respiration center.
- Respiratory depression is managed using conservative treatment.
- Many of these drugs can cause drowsiness, sedation, mood/behavior changes (particularly depression).
- Withdrawal of antiseizure drugs should be gradual; sudden cessation can cause increased frequency and/or severity of seizures.
Selection of antiseizure drugs

<table>
<thead>
<tr>
<th></th>
<th>GTC Seizures</th>
<th>Focal (Partial) Seizures</th>
<th>Typical Absence Seizures</th>
<th>Atypical Absence Seizures, Myoclonic Seizures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First line</strong></td>
<td>Valproic acid</td>
<td>Lamotrigine</td>
<td>Ethosuximide(^a)</td>
<td>Valproic Acid</td>
</tr>
<tr>
<td></td>
<td>Topiramate</td>
<td>Carbamazepine (or oxcarbazepine)</td>
<td>Valproic acid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phenytoin</td>
<td>Phenytoin</td>
<td></td>
<td>Lamotrigine</td>
</tr>
<tr>
<td></td>
<td>Phenobarbital (infants)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Second Line</strong></td>
<td>Phenobarbital (adults)</td>
<td>Phenobarbital</td>
<td>Lamotrigine(^c)</td>
<td>Clonazepam</td>
</tr>
<tr>
<td></td>
<td>Phenobarbital</td>
<td>Valproic Acid</td>
<td>Clonazepam(^d)</td>
<td>Levetiracetam</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Zonisamide</td>
<td>Zonisamide</td>
</tr>
<tr>
<td><strong>Adjuncts (in refractory cases)</strong></td>
<td>Perampanel</td>
<td>Gabapentin</td>
<td></td>
<td>Felbamate</td>
</tr>
<tr>
<td></td>
<td>Levetiracetam</td>
<td>Pregabalin</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Zonisamide</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)primarily in uncomplicated cases of absence seizures

\(^b\)useful in cases accompanied by GTC or myoclonic seizures

\(^c\)alone or as an adjunct

\(^d\)main side effects include drowsiness and sedation; tolerance may develop with longer use

Other Epileptic Conditions

Status epilepticus

Status epilepticus is a series of epileptic episodes (usually **tonic-clonic**) without recovery of consciousness between attacks. It is a **life-threatening emergency**.

Management of status epilepticus:

- Securing airway, breathing, and **circulation**
- Start IV benzodiazepine (diazepam or lorazepam) for immediate control
- Maintenance by phenytoin (fosphenytoin)
- If seizures continue, a loading dose of phenobarbital
- If seizures still continue, intubate and administer **general anesthesia**.

Infantile spasms

Infantile spasms are an epileptic syndrome characterized by **myoclonic jerks**; however, the manifestation varies.

- Reported association with infection, **kernicterus**, **tuberous sclerosis**, and **hypoglycemia**
- Patients usually have **cognitive deficiency**, and therapy may not alleviate this.

Management of infantile spasms:

- Intramuscular corticotropin or oral prednisolone; if seizures recur, repeat the course.
- Benzodiazepines—clonazepam or nitrazepam (as effective as corticosteroids)
- Vigabatrin (sometimes considered the drug of choice)
Nonepileptic Uses of Antiseizure Drugs

- Phenytoin is a group 1B antiarrhythmic agent.
- Several drugs, especially carbamazepine and lamotrigine, are useful for bipolar disorder.
- Gabapentin is useful in postherpetic neuralgia.
- Carbamazepine is the drug of choice of trigeminal neuralgia.
- Many drugs are useful in migraine, e.g., phenytoin, gabapentin, topiramate.

### High-yield points to remember regarding antiseizure drugs

<table>
<thead>
<tr>
<th>High drug-drug interactions</th>
<th>Phenytoin, carbamazepine, valproic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose adjustment/cessation required in renal insufficiency/failure</td>
<td>Gabapentin, levetiracetam, topiramate, vigabatrin</td>
</tr>
<tr>
<td>Preferred in the elderly</td>
<td>Gabapentin</td>
</tr>
<tr>
<td>Increase weight</td>
<td>Carbamazepine, valproic acid</td>
</tr>
<tr>
<td>Decrease weight</td>
<td>Felbamate, topiramate</td>
</tr>
<tr>
<td>Weight neutral</td>
<td>Lamotrigine, levetiracetam, phenytoin</td>
</tr>
<tr>
<td>Can exacerbate seizures</td>
<td>Carbamazepine—absence, atonic, or myoclonic seizures</td>
</tr>
<tr>
<td></td>
<td>Phenytoin, vigabatrin—generalized seizures</td>
</tr>
<tr>
<td></td>
<td>Gabapentin—myoclonic jerks</td>
</tr>
</tbody>
</table>

### Review Questions

The correct answers can be found below the references.

1. A 37-year-old female with a BMI of 29.6 is diagnosed with absence seizures. Which of the following is the most suitable drug?
   A. Carbamazepine  
   B. Valproic acid  
   C. Lamotrigine  
   D. Felbamate  
   E. Phenytoin

2. A 17-year-old male presented to the emergency department with fever,
vomiting, facial edema, and an erythematous rash over his face, neck, chest, and back. He had been diagnosed with juvenile myoclonic epilepsy two weeks ago and had been started on an antiepileptic drug. Which of the following drugs could be responsible?

- A. Phenytoin
- B. Lamotrigine
- C. Clonazepam
- D. Carbamazepine
- E. Ethosuximide

3. A 68-year-old woman was newly diagnosed with epilepsy. Considering the adverse effect profile, especially in an elderly person, which of the following drugs should be prescribed?

- A. Carbamazepine
- B. Phenytoin
- C. Phenobarbital
- D. Valproic acid
- E. Lamotrigine

References


Antiseizure drugs: Mechanism of action, pharmacology, and adverse effects via uptodate.com

Epilepsy and Seizures via medscape.com

Correct answers: 1C, 2B, 3E

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