Local Anesthetic (LA) — Classification and Chemistry

Local anesthesia is required for many surgical procedures, be it minor or major. Local anesthetics act by blocking the neuronal impulses in the area they have been administered at, and this is achieved primarily by blocking voltage-gated sodium channels. Local anesthetic drugs have a variable onset and duration of action, ranging from a few minutes to a few hours. While they are generally safe, they may cause an allergy, cardiotoxicity or neurotoxicity. In this article, we will study the pharmacodynamics, pharmacokinetics, mechanism of action, important indications and toxicity of local anesthesia.

Chemistry of Local Anesthetics

Local anesthetics exist in ionized (cation) and unionized forms. Ionization of the drug affects its transportation across the lipid plasma membrane. The ionized form (water soluble but lipid insoluble) of a local anesthetic is important as it is the most active at the receptor site (lipidic plasma membrane/axon). However, this form has poor penetration in the neuronal membrane (where lies the receptor site for local anesthetics).

Always remember: pKa of the drug is the pH at which the ionized and unionized forms of the drug are present in equal amounts. The ionized form of the drug is water soluble and the non-ionized form of the drug is lipid soluble.
The $pH$ and $pKa$ are important in determining the ionization of the drug. In regional anesthesia, for example, when the drugs are injected into the infected tissues, the local pH is low, which leads to a more ionized form. Thus, there is reduced diffusion into the membrane and slow clinical effect. This can be facilitated by adding bicarbonate to the local anesthetic, thereby leading to a faster onset of action.

However, it is important to note that the action of local anesthetics is dependent on both the ionized and non-ionized forms of the drug. The ionized form of the drug is water soluble and the non-ionized form of the drug is lipid soluble (soluble in plasma membrane of a cell/axon).

Before reaching (the non-ionized form of drug), the plasma membrane of axon (site of action), a drug (ionized form of drug) must pass through the aqueous extracellular phase.

**Classification of Local Anesthetics**

Structurally, local anesthetics have a lipophilic aromatic ring, which is connected to a hydrophilic group by an intermediate chain, which can be an amide or an ester.

**Amides**

Lidocaine (or lignocaine), prilocaine, mepivacaine, etidocaine, bupivacaine, ropivacaine and levobupivacaine.

**Example: Lidocaine pKa 7.7**

- Inflamed tissue may have a pH as low as 6.8 (normal tissue 7.4)
- Lidocaine is sometimes given with bicarbonate to alkalinize the area, and make the drug more lipid soluble.
- Once inside the neuron, the pH is 6.9, so it becomes more polar and water soluble.

**Esters**

Cocaine, procaine, chloroprocaine, tetracaine (amethocaine) and benzocaine

**Mnemonics to remember esters:**

Professional chlorine, benzene and cocaine are tetra packed. It is also easy to remember that amides have names with more than one letter ‘i’ while esters have one.

**Mode of Action of Local Anesthetics**

Local anesthetics act primarily by inhibiting the voltage gated sodium channels (they also inhibit potassium channels) on the neuronal membrane and thus block peripheral nerve conduction. They bind more to the open or inactive sodium channels than those in
their resting phase.

- The effect is **concentration dependent**: first, the impulses are slowed down and then, completely stopped.
- The binding is **reversible**.
- The higher the affinity of binding (or the lower the dissociation), the higher the potency.
- **Potassium channel blockage** further enhances the binding of the drug and, thereby, the anesthetic blockade itself.
- For **myelinated axons**, the smaller the diameter of the fiber, the greater the blockage. Thus, Ay and Aδ fibers and type B preganglionic fibers are the most susceptible.
- The **non-myelinated C fibers** are less easily blocked. For the non-myelinated fibers, the smaller the fiber, the less susceptible it is.
- Other mechanisms by which local anesthetics may act involve **G-protein receptors, endothelial nitric oxide** and **muscarinic receptors**.

**Pharmacokinetics of Local Anesthetics**

**Absorption**

Usually, local anesthetics are absorbed rapidly into the blood from the site of injection. The duration of the action is limited, but can be prolonged if the blood flow is reduced (e.g. by concomitant use of a **vasoconstrictor** such as epinephrine).

**Functions of Vasoconstrictor:**

Reduces systemic absorption, thus reduces the **systemic toxicity**.

Is more effective for shorter-acting drugs (e.g., lidocaine) than longer-acting drugs (e.g. bupivacaine and tetracaine).

Amides show a **biphasic absorption pattern** (initial rapid followed by a slow phase).

**Distribution**: a lot of factors are to be considered when analyzing the local and systemic distribution: tissue blood flow (and factors affecting that), patient position, etc.

**Metabolism:**

Esters are metabolized by **plasma cholinesterase (pseudocholinesterase)**. This leads to the production of the metabolite **para-aminobenzoic acid (PABA)**, which leads to **allergic or anaphylactic reactions**. Metabolism is reduced in patients with pseudocholinesterase deficiency/ataypical pseudocholinesterase.

Amides are mainly metabolized by the **liver**, and are reduced in the presence of potent CYP450 inhibitors, such as ketoconazole. Since PABA is not produced, allergic reactions are rare.

**Plasma half-life**: the half-life is short for esters (1-8 min) because metabolism by plasma cholinesterase is faster, whereas it is longer for amides (lidocaine and prilocaine < 2 h; others 3-4 h) because liver enzymes are relatively slower to act.

**Clearance**: excretion of the uncharged drug is limited because of poor water solubility.

**Placental transfer**: esters do not cross the placenta in significant amounts as they are
subjected to rapid \textit{hydrolysis}. For amides, the rate of transfer is dependent on protein binding: the higher the binding (e.g., bupivacaine), the lower the transfer.

**Pharmacological Properties of Some Local Anesthetics**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Onset</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bupivacaine</td>
<td>Slow</td>
<td>Long</td>
</tr>
<tr>
<td>Chloroprocaine</td>
<td>Fast</td>
<td>Short</td>
</tr>
<tr>
<td>Etidocaine</td>
<td>Rapid</td>
<td>Long</td>
</tr>
<tr>
<td>Lidocaine</td>
<td>Fast</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Mepivacaine</td>
<td>Moderate</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Prilocaine</td>
<td>Fast</td>
<td>Short</td>
</tr>
<tr>
<td>Procaine</td>
<td>Fast</td>
<td>Short</td>
</tr>
<tr>
<td>Ropivacaine</td>
<td>Moderate</td>
<td>Long</td>
</tr>
<tr>
<td>Tetracaine</td>
<td>Slow</td>
<td>Long</td>
</tr>
</tbody>
</table>

**Toxicity of Local Anesthetics**

The symptoms and signs of toxicity of local anesthetics, including the timing of onset, are somewhat unpredictable. A high level of suspicion is advised, especially in patients who have alterations in mental or cardiovascular status following the injection of a local anesthetic.

**Central nervous system effects:** can be of excitation or depression, and can be initially subtle and nonspecific - for example, light-headedness, sedation, restlessness, and nystagmus.

**Transient neurologic symptoms:** severe pain and/or dysesthesia following administration of local anesthetics (mainly lidocaine) for spinal or epidural blocks.

**Cardiovascular effects:** most local anesthetics (except cocaine) are vasodilators. (Mepivacaine has low to no vasodilator activity.) They may exacerbate existing heart conditions and lead to heart block or other electrical conducting system dysfunctions of the heart.

**Cardiac toxicity** is somewhat enhanced in the presence of \textit{hyperkalemia} as there is increased depolarization, which means that more channels are in the inactive state.

Management of **serious systemic toxicity** includes the following:

- Airway, breathing, circulation support
- Control of seizures (tonic-clonic convulsions), if any
- Administration of 20 % lipid emulsion (lipid rescue therapy)
- Cardiopulmonary resuscitation, if needed

Dosage in the elderly (of the drug, as well as of the concomitant epinephrine) should be somewhat reduced as they usually have slightly compromised liver function.

**Individual Local Anesthetics**

<table>
<thead>
<tr>
<th>Drug</th>
<th>Properties</th>
<th>Use</th>
<th>Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bupivacaine</td>
<td>The duration of effect is 6—18 hours. Causes more sensory than motor block. One of the longest acting local anesthetics (half-life, 3.5 h).</td>
<td>Not recommended for regional anesthesia procedures that require a high volume. Agent of choice for postoperative/labor epidural analgesia (liposome injectable suspension can provide postoperative analgesia lasting ≥ 24 h).</td>
<td>Considerable risk of cardiotoxicity: accidental IV injection can cause pronounced cardiotoxicity.</td>
</tr>
<tr>
<td>Chloroprocaine</td>
<td>Its effect lasts 45 min. Minimal transplacental passage.</td>
<td>Initial drug for extradural labor block (followed by bupivacaine or ropivacaine).</td>
<td>Paraplegia after intradural use (probably due to sodium metabisulphite in the solution) is not recommended intradurally.</td>
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<tr>
<td>Cocaine</td>
<td>It has significant surface local anesthetic activity. It is the only local anesthetic with intrinsic vasoconstrictor activity; this helps reduce intraoperative bleeding.</td>
<td>Preferred in head, neck and pharyngeal surgery</td>
<td>Less toxic than bupivacaine and more toxic than lidocaine.</td>
</tr>
<tr>
<td>Etidocaine</td>
<td>More motor blockade.</td>
<td>Motor block makes it unsuitable for use during labor.</td>
<td>Slightly lower cardiotoxicity than the racemic mixture.</td>
</tr>
<tr>
<td>Mepivacaine</td>
<td>Not metabolized by neonates. Anti-arrhythmic properties.</td>
<td>Not recommended in obstetric anesthesia.</td>
<td>Can cause methemoglobinemia when doses &gt; 600 mg (because of the metabolite orthotoluidine).</td>
</tr>
<tr>
<td>Prilocaine</td>
<td>It is metabolized very rapidly by pseudocholinesterase (half-life, 1–2 min).</td>
<td>Agent of choice when there is a history of malignant hyperpyrexia. Used in patients with an allergy to amides.</td>
<td>Relatively nontoxic.</td>
</tr>
<tr>
<td>Procaine</td>
<td>One of the longest acting local anesthetics (half-life, 4.2 h). Causes more sensory than motor block.</td>
<td>High-dose peripheral blocks. Postoperative/labor epidural analgesia.</td>
<td>Less toxic than bupivacaine.</td>
</tr>
<tr>
<td>Ropivacaine</td>
<td>Has some surface activity.*</td>
<td>Intradural blocks.</td>
<td>Can cause cardiac asystole or ventricular fibrillation.</td>
</tr>
<tr>
<td>Tetracaine</td>
<td>Has some surface activity.*</td>
<td>Routes of administration: intravenous or intramuscular; it is first-pass effect and also because the metabolites are more cardiotoxic.</td>
<td>Cardiovascular and neurotoxic effects (usually CNS stimulation, including seizures). Cardiotoxicity can be enhanced in the presence of hyperkalemia. Rashes, but overt allergy is rare. High incidence of transient neurologic symptoms. Important/other remarks: Cimetidine reduces lidocaine clearance, and can thus increase its toxicity.</td>
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</tbody>
</table>

Notes:
*ability to act on the superficial nerves when applied to the mucous membrane.

Review Questions

The correct answers can be found below the references.

1. For the commencement of a surgical procedure, the maxillofacial surgeon injected 7 mL of 0.5% lidocaine in the maxillary vestibule, along with 1:200,000 of epinephrine. What was the total dose of lidocaine injected?
   
   A. 5 mg  
   B. 0.35 mg  
   C. 35 mg  
   D. 0.05 mg  
   E. 0.5 mg

2. Which of the following factors do not affect the duration of action of local anesthetics?
   
   A. Hepatic blood flow  
   B. Genetic defect in pseudocholinesterase activity  
   C. Local pH of the tissue  
   D. Concomitant use of epinephrine  
   E. Inflammation at the injection site

3. A 35-year-old male has a history of allergy to bupivacaine, an amide
anesthetic. Which of the following drugs would you use instead for postoperative epidural analgesia in this patient?

A. Procaine  
B. Ropivacaine  
C. Chloroprocaine  
D. Cocaine  
E. Ibuprofen

References


Infiltration of local anesthetics via uptodate.com


Correct answers: 1C, 2A, 3B

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