

Spinal Anesthesia: A Comprehensive Review of Intrathecal Local Anesthetics and Adjuvant Agents

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Abstract:

Spinal anesthesia is a widely used neuraxial technique that provides effective surgical anesthesia and postoperative analgesia while avoiding many of the adverse effects associated with general anesthesia. Selection of an appropriate intrathecal agent is essential for achieving a rapid and reliable sensory and motor block while allowing predictable recovery with minimal adverse effects. Local anesthetics used for spinal anesthesia differ considerably in their pharmacological characteristics including onset, duration of action, baricity, and safety profile. Short-acting agents such as chlorprocaine and lidocaine facilitate rapid recovery, whereas intermediate-acting agents such as mepivacaine and ropivacaine provide a balance between block duration and postoperative mobilization. Long-acting agents including bupivacaine and levobupivacaine, provide prolonged and predictable anesthesia for longer surgical procedures. Furthermore, intrathecal adjuvants including opioids, $\alpha 2$ -adrenergic agonists, ketamine, magnesium sulfate, and nalbuphine may enhance block quality, prolong analgesia, and reduce local anesthetic requirements, although their potential adverse effects should be considered. Understanding the available drug options and their pharmacological properties is therefore essential for tailoring spinal anesthesia to the individual patient and surgical procedure.

Keywords: Spinal anesthesia; Intrathecal anesthesia; Local anesthetics; Bupivacaine; Ropivacaine; Chlorprocaine; Intrathecal adjuvants; Postoperative analgesia.

Introduction:

Pain is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage. Regional anesthesia is highly effective both for surgical procedures and postoperative pain management. It has lower adverse effects and sequelae than general anesthesia (1).

The ideal intrathecal agent for such a surgery should have a rapid onset of motor and sensory blockage, predictable regression within an acceptable duration and a low incidence of side effects. Anesthetic monitoring ends when the motor block induced by spinal anesthesia resolves, and in the absence of complications (2).

(A)classification and Pharmacological Properties of Spinal Anesthetic Agents:

Local anesthetics used in spinal anesthesia are broadly categorized into ester and amide compounds, each possessing distinct metabolic pathways and risk profiles. Ester agents tend to produce para-aminobenzoic acid as a breakdown product, making allergic reactions more common, whereas amide anesthetics demonstrate more stable metabolic behavior and broader clinical acceptance. The availability of multiple formulations allows anesthesiologists to select agents based on onset speed, duration, and safety considerations, aligning drug choice with surgical complexity and patient factors (3).

The pharmacological diversity among spinal anesthetics is further highlighted by varying onset times and durations. Short-acting drugs such as chlorprocaine and lidocaine offer rapid onset and limited duration, enabling their use in short procedures and ambulatory settings. Intermediate-acting drugs like mepivacaine and ropivacaine provide longer sensory and motor effects while balancing hemodynamic stability, making them suitable for procedures requiring greater block persistence. Longacting agents such as bupivacaine and levobupivacaine remain preferred for extended operations due to their dense block and predictable duration (4).

Baricity is a critical factor influencing drug behavior within cerebrospinal fluid, determining whether an agent spreads to dependent, non-dependent, or gravity-neutral regions of the spinal canal. Hyperbaric preparations, typically produced by adding dextrose, sink within the CSF and generate more predictable levels, whereas hypobaric solutions—created by adding sterile water or warming the solution—rise within the CSF and facilitate selective distribution for procedures requiring unilateral or posterior spinal anesthesia. This modulation of baricity enables highly tailored anesthesia with improved hemodynamic stability and reduced sympathetic blockade (5).

Temperature, concentration, and solution density further modify baricity and ultimately determine the spread of the block. Increasing the temperature of isobaric solutions decreases their density enough to induce hypobaric characteristics, changing their distribution pattern in the spinal canal. Similarly, lowering drug concentration enhances preferential sensory block with limited motor involvement, while high volumes introduce greater variability in spread. Understanding these relationships is essential for balancing rapid onset with controlled distribution (6).

(B) Short-Acting, Intermediate-Acting, and Long-Acting Local Anesthetic Options:

Short-acting local anesthetics remain essential in spinal anesthesia for day-case surgeries requiring rapid turnover. Agents such as chlorprocaine produce anesthesia within minutes and dissipate within one hour, allowing full recovery of motor and sensory function shortly after the procedure. Because of their limited duration and lower neurotoxicity profile, these agents are well-positioned for ambulatory interventions and situations in which prolonged motor block would delay discharge (7).

Intermediate-acting agents offer a balance between rapid onset and sustained effect. Mepivacaine provides a block that lasts up to three hours and offers favorable conditions for surgeries requiring moderate operative time. Ropivacaine, also in this category, is valued for its reduced cardiac toxicity and diminished motor block relative to bupivacaine, offering improved hemodynamic stability and earlier mobilization. These features make intermediate-acting agents particularly useful in patients with limited physiologic reserve (8).

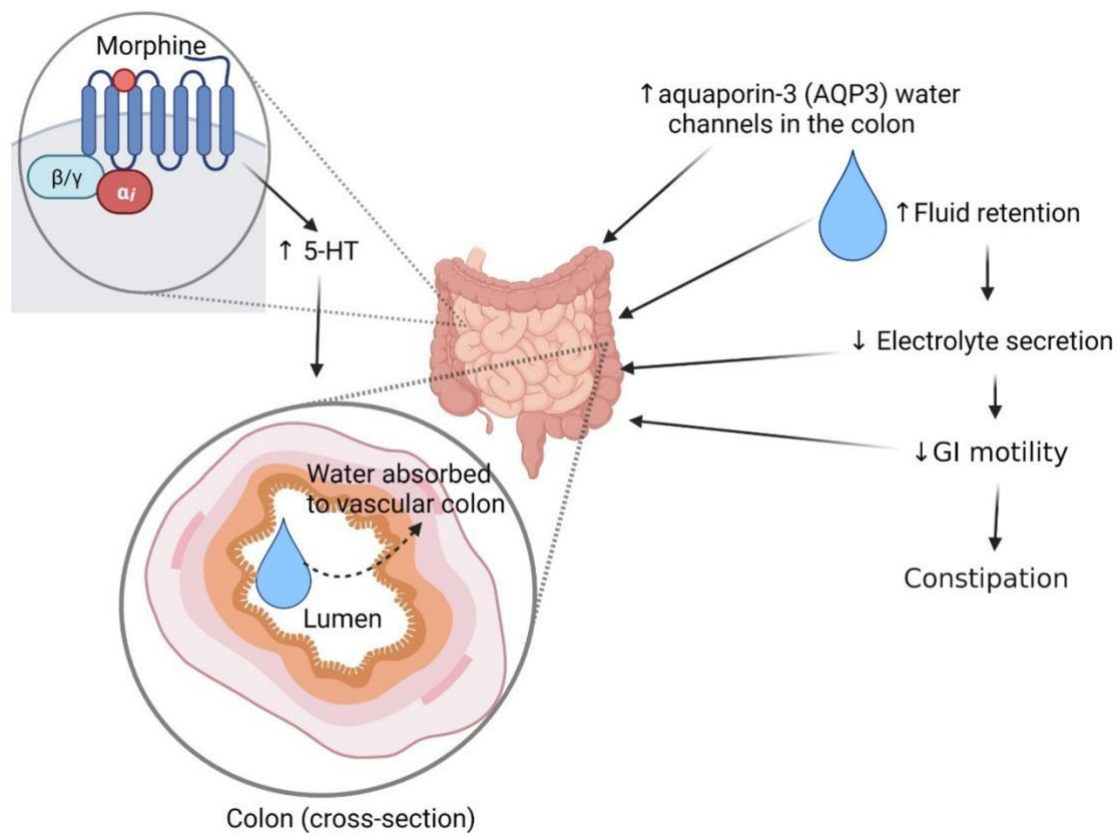
Long-acting agents, especially bupivacaine and tetracaine, deliver prolonged sensory and motor anesthesia suitable for extended operations. Bupivacaine remains one of the most widely used due to its predictable distribution, low incidence of hypotension, and suitability for both hyperbaric and isobaric preparations. Levobupivacaine, provides comparable anesthetic depth with reduced cardiotoxicity, making it advantageous in patients with cardiovascular risk factors. These agents ensure stable, long-lasting blocks that minimize the need for supplemental anesthesia (5).

(C) Adjuvant Medications and Their Role in Enhancing Block Quality:

Adjuvants play a pivotal role in modifying the onset, intensity, and duration of spinal anesthesia. Opioid adjuvants, such as fentanyl and sufentanil, enhance sensory block without substantially increasing motor blockade. Their lipophilic properties promote rapid onset and improved intraoperative comfort while reducing the required dose of local anesthetic. These opioids also reduce the need for systemic analgesics postoperatively, contributing to smoother recovery (9).

Other adjuvants include hydrophilic opioids like morphine, which provide extended postoperative analgesia lasting up to 24 to 48 hours. While offering significant pain relief, these agents require careful titration to avoid side effects such as pruritus, nausea, constipation and respiratory depression

(Figure 1).

**Figure 1: Complication of Morphine in GIT (7).**

Non-opioid adjuvants such as clonidine, dexmedetomidine, and ketamine provide additional tools for block enhancement. Alpha-2 agonists prolong both sensory and motor block while improving block density and decreasing shivering, though close monitoring is necessary due to risks of bradycardia and hypotension. Ketamine possesses local anesthetic-sparing effects but may introduce undesirable central effects, limiting its suitability to select cases. These agents expand the customization options available to clinicians **(10)**.

Magnesium sulfate and nalbuphine represent further developments in spinal adjuvant therapy. Magnesium sulfate modulates NMDA receptor activity and contributes to reduced anesthetic requirements, though dosing errors and limited efficacy narrow its application. Nalbuphine, acting primarily on κ -receptors, enhances postoperative analgesia while reducing μ -opioid side effects, making it an appealing alternative in multimodal spinal anesthesia strategies **(5)**.

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