Safe Practice of Ultrasound Guided Regional Anesthesia

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Case Stem As a regional anesthesiology fellow, you are meeting your first patient of the day in the preoperative holding area. Patient is a 61-year-old man with a BMI of 18 (weight of 45 kg) presenting for elective total shoulder arthroplasty (TSA) for treatment of his primary osteoarthritis. His past medical history includes hypertension, diabetes, coronary artery disease with a drug-eluting stent placed 1 year earlier, Wolf-Parkinson-White syndrome, and emphysema secondary to a 30-pack year smoking history. He also has a history of polysubstance abuse, and successfully tapered off of methadone completely just this past year. His medications include Aspirin 81 mg, Clopidogrel (which he had stopped 7 days ago), Atorvastatin, Amlodipine, Metformin, Insulin, Carvedilol, and Albuterol. His electrocardiogram was notable for left anterior hemiblock and pathologic Q waves in the anterior distribution. A recent stress echocardiogram demonstrated left ventricular hypertrophy, moderate pulmonary hypertension, an ejection fraction of 35%, and multiple areas of reversible ischemia. On exam, patient was noted to have a mallampati III airway, small mouth opening, and limited cervical exten-

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sion. He is interested in regional anesthesia in order to avoid opioids given his history of substance abuse. You are also made aware of the fact that he will not be expected to participate in physical therapy until postoperative day 1.

Key Question 1
What peripheral nerve blocks (PNBs) can be performed for this patient? Compare and contrast single-shot versus continuous methods. Which technique do you believe is best suited for this patient?

PNBs can generally be administered by one of two possible techniques: a one-time injection (i.e. "single-shot" or SSPNB) of local anesthetic (LA), or a continuous infusion of LA via a percutaneously placed catheter (CPNB). Each technique has distinct advantages and disadvantages that should be carefully considered and thoroughly discussed with both the patient and the perioperative team.

CPNBs involve infusion of LA to a target nerve or nerve plexus in an attempt to extend the benefits of SSPNB. CPNBs offer several distinct advantages, particularly in the postoperative period. Advantages of CPNBs are summarized in Table 1 based on a plethora of research validating CPNBs in various surgical models, particularly those related to orthopedics [1–3].

Despite these many advantages, CPNBs are also associated with some drawbacks that have prevented them from being used routinely. Catheter specific complications include [4–6]:

- Dislodgement (up to 15% of all catheters, 5% with ISB catheters) [4]
- Infections

Table 1 Advantages of continuous peripheral nerve blocks (CPNBs) relative to single-shot peripheral nerve block

• Superior and prolonged postoperative analgesia
• Reduced supplemental opioid consumption and opioid related adverse effects
• Improved postoperative rehabilitation/ambulation
• Reduced length of hospital stay and expedited discharge to home
• Improved patient satisfaction

- Local anesthetic systemic toxicity (LAST), and LA induced myo- and neurotoxicity
- Increased incidence of falls (with femoral CPNB due to resultant quadricep muscle weakness [7])

Indications for CPNB tend to vary between different institutions, but generally include palliative management (i.e., non-operative femoral neck fractures) and circumstances in which systemic opioids should be minimized or avoided entirely (i.e., substance abuse, opioid-induced hyperalgesia). Our patient has a longstanding history of opioid abuse and it would undoubtedly be in his best interest to minimize systemic opioids in the perioperative period with CPNB. CPNBs can also provide adequate pain control to ensure that patient can tolerate aggressive physical therapy (PT) on postoperative day 1 (POD1).

Case Stem At the end of your preoperative discussion with the patient, you collectively agree to perform an ultrasound-guided interscalene nerve catheter (US-ISB). After obtaining informed consent, you set up an ultrasound machine at the bedside. You recall and confirm that the patient is having a right-sided procedure, and so you place the ultrasound machine on the left side of the patient's stretcher.

Key Question 2

During your preparation for the US-ISB catheter, a visiting medical student asks you what equipment/medications he/she could help gather?

A principal means of delivering safe and effective local and regional anesthesia involves maintaining a practice aimed at avoiding adverse outcomes and preventing known complications. Achieving this goal generally requires consistency on the part of the anesthesiologist when it comes to preparation and basic setup for every case.

Standard American Society of Anesthesiologist (ASA) monitors, such as pulse oximetry, electrocardiography, and non-invasive blood pressure measurement should be utilized for any type of anesthetic, and regional anesthesia (RA) is no exception. These monitors are crucial given that neuraxial and peripheral nerve blocks are generally performed in patients who have received some degree of sedation, both for improved procedural conditions as well as for patient comfort. Over sedation and its undesirable sequelae, including hypoventilation, airway obstruction, and hypoxemia, can be easily avoided with steadfast monitoring of oxygenation and ventilation.

Patient sedation while performing PNB has been shown to be beneficial for numerous reasons. Sedation reduces procedural pain and recall of the procedure, which in turn has resulted in increased patient satisfaction during block performance and greater tolerance of nerve blocks [8]. Furthermore, sedation with benzodiazepines or propofol increases the seizure threshold, thereby potentially reducing the risk for neurotoxic sequelae associated with systemic toxicity [9]. Table 2 outlines a number of medications that are frequently used for sedation in regional anesthesia. Doses are titrated to patient comfort while ensuring that patients maintain levels of consciousness that are necessary for communication and cooperation.

Although the use of ultrasound has significantly mitigated the risk of severe LAST by allowing direct visualization of vascular structures and injectate, the risk has not been completely elimi-

Table 2 Sedatives for regional anesthesia

Drug	Onset (min)	General IV drug dose range	Benefits and complications
Midazolam	1–2	1–4 mg	Significant anxiolysis, anterograde amnesia. Synergistic with opioids in causing respiratory depression
Fentanyl	3–5	25–100 micrograms	Significant analgesia, respiratory depression
Ketamine	Variable	5–20 mg	Significant analgesia with minimal respiratory depression
Propofol	<1	10–50 mg	Hypnosis with significant respiratory depression

nated [10]. Therefore, emergency drugs and resuscitation equipment should always be readily available when administering any regional anesthetic to obtain timely control of the airway, stabilize vital signs, and treat both cardiotoxic and neurotoxic effects of LAST. Resuscitation equipment and emergency medications are shown in Table 3.

All PNBs require some mode of nerve localization to ensure that the injectate/catheter is deposited in the correct location adjacent to the target nerve. SSPNB are performed with insulated needles (to conduct electrical stimulus for nerve stimulation) or echogenic needles (for ultrasound guidance) of different lengths and diameters (see Fig. 1). Shorter, larger-diameter needles allow for better handling and manipulation, whereas longer, smaller-diameter needles offer less control and are more easily distorted when traversing different layers of tissues (muscles, subcutaneous tissues, fascial layers, etc.); however, these longer, smaller-diameter needles are often required simply to perform deeper blocks that would otherwise be out of reach.

Case Stem You summarize the patient's pertinent medical history and airway exam to the medical student. You show the medical student the equipment you have gathered thus far, including 18-gauge continuous block needle system, chlorhexidine prepara-

Table 3 Resuscitation equipment and emergency medications for regional anesthesia

Resuscitation equipment	Emergency medications
• Self-inflating bag-mask ventilation device (i.e., Ambu bag) • Suction • Oxygen-supply with face mask • Endotracheal tube(s), oral airways, nasal airways • Laryngoscopes (Macintosh and Miller blades) • Defibrillator	• Induction agent (i.e., Propofol should be avoided in LAST) • Succinylcholine • Atropine • Ephedrine vs. Phenylephrine • Glycopyrrolate • 20% Intralipid (ideally, together with LAST protocol for use and necessary equipment to draw up the medication)

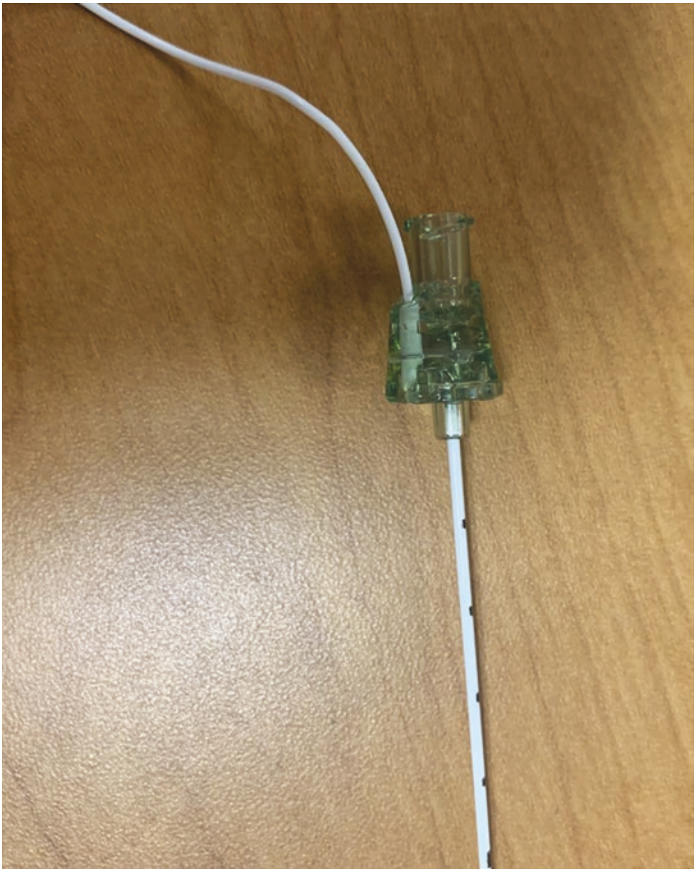

Fig. 1 18-gauge insulated CPNB needle with stimulation wire

tion, sterile drape, skin adhesive (i.e., Dermabond), transparent dressing, sterile ultrasound transducer covers, and sterile ultrasound gel (see Fig. 2).

Key Question 3

The medical student states that he has never seen a PNB performed before, and asks how the ultrasound machine is able to produce accurate and clinically useful images.

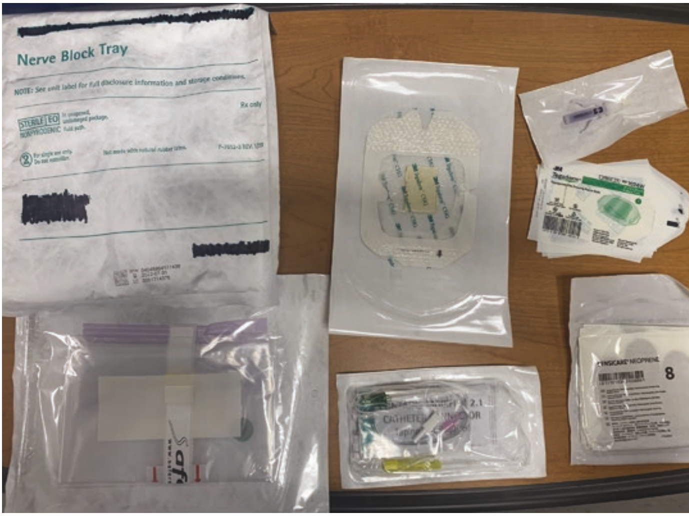

Fig. 2 CPNB supplies: (Upper left counterclockwise) PNB tray (sterile drape, syringes, etc.…), chloroprep impregnated tegaderm, dermabond sealant, small tegaderm, sterile gloves, CPNB needle kit with catheter, sterile ultrasound cover

UG is used in conjunction with anatomic landmarks to locate targeted nerves. Ultrasound imaging enables direct visualization of:

- Needle and its relation to muscles, bones, blood vessels, and other nerves
- LA distribution during and after injection.

Ultrasound waves are a type of acoustic energy that are generated when piezoelectric crystals within an ultrasound transducer vibrate at high frequency in response to an alternating current. When placed in contact with skin via a conductive gel, the transducer transmits the rapid vibrations that then propagate sound waves longitudinally into the body, reflect off tissue interfaces, and back to the receiver part of the same transducer. When ultrasound waves return to the transducer, the piezoelectric crystals will vibrate again, thereby transforming acoustic energy into electrical energy and generating a clinically useful ultrasound image [11].

When passing through any given medium, an ultrasound wave is subject to several interactions at tissue interfaces including reflection, refraction, and attenuation [11]:

- Reflection: Acoustic impedance (resistance to passing of ultrasound waves) between the two media account for degree of reflection
- Refraction: sound waves change direction with different acoustic velocities
- Attenuation: acoustic energy is progressively lost as sound waves travel deeper into tissue. Attenuation can degrade image quality to the point where performing a nerve block would be impractical, or even unsafe
- Certain functions the ultrasound machine, such as increasing gain, can artificially increasing the signal intensity from a specific or all points in the field.
- Resolution is the ability to distinguish between two separate objects

Case Stem Shortly before you begin the block, you discover that the ultrasound machine is not functional and so you opt to perform the interscalene nerve catheter using peripheral nerve stimulation.

Key Question 4: What Is Peripheral Nerve Stimulation (PNS) and How Does It Assist in Nerve Localization?
PNS is a nerve localization technique that uses an insulated block needle to deliver low-intensity (up to 5 mA), short-duration (0.05–1 ms) electrical stimuli to elicit predefined responses (i.e., twitch in a specific muscle or muscle groups vs. sensory responses in the form of paresthesias within certain dermatomes) in order to locate a target nerve/plexus prior to injecting local anesthetic [12]. The overall goal of this technique is to approximate the needle (and thus, LA delivery) and nerve as much as possible without

violating essential neural structures (such as intraneural fascicles). Both needle trauma and LA toxicity caused by intraneural injections could potentially be associated with transient and/or permanent nerve damage. Successful use of PNS is dependent on a strong foundational knowledge in anatomy and a comprehensive understanding of electrophysiology.

PNS incorporates several different principles of electrophysiology. Stimulation of nerve fibers occurs when a delivered charge to a nerve result in a change in transmembrane voltage (i.e., difference between intracellular and extracellular voltage) that is greater than the threshold to generate an action potential or series of action potentials along the nerve fiber. The peripheral nervous system consists of various types of nerve fibers, each of which can be distinguished by its diameter, as well as by its degree of myelination. In general, the speed of impulse propagation of action potentials is greater/threshold of excitability is lower in myelinated, large-diameter fibers (i.e., Aα motor fibers), whereas the speed of impulse propagation of action potentials is lower/threshold of excitability is higher in non-myelinated, small-diameter fibers (i.e., C fibers) [13].

When operating the nerve stimulator, the starting amplitude/current that is used depends on the projected depth of the target nerve. An initial amplitude of 1 mA is appropriate for superficial nerves (i.e., upper extremity nerves), whereas amplitudes of 1.5–3.0 mA may be required for deeper nerves (i.e., paravertebral or lower extremity nerves). After the intended muscle response is observed, current is gradually decreased while simultaneously advancing the block needle until the observed motor response is elicited with a current of 0.2–0.5 mA at 0.1 ms stimulus duration. At this point, 1–2 mL of local anesthetic is injected as a test dose to observe for timely termination of the muscle twitch, followed by injection of the remaining volume of local anesthetic [13].

Case Stem As you begin positioning the patient to perform the block, the surgeon pulls you aside and quietly requests something “long acting” for the patient because he anticipates that the procedure may take slightly longer than usual and that the patient may be in a significant amount of pain.

Key Question 5: What Factors Are Involved When Choosing LA to Administer for Any Peripheral Nerve Block?
When performing regional anesthesia, the anesthesiologist must decide on not only the specific LA agent to be used, but also the volume, concentration, and dose to be administered. These decisions are generally based on the desired outcomes of block onset, duration, density and degree of motor blockade, and adverse effects. In turn, the desired characteristics of specific LA agents is dependent on clinical circumstances. For example, motor blockade is beneficial when a peripheral nerve bock serves as a sole surgical anesthetic or when prolonged postoperative analgesia is needed. However, motor blockade would be unattractive when a patient is expected to participate in PT in the early postoperative period or if adequate neurological exam/sensory assessment recovery is immediately following the conclusion of surgery [14].

- Onset dependent on proximity to nerve (likely most important factor). Other factors include total LA dose (not LA volume or concentration), as well as the hydrophobicity of specific LA used [14].
- Potency dependent on lipophilicity of LA, which facilitates LA penetration through the axon [14].
- Duration of action influenced primarily by rate of clearance of LA. Other factors include hydrophobicity (hydrophobic LA have longer duration) and the total LA dose (larger LA doses produce longer blocks) [14].
- General guidelines for maximum LA doses are shown in Table 4 [14].

Case Stem With US not functioning, you decided it would be safer to place a US-ISB SSPNB using the nerve stimulator with 30 mL of 0.5% Ropivacaine and a 22-gauge insulated block needle. As you are manipulating the block needle, the patient

Table 4 Local anesthetic properties [14]

Anesthetic	Onset (minutes)	Duration of Action (hours)	Maximum Dose Without Epi (mg/kg)	Maximum Dose with Epi (mg/kg)
2% lidocaine	10–20	2–8	4.5	7
1.5% mepivacaine	10–20	2–10	5	7
0.2% ropivacaine	15–30	5–15	3	3.5
0.5% ropivacaine	15–30	4–24	3	3.5
0.25% bupivacaine	15–30	5–25	2.5	3
0.5% bupivacaine	15–30	5–30	2.5	3

suddenly complains of shooting pain down his arm. You immediately reposition the needle until the intended muscle response is elicited with a current of 0.3 mA. You confirm that the patient's paresthesias have subsided, and inject the LA. Following block placement, TSA is completed by the surgeon without event, and you transfer the patient to the recovery room. During your routine postoperative phone call with the patient the following day, he endorses slightly decreased sensation in the extremity.

Key Question 6: What Are the Complications Associated with Peripheral Nerve Blocks?

Fortunately, serious complications of PNBs are exceedingly rare when proper techniques and equipment are utilized; however, when they do occur, these complications can be potentially devastating for both patient and provider. Therefore, it is imperative that patients be presented with the necessary information to fully comprehend the risks associated with peripheral nerve blocks and to participate in informed decision making. Serious complications of PNBs that should be discussed prior to procedure include bleeding, catheter infection, nerve injury, and LAST.

- Inadvertent puncture of neighboring vascular structures during PNB can result in perineural hematoma formation. Hematomas can cause compression of nerves and lead to neurologic sequelae.
- Bleeding in non-compressible areas (especially with deeper blocks) can rarely occur, sometimes requiring surgical decompression. As such, it is often wise to avoid performing peripheral nerve blocks in non-compressible areas for patients with abnormal coagulation profiles. Anticoagulation guidelines for PNBs do exist but extend beyond the scope of this discussion.
- Infection risk for SS PNBs is minimal whereas bacterial colonization of CPNB is higher-ranging between 7.5 and 57%. Nevertheless, colonization rarely leads to systemic infection, with overall risk of infection ranging between 0 and 3.2% [15]. Femoral and axillary nerve catheters are associated with the highest rates of colonization, while rates of colonization of popliteal catheters are low [15]. Other independent risk factors for PNC infection include intensive care unit (ICU) admission, trauma, immunocompromised states (i.e., diabetes), indwelling catheters for >48h, male sex, and the absence of antibiotics.
- Nerve injury:
  - Rare occurrence with exact incidence that remains controversial and highly variable across studies.
  - Persistent symptoms of nerve injury (i.e., pain, tingling, or paresthesia) can be as high as 8–10% in the days following the block [16].
  - Majority of symptoms are transient (days to less than 6 months). Permanent symptoms range between 0.015 and 0.09% [17].
  - Historically associated with intraneural injection but controversial evidence
- LAST:
  - Can be caused by inadvertent injection of LA into blood vessels or delayed uptake of LA by small veins (via indwelling CPNBs or catheter migration, for example) [18].

- Highly variable clinical presentation:
  Mild: tinnitus, perioral numbness, metallic taste
  Severe: Seizure, coma, respiratory depression, and cardiovascular collapse (i.e. hypertension vs. hypotension, tachycardia vs. bradycardia, arrhythmias, and arrest).
- Guidelines for prevention and treatment of LAST will be discussed in later chapters.

1 Summary

- PNB may be performed as SS PNB or infusion of LA via perineural catheters (CPNB)
- CPNBs allows prolonged analgesia and have been successfully used in numerous settings
- Emergency drugs and resuscitation equipment should always be readily available when administering any regional anesthetic in the event of acute complications
- Peripheral nerve localization techniques include direct visualization via ultrasound guidance and/or electrical nerve stimulation to observe for motor responses
- Thorough understanding of ultrasound physics and technique is necessary to prevent serious adverse effects, such as hemorrhagic/infectious complications and LAST.

Common Pitfalls

- Failure to adequately explain the indications/risks/benefits/alternatives of PNB may limit patients' ability to make informed decisions.
- Failure to follow-up with ambulatory patients discharged with CPNBs may cause delays in diagnosis/treatment of complications.
- Failure to consider all perioperative circumstances when selecting LA for a given procedure may lead to block failure or other unexpected complications.

Clinical Pearls

- Although the use of ultrasound has significantly reduced the risk of complications, this risk has not been completely eliminated.
- Under the appropriate clinical circumstances, CPNBs can be an effective way to extend analgesia, facilitate earlier and dynamic PT, and reduce overall hospital costs.
- When utilizing ultrasound guidance, it is imperative to select the appropriate transducer and settings for a given procedure.
- While peripheral nerve stimulation can be an alternative to ultrasound for nerve-localization, it can also be used to confirm ultrasound findings.

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