Antidepressants have also been evaluated for efficacy in the treatment of acute postoperative pain, but there is currently insufficient evidence to recommend their use in this setting [2].

2. List additional non-opiate parenteral analgesic medications that can be used intraoperatively to help with pain control and decrease opioid requirements.

Parenteral non-opiate analgesic adjuvants include ketamine, alpha-2 agonists (clonidine and dexmedetomidine), and dexamethasone. Acetaminophen and ketorolac can also be administered intravenously. Other proposed parenteral analgesic adjuvants include magnesium and low-dose naloxone, but evidence of their efficacy is scant (Table 1.1) [3–4].

3. For each of the above medications, describe their mechanism of action and the evidence for their utility.

Acetaminophen
- **Mechanism:** The precise mechanism of action of acetaminophen is unclear. It is believed to act primarily via inhibition of cyclooxygenase 1 and 2 (COX-1 and COX-2) enzymes in the central nervous system [5].
- **Efficacy:** Acetaminophen has a modest opioid-sparing effect. Several systematic reviews and meta-analyses have been conducted to evaluate...
Section 1: General considerations in regional anesthesia

Table 1.1 A review of non-opiate analgesics.

<table>
<thead>
<tr>
<th>Drug</th>
<th>Mechanism</th>
<th>Opioid-sparing effect</th>
<th>Adverse effects</th>
<th>Dosing guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetaminophen</td>
<td>Possibly COX-1 and COX-2 inhibition in the CNS</td>
<td>20–30% opioid-sparing effect</td>
<td>Liver damage at high doses</td>
<td>Max 3 g/24 h (in divided doses)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No decreased incidence of opioid-related adverse events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-selective NSAIDs</td>
<td>COX-1 and COX-2 inhibition</td>
<td>30–50% opioid-sparing effect</td>
<td>GI effects, bone healing, hypersensitivity reactions, asthma exacerbations, renal insufficiency, bleeding</td>
<td>Individualized per each NSAID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased PONV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coxibs</td>
<td>Selective COX-2 inhibition</td>
<td>Equivalent to non-selective NSAIDs</td>
<td>Increased incidence of thrombus/stroke/MI</td>
<td>Celecoxib 200 mg PO BID</td>
</tr>
<tr>
<td>Gabapentin</td>
<td>Binds to voltage-sensitive calcium channels</td>
<td>20–62% opioid-sparing effect</td>
<td>Somnolence, dizziness, headache, balance problems, peripheral edema, sweating, dry mouth, nausea and vomiting</td>
<td>No clear optimal dose. Studies have used 300–1,200 mg PO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased vomiting, pruritis, and urinary retention</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pregabalin</td>
<td>Binds to voltage-sensitive calcium channels</td>
<td>25–30% opioid-sparing effect</td>
<td>Same as above (somnolence, dizziness, visual disturbances most common)</td>
<td>No clear optimal dose. Studies have used 50–750 mg/day (individual doses of 50–310 mg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased PONV and pruritis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ketamine</td>
<td>NMDA receptor antagonist</td>
<td>30–50% opioid-sparing effects</td>
<td>Dysphoria, hallucinations, vivid unpleasant dreams, psychoses, dizziness, nausea/vomiting, blurred vision (all unlikely at low doses)</td>
<td>No clear optimal dose. Subanesthetic dose is &lt;1 mg/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unclear if decreased opioid-related adverse effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clonidine</td>
<td>Centrally acting alpha-2 agonist</td>
<td>25% opioid-sparing effect</td>
<td>Intra- and postoperative hypotension</td>
<td>No clear optimal dose. Studies have used 2–5 µg/kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased nausea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dexmedetomidine</td>
<td>Centrally acting alpha-2 agonist</td>
<td>30% opioid-sparing effect</td>
<td>Intra- and postoperative bradycardia</td>
<td>1 µg/kg bolus followed by 0.5–1µg/kg/h infusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased nausea and pruritis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dexamethasone</td>
<td>Glucocorticoid</td>
<td>10% opioid-sparing effect</td>
<td>Mild hyperglycemia</td>
<td>No clear optimal dose. Usually given 4–8 mg IV × 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decreased PONV</td>
<td>Impaired wound healing and increased infection unlikely with single dose</td>
<td></td>
</tr>
</tbody>
</table>

Coxibs: COX-2 selective NSAIDs; CNS: central nervous system; GI: gastrointestinal; MI: myocardial infarction; PONV: postoperative nausea and vomiting.

the analgesic efficacy of acetaminophen in the treatment of acute postoperative pain [6–9]. Remy et al. found a 20% reduction in morphine consumption [6]. McNicol et al. found the number needed to treat (NNT) for at least 50% pain relief was 4.0 (95% CI 3.5, 4.8) [7]. Despite opioid-sparing effects, a decrease in opioid-related adverse events has not been found in subjects receiving acetaminophen as part of a multimodal analgesic approach [6–8, 10].

- **Adverse effects:** Acetaminophen is generally well tolerated, with infrequent side effects. Liver damage is possible when acetaminophen is administered at high doses.

- **Dosing guidelines:** Acetaminophen may be delivered orally, rectally, or intravenously. Intravenous and oral acetaminophen have similar efficacy and dosing guidelines. The maximum daily recommended dose in the United States is 3 g/24 h in divided doses. Typical dosing is 1,000 mg every 8 h or 650 mg every 6 h. A meta-analysis examining the efficacy of oral acetaminophen found that there was no clear dose–response relationship and that lower doses were equally efficacious [9].
Non-selective NSAIDs

- **Mechanism:** NSAIDs work via inhibition of COX-1 and COX-2. This inhibition results in decreased production of prostaglandins and thromboxanes, accounting for the analgesic, antipyretic, and anti-inflammatory effects of this drug class.
- **Efficacy:** NSAIDs provide a 30 to 50% morphine-sparing effect and improved analgesia when co-administered with a morphine PCA compared with using a PCA alone [11–12]. For multiple-dose regimens, 24-hour morphine consumption is significantly reduced when NSAIDs are administered, with an opioid-sparing effect of 19.7 mg morphine per 24 h [8]. Unlike acetaminophen, NSAIDs are associated with decreased opioid-related side effects [8, 12]. This includes a 30% decrease in morphine PCA-related PONV and a 29% decrease in sedation [12].
- **Adverse effects:** Non-selective NSAIDs have several potential adverse effects. These include gastritis, renal dysfunction, asthma exacerbation, and hypersensitivity reactions. Their effect on bone healing is controversial. NSAIDs affect platelet function and can increase surgical bleeding. One study noted 2.4% of subjects receiving an NSAID experienced surgical-related bleeding compared with 0.4% of those receiving placebo [8].
- **Dosing guidelines:** Each oral and intravenous NSAID available for clinical use has its own dosing recommendations.

COX-2 selective NSAIDs (coxibs)

- **Mechanism:** Coxibs are selective inhibitors of COX-2.
- **Efficacy:** The analgesic efficacy of selective COX-2 inhibitors is similar to that of non-selective NSAIDs [10]. In one study, the opioid-sparing effect of monotherapy with COX-2 inhibitors was approximately 10.9 mg morphine per 24 h [8]. However, this was not associated with a decrease in opioid-related adverse effects [12].
- **Adverse effects:** The selective nature of COX-2 inhibitors makes them less likely than non-selective NSAIDs to cause gastritis and bleeding complications related to platelet dysfunction [5]. The major concern surrounding coxibs is the increased risk of vascular thrombus, causing increased incidence of myocardial infarction (MI) and stroke.
- **Dosing guidelines:** Celecoxib is typically administered 100 to 200 mg orally, twice daily, for the treatment of acute postoperative pain.

Gabapentin

- **Mechanism:** Gabapentin binds to the presynaptic voltage-sensitive calcium channels of cortical and dorsal horn neurons, inhibiting calcium influx and subsequently attenuating the release of excitatory neurotransmitters [13–14].
- **Efficacy:** Multiple systematic reviews and meta-analyses have confirmed the significant analgesic efficacy and opioid-sparing effects of gabapentin in the perioperative setting [13, 15–17]. Purported opioid-sparing effects have ranged from 13 to 32 mg morphine per 24 h for various dosing regimens [10]. The opioid-sparing effect ranges from 20 to 62% for a single preoperative dose of gabapentin 300 to 1,200 mg administered 1 to 2 h prior to surgery [13]. A reduction in opioid-related adverse events, such as nausea and pruritis, has been noted in the first 24 hours postoperatively [15].
- **Adverse effects:** Overall gabapentinoids are well tolerated. The most common adverse effects include somnolence, dizziness, headache, balance problems, peripheral edema, sweating, dry mouth, nausea and vomiting [3]. For gabapentin (1,200 mg) to cause excessive sedation, the number needed to harm (NNH) was 35, and for dizziness, the NNH was 12 [13].
- **Dosing guidelines:** Trials examining the postoperative analgesic efficacy of gabapentin have used multiple dosing regimens, with doses ranging from 300 to 1200 mg PO [13, 15–16]. Tiippana and colleagues found that the reduction in opioid consumption was not dependent on the dose of gabapentin [13]. Currently no evidence-based data exists to establish the optimal dose, timing, or duration of treatment.

Pregabalin

- **Mechanism:** Pregabalin is similar in structure to its precursor, gabapentin, and works via the same mechanism.
- **Efficacy:** Like gabapentin, pregabalin is an effective non-opioid analgesic, reducing pain and
Section 1: General considerations in regional anesthesia

opioid consumption in the acute postoperative period. One meta-analysis of 18 studies found a reduction in pain and a 30.8% overall decrease in postoperative analgesic requirements [18]. The most recent meta-analysis, published by Mishriky and colleagues, found an overall opioid-sparing effect of 25% at 24 hours postoperatively [19]. They also noted a reduction in the opioid-related side effects of PONV (38% reduction relative to placebo at 24 hours postoperatively) and pruritis (51% reduction) [19].

- **Adverse effects**: Pregabalin has the same potential adverse effects as gabapentin. Zhang and colleagues found a higher incidence of visual disturbances in subjects taking pregabalin [20]. Tiippana and colleagues noted an NNH to produce excessive sedation was 35 and to produce dizziness was 12 [13].

- **Dosing guidelines**: Studies have evaluated doses from 50 to 750 mg/day using single- and multiple-dose regimens [18–20]. In subgroup analysis Mishriky et al. found no statistically significant difference in opioid sparing at 24 hours between a single preoperative dose vs. multiple doses and no difference in opioid sparing at 24 hours between a single preoperative dose vs. multiple doses and no difference in opioid-sparing effect for clonidine and dexmedetomidine found an NNH to 21/37 trials showed an absence of psychomimetic effects and concluded that ketamine-related adverse effects were mild or absent [21].

- **Dosing guidelines**: Ketamine has been administered by several possible routes, including intravenous, subcutaneous, epidural, transdermal, and intra-articular [21]. The optimal dose of ketamine used for acute postoperative pain has not been determined. The analgesic effect of ketamine is independent of timing of administration (pre- or post-incision) or dose [22].

**Clonidine and dexmedetomidine**

- **Mechanism**: Clonidine is a partial alpha-2 adrenergic receptor agonist, with an α-2α-1 receptor selectivity of 39:1. Dexmedetomidine is eight times more specific for the α-2 receptor than clonidine. Stimulation of α-2 receptors in the CNS and spinal cord give these drugs their antinociceptive effects [24].

- **Efficacy**: Clonidine and dexmedetomidine have both been shown to have analgesic effects in the perioperative setting. A meta-analysis reviewing clonidine and dexmedetomidine found an approximately 25% decrease in cumulative morphine equivalents for clonidine and approximately a 30% decrease for dexmedetomidine [24]. Administration of clonidine or dexmedetomidine decreases the incidence of nausea [24]. Additionally, dexmedetomidine decreases the incidence of pruritis [25].

- **Adverse effects**: The most important possible adverse effect seen with clonidine administration is hypotension. An increased risk of intraoperative and postoperative hypotension in patients treated...
Dexamethasone

- **Mechanism:** Dexamethasone is a glucocorticoid. It has immunomodulatory effects that may contribute to decreased pain caused by inflammation [3].

- **Efficacy:** Two recent meta-analyses have shown that glucocorticoids reduce postoperative pain and the need for supplemental opioids [26–27]. Intermediate doses of dexamethasone (0.11 to 0.2 mg/kg) reduce pain both at rest and during mobilization [26]. One meta-analysis noted a 10% reduction in opioid consumption with a single intravenous perioperative dose of dexamethasone (2.33 mg morphine per 24 h) [27].

- **Adverse effects:** Many potential complications have been associated with prolonged or high-dose glucocorticoid use. However, meta-analyses suggest that a single perioperative dose of dexamethasone should not cause concern for wound healing or infection [26–27]. Mild hyperglycemia may be a side effect even with low-dose dexamethasone [27].

- **Dosing guidelines:** Dosing regimens in studies on dexamethasone have been variable. De Oliveira et al. evaluated doses of dexamethasone ranging from 0.11 to 0.2 mg/kg and found that doses >0.1 mg/kg, but not doses less than that, impacted analgesia [26]. In contrast, Waldron et al. evaluated doses between 1.25 and 20 mg and did not find a dose-dependent opioid-sparing effect [27]. Most individual studies have used a dose of 8 mg or less [10].

4. Discuss which medications, oral and parenteral, act alone and which act synergistically

Most studies and subsequently most systemic reviews compare a single non-opioid analgesic administered with an opioid with a placebo administered with an opioid. There is a paucity of literature evaluating the synergistic or additive effects of multiple non-narcotic analgesics used concomitantly. However, meta-analyses have examined the use of acetaminophen and NSAIDs together or alone [28–29]. The use of acetaminophen with an NSAID is superior to the administration of either drug alone, with regards to both pain scores and opioid-sparing effect [29]. With this exception, the evidence for the use of different multimodal combinations is limited.

References


Section 1: General considerations in regional anesthesia


A 62-year-old female presents for an open reduction and external fixation of a radius fracture. The surgeon is requesting that the procedure be performed with a peripheral nerve block. The hospital currently has both an ultrasound (US) machine and a nerve stimulator available for use.

Peripheral nerve stimulators are used to locate peripheral nerves. The physiological principle of peripheral nerve stimulation (PNS) is that the closer the needle tip to the nerve, the lower the current needed to stimulate a muscle contraction [1]. The peripheral nerve stimulator is battery powered, and configured so that current flows from the anode to the cathode, reducing the ionic gradient across the cell membrane [2]. Once an electrical threshold is reached, an action potential is generated. For clinical use, the EKG skin electrode is the grounded positive anode (colored red) and the tip of the needle is chosen as the negative cathode (colored black). Reversal of anode and cathode positions inhibits nerve depolarization because the intraneural electrical potential becomes more negative and resistant to firing. The skin electrode position does not influence block performance.

Nerve depolarization depends on the amount of electrical charge delivered to the nerve. Electrical charge is the product of the current (milliamps) and the duration of the square wave electrical impulse (milliseconds). Thus, for a given electrical charge, the greater the duration of impulse, the less current required to stimulate the nerve and vice versa. Rheobase is the threshold intensity at longest pulse duration that stimulates nerves. Comparison of firing threshold between different nerve modalities uses a term called chronaxie – the duration of stimulus required to stimulate the nerve at twice the rheobase.

Difference in chronaxie between sensory and motor nerves is clinically advantageous. For example, Aα motor fibers have a smaller chronaxie (50–100 μs compared to Aδ delta (150 μs), or unmyelinated
Section 1: General considerations in regional anesthesia

C fibers (400 μs). Thus twitching of muscles in response to nerve stimulation can be achieved without pain.

A typical peripheral nerve stimulator should generate a constant current output by varying voltage in order to accommodate 10- to 20-fold changes in tissue resistance. A short pulse width (50 μs or 100 μs pulse) is used, corresponding to the chronaxie of Aα fibers in peripheral nerves.

Block needles have an insulated shaft, allowing current to flow from the tip. When the block needle tip is positioned on the skin, a circuit is completed with the stimulator and a flashing LED confirms a circuit has been achieved.

The current needed to stimulate a peripheral nerve is dependent on the distance between the needle tip and target nerve. Thus, by keeping the pulse duration fixed, less charge is needed the closer the tip is to the nerve.

The PNS current is set (1.0–1.5 mA) before needle insertion. The needle is advanced until a desired motor response is obtained and the current is reduced until muscle contractions disappear. An electrical current <0.5 mA is commonly considered an acceptable endpoint. If the motor response disappears above this stimulus, the current should be increased and the needle reoriented to obtain a stronger muscle contraction followed by a gradual current reduction to <0.5 mA. If a motor response is present at 0.2 mA, the tip of the needle may be within the nerve and should be withdrawn. It is classically thought that an injection should occur at a threshold current 0.4 to 0.5 mA. Motor twitches typically disappear after injection of 1 ml of local anesthetic.

2. List advantages and limitations to nerve stimulation

Advantages

The principal advantage of PNS is that it can identify peripheral nerves by eliciting an appropriate motor response. The machine is portable and relatively inexpensive.

Limitations

Peripheral nerve stimulation techniques are limited by anatomical and technical factors.

Anatomical

A detailed knowledge of surface, nerve, and muscle anatomy is required to position and direct block needles, interpret muscle contractions in response to electrical stimulation, and reposition needles based on a given response.

Technical

Poor EKG skin electrode (anode) application may increase voltage output and electrical impedance changes according to tissue type. Increased charge or frequency is often needed to stimulate nerves in patients with peripheral neuropathy and diabetes.

Accuracy

The accuracy of PNS has been investigated at three regions of interest: extraneural, surface of epineurium, and intraneural. Peripheral nerve stimulation accuracy was investigated by Perlas et al. [3]. Utilizing US, needle tips were placed close to but not touching epineurium and PNS observed. Despite close nerve proximity, muscle stimulation was not observed in 25% of cases with an electrical stimulation <0.5 mA. The authors concluded that sensitivity of nerve stimulation was 0.75, but that the proportion of false negatives was 0.25. From a clinical perspective, this means that in one quarter of cases when a needle tip is positioned correctly, a muscle contraction is not possible using electrical currents between 0.2 mA and 0.5 mA.

Interestingly, in the same study [3], the sensitivity of the paresthesia technique was 0.38, suggesting that peripheral nerve simulation was clearly a more accurate technique than paresthesia. Based on this result and similar findings by Urmey and Stanton [1], paresthesia should not be used for nerve localization (Table 2.1).

The accuracy of nerve stimulation in differentiating between intraneural and extraneural injection has also been investigated in animal and human studies. Experimental designs have examined electrical current thresholds at needle to epineurium contact and neural penetration. Figure 2.1, derived from Tsai et al. [4], shows a range of measurements associated with thresholds obtained 1 mm away from the nerve, on the epineurium, and within the nerve in a porcine model. The data distribution of electrical thresholds is non-parametric, and the ranges of values from each modality overlap. The reduced number of measurements obtained 1 mm from the nerve is indicative of a false-negative rate of approximately 0.25, as seen in clinical studies. Interestingly, little difference was observed in the threshold profile from needle tips touching or penetrating the epineurium. Although nerve stimulation <0.2 mA was associated only with
Chapter 2: Nerve localization techniques

3. Discuss the use of ultrasound for nerve localization

Ultrasound probes used for regional anesthetic blocks are no different from probes used for radiological diagnosis. Probes have a linear array of US elements placed in a straight or curvilinear line, allowing a cross-sectional or short-axis view of the peripheral nerve. Long-axis or longitudinal views are difficult to interpret although are useful when visualizing blood flow using color Doppler. Needles are often inserted in the plane parallel to the linear array of the US probe, in order to optimize needle and tip visibility.

4. Analyze the benefits and drawbacks to ultrasound guidance

Benefits

The primary benefit of US guidance is the ability to see the nerve, needle, and local anesthetic spread, and to recognize anatomic variations. A recent meta-analysis identified 49 comparisons of US guidance with PNS: more patients whose blocks were performed with US (94%) did not require rescue or general anesthesia compared with those with PNS (85%) [7]. Moreover, US was associated with shorter procedural times; fewer needle insertions; fewer paresthesias; shorter sensory and motor block onset; longer block duration; and eight-fold less vascular punctures. However, the incidence of transient neuropraxia remains unchanged.

Drawbacks

The drawbacks of US guidance are primarily economic; however, good-quality US systems are available for $30,000 to 50,000. Concerns have been raised regarding the potentially harmful effects on human tissue and nerves of the cumulative US energy administered, but no evidence exists.

Table 2.1  Sensitivity of needle tip placement using paresthesia, peripheral nerve stimulation, and ultrasound. The study of Perlas et al. measured the sensitivity of paresthesia and nerve stimulation when the needle tip was placed close to the nerve. Other studies measured the sensitivity of intraneural/extraneural needle tip placement.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Sensitivity</th>
<th>β</th>
<th>Model</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paresthesia</td>
<td>0.30</td>
<td>0.70</td>
<td>Clinical</td>
<td>Urmey and Stanton, 2002 [1]</td>
</tr>
<tr>
<td>Peripheral nerve stimulation</td>
<td>0.38</td>
<td>0.62</td>
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<td></td>
<td>0.70</td>
<td>0.30</td>
<td>Pig</td>
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<td></td>
<td>0.75</td>
<td>0.25</td>
<td>Clinical</td>
<td>Perlas et al., 2006 [3]</td>
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<tr>
<td></td>
<td>0.58</td>
<td>0.42</td>
<td>Clinical</td>
<td>Sinha et al., 2007 [29]</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>0.83</td>
<td>0.17</td>
<td>Clinical</td>
<td>Liu et al., 2011 [10]</td>
</tr>
<tr>
<td></td>
<td>0.84</td>
<td>0.16</td>
<td>Clinical</td>
<td>Hara et al., 2012 [11]</td>
</tr>
</tbody>
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Figure 2.1  Derived from results of Tsai et al. [4]. Median (range) current threshold at three needle tip positions, 1 mm from epineurium, contact with epineurium, and penetrated through epineurium intraneural. Of note 25% of needles within 1 mm of epineurium did not generate a muscle contraction; no difference existed between electrical thresholds either contacting or penetrating epineurium, and a threshold stimulating current >0.5 mA did not exclude intraneural needle placement.

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5. Discuss benefits and drawbacks to combining nerve stimulation with ultrasound guidance

The combined use of US and PNS may be beneficial when the target nerves or the needle tip are difficult to visualize. A recent meta-analysis revealed that combining US and PNS was more efficacious than PNS alone but not US alone [7]. Utilization of two modalities ideally should improve the accuracy of nerve identification and needle positioning. However, the corollary is that any improvement in efficacy may be negated by increased number of needle passes, procedural time, and patient discomfort.

6. Present the evidence about the incidence and complications secondary to intraneural injections with both peripheral nerve block methods

Intraneural injection is associated with nerve expansion and a reduction in nerve echogenicity when using US [8–9]. Two studies retrospectively analyzed nerve block videos and showed that novices inadvertently injected into nerves on approximately one out of six occasions [10–11]. Curiously, despite this, the incidence of permanent nerve damage has been reported to be 2 to 4 per 10,000 nerve blocks [12], albeit reports of transient neuropraxia are >100-fold more common [13–14]. Proposed mechanisms include: needle trauma [15], intraneural injection of local anesthetics [16–17], and high injection pressures [18–19].

Despite the frequency of intraneural injection, the most common sequela is a transient neurologic disturbance, not permanent damage. Prospective clinical studies purposefully injecting local anesthetic into nerves have failed to demonstrate evidence of nerve damage [20–21]. One hypothesis is that subperineural injection (into fascicles) rather than subpialneural injection is responsible for nerve damage and that needles tend to deflect fascicles rather than enter their substance.

7. Describe the development of new needle-guidance systems to complement ultrasound imaging

New technological developments include electromagnetic guidance systems, injection pressure monitoring, and optical needles.

Needle-guidance system

Biopsy technology, particularly to detect breast and prostate cancer, has driven the development of accurate needle-guidance systems. An electromagnetic needle-guidance system (Sonix GPS, Ultrasonix, Vancouver, Canada) has been adapted for regional anesthesia and consists of a transmitter with sensors at the needle tip and in the transducer allowing real-time tracking in three dimensions [22]. Before the block, the sensor needle is held on the skin, aiming for the target and a trajectory plotted on the screen. Needle tracking is guided by orientation bars and a schematic diagram of needle probe alignment. The principal advantages of this system are: (1) optimal needle orientation is decided before insertion, potentially reducing the number of needle passes, and (2) the needle tip is seen irrespective of plane or angle. Utilization is possible with linear and curvilinear transducers and one study has reported successful performance of spinal anesthesia using electromagnetic guidance [22].

Injection pressure

Animal and cadaver studies indicate that intraneural injection is associated with higher injection pressures compared to extra-fascicular injection [23]. Although peak injection pressure varies according to nerve size, fascicular density, needle size, injection rate, injection volume, and species, current recommendations suggest keeping pressure below 15 psi to lower the risk of fascicular injection. However, needle–nerve contact may increase needle-tip pressure and increase the proportion of false-positive results.

Optical needles

Knowledge of real-time tissue properties during needle movement could potentially improve the accuracy of regional anesthesia. The optical characteristics of tissues, measured using spectroscopy, have been investigated as a means of differentiating between different tissues and may indicate the position of the needle tip. Integrated optical fibers transmit light from the tip of the needle or introducer, and spectroscopic analysis of reflected light estimates the scattering coefficient and the absorption coefficient of tissue. Each tissue has a characteristic narrow absorption peak.

Experiments conducted in pigs have identified the ligamentum flavum and epidural space and transitions from muscle to nerve in the axillary region [24–25]. Proximity to peripheral nerves was associated with higher lipid and lower hemoglobin values in pigs [26].