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Nerve Injury After Peripheral Nerve Blockade: Best Practices and Medical-Legal Protection Strategies

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Stem Case and Key Questions Content

A 23 year old fit female triathlete presents for arthroscopic repair of a torn labrum and partial tear of her rotator cuff. She has experienced several episodes of shoulder dislocations beginning at age 16, and despite aggressive physical therapy and medical management, she finds that her shoulder instability is interfering with her training regimen and threatens her life-long dream to qualify for the Ironman Triathlon in Hawaii. She has no other medical issues, no known allergies, and has been taking p.r.n. over the counter non-steroidal medications. She is 5'5 tall, weighs 128 lbs, and is a graduate student at a nearby university.

1. What constitutes informed consent, and how would you document this?
2. What are the risks associated with peripheral nerve blocks?
3. Do you need separate anesthesia consent or is a surgical consent sufficient?

After a brief discussion about the anesthesia options, she tells you that she would like to have a peripheral nerve block, because it is her understanding that this is a painful procedure, and she is highly motivated to do anything that may improve her rehabilitation potential. She is scheduled for surgery in the beach chair position, the procedure is supposed to last 2 hours, and she is supposed to be discharged home this afternoon. Her surgeon has informed her that he may need to stage this procedure, with the labral repair today, and have her return 10 days later for the rotator cuff repair.

4. Is there any other history that you would like to know about her before you get started? What type of exam would you do before you perform your nerve block?

You are in the ambulatory center, the patient has been delayed and arrives late to the pre-operative holding area, so you decided to take her straight into the operating room and lightly sedate her with midazolam and fentanyl. There is no ultrasound machine available, but you are experienced using neurostimulation and decide to perform an interscalene block using conventional landmark techniques. You obtain a deltoid twitch after several needle passes, dial the stimulator current down to 0.53 mA, and sequentially inject a total volume of 30 mL of 0.25% bupivacaine with 1:200,000 epinephrine. She tolerates the procedure well and there is no evidence of paresthesia or pain on injection. General anesthesia is induced promptly with

propofol, endotracheal intubation is facilitated with vecuronium, and she is positioned in the beach chair position.

5. How would you document this block on your anesthesia record?
6. Can the block be performed using a smaller volume, or smaller total dose (mass) of local anesthetic?
7. Is it necessary to add epinephrine?
8. Is the minimum stimulating current a reliable indicator to avoid inadvertent intra-neural injection?
9. Are there any special precautions associated with the beach chair position?
10. Is there an increased risk of nerve injury with this position as compared to the lateral decubitus position?

The surgery proceeds uneventfully, but near the end of the labral repair there is significant swelling and difficulty visualizing the surgical field through the portals. The surgeon decides to abort the procedure and return in a week or so for the rotator cuff repair. The patient is awakened from general anesthesia and is taken to the recovery area, where she is observed to be comfortable, and is discharged home later on that afternoon.

8. Is there any other information about her recovery that you would like to know, or have documented?
9. How would you follow her up after discharge?

She returns to the ambulatory center 10 days later for her rotator cuff repair, and you are scheduled to take care of her again. She appears to be in no apparent distress and is looking forward to getting this over with, and getting on with her recovery.

10. Is there any other information or history that you would like to have prior to starting your block procedure?
11. Should you examine this patient again prior to initiating your block?

You have a discussion with the patient about the advantages of using a continuous catheter technique, and since you have plenty of time, you place the block in a designated part of your preoperative holding area. This time, you decide to use 30mL of 1.5% lidocaine with 1:200,000 epinephrine, and since you have an ultrasound machine available, you place the block and catheter (non-stimulating) under ultrasound guidance, and the procedure goes uneventfully. She is comfortably sedated and there were no paresthesias or pain associated with injection, and the patient appears comfortable.

12. How would you document the placement of a continuous plexus or nerve catheter?
13. Are there any commonly used local anesthetics or additives/adjuvants that can increase or decrease the risk of neurological injury after nerve block?
14. Can ultrasound-guided blocks reduce or eliminate the risk of block related transient or permanent nerve injury?

The patient is brought to the operating room, general anesthesia is induced with propofol and a LMA is inserted. She is positioned in the beach chair position, and general anesthesia is maintained under sevoflurane with spontaneous ventilation. The surgery proceeds uneventfully,

and at the end of the case, the LMA is removed and she is taken to the recovery area. While in the recovery area, she is comfortable, and an ambulatory elastomeric pump is attached to her interscalene catheter, and the reservoir is filled with ropivacaine 0.2%. She appears comfortable, and is sent home with discharge instructions pertaining to the pump and catheter.

15. What should these instructions entail?
16. How would you follow-up and document your patient contact while she is at home and until the catheter is removed?

The patient is seen in the surgeon's office by his physician assistant 5 days after surgery, and 2 days after the catheter was removed. She notes that her fingers are still numb. The PA calls the surgeon and your office is contacted.

17. What would you do? What further information would you like to have? Is a neurology consult appropriate at this time?

You call the patient but are unable to get in contact with her and leave a message. You do not hear back from her. When the patient returns to clinic 3 weeks later, she is noted on exam to have no sensation to pinprick in the ulnar nerve distribution of her hand, along with 1st interosseous muscle wasting, decreased hypothenar eminence prominence, and inability to abduct her fingers. She is referred to a neurologist for consultation and testing. Further review of her chart shows that immediately prior to her rotator cuff repair (second surgery), the pre-operative clinic nurse recorded a history of a shooting tingling sensation from her shoulder into her elbow.

18. What type of injury does she seem to have? Is this consistent with a brachial plexus injury?
19. Does it seem reasonable that the interscalene block or catheter is the cause of this injury?
20. Is there anything unique to arthroscopic shoulder surgery that puts a patient at risk for a nerve injury?
21. What type of forces can cause injury to nerve plexuses or peripheral nerves during surgery and anesthesia?
22. How is the severity of these lesions graded, and what is the outcome for their prognosis?
23. Can electrodiagnostic studies help make a diagnosis of injury location, cause, severity, and prognosis for recovery?

Her electrodiagnostic studies localize the lesion to her elbow and a diagnosis of ulnar nerve entrapment is made, and she is scheduled to have ulnar nerve transposition surgery to relieve her symptoms.

24. Would you offer her a regional anesthetic for this procedure? Does a regional anesthetic increase her risk for further injury?

She undergoes the nerve transposition procedure and several months later, with intensive physical therapy, recovers much of her function, but still has not improved to 100% baseline strength in her hand. She decides to file a lawsuit against the surgeon and you. During the deposition phase, new information is obtained that she had a previously undisclosed dislocation of that elbow.

25. Did negligence occur? If so, who was at fault? Is there anything that could have been done differently to prevent this outcome?

Model Discussion Content
Informed consent
Although we may be eager as anesthesiologists to tout the benefits of peripheral nerve blocks, many of us are not doing a very good job of disclosing the potentially catastrophic risks of these procedures to our patients. A 2007 survey of academic regional anesthesiologists indicated that most of them disclosed the minor risks of bruising, pain, and minor temporary neurologic symptoms such as paresthesias and dysesthesias, but almost 40% did not disclosure the risk of local anesthetic systemic toxicity (seizure and cardiac arrest) or long-term and disabling neurological injury.[1] At the same time, a recent international survey measuring patient satisfaction after peripheral nerve blockade affirmed that 90% of the respondents were satisfied or completely satisfied with the information provided about the nerve block, as well as the patient anesthesiologist interaction.[2] A shared decision making approach when approaching a patient for a peripheral nerve block procedure is a good idea, given the fact that the benefits of the block are short term in nature (pain, nausea, readiness to discharge), without accompanying long term benefits such as improved functional outcomes.

Informed consent for a procedure involves 4 separate aspects, including:
1. A state of voluntariness
2. Competency and capacity for decision making
3. Disclosure of information about the procedure and risks associated with that procedure
4. Authorization by the patient to undergo the procedure

This discussion should be documented in the medical record. There is a trend to have an anesthesia consent that is separate from the surgical consent (although this is not required by regulatory agencies), and recent publications question whether or not a patient who is competent to sign a surgical consent has the same competency and capability to understand an anesthesia consent.[3] My personal practice is to circle the words, “nerve injury,” on the consent form and initial it, to document that I specifically discussed this with the patient.

Lack of informed consent is a frequent allegation made by patients, but normally successfully defended. Unfortunately, poor expectation management can set the litigation process in motion, and root cause analysis frequently demonstrates that patients and their families did not know a bad outcome could occur, which led to negative emotions, triggering a desire to sue. Only 1% of the claims in the ASA Closed Claims project are based on informed consent issues.[4]

Risk of nerve injury
The risk of permanent or severe nerve injury after peripheral nerve block is extremely low, irrespective of its etiology (anesthesia related, surgery relation, patient related). In fact, it may be better to define this phenomenon as post-operative neurologic symptoms (PONS) or perioperative nerve injury (PNI) in order to help standardize terminology. Several large prospective observational studies indicate an incidence of severe or long term neuropathy to be in the range of 1/1,000-4/10,000, or between 0.1%-0.04.[5-13] A 2009 published study involving over 7000 peripheral nerve blocks conducted in Australia showed that when a post-operative

neurologic symptom was diagnosed, it was 9 times more likely to be due to a non-anesthesia block related cause.[11] On the other hand, it is well documented in the orthopedic and anesthesia literature that there is an alarmingly high incidence of post-operative neurologic symptoms after arthroscopic shoulder surgery, both with and without regional blocks. Most of these involve minor sensory paresthesias and dysesthesias, but they can range as high as 16-30% in the first post-operative week.[9, 12,-13] We can say that about 95% of these lesions will resolve at 3 months, and over 99% will have resolved within one year.

A recent 2012 publication from the Mayo Clinic reviewing all patients from their institutional total joint registry, who had undergone total shoulder replacement (TSA) between 1993 and 2007, revealed that the overall incidence of PNI was 2.2%[6]. Fortunately, most patients ultimately experienced complete (71%) or partial (26%) neurologic recovery at up to two and a half years follow-up. What is fascinating is that patients who received interscalene blocks (ISB) were less likely to experience PNI, versus those patients receiving general anesthesia only, with an odds ratio of 0.47 for PNI. What is also fascinating is that among the patients who received an ISB and also experienced a PNI, only half of those injuries were related to the ISB, suggesting alternative etiologies for the presenting symptoms. Finally, the recovery rate from PNI in patients who received ISB's was similar to those patients with PNI without blocks, suggesting that both types of injuries were of similar severity and prognosis.

The beach chair position is associated with a lower risk of stretch related positioning injuries as compared to the lateral decubitus position. Modern shoulder and arm fixation devices may be less likely to cause trauma as compared to having an assistant hold the arm in position. Unfortunately, the beach chair position puts the patient at increased risk for cerebral hypo-perfusion events, given that the blood pressure being measured with an arm cuff or leg cuff will underestimate the cerebral perfusion pressure. Allowances should be made for this pressure differential and permissive hypertension should be goal during the intra-operative course, even though the surgeons will ask you to lower the blood pressure in order to minimize bleeding and improve their view through the arthroscopic portals.

Strategies to reduce medical-legal risk

Prior to initiating a block, and particularly in a patient with previous injuries, I recommend that you take a focused history about presence of current or previous paresthesias, dysesthesias, or pain in the limb that you are about to block. It would also be helpful to do a quick, focused sensory and motor neurologic exam. Many of these patients have pre-existing lesions; unfortunately, they are not noticed until the post-operative period, when we become much more observant of abnormalities.

Be cautious in the amount of sedation during the block procedure, in order not obscure any symptoms of paresthesia, dysesthesia or pain during injection.[14] Refer to the ASRA (American Society of Regional Anesthesiologists) Practice Advisory on Regional Anesthesia.[15] Be advised that a favorite tactic of med-mal attorneys is to try and argue that patients given ANY amount of sedation would be unlikely to be able to report pain or paresthesia on injection. I would recommend that you document on the chart something to the effect that meaningful verbal contact with the patient was maintained throughout the block procedure.

Documentation of blocks is essential, for clinical care, regulatory, billing and medical legal reasons. ASRA has published a recommended PNB note template[16] . My experience reviewing

cases for potential medical-legal problems has shown me that many of the block notes are poorly documented. An example of a block form could include the following items:

1. Focused neurologic exam prior to block
2. Time out (patient and block site identified and marked, informed consent verified)
3. Patient level of awareness during block
4. Aseptic skin prep, drape
5. Type of needle used, depth to target prior to injection, if catheter, depth at skin.
6. Ultrasound and/or nerve stimulator, minimum threshold current
7. Presence or absence of paresthesia or pain. If paresthesia, did it immediately resolve?
8. Presence or absence of resistance to injection. If resistance, was the needle repositioned?
9. Negative or positive aspiration for blood
10. Local anesthetic, concentration and volume
11. Additives (perineural or i.v.), including total dose and preservative free documentation
12. Success of block (complete, partial, not yet assessable, failed)
13. Block supplementation (yes or no)
14. Ultrasound pre-injection and post-injection image capture and storage

Patients discharged home after a peripheral nerve block procedure should receive written instructions with precautions about how to take care of an insensate extremity, and how to prevent injury. Patients with a single injection block should be called the next day, and questioned about complete block resolution or persistent symptoms, and this contact should be documented. If a continuous ambulatory catheter is being used, then daily phone calls with chart documentation should be noted, and a follow-up call the day after catheter removal should be made to document block resolution.

You should be particularly vigilant when dealing with a patient for a repeat shoulder arthroscopic procedure in such a short period of time. Nerve injury can exist with sub-clinical symptoms, and a second insult, either distal or proximal, without necessarily having anything to do with your nerve block, can elicit clinical findings post-operatively. This phenomenon is known as the double-crush theory of nerve injury.[17]

Is there anything we can do to prevent nerve injury?
Ultrasound-guided techniques have been shown to have many advantages including shorter procedure time, faster block onset, lower drug mass, fewer vascular punctures, and most recently, a reduction in the incidence of local anesthetic systemic toxicity (relative risk reduction of 65%.).[5,18-21] Although there are many benefits associated with ultrasound guided blocks, as of yet, there is insufficient evidence to demonstrate a lower neurologic complication rate with the use of this technique.[22-24] For that matter, there is no evidence to show fewer neurologic complications associated with neurostimulation techniques versus paresthesia seeking techniques.[25]

There are many publications that call into question the sensitivity and specificity of nerve stimulation techniques, and studies demonstrate that intra-neural injections (defined as sub-epineural, not sub-perineural or intra-fascicular) as observed with ultrasound occur frequently and do not invariably lead to nerve injury, during both supraclavicular and axillary blocks.[26] Inadvertent intra-neural injections have also been shown to occur during ultrasound-guided blocks (without paresthesias) in about 17% of upper and lower extremity blocks in two case

series without neurologic complications, even with experienced regional anesthesiologists.[27,28] There has been an ongoing debate about whether or not these intraneural injections are preventable or not, whether they are sub-epineural or below a connective tissue outer wrapper outside the epineurium[29] (sub-paraneural), and whether or not they invariably lead to harm. Due to the limited resolution of current ultrasound probe technology, combined with the fact that it is difficult to keep the tip of the needle visualized in the plane of the ultrasound beam at all times, it is difficult to distinguish between a sub-fascial, sub-epineural, or intra-fascicular injection.[30] Even exceptionally well trained experts in regional anesthesia have subsequently realized that they may have contributed to a PNI after reviewing video clips of an interscalene block demonstrating intra-neural injection, despite an uneventful block procedure without pain or paresthesia occurring.[31]

Current thinking is geared to depositing local anesthesia farther away from the nerves, rather than around the nerves in the interscalene brachial plexus region.[32] We should think about the maximum effective distance from the plexus that will still result in an effective block[33], with a para-plexus approach rather than an intra-plexus approach A conservative approach would involve using a hydro-dissection approach with needle advancement, along with a nerve stimulator (no data to support this), and a lower anesthetic mass and volume.[34]
Although the presence of a catheter might seem to be theoretically predisposed to be more likely to cause nerve injury than a single injection, multiple large series case studies and a recent meta-analysis have not shown this to be the case[13, 35-36.]

The rationale for using adjuvants is to improve the quality, duration or safety of the block. When using continuous infusions for peripheral nerve block catheters, there is no rationale for this practice, other than perhaps when re-bolusing a catheter after a secondary block failure, and adding epinephrine as a marker for intravascular injection.

Epinephrine, in concentrations of 1:200,000 to 1:400,000 has been used as a marker for intravascular injection, in non-beta blocked patients, in order to prevent delivering a full dose of local anesthetic and potentially preventing LAST. Epinephrine containing solutions have also been used to decrease systemic levels of local anesthetics via vasoconstriction and minimizing local absorption, and hence also increase duration of action, particularly with intermediate duration local anesthetics such as mepivacaine and lidocaine. Interestingly, the studies demonstrating a reduction in LAST with the use of ultrasound, were performed in patient populations where the majority did not receive local anesthetic injections containing epinephrine.[5,18,20] There is concern in animal models that when local anesthetic solutions with epinephrine are used in diabetic animal models, there is an increase in neurotoxicity.[37] Human case series in diabetic patients receiving epinephrine in local anesthetic solutions also show excessively prolonged block duration, hence a conservative approach in diabetic patients may be to avoid epinephrine altogether, especially in large diameter nerves such as the sciatic nerve.

Other commonly used adjuvants to enhance block quality and extend duration include buprenorphine, clonidine, dexmedetomidine, and dexamethasone.[38] Remember that the use of these agents is an off-label use. When evaluating adjuvants, it's important to distinguish between systemic versus perineural effects, while also appreciating the potential for perineural toxicity.[39] Buprenorphine, clonidine, dexmedetomidine[40] appear to have direct perineural effects, without perineural toxicity[39], when used in normal clinical doses in preservative free solutions,

and have been shown to increase the duration of peripheral nerve blocks. Dexmedetomidine may even have neuro-protective effects in animal models of nerve injury.[40] Dexamethasone has become an increasingly popular adjuvant, as studies have shown it enhances the duration of ropivacaine blocks in the upper and lower extremity by a factor of 1.9, when given in doses of 8-10mg perineurally.[41,42] However, this effect is also present when the drug is administered systemically(i.v. or i.m.) rather than perineurally.[41,42] Given that tissue models of neurotoxicity show that the addition of dexamethasone to ropivacaine solutions in isolated rat nerve models potentiate neurotoxicity with perineural concentrations that mimic these doses (4 mg or higher), it would be more prudent to administer dexamethasone as a systemic dose.[39] Furthermore, animal models indicate that perineural dexamethasone has no effect on A-delta or C fiber action potentials; hence, its effect is exerted systemically, and probably via effects on intra-spinal prostaglandin synthesis.[43]

A patient who presents for a follow-up appointment 48 hours after a continuous catheter block has been removed and still has a complete sensory block is a cause for concern, and should probably be addressed with immediate neurological consultation. If symptoms are severe or progressive, a treatable cause such as an expanding hematoma or pseudoaneurysm causing compression of a nerve or plexus that is amenable to surgical treatment must be excluded. A mononeuropathy in the distribution of the ulnar nerve is unlikely to be causally related to the interscalene block procedure, given the fact that this block is performed at the level of the roots/superior trunk of the brachial plexus, in the C5-C6 nerve root distribution.

Mechanisms of nerve injury

When analyzing the cause of neurologic injury after regional anesthesia[44], it may be conceptually helpful to organize the causes of injury as being either related to the patient's underlying condition, the surgical procedure, and the block procedure. Most of the cases of PNI that we see are multi-factorial in origin, and it is difficult to tease out the magnitude of the contribution to the overall injury from among the many component factors. One of the largest retrospective studies of post-operative nerve injuries, looking at 300,000 patients undergoing anesthetic procedures over a 10-year period at a major academic medical center, was published in 2009, and showed that peripheral nerve blockade was not an independent predicator of nerve injury after surgery.[45] On the other hand, patients with diabetes, hypertension and those using tobacco products were at higher risk, along with patients undergoing orthopedic surgery.

The forces that cause injury to nerves can be classified as those relating to stretch, compression, ischemia, metabolic or toxic chemical injury, inflammatory (Parsonage-Turner), and trauma (blunt or lacerating). Injury to the brachial plexus associated with performance of the block would cause either blunt or lacerating trauma as a mechanism of injury
Arthroscopic shoulder surgery has its own inherent risks of nerve injury[12], independent of anesthetic techniques, and these risks are associated with traction on the brachial plexus, due to positioning during surgery, with abduction of the shoulder joint. In addition, irrigating fluid extravasation can cause tissue edema and compress the brachial plexus and peripheral nerves. And finally, the arthroscopic portals can damage nerves, especially given the anatomic variability of nerve distribution.

A generally accepted and useful clinical model to use for injury severity and prognosis divides peripheral nerve injuries into three grades.[44, 46, 47] Neurapraxia is the most common and the least

severe, and has the best prognosis. This injury entails injury to the myelin sheath around the individual axon. Depending on the extent of damage to the sheath, nerve conduction may be completed blocked or reduced. This is the injury seen usually as the result of compression, stretch or tourniquet related ischemia. Since the nerve remains in continuity, it usually returns to normal function over a period of days to weeks, and complete recovery occurs. Axonotmesis is a more serious injury, with injury to the axon along with the myelin sheath. Due to preservation of the endoneurium, perineurium and epineureum connective tissue highway, the nerve has the potential to regenerate on its own. Neurotmesis is the most severe type of injury, and involves complete transaction of the nerve, including the connective tissue highway. Surgical repair may partially restore function, but the results are highly variable.

Electrodiagnostic studies: What to get and when

Electrodiagnostic studies, electromyogram (EMG) and nerve conduction velocity studies (NCS), are helpful in that they can provide clues to the location of the injury; the timing of the injury; the severity of the injury; and early signs of recovery.[47-48] Unfortunately, they cannot distinguish the cause of the injury, although when interpreted in the light of the clinical picture they may be of help.Although it is usually recommended to obtain nerve conduction studies 2-3 weeks after the diagnosis of a nerve injury, since most of them will resolve spontaneously, in the event of a severe or profound deficit a baseline study is appropriate. If there is a previously underlying and undetected injury, the EMG will show signs of chronic denervation, including increased insertional activity, fibrillation potentials, and sharp waves. NCS can localize the site of the conduction block, and either confirm or refute that the PNI lesion is at the site of the peripheral nerve block.

There is no reason not to offer a regional anesthetic for an ulnar nerve transposition procedure in this patient, as the literature does not show any increased risk of residual injury when using regional anesthesia versus general anesthesia.[49] At the same time, a patient with a nerve injury after a previous regional anesthetic would probably not elect to go that route again, and should never be coerced into doing so.

Negligence

Did negligence occur in this case scenario? There is no reason to support that conclusion, even though the patient had an adverse outcome. You could question whether or not she truly received informed consent, based on the fact that she signed a surgical consent that included the anesthesia consent. Perhaps she would have made a different decision had she been consented under a shared decision making paradigm. Once a complication occurred and the anesthesiologist remained out of the loop during the follow-up process, it was not surprising that this patient and her family would feel alienated from the anesthesiologist and decide to pursue a legal remedy, even though her anesthetic care did not did deviate from the ASRA Practice Advisory.

References

1.
Brull R, McCartney CJ. Disclosure of risks associated with regional anesthesia: A survey of academic regional anesthesiologists. Reg Anesth Pain Med 2007;32:7-11.
2.
Ironfield CM, Barrington MJ, Kluger R, Sites B. Are patients satisfied after peripheral nerve

blockade? Results from an international registry of regional anesthesia. Reg Anesth Pain Med 2014;39:48-55.
3.
Marcucci C. Capacity to give surgical consent does not imply capacity to give anesthesia consent: Implications for anesthesiologists. Anesth Analg 2010;110:596 –600
4.
Domino KB. Informed consent for regional anesthesia: What is necessary? Reg Anesth Pain Med 2007;32:1-2.
5.
Sites S et al. Incidence of local anesthetic systemic toxicity and postoperative neurologic symptoms associated with 12,668 ultrasound guided nerve blocks. Reg Anesth Pain Med 2012;37:478-82.
6.
Sviggum HP, Jacob AK, Mantilla CB, Schroeder DR, Sperling JW, Hebl JR. Perioperative nerve injury after total shoulder arthroplasty. Reg Anesth Pain Med 2012;37:490-94.
7.
Barrington MJ, Snyder GL. Neurologic complications of regional anesthesia. Current Opinion Anaesthesiology 2011; 24(5): 554-60.
8.
Neal JM, Wedel DJ. Ultrasound guidance and peripheral nerve injury: Is our vision as sharp as we think it is? Reg Anesth Pain Med 2010;35:335-337.
9.
Borgeat A, Aguirre J, Curt A. Case scenario: Neurologic complications after continuous interscalene block. Anesthesiology 2010;112:742-5.
10.
Fredrickson MJ, Kilfoyle DH. Neurological complication analysis of 1000 ultrasound guided peripheral nerve blocks for elective orthopaedic surgery: A prospective study. Anaesthesia 2009; 64:836-44.
11.
Barrington MJ, Watts SA, Gledhill SR, Thomas RD, Said SA, Snyder GL, Tay VS, Jamrozik K. Preliminary results of the Australasian regional anaesthesia collaboration: A prospective audit of more than 7000 peripheral nerve and plexus blocks for neurologic and other complications. Reg Anesth Pain Med 2009; 34:534-41.
12.
Webster S. Complications associated with arthroscopic shoulder surgery. Arthroscopy 2002;18:88-95.
13.
Borgeat A et al. Acute and non-acute complications associated with shoulder surgery. Anesthesiology 2001;95:875-80
14.
Bernards CM, Hadzic A, Suresh S, Neal JM. Regional anesthesia in anesthetized or heavily sedated patients. Reg Anesth Pain Med 2008; 33:449-60
15.
Neal JM, Bernards CM, Hadzic A, Hebl JR, Hogan QH, Horlocker TT, Lee LA, Rathmell JP, Sorenson EJ, Suresh S, Wedel DJ. ASRA practice advisory on neurologic complications in regional anesthesia and pain medicine. Reg Anesth Pain Med 2008; 33:404-15
16.
Gerancher JC, Viscusi ER, Liguori GA, McCartney CJ, Williams BA, Ilfeld BM. Grant SA, Hebl

JR, Hadzic A. Development of a standardized peripheral nerve block procedure note form. Reg Anesth Pain Med 2005; 30:67-71.
17.
Upton AR, McComas AJ. The double crush in nerve entrapment syndromes. Lancet 1973;2:359-72.
18.
Barrington MJ, Kluger R. Ultrasound guidance reduces the risk of local anesthetic systemic toxicity following peripheral nerve blockade. Reg Anesth Pain Med 2013;38:289-299.
19.
Neal JM. Local anesthetic systemic toxicity: Improving patient safety one step at a time. Reg Anesth Pain Med 2013;38:259-261.
20.
Orebaugh SL, Kentor ML, Williams BA. Adverse outcomes associate with nerve stimulator-guider and ultrasound-guided peripheral nerve blocks by supervised trainees: update of a single-site database. Reg Anesth Pain Med 2012;37:577-582.
21.
Laur JJ, Weinberg GL. Comparing safety in surface landmarks versus ultrasound-guided peripheral nerve blocks: an observational study of a practice in transition. Reg Anesth Pain Med 2012;37:569-570.
22.
Neal J, Brull R, Chan V, Grant S, Horn JL, Liu S, McCartney C, Narouze S, Perlas A, Salina F, Sites B, Tsui B. The ASRA evidence-based medicine assessment of ultrasound-guided regional anesthesia and pain medicine: Executive Summary. Reg Anesth Pain Med 2010; 35:S1-S9.
23.
Liu SS, Ngeow JE, YaDeau J. Ultrasound-guided regional anesthesia and analgesia: A qualitative systematic review. Reg Anesth Pain Med 2009; 34:47-59.
24.
Liu SS, Zayas VM, et al. A prospective, randomized controlled trial comparing ultrasound versus nerve stimulator guidance for interscalene block for ambulatory shoulder surgery for postoperative neurological symptoms. Anesth Analg 2009; 109:265-71.
25.
Liguori G et al. Nerve localization techniques for interscalene brachial plexus blockade: A prospective randomized comparison of mechanical paresthesia vs. electrical stimulation. Anesth Analg 2006;103:761-7.
26.
Bigeleisen P. Nerve puncture and apparent intraneural injection during ultrasound guided axillary block does not invariably result in neurologic injury. Anesthesiology 2006;105:779-83.
27.
Liu SS, YaDeau JT, Shaw PM, Wilfred S, Shetty T, Gordon M. Incidence of unintentional intraneural injection and postoperative neurological complications with ultrasound-guided interscalene and supraclavicular nerve blocks. Anaesthesia 2011;66:168-174
28.
Hara K, Sakura S, Yokokawa N, Tadenuma S. Incidence and effects of unintentional intraneural injection during ultrasound-guided subgluteal sciatic nerve block. Reg Anesth Pain Med 2012;37:289-293.
29.
Franco C: Connective tissue associated with peripheral nerves. Reg Anesth Pain Med 2012;37:363-365.

30.
Orebaugh SL, McFadden K, Skorupan H, Bigeleisen PE. Subepineurial injection in ultrasound-guided interscalene needle tip placement. Reg Anesth Pain Med 2010;35:450-454. 29.
31.
Cohen JM, Gray AT. Functional deficits after intraneural injection during interscalene block. Reg Anesth Pain Med 2010;35:397-399.
32.
Spence BC, Beach ML, Gallagher JD, Sites BD. Ultrasound-guided interscalene blocks: understanding where to inject the local anaesthetic. Anaesthesia 2011;66:509-514.
33.
Albrecht E, Kirkham KR, Taffe P, Endersby RVW, Chan VS, Tse C, Brull R. The maximum effective needle-to-nerve distance for ultrasound-guided interscalene block: an exploratory study. Reg Anesth Pain Med 2014;39:56-60.
34.
McCartney CJL, Patel S. Local anesthetic volume for peripheral nerve blocks: How low can (or should) we go? Reg Anesth Pain Med 2012;37:239-241.
35.
Capdevila X et al. Continuous peripheral nerve blocks in hospital wards after orthopedic surgery. Anesthesiology 2005;103:1035-45.
36.
Bingham AE, Fu, F, Horn JL, Abrahams MA. Continuous peripheral nerve block compared with single-injection peripheral nerve block: A systematic review and meta-analysis of randomized controlled trials. Reg Anesth Pain Med 2012;37:583-594.
37.
Willaims BA, Murinson BB, Grable BR, et al. Future considerations for pharmacologic adjuvants in single-injection peripheral nerve blocks for patients with diabetes mellitus. Reg Anesth Pain Med 2009;34:445-457.
38.
Brummett CM, Williams BA. Additives to local anesthetics for peripheral nerve blockade. Int Anesth Clinics 2011;49(4):104-116.
39.
Williams BA, Hough KA, Tsui BYK, et al. Neurotoxicity of adjuvants used in perineural anesthesia and analgesia in comparison with ropivacaine. Reg Anesth Pain Med 2011;36:225-20.
40.
Fritsch G, Danniger T, Allergerger K, Tsodikov A, Felder TK, Kapeller M, Gerner P, Brummett CM. Dexmedetomidine added to ropicacaine extends the duration of interscalene brachial plexus blocks for elective shoulder surgery when compared with ropivacaine alone: A single-center, prospective, triple-blind, randomized controlled trial. Reg Anesth Pain Med 2014;39:37-47.
41.
Desmet M, Braems H, et al. I.V. and perineural dexamethasone are equivlatent in increasing the analgesic duration of a single-shot interscalene block with ropivacaine for shoulder surgery: a prospective, randomized, placebo-controlled study. Br J Anaesth 2013;111:445-52.
42.
Frederickson MJ, Danesh-Clough TK, White R. Adjuvant dexamethasone for bupicacaine sciatic and ankle blocks. Results from 2 randomized placebo-controlled trials. Reg Anesth Pain Med 2013;38:300-307,

43.
Yilmaz-Rastoder E, Gold MS, Hough KA, Gebhart GF, Williams BA. Effect of adjuvant drugs on the action of local anesthetics in isolated rat sciatic nerves. Reg Anesth Pain Med 2012;37:403-409.
44.
Sorenson EJ. Neurological injuries associated with regional anesthesia. Reg Anesth Pain Med 2008; 33:442-48.
45.
Welch MB, Brummett CM, et al. Perioperative peripheral nerve injuries: A retrospective study of 380,680 cases during a 10-year single period at a single institution. Anesthesiology 2009; 111:490-7.
46.
Grant GA, Goodkin R, Kliot M. Evaluation and surgical management of peripheral nerve problems. Neurosurgery 1999; 44:825-39.
47.
Aminoff MJ. Electrophysiologic testing for the diagnosis of peripheral nerve injuries. Anesthesiology 2004; 100:1298-303
48.
Picard J, Ross-Anderson D. Neurological deficit after a peripheral regional anaesthetic: flying on instruments, the black box, crash investigation and other aeronautics. Anaesthesia 2011;66:435-445.
49.
Hebl, JR, Horlocker, TT, Sorenson, EJ, Schroeder, DR. Regional anesthesia does not increase the risk of postoperative neuropathy in patients undergoing ulnar nerve transposition. Anesthesia and Analgesia 2001;93:1606-1611.