The Second ASRA Practice Advisory on Neurologic Complications Associated With Regional Anesthesia and Pain Medicine

Executive Summary 2015

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Abstract: Neurologic injury associated with regional anesthetic or pain medicine procedures is extremely rare. The Second American Society of Regional Anesthesia and Pain Medicine Practice Advisory on Neurologic Complications Associated With Regional Anesthesia and Pain Medicine focuses on those complications associated with mechanical, ischemic, or neurotoxic injury of the neuraxis or peripheral nervous system. As with the first advisory, this iteration does not focus on hemorrhagic or infectious complications or local anesthetic systemic toxicity, all of which are the subjects of separate practice advisories. The current advisory offers recommendations to aid in the understanding and potential limitation of rare neurologic complications that may arise during the practice of regional anesthesia and/or interventional pain medicine.

What's New: The Second American Society of Regional Anesthesia and Pain Medicine Practice Advisory on Neurologic Complications Associated With Regional Anesthesia and Pain Medicine updates information that was originally presented at the Society's first open forum on this subject (2005) and published in 2008. Portions of the second advisory were presented in an open forum (2012) and are herein updated, with attention to those topics subject to evolving knowledge since the first and second advisory conferences. The second advisory briefly summarizes recommendations that have not changed substantially. New to this iteration of the advisory is information related to the risk of nerve injury inherent to common orthopedic surgical procedures. Recommendations are expanded regarding the preventive role of various monitoring technologies such as ultrasound guidance and injection pressure monitoring. New clinical recommendations focus on emerging concerns including spinal stenosis and vertebral canal pathologies, blood pressure management during neuraxial anesthesia, administering blocks in anesthetized or deeply sedated patients, patients with preexisting neurologic disease, and inflammatory neuropathies. An updated diagnostic and treatment algorithm is presented.

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In 2005, the American Society of Regional Anesthesia and Pain Medicine (ASRA) convened a group of experts to develop a practice advisory on neurologic complications associated with regional anesthesia and pain medicine. That initiative resulted in a series of articles published in 2008.[1–6] Consistent with ASRA's commitment to update its practice advisories as new knowledge emerges, the Society convened its second practice advisory in 2012 with the same goal, "to provide information for practitioners of regional anesthesia and pain medicine regarding the etiology, differential diagnosis, prevention, and treatment of neurologic complications."[4] As before, the current practice advisory focuses on neurologic injuries apart from those caused by hemorrhagic or infectious complications or local anesthetic systemic toxicity, which are the subjects of other ASRA-sponsored practice advisories.[7–9] This executive summary condenses findings and recommendations from subtopics of the second practice advisory, which reflects both the proceedings of the conference and interval updates. Practitioners are encouraged to read the supporting articles that accompany this summary; they contain the details on which individual recommendations are based.[10–16]

"Consistent with a recent editorial call to focus practice advisory and consensus conference updates on new material,[17] most supporting articles for individual topics considered by this advisory are built on 2 components. First, to provide perspective, those topics and associated recommendations for which no substantially new knowledge has emerged are reviewed briefly. To provide consistency across time or when appropriate, text and especially recommendations are presented essentially *verbatim* from those of our original work. The second component focuses on topics that have significantly new information to add to our previous understanding and/or that we felt deserved more extensive discussion than was provided in the first iteration of this advisory."[13] Completely new to the second practice advisory is an in-depth presentation of baseline nerve injury risk inherent to common elective orthopedic surgical procedures.[11,12,14] With the growth of registries and their impact on determining accurate and contemporary incidences of complications, the panel added expertise in large epidemiologic studies. Similarly, emerging concerns relating to various ischemia-related neuraxial injuries led to the addition of expert neuroanesthesiologists.

METHODS

The Second ASRA Practice Advisory on Neurologic Complications in Regional Anesthesia and Pain Medicine was

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convened on March 16, 2012, at the Society's 37th Annual Regional Anesthesiology and Acute Pain Medicine meeting in San Diego, California. The ASRA Continuing Medical Education Committee and Board of Directors approved the first and second advisories. Lead members of the advisory panel presented their summaries in a daylong open forum at the annual meeting. Those advisory panelists are listed as authors of this executive summary; additional writers of the individual supporting documents are recognized in the acknowledgments and as individual authors on their articles. Primary panelists were chosen based on their demonstrated expertise in various issues related to neurologic injury and/or guideline creation. As with our first practice advisory, "panelists received no compensation for their contributions nor did any declare a conflict of interest pertinent to the topic" (Dr Hadzic's disclosure appears in the attributions). Panelists were charged with performing an extensive review of the literature, summarizing and presenting their findings at the conference, and producing an article based on their scholarly work. During the San Diego conference, panelists and attendees discussed several issues related to neurologic injury in open forum format. All subsequent recommendations were reviewed and approved by members of the panel. Manuscripts were first peer reviewed internally by at least 3 members of the advisory panel and subsequently peer reviewed externally using this journal's standard peer review process.[4]

Individual supporting articles[10–16] describe the specific search methodology used to research that topic. In general, standard search engines and cross-referenced citations provided the literature basis for the updated material contained within this review.

As paraphrased from our 2008 review, "The strength of scientific evidence that is used to arrive at these recommendations is not easily measured by traditional stratification methodologies such as the Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence."[18] We have used this methodology to rate the level of evidence wherever possible (Appendix 1). However, because of the extreme rarity of the specific complications that are addressed in this article, traditional methodologies such as randomized controlled trials or meta-analyses rarely exist and are unlikely to exist in the future. Our recommendations are therefore based on methodologies that are necessarily less robust, such as anatomic or pathophysiologic studies of human cadavers or animals, nonrandomized trials, retrospective series, case reports, and/or expert opinion. The grading of recommendations offered by this practice advisory has been modified from an American College of Cardiology/American Heart Association construct[19] that classifies the strength of guidelines for perioperative cardiac evaluation[3,13] (Appendix 2).

"Readers of this manuscript are reminded that practice advisories are created when data on a subject are limited or nonexistent. Advisories rely on limited clinical and animal data and, as such, the synthesis and interpretation of data by 1 group of experts may differ from conclusions by another set of equally qualified experts. Thus, practice advisories represent a level of recommendation that is less than that offered by standards or clinical practice guidelines.[20] The recommendations contained herein do not define standard of care. They are not intended to replace clinical judgment as applied to a specific patient scenario. Importantly, in this imperfect setting of controversial topics, limited data, and bias inherent to expert opinion, the Panel consistently tended towards conservative recommendations. These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge of specific complications advances."[4,13]

INCIDENCES OF NEUROLOGICAL INJURY

The incidence of *peripheral nerve injury* (PNI) has remained stable in recent decades, despite the introduction of ultrasound guidance.[21] The reported frequency of long-term neurologic symptoms after peripheral nerve block using ultrasound guidance[22–24] is virtually identical to that reported a decade earlier when peripheral nerve stimulation (PNS) was the primary nerve localization tool.[25,26] In both cases, the reported rate of long-term injury is in the 2 to 4 per 10,000 block range. Conversely, accumulating evidence suggests a rising incidence of some catastrophic *neuraxial* complications associated with regional anesthetic and interventional pain medicine procedures. Whether these observations signal an absolute increase in complication rates is unclear. The reported increase in neuraxial complications may reflect more robust registries and improved reporting mechanisms that allow capture of large population data from single countries and institutions and/or databases from health insurers or national quality assurance records.[22,27–35] It is also possible that incidences have increased as practitioners extend the limits of neuraxial blockade to sicker, older, and frailer patients who are at an increased risk from their comorbidities. Furthermore, perioperative nerve injury incidence data pertinent to either peripheral or neuraxial injury can vary widely between reports for a myriad of reasons, including 1) definition of the complication, 2) duration of follow-up, 3) associated risk factors specific to the cohort studied, 4) robustness of data recording (eg, retrospective vs prospective; registries vs quality assurance databases vs insurance company records vs self-report; single institution vs continent-wide); and 5) discriminating the cause of injury (eg, anesthetic vs surgical vs patient vs a combination; transient vs permanent).

Incidence of Neuraxial Injury

Neuraxial complications are extremely rare, but when they occur, they often result in life-altering injuries. For instance, there were 127 serious complications in more than 1.7 million neuraxial anesthetics performed during the 1990s in Sweden; 85 (67%) of which resulted in permanent injury.[28] The relative occurrence of complications from this report is presented in Table 1. From a medicolegal perspective, closed claims analysis shows that spinal hematomas are the most common cause of neuraxial injuries that proceed to litigation, and these injuries are often permanent. Conversely, infectious complications have a higher likelihood of at least partial recovery.[36]

The incidence of neuraxial injury associated with regional anesthetic techniques varies widely—so much so that it is extremely difficult to cite a meaningful overall risk for injury. Indeed, incidence can even vary among cohorts within the same study. To illustrate this point, the previously noted Swedish study reported vastly different incidences of spinal hematoma—from a risk of 1:200,000 in young women having obstetric epidural blockade to a risk of 1:22,000 in elderly women undergoing hip fracture repair to 1:3600 for those undergoing knee arthroplasty.[28] With regard to infectious complications, risks tend to rise in immunocompromised patients, with prolonged epidural catheterization, when the proceduralist unknowingly harbors virulent nasopharyngeal pathogens and does not wear a mask, and/or when practitioners breach aseptic technique.[7,28,37–40]

Table 2 lists studies reported since 1990 that document incidences of neuraxial injury (often combining hematoma, infection, direct spinal cord injury, etc). These studies point to several common themes. First, the risk of hematoma is higher with epidural than with subarachnoid techniques. Second, the risk of neuraxial injury increases when there are associated coagulation abnormalities (whether from disease or intended anticoagulation), increased

TABLE 1. Relative Frequency of Complications in 1.7 Million Neuraxial Blocks

	Epidural Blockade	Combined Spinal-Epidural Blockade	Spinal Blockade	Continuous Spinal Blockade	Total
Spinal hematoma	21	4	7	1	33
Cauda equina syndrome	8	4	18	2	32
Purulent meningitis	5	1	20	3	29
Epidural abscess	12	—	1	—	13
Traumatic cord lesions	8	—	1	—	9
Cranial subdural hematoma	3	—	2	—	5
Paraparesis	3	—	1	—	4
Other	2	—	—	—	2
Total	62	9	50	6	127

Eight cases of spinal hematoma were associated with thoracic epidural blockade and 17 cases with lumbar epidural blockade.
Data from Moen et al.[28] Used with permission.

age, or female sex. Furthermore, concurrent spinal stenosis or some preexisting neurologic diseases may worsen injury severity in the presence of neuraxial hemorrhage or infection. Third, risk is lower for obstetrical and higher for orthopedic surgeries. Fourth, risk varies when segregated by final outcome (temporary vs permanent vs death).

To illustrate how incidence data can vary depending on how they are collected and what specific population they reflect, consider the following approximations as presented in Table 2. Preexisting neurologic disease may affect overall injury incidence: patients with spinal canal pathology or some preexisting neurologic diseases (especially diabetes mellitus) may experience a transient or permanent new neurologic deficit, or worsening of an existing deficit, in 0.3% to 1.1% of neuraxial anesthetics.[49,50,58] Conversely, in the general population, the incidence of neuraxial injury from any cause is much less, ranging from less than 0.001% to 0.07%. If one defines serious neuraxial complications based on the need for emergency decompressive surgery, injury incidence ranges from less than 0.01% to 0.05%. Indeed, when propensity scoring was used to remove important baseline differences between patients who underwent intermediate- to high-risk noncardiac surgery with either epidural or general anesthesia, there was actually no difference in the necessity for decompressive laminectomy at 30 days.[67] Overall, 3 studies point to an approximate 1:8000 incidence of laminectomy after neuraxial blockade.[27,52,67] Still another way to view incidence data is by using pessimistic versus optimistic estimates. The United Kingdom National Health Service has estimated the risk of paraplegia or death from neuraxial techniques from a pessimistic 1.8:100,000 (95% confidence interval [95% CI], 1.0–3.1) to an optimistic 0.7:100,000 (95% CI, 0–1.6). Similarly, the risk of permanent injury (but not death or paraplegia) ranged from a pessimistic 1:5800 adult epidural anesthetic blocks to an optimistic 1:12,200.[27] Thus, incidence data from neuraxial injury vary widely in accordance with those circumstances that frame the reporting process.

Incidence of PNI

Similar to neuraxial injuries, the reported incidence of PNI associated with regional anesthesia and pain medicine techniques is quite variable. In addition to those factors mentioned for neuraxial injury, the type of peripheral nerve block and its use relative to other blocks may influence injury rate. Because proximal nerves contain a higher proportion of neural tissue as compared with connective tissue,[68] it has been speculated that proximal nerve blocks are riskier than more distal approaches. However, there are no convincing data to confirm or refute this notion.[22,26,35,69] Evidence strongly suggests that the choice to use a regional anesthetic technique (neuraxial, peripheral, or combined) for total joint arthroplasties does not inherently increase the risk for neurologic injury when compared with general anesthesia alone.[70–72] A large retrospective study has also shown that peripheral nerve blocks are not an independent risk factor for perioperative nerve injury.[73]

Table 3 details the incidences of neurologic outcomes associated with peripheral nerve blockade reported since 1997. Consistent with previous reviews,[35,100] early transient postoperative neurologic symptoms (PONSs) are very common in the first days to month after peripheral nerve blockade. However, the incidence is reduced sequentially with time—0% to 2.2% at 3 months, 0% to 0.8% at 6 months, and 0% to 0.2% at 1 year. Importantly, PNIs are not all block related. For perspective, the overall incidence of perioperative nerve injury in more than 380,000 operations conducted for 10 years at a single institution was 0.03%; perioperative nerve injury was associated with hypertension and smoking but not peripheral nerve block.[73]

In summary, the incidence of perioperative nerve injury is extremely difficult to pinpoint with any degree of accuracy. We have instead chosen to present several different approaches to incidence reporting. The incidence of injury after neuraxial blockade is extremely low, but the injuries are often permanent. Conversely, PONSs after peripheral nerve blockade are common but rarely result in long-term or permanent injury. Complicating this analysis are examples of how individual hospital systems can influence patient outcomes when practices are vigilant, evidence based, and use rapid diagnosis and early treatment.[28,32,64] This implies that decreased injury rates and better patient outcomes are attainable when hospitals develop systems that signal risk factors for neuraxial complications (such as concurrent anticoagulation) or devise emergency diagnostic and therapeutic pathways for when a potentially reversible neuraxial injury is suspected.

NEUROLOGIC COMPLICATIONS OF ELECTIVE ORTHOPEDIC SURGERIES

New to this practice advisory is a series of articles[11,12,14] that explore the rate of neurologic complications related to common elective orthopedic surgical procedures. Knowledge of these injuries and their mechanisms is beneficial for the perioperative physician to ascertain potential etiologies for perioperative neural

TABLE 2. Serious Neurologic Complications After Neuraxial Blockade—As Reported Since 1990

Author, Year	Type	N	Complication (n)	Incidence (%)	Potential Risk Factors	Comment/Outcome
Scott and Hibbard, 1990[41]	E	505,000	Permanent disability (5)	0.001		Postal questionnaire, data from 203 obstetric units
Dahlgren and Tornebrandt, 1995[42]	S, E	17,733	Hematoma (3)	0.03 (E)	Impaired coagulation	Paraplegia in 9232 epidural techniques
Wulf, 1996[43]	S, E	1,334,506	Hematoma (6) Serious complications (34)	0.0005 0.005	Impaired coagulation and anticoagulant therapy, ankylosing spondylitis	Risk of hematoma estimated from analysis of case reports/series where denominator could be estimated; however, in total, 51 case reports identified 1966–1985
Giaufré et al, 1996[44]	E, C	15,013	Neurologic complication	0	—	Pediatric cohort, caudal most frequently performed CNB
Aromaa et al, 1997[34]	S, E	720,000	Hematoma (5)	0.005 (S) 0.005 (E)	Spinal canal stenosis, preexisting neurological or vascular disease	Reports from a no-fault insurance scheme. 25 and 9 serious complications from S and E, respectively, occurred, including paraplegia (5), paraparesis (1), CES (2), other permanent deficits (8) for S and E combined
Auroy et al, 1997[25]	S, E	71,053	Radiculopathy (24) CES (5) paraplegia (1)	0.007*	Paresthesia during puncture, pain during injection, intraoperative, hypovolemic hypotension	All presented within 48 h and resolved within 3 mo except for paraplegia (1 patient), radiculopathy (3 patients), CES (1 patient). There were no hematomas
Wang et al, 1999[32]	E	17, 372	Abscess (9)	0.05	Immune status, prolonged catheterization, delayed diagnosis	Poor neurological outcome in 4 of 9 patients: paraplegia (2), paraparesis (2), operative intervention required in 0.01%
Auroy et al, 2002[26]	S, E	76, 630	Peripheral neuropathy (11) CES (3)	0.007†	Lidocaine > bupivacaine; paresthesia during puncture	9 of 14 complications including 3 CESs occurred in nonobstetric population (n = 41, 000). 3 complications persisting at 6 mo
Horlocker et al, 2003[45]	E	4298	Neurologic complication (0)	0.08§	—	Lumbar epidural placement under general anesthesia
Moen et al, 2004[28]	S, E	1, 260, 000	Hematoma	0.006§	Orthopedic surgery, epidural anesthesia, spinal canal stenosis	Higher risk with female sex, age, degenerative change in vertebrae. Lower risk with obstetrics
Lee et al, 2004[36]	E	821	Hematoma, abscess	—	Hematoma associated with coagulopathy in 72% of cases	Closed claims analysis, denominator unknown. Hematoma is most common cause (57%) of nonobstetric injury, worse outcome compared with infection
Ruppen et al, 2006[46]	E	1,370,000	Hematoma (6) Epidural infection (11) Persistent neurological injury (3)	0.0006 0.0009 0.0004	—	Obstetric anesthesia/analgesia, results pooled from 27 studies from 1966 to 2005
Ruppen et al, 2006[47]	E	14,105	Hematoma (0)	0.02§	—	Data pooled from 12 studies of cardiac, thoracic, and vascular surgery
DeVera et al, 2006[48]	E	579	Neurologic complication	0	—	All CNB performed in anesthetized children

Hebl et al, 2006[49]	S, E	567	New neurologic deficits (2)	0.4	Cohort–preexisting peripheral neuropathies	Exacerbation of diabetic neuropathy (1) causing urinary retention; lumbar plexopathy (1) symptoms improving at 1 y
Hebl et al, 2006[50]	S, E, CSE	139	New neurologic deficits (0)	0.3†	Cohort–preexisting CNS disorders	—
de Sèze et al, 2007[51]	S, E	966,000–1,064,504	Neurologic complication (12)	0.001	Mechanisms of injury: hemorrhage (3), direct trauma (2), associated anomaly (2), ischemia (1), uncertain (4)	Cohort of patients admitted to spinal cord injury units. Sequelae—paraplegia (1), monoparesis (2), injury to single nerve (2), bladder/sphincter dysfunction (5), other (2)
Cameron et al, 2007[52]	E	8210	Hematoma, abscess	0.1	—	Operative intervention 0.01%. There were no permanent neurologic deficits
Christie and McCabe, 2007[53]	E	8100	Hematoma (3) Abscess (6) Meningitis (3)	0.04 0.0007 0.04	Immune status, low-molecular-weight heparin	Operative intervention (0.05%). Complete recovery in patients with meningitis, 5 of 6 with abscess and 1 of 3 with hematoma. 3 patients had permanent neurologic deficits
Pöpping et al, 2008[54]	E	14, 223	Hematoma (3), Abscess (2), Meningitis (1)	0.04	Lower limb surgery, elderly female patients	Operative intervention (0.007%). Permanent neurologic deficit (urinary incontinence) in 1 patient with abscess
Cook et al, 2009[27]	E, S, CSE, C	707, 455	Paraplegia/death (13) Permanent injury (30) Permanent harm (postoperative E)	0.002‡ 0.04 0.02	Postoperative epidural analgesia, CSE	"Pessimistic" incidences reported in this table. 30 complications used for "pessimistic" incidences including abscess (8), hematoma (5), nerve injury (7), ischemia (4). 22 of 54 patients made complete recovery
Li et al, 2010[55]	E	125,821	Hematoma	0.002	Emergency surgery, bacterial infection	—
Ecoffey et al, 2010[56]	C, E, S	10, 556	Neurologic complication	0	—	Pediatric regional anesthesia, minor events of duration 48 h to 9 mo
Wallace et al, 2010[57]	E	415	Abscess (2)	0.48	Cohort–open abdominal aortic aneurysm repair	6 patients required MRI
Hebl et al, 2010[58]	S, E	937	Neurologic complication (10)	1.1	Cohort– spinal canal pathology, including spinal stenosis and lumbar disk disease	Deficits coincided with operative side in 5 of 6 patients having unilateral surgery, difficulty separating etiologies—surgical, anesthetic, or evolution of spinal pathology
Liu et al, 2011[59]	E	4365	Hematoma (0)	0.069§	—	4365 patients had uncomplicated removal of epidural catheters despite INRs ranging from 1.5 to 5.9
Volk et al, 2012[31]	E	33,142	Hematoma (6)	0.02		General surgical population
Polaner et al, 2012[30]	All	9156	Neurologic complication	0.02‖	—	Pediatric regional anesthesia

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TABLE 2. *(Continued)*

Author, Year	Type	N	Complication (n)	Incidence (%)	Potential Risk Factors	Comment/Outcome
Sviggum et al, 2012[60]	S	12,465	Neurologic complication	0.04	Chlorhexidine gluconate skin asepsis did not increase risk of complications	All complications resolved by 30 d
Bateman et al, 2013[61]	E	62,450	Hematoma (7)	0.01	Anticoagulant guidelines not adhered to, perioperative epidural analgesia	All complications occurred in patients with perioperative E, no complications in 79,837 obstetric patients
Hemmerling et al, 2013[62]	E	16,477	Hematoma (3)	0.02	Risk comparison with other medical and nonmedical activities	Cohort comprises all publications between 1966 and 2012
Pitkänen et al, 2013[29]	S, E, CSE	1,372,000	Neuraxial hematoma (13)	0.0001 (S) 0.004 (E) 0.006 (CSE)	Anticoagulant guidelines not adhered to, spinal canal stenosis	10-y-long nationwide study from no-fault insurance system in Finland. Sequelae–paraplegia (4), paraparesis (4), incontinence (2), CES (1), recovery (1)
Ehrenfeld et al, 2013[63]	E	43,200	Hematoma (6)	0.01	Perioperative anticoagulation	Cases identified using multiple search strategies, lower extremity weakness present in all cases. Sequelae–paralysis (1), paraparesis (2), recovery (3)
Pumberger et al, 2013[64]	E, S	100,027	Hematoma (8)	0.008	Perioperative anticoagulation	Total hip and knee arthroplasty
Kang et al, 2014[65]	E	5083	Hematoma (1)	0.02		Nonobstetric case load
Gulur et al, 2015[66]	E	11,600	Hematoma (2)	0.02	Abnormal coagulation	Risk 1 in 315 patients with abnormal coagulation

*Incidence 3 months; †Incidence 6 months postoperatively; ‡No complications occurred, upper limit of 95% confidence level reported; §There were no deaths or complications with sequelae lasting more than 3 months, upper limit of 95% confidence level presented; ||Incidence of final outcome reported.

E indicates epidural anesthesia; S, spinal anesthesia; C, caudal anesthesia; CSE, combined spinal-epidural anesthesia; CNB, central neuraxial block; N, denominator; n, number of events.

TABLE 3. Incidence of Neurologic Outcomes Associated With Peripheral Nerve Blockade—As Reported Since 1997

Author, Year	PNB Type	Technique Used	N	Neurologic Outcome	Incidence (%) (time)*	Potential Risk Factors	Comment
Giaufré et al, 1996[44]	UL, LL	-	4090		0	-	No complication reported after PNB
Auroy et al, 1997[25]	All	-	21,278	Radiculopathy	0 (3 mo)	Paresthesia during puncture, pain during injection	Transient radiculopathy in 0.02%
Fanelli et al, 1999[69]	UL, LL	NS	3996	Neurological complication	0.03 (3 mo)	Tourniquet inflation pressure >400 mm Hg	Transient neurologic dysfunction in 1.7%. All resolved by 6 mo
Borgeat et al, 2001[74]	ISB	NS	521	Plexus lesion	0.2 (9 mo)	Sulcus ulnaris and carpal tunnel syndromes	Neurologic features present in 7.9%, 3.9%, and 0.9% at 1, 3, and 6 mo; serial EMGs performed
Hebl et al, 2001[75]	Ax	NS, LM	100	PONS	6	Bupivacaine (0.375%): an independent risk factor	Anesthetic (GA or Ax block) did not affect neurological outcome after UT
Weber and Jain, 2002[76]	ISB	NS	218	Neurologic complication‡	0.5 (2 y)	Pain during ISB	Retrospective chart review, permanent injury in 1 patient
Auroy et al, 2002[26]	All	NS, LM	50,223	Neurologic complication‡	0.014 (6 mo)	Popliteal SNB (0.3%), paresthesia during PNB	50,223 PNB, 12 complications in total, 7 present at 6 mo
Bergman et al, 2003[77]	Ax, CPNB	NS, LM	405	Neurologic complication‡	0.5	Profound sensorimotor deficits–poor recovery (1 patient)	2 of 4 patients with new deficits were related to anesthesia
Capdevila et al, 2005[78]	CPNB	NS	1416	Neurologic complication‡	0 (3 mo)	Anesthetized during PNB	Incidence 0.21% in early postoperative period. All resolved by 3 mo
Candido et al, 2005[79]	ISB	NS	693	Neurologic sequelae	0.1 (3 mo)	Paresthesia at needle insertion, ISB site pain or bruising at 24 h	Neurologic sequelae present in 3.3%, 0.1% at 1, 3 mo
Liguori et al, 2006[80]	ISB	NS, MP	218	PONS	0 (12 mo)	PONS: 10.1% with NS, 9.3% with MP	Median duration of PONS, 2 mo. Resolved within 1 y
Bishop et al, 2006[81]	ISB	NS	277	Neuropathy	0	—	Transient sensory neuropathies all resolved (5 wk)
Ben-David et al, 2006[82]	Ax	TA	336	Neurologic complication‡	0.3	Nerve injury: 7.5% with PNB performed under GA vs 2.6% with sedation	All complications resolved except for 1 permanent injury
Faryniarz et al, 2006[83]	ISB	NS	133	Neuropraxia	0 (2 mo)	—	Detailed perioperative neurological assessment, all events transient (1.4%)
DeVera et al, 2006[48]	UL, LL	NS	1529	PONS	0 (1 mo)	Duration of tourniquet inflation	Persistent paresthesia after FNB, resolved by 1 mo
Wiegel et al, 2007[84]	CPNB	NS	1398	Neurologic complication‡	0.07	—	Retroperitoneal hematoma led to long-term femoral neuropathy
Lenters et al, 2007[85]	ISB	NS, MP	3172	Neurologic complication‡	0.2–0.4 (6 mo)	Volume of practice	Incidence of serious, long-term PNB-related injury higher than other studies
Pöpping et al, 2008[54]	CPNB	—	3111	Neurologic complication	0 (4 wk)	Incidence 0.06%, complete recovery within 4 wk	Difficulty distinguishing anesthetic from nonanesthetic etiology after ISB
Christ et al, 2009[86]	ISB	NS	273	Neurologic complication‡	0 (6 mo)	Superficial cervical plexus involvement: 7.7% at 24 h, 1.8% at 1 mo	All deficits resolved by 6 mo

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TABLE 3. *(Continued)*

Author, Year	PNB Type	Technique Used	N	Neurologic Outcome	Incidence (%) (time)*	Potential Risk Factors	Comment
Fredrickson and Kilfoyle, 2009[87]	BP, FNB, SNB	US	1010	PNI	0.6 (6 mo)	Paresthesia during PNB	Most PNI unrelated to PNB
Liu et al, 2009[88]	ISB	US	230*	PONS	0.8–1.1 (1 wk)	—	No difference in PONS, US compared with NS
Welch et al, 2009[73]	All		380,680*	PNI	0.03	EA, GA, hypertension, diabetes mellitus, tobacco use, surgical specialty	Retrospective study using 3 databases including QI database
Barrington et al, 2009[22]	All	US, NS, LM	8189	Neurologic complication‡	0.02 (6 mo)	Comorbidities: vascular disease, lumbar stenosis, radiculopathy, neuropathy	Systematic postoperative follow-up. No significant difference: US vs NS techniques
Davis et al, 2009[89]	ISB	US	200	Neurologic deficits	0	—	Transient neurological deficits (1%)
Perlas et al, 2009[90]	SCB	US	510	Neurologic deficits	0	—	0.4% reported transient numbness in fingers
Sharma, 2010[91]	FNB	NS	729*	Femoral neuropathy/neuritis	0.14 (12 mo)	Neuropathy: 0.7% with FNB, 0.4% with no FNB	1 patient after FNB had residual sensory symptoms at 12 mo
Ecoffey et al, 2010[56]	UL, LL, Trunk	Not stated	20, 576	Neurologic complication	0	Pediatric study	Femoral distribution hypoesthesia (iliofascial block) resolved <48 h
Liu et al, 2010[92]	ISB, SCB	US	1169	PONS	0.4	—	No permanent injuries
Jacob et al, 2011[71]	LL	NS, LM	12,329*	PNI	0.79 (3 mo)	Tourniquet time and bilateral surgery	PNI was not associated with PNB or type of anesthesia
Jacob et al, 2011[70]	LL	NS, LM	12,998*	PNI	0.72 (3 mo)	Age, female, surgical duration, posterior approach	PNI was not associated with PNB or type of anesthesia
Misamore et al, 2011[93]	ISB	NS	910	Neurologic complication‡	0.8 (6 mo)	Diffuse mild brachial plexopathy confirmed on EMG	Radial nerve palsy (n = 1), mild forearm/hand paresthesias (n = 5), Horner syndrome (n = 2)
Singh et al, 2012[94]	ISB	US	1319	Neurological complication	0 (4 mo)	Brachial plexitis (3 cases) related to underlying comorbidities	Digital numbness (0.6%), all resolved by 4 mo, ulnar neuropathy (1 case) resolved
Sviggum et al, 2012[72]	ISB	NS, LM	1569	PNI	2.2 (3 mo)	ISB did not increase the risk of PNI. GA used as primary anesthetic in 1569 patients	Complete resolution of symptoms in 97% of patients after TSA
Sites et al, 2012[33]	All	US	12,668	PONS	0.09 (6 mo)	ISB and shoulder surgery	PONS defined as sensory/motor dysfunction >5 d
Orebaugh et al, 2012[24]†	UL, LL	US, NS	9069	Neurologic complication‡	0.04 (6 mo)	No significant difference: US vs NS techniques	1 sensorimotor deficit persisted >1 y after FNB
Polaner et al, 2012[30]	All	US, NS	5761	Neurologic complication	0 (3 mo)	Possible exacerbation of preoperative symptoms after LPB	Pediatric regional anesthesia
Hara et al, 2012[95]	SNB	US	325	Neurologic complication‡	0	Unintentional intraneural injection occurred in 16.3%	No clinical evidence of nerve injury
Henningsen et al, 2013[96]	SNB	US	97	Neurologic complication	0 (6 mo)	Infrapatellar branch involved in 84% (surgical etiology)	Neurologic examination of patients after TKA
Lecours et al, 2013[97]	ICB	US	627	Neurologic complication‡	0.2 (1 y)	1 patients had biceps weakness >1 y	4 patients with features potentially related to ICB

Rohrbaugh et al, 2013[98]	ISB	US or PNS	15,014	Neuropathy	0.03 >6 mo	—	All sitting position, sensory neuropathy, 1 phrenic nerve injury (0.07%)
Nye et al, 2013[99]	CLPB	PNS	213 PONS		2.8 (>6 mo)		Hip arthroplasty cohort

*Indicates elapsed postoperative time period when incidence calculated; PNB, peripheral nerve or plexus block; N, number of PNB procedures or *Number of patients receiving all anesthetic types (GA and regional); CPNB, continuous peripheral nerve block; ISB, interscalene block; ICB, infraclavicular block; Ax, axillary brachial plexus block; BP, brachial plexus; FNB, femoral nerve block; FIB, fascia iliaca block; PCB, psoas compartment block; SNB, sciatic nerve block; UL, upper limb PNB; LL, lower limb PNB; NS, nerve stimulator; LM, landmark; CLPB, continuous lumbar plexus block; TA, transarterial; MP, mechanical paresthesia; US, ultrasound; PNI, new perioperative nerve injury due to any cause; PONS, postoperative neurologic symptom (in distribution of PNB); GA, general anesthesia; EA, epidural anesthesia; EMG, electromyography; QI, Quality improvement; UT, ulnar transposition; TSA, total shoulder arthroplasty; SaNB, saphenous nerve block.

†Results of smaller cohort published in 2009, included in 2012 publication; ‡PNB thought to be the cause.

deficits, which might include surgical, anesthetic, and patient-related factors (Table 4). In consultation with the operating surgeon and neurologist, the knowledgeable anesthesiologist might facilitate global awareness of possible injury mechanisms, which in turn may optimize postoperative diagnostic and therapeutic interventions. Despite this optimistic goal, determining causation in the setting of concurrent surgery and regional anesthesia is often challenging because of confounding factors such as double-crush injury and/or the technical limitations of diagnostic imaging and neurophysiologic testing. Furthermore, orthopedic surgery literature rarely designates nerve injury as a primary outcome, is often retrospective, and therefore lacks sufficient granularity to fully understand the mechanism of injury. These limitations likely result in underreporting. Thus, although the literature affords a glimpse into the "overall baseline nerve injury" associated with specific surgeries, precise determination of causation is often speculative.

Similar to anesthesia-related injuries, the vast majority of neural injuries associated with orthopedic procedures are transient, yet the rate of long-term injury is of consequence. Most injuries result from a short list of perioperative causes such as direct nerve trauma, positioning, stretch, retraction, or compression from hematoma or dressings. What follows is a brief summary of well-recognized injuries specific to surgery type. To more completely understand this topic, we urge study of the supporting articles and their excellent accompanying illustrations.[11,12,14]

Shoulder Surgery

The frequency and etiology of nerve injury associated with shoulder surgery vary by surgical approach. Arthroscopic shoulder surgeries are associated with nerve injury ranging from less than 0.1% to 10%,[11] most of which are caused by surgical traction to improve exposure or by arthroscopic portal placement. Shoulder surgeries performed in the lateral decubitus position are associated with transient neuropraxia affecting the operated limb in up to 10% of patients, especially when documented by intraoperative somatosensory evoked potentials.[101] Portal placement too close to typical nerve pathways is particularly risky for axillary or musculocutaneous nerve injury. These same nerves are at risk during open (nonarthroscopic) shoulder surgeries, but the cause is more likely surgical traction to the arm. Open rotator cuff surgery is associated with mostly transient injuries (<2%), but open shoulder stabilization procedures increase injury frequency up to 8.2%.[102] Anatomic total shoulder replacement is most often associated with diffuse brachial plexus injuries, which may occur transiently in up to 17% of patients. Patients with stiff shoulders or prior shoulder surgery are at an increased risk.[103] The 0.6% to 3.6% incidence of nerve injury associated with reverse total shoulder replacement[11] is 11-fold higher than that reported for anatomic shoulder replacement and is primarily related to the permanent arm lengthening associated with that procedure.[104]

Elbow Surgery

Surgery of the elbow is particularly hazardous because of the minimal soft tissue protection available to the multiple nerves that traverse the joint. Ulnar neuropathy persists in up to 10% of elbow replacement patients.[105] Up to 4.2% of elbow arthroscopies are associated with transient iatrogenic nerve injury[106] in part because portals are placed blindly in a nerve-rich area.

Hip Surgery

The frequency of nerve injury after total hip arthroplasty (THA) varies widely but generally falls in the 1% range.[12] The cause of these injuries is attributed to compression from retractors, traction from intraoperative hip dislocation and manipulation, or excessive leg lengthening. The common peroneal branch of the

sciatic nerve is most frequently injured during THA (0.08%–3.7%)[107]; injuries to the femoral and superior gluteal nerves occur less often. Transient injury to the lateral femoral cutaneous nerve is frequent (15%–88%) after the anterior approach to THA.[108,109] Two conditions uniquely increase the risk of nerve injury associated with primary THA—developmental dysplasia sometimes requires leg lengthening, which increases the risk 4-fold,[110] whereas revision THA increases the risk 3-fold.[111] The incidence of nerve injury associated with hip arthroscopy ranges from 0.4% to 13.3%[12] and carries with it a unique set of traction-associated risks to the pudendal nerve (from longitudinal traction against the pudendal post) or to the sciatic and femoral nerves.[12]

Knee Surgery

The incidence of major nerve injury after total knee arthroplasty (TKA) ranges from 0.3% to 9.5%.[12] The upper end of this incidence range represents injury to the common peroneal nerve, which is particularly at risk in those patients with severe valgus deformity (>12 degrees), flexion contractures (>10 degrees), prolonged tourniquet times (>120 minutes), or preexisting neuraxial neuropathy (spinal stenosis or lumbar radiculopathy). Disruption of the infrapatellar branch of the saphenous nerve and/or the cutaneous nerves of the thigh is quite common but tends to resolve within 2 years. Arthroscopic knee surgeries are associated with frequent (up to 25%) sensory loss to the anterior knee.[112] Similarly, paresthesia from injury to the infrapatellar and sartorial branches of the saphenous nerve is common (up to 75%) after arthroscopic anterior cruciate ligament repair.[113] Inside-out techniques for arthroscopic medial meniscus repair are associated with saphenous nerve injury from direct trauma or suture entrapment.

TABLE 4. Evidence Statements Regarding Anesthetic, Patient, and Surgical Factors That Contribute to Perioperative PNI

Anesthetic Factors

- Postoperative neurological features are more likely to be related to patient and surgical factors than to be related to peripheral nerve blockade (Level 3)
- Peripheral nerve injection injury with local anesthetic is greatest when the injection is intrafascicular in location. This is likely related to:
  - Exposure of axons to vastly higher concentrations of local anesthetics compared with extraneural application of anesthetics and
  - Mechanical damage to the perineurium and associated loss of the protective environment contained within the perineurium (Level 3)
- Intrafascicular injections are associated with higher opening injection pressures and risk of PNI compared with perineural injection (Level 3)
- Local anesthetic toxicity is time and concentration dependent (Level 3)
- Epidural and general anesthetics, but not PNB, have been associated with PNI. Furthermore, PNB is not associated with PNI after TKA, THA, or TSA (Level 2)

Patient Factors

- The presence of a preoperative neurologic deficit or neural compromise theoretically places a patient at increased risk of perioperative PNI (Level 4)
- The ulnar nerve at the elbow and the common peroneal nerve are at increased risk of PNI (Level 3)

Surgical Factors

- Tourniquet neuropathy can be associated with marked clinical deficits and pathological changes on electromyography. The duration of inflation and pressure are important factors contributing to its severity (Level 2)
- Surgical procedures have unique risk profiles (Level 2)
- Inflammatory mechanisms for PNI are recognized and exhibit features that are physically and temporally remote from PNB (Level 4)

Levels of evidence are based on the 2011 Oxford construct.[18]

PNB indicates peripheral nerve block; TSA, total shoulder arthroplasty.

TABLE 5. Recommendations: Factors That May Limit Neuraxial Injury

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

Anatomic Factors

- Misidentification of vertebral level, unrecognized lateral needle placement or deviation, abnormal caudad termination of the spinal cord, or failure of the ligamentum flavum to fuse in the midline may contribute to direct needle injury of the spinal cord. Clinicians are advised to be aware of these anatomic conditions, particularly in patients with challenging surface anatomy *(eg, as may occur with obesity, kyphoscoliosis, and other conditions)*. Ultrasonography or fluoroscopy could be considered as an adjunct for accurate determination of vertebral level in these challenging patients (Class I).
- Surgical positioning, severe spinal stenosis, and specific space-occupying extradural lesions (eg, epidural lipomatosis, ligamentum flavum hypertrophy, synovial cysts, or ependymoma) have been associated with temporary or permanent spinal cord injury in conjunction with neuraxial regional anesthetic techniques. These conditions are particularly relevant when they coexist with an epidural hematoma or abscess. Awareness of these conditions should prompt consideration of risk-vs-benefit when contemplating neuraxial regional anesthetic techniques *(Class I)*.
- Patients with known tumor in the epidural space should undergo neuraxial imaging studies to define the extent of tumor mass. If the tumor is close to the planned site of epidural solution injection, alternative methods of anesthesia or analgesia should be considered (Class II).
- For patients receiving neuraxial injection for treatment of pain (eg, cervical epidural injection of steroids via an interlaminar route), radiologic imaging studies such as computed tomography or MRI should be used to assess the dimensions of the spinal canal, and this information should be considered in the overall risk-to-benefit analysis as well as guiding the selection of the safest level for entry (Class II).

Physiologic Factors

- Clinicians are advised to be aware of and to avoid conditions that have been linked to the formation of epidural hematoma or epidural abscess, as noted in previous American Society of Regional Anesthesia and Pain Medicine Practice Advisories. Such conditions include concurrent or imminent anticoagulation, the use of multiple anticoagulants, improper aseptic technique, and needle placement during untreated active infection (Class I).[7,8,38,39]

Recommendations contained within Table 5 have been modified minimally from our 2008 advisory.[3] Significant changes are in *italics*.

Levels of evidence are based on the 2011 Oxford construct.[18]

Foot and Ankle Surgery

Elective foot and ankle surgery using arthroscopy or involving joint replacement is a relatively new field. Literature related to

nerve injury in these patients is sparse and mostly retrospective. Iatrogenic injury, especially to cutaneous nerves, seems to be relatively common, albeit mostly well tolerated by patients unless the sensory deficit involves the plantar aspect of the foot.[14] Adequate surgical exposure for ankle arthroscopy places all nerves that cross the ankle joint at risk for traction neuropraxia. Cutaneous nerves of the foot are at risk from portal placement or direct surgical trauma during the anterior arthroscopic approach, ankle replacement, or open triple arthrodesis ankle fusion. Fortunately, persistent defects are rare (0.2% at 10 years).[114] Total ankle arthroplasty carries an overall nerve injury rate of 1.3%[115] and most commonly involves the peroneal nerve if the anterior approach is used. Cutaneous nerve sensory deficits after hallux valgus deformity (bunion repair) are poorly documented, and their reported incidence ranges widely.[14]

Recommendations

- Awareness of the causation, location, and frequency of nerve injuries associated with elective orthopedic surgery might assist the anesthesiologist in diagnosis and treatment of perioperative nerve injury. Actual discrimination between surgical, anesthetic, and patient factors is often difficult (Class I).
- Differential diagnosis should include prolonged use of a pneumatic tourniquet (>120 minutes), which has been associated with nerve injury. These injuries often present as diffuse sensorimotor deficits (Class I).
- Consider delaying placement of regional blocks if assessment of postoperative nerve function is important for the surgeon (Class III).

ANATOMY AND PATHOPHYSIOLOGY OF NEURAXIAL INJURY

Since our 2008 practice advisory,[3,4] we have expanded recommendations on 5 specific topics that relate to the anatomy and pathophysiology of spinal cord injury associated with regional anesthesia and pain medicine: spinal stenosis, blood pressure control during neuraxial anesthesia, neuraxial injury subsequent to transforaminal techniques, cauda equina syndrome (CES)/local anesthetic neurotoxicity/arachnoiditis, and performing regional anesthetic or pain procedures in patients receiving general anesthesia or deep sedation.[13,116] Recommendations that remain unchanged from 2008 are summarized in Table 5.

Spinal Stenosis

After gaining attention shortly before the creation of our 2008 advisory,[28,51] evidence has continued to accumulate that suggests an increased risk of spinal cord injury after neuraxial techniques are performed in patients with spinal canal pathology, especially spinal stenosis.[29,58] These studies suggest a slightly increased rate (compared with institutional norms) of new or worsening neurologic deficits in those patients with *known* spinal canal pathology who undergo spinal anesthesia.[58] Conversely, studies also report the *unexpected* discovery of spinal stenosis when (especially elderly women) patients undergo neuroimaging during diagnostic workup for spinal hematoma and CES.[28] It remains unclear if these observations represent cause and effect or simply associate spinal stenosis with the complication. Alternatively, the injuries could have been caused by surgical factors, natural progression of the underlying spinal pathology, or a combination thereof. From a pathophysiologic perspective, spinal stenosis may contribute to spinal injury by reducing the vertebral canal cross-sectional area, thereby inducing spinal cord ischemia via compressive mechanisms and/or by limiting the clearance or free distribution of local anesthetic within the neuraxis, thereby contributing to neurotoxicity.[13] Although the preponderance of these injuries have been associated with epidural or combined spinal-epidural techniques,[28] injuries have also been associated with spinal anesthesia.[58,116]

As supported by a few large population studies and a multitude of case reports and series,[13] the advisory panel speculates that patients with spinal stenosis may be especially vulnerable to

TABLE 6. Recommendations: Patients With Spinal Stenosis

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

- Spinal stenosis represents a continuum of spinal canal encroachment by hypertrophied ligamentum flavum, bony overgrowth, and/or degenerative changes such as from osteoporosis or herniated nucleus pulposus. Patients with spinal canal pathology (eg, spinal stenosis, lumbar disk disease) may have clinical or subclinical evidence of a preexisting neurologic deficit because of neural compromise from the disease state. However, even moderately severe spinal stenosis is not always symptomatic; many patients (or their health care providers) are unaware that they have the condition (Class I).
- When neuraxial anesthesia is complicated by the development of mass lesions within the spinal canal (eg, hematoma or abscess), resultant postoperative neurologic complications may be more likely or more severe in patients with spinal stenosis or other obstructive spinal canal pathology, including changes brought on by patient positioning (Class I).
- In patients with known severe spinal stenosis or symptoms suggestive thereof, we recommend that risk-to-benefit be considered before performance of neuraxial anesthesia because of the association of spinal stenosis with neurologic complications in the setting of neuraxial blockade. If neuraxial blockade is performed, we recommend heightened perioperative vigilance for symptoms suggestive of neural compromise (Class II).
- There is no firm linkage to injury if spinal stenosis is at a site distant from the level of neuraxial block placement (Class III).
- If neuraxial anesthesia is planned, the practitioner may consider reducing the total mass (volume × concentration) of local anesthetic in an effort to reduce segmental spread, local anesthetic neurotoxicity (which is related to concentration), and/or facilitate neurologic assessment by earlier block resolution. Although we are unaware of routinely administered volumes of local anesthetic being associated with injury in patients with spinal stenosis, reports have postulated linkage between high volumes and neuraxial injury in the setting of other mass lesions such as epidural lipomatosis (Class III).
- The literature has established an association between spinal stenosis and injury after neuraxial blockade, most often affecting patients in whom the diagnosis of spinal stenosis was made during workup for the injury. There is no clear evidence that spinal stenosis per se caused these injuries (Class II).
- Currently, it is unclear whether the development of new or worsening neurologic symptoms after neuraxial anesthesia or analgesia is caused by surgical factors, the anesthetic technique, the natural progression of spinal pathology, or a combination of these factors (Class II).

neuraxial injury in the concurrent settings of preexisting neuraxial disease, non-neutral positions during the perioperative period (eg, hyperlordosis or extreme lateral flexion), or other conditions that compete with the spinal cord for space within the vertebral canal, for example, epidural hematoma or abscess, spinal arachnoid cyst, or ankylosing spondylitis (Fig. 1). When the diagnosis of moderate-to-severe spinal stenosis is known, we recommend consideration of the risk versus benefit of a neuraxial technique. If such a technique is chosen, we suggest increased vigilance for signs of postoperative neurologic compromise. Finally, we acknowledge that significant spinal stenosis is common (19% prevalence in patients in their sixties[118]) and often unrecognized by both patients and their health care providers. The majority of patients with spinal stenosis tolerate neuraxial blockade without clinically apparent injury. Nevertheless, the panel advises that increased reporting of neuraxial injury in the setting of spinal stenosis should elevate the anesthesiologist's awareness of this disease process. Our recommendations regarding spinal stenosis are presented in Table 6.

Blood Pressure Control During Neuraxial Anesthesia

The current advisory places increased emphasis on the importance of avoiding prolonged hypotension during neuraxial anesthetics (>20%–30% below baseline mean arterial pressure [MAP] especially for 20 minutes or longer).[13] We base this recommendation on evolving knowledge that the lower limit of autoregulation (LLA) for cerebral and spinal cord blood flow (SCBF) is likely higher than previously believed and ongoing case reports and medicolegal experience wherein patients have suffered spinal cord ischemia or infarction in the setting of prolonged hypotension or hypoperfusion.

Perioperative spinal cord ischemia or infarction is an extremely rare event that is most often associated with specific surgeries (aortic, cardiac, spine). Other risk factors for spinal cord infarction include those classically recognized for vascular disease, that is, atherosclerosis, hypertension, and tobacco abuse. An insult to the spinal cord circulation that is sufficient to cause ischemia or infarction implies either mechanical injury to the spinal vasculature, an embolic event, or hypoperfusion, as may occur during prolonged periods of hypotension. Recent data and opinion suggest that the LLA for SCBF is likely closer to a MAP of 60 to 65 mm Hg rather than the classically understood MAP of 50 mm Hg.[119–122] Moreover, direct and surrogate measures of the LLA for cerebral blood flow in humans suggest that the LLA varies widely among subjects and, contrary to common belief, is usually not related to or predicted by baseline blood pressure.[121] There exists a "physiologic reserve" between the LLA and the blood pressure at which cellular injury or death actually occurs. Clinical experience suggests that the vast majority of patients whose blood pressure is low during a neuraxial technique do not suffer spinal cord ischemic injury most likely because 1) the blood pressure is not critically low for that individual (ie, the blood pressure is higher than that patient's LLA or within their physiologic reserve) and/or 2) limited duration at the lower blood pressure. However, case reports also reveal that an extremely small subset of patients either have a higher set point for their personal LLA and/or cannot withstand prolonged periods of "low-normal" blood pressure. Moreover, the risk for ischemic injury is likely increased in these patients when hypotension is interposed with other factors that may compromise SCBF, such as vascular stenosis, embolic phenomena, non-neutral spinal column positioning (eg, hyperlordosis, extreme lateral flexion, or lithotomy), hypocapnia, raised intrathoracic pressure, and/or surgical retraction.

The extreme rarity of perioperative ischemic spinal cord injuries makes it impossible to assume cause and effect in those patients identified with concurrent periods of hypotension particularly when the degree of hypotension is not extreme and/or of extreme duration. Nevertheless, because the chance for recovery after spinal cord infarction is dismal and the ability to predict an individual patient's LLA is clinically difficult if not impossible, the panel "recommends that anesthesiologists strive to maintain blood pressure within 20% to 30% of baseline and that persistent hypotension be treated."[13] If an ischemic injury is suspected, immediate neuroimaging is necessary to rule out a potentially treatable condition, such as spinal hematoma or abscess. If such a condition is excluded, the panel recommends normalizing or increasing the patient's blood pressure to high-normal range and considering cerebrospinal fluid (CSF) drainage. The role of corticosteroids specifically for anesthesia or pain medicine–related injuries is unknown. The use of corticosteroids may be beneficial in instances of direct spinal cord trauma from interventional procedures. Conversely, the known linkages to worsened neurologic outcome from direct corticosteroid-induced neurotoxicity and indirect hyperglycemia lead us to recommend avoiding corticosteroids when spinal cord ischemia is suspected. In either case, maintain normoglycemia by using insulin in those patients with elevated glucose levels. These decisions are best made in consultation with neurological colleagues. Recommendations for the diagnosis and treatment of spinal cord ischemia or spinal cord infarction are presented in Table 7.

Transforaminal Pain Medicine Procedures

Our 2008 practice advisory[4] made recommendations regarding the then emerging awareness of catastrophic neurologic injuries associated with transforaminal pain medicine procedures. In the interim, a collaboration took place between the US Food and Drug Administration Safe Use Initiative and a group with representation from specialties with expertise in interventional treatment of spinal disorders.[123] This initiative puts forth a series of expert opinions meant to improve patient safety during the provision of transforaminal procedures. In addition, a number of case reports and small series continue to describe infarctions of the spinal cord, brainstem, cerebrum, or cerebellum after both cervical[124,125] and lumbar[126,127] transforaminal injections. More evidence for the role of particulate steroids in these injuries has come forth, including reports that the effectiveness of nonparticulate steroidal preparations, such as dexamethasone, may be similar to that of particulate preparations.[128–130] Our previous recommendations regarding transforaminal injections have been modified based on these studies plus the US Food and Drug Administration Safe Use Initiative and are presented in Table 8.

CES, Local Anesthetic Neurotoxicity, and Arachnoiditis

Since the 2008 practice advisory,[3,4] there has been relatively little new data on CES, local anesthetic neurotoxicity, and arachnoiditis—topics that we have loosely combined because of commonality to a presumed etiology that involves neural tissue toxicity. Recommendations specific to these entities are summarized in Table 9.

Cauda Equina Syndrome

Injury to the cauda equina manifests as bowel and bladder dysfunction with various degrees of bilateral lower extremity weakness and sensory impairment. There are multiple etiologies for CES, ranging from neural element compression from hematoma, abscess, or herniated intervertebral discs to poorly understood

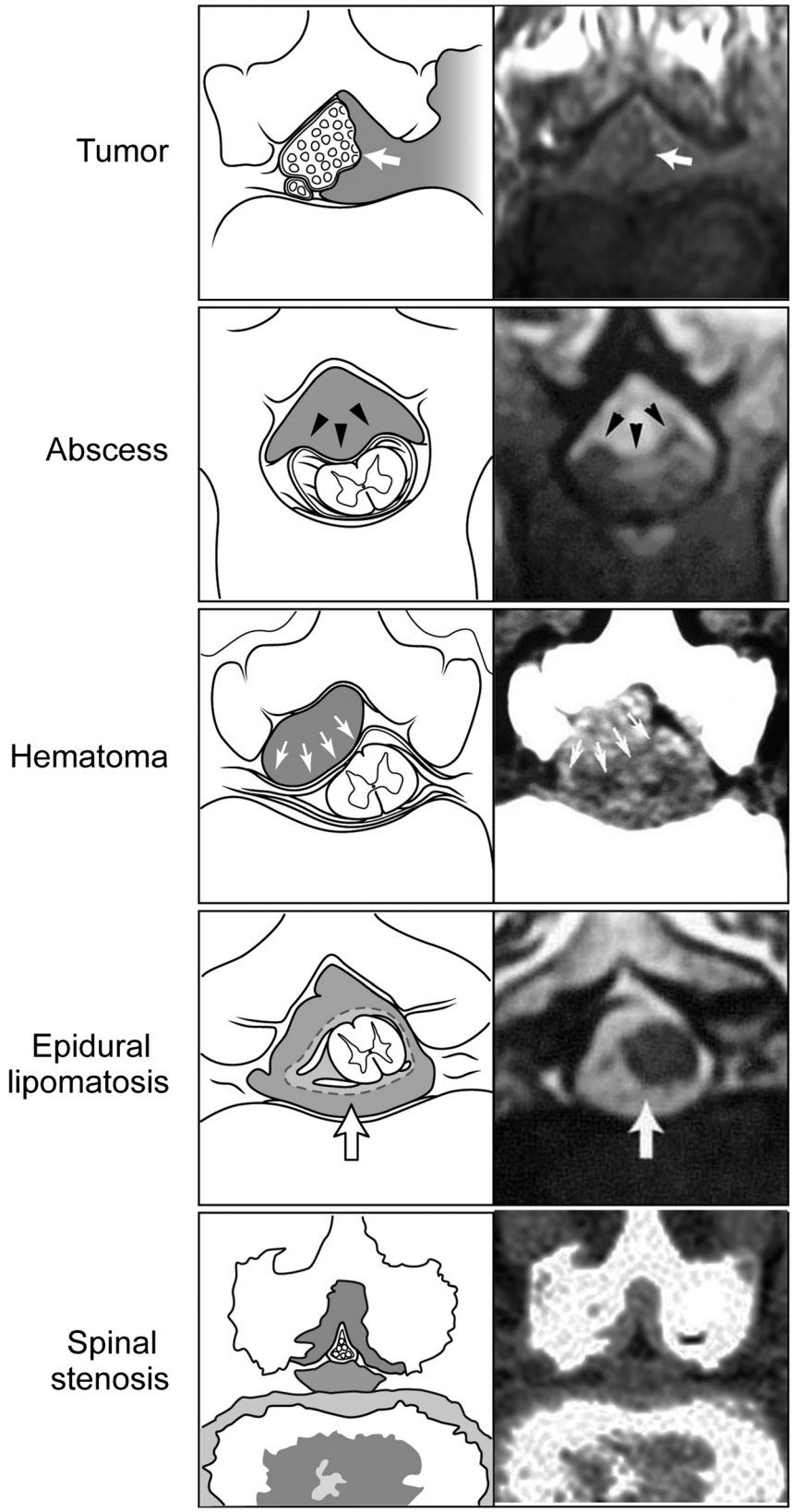

FIGURE 1. Extradural mass lesions. Note how various conditions can reduce spinal canal cross-sectional area and either directly compress the spinal cord or the cauda equina (arrows) or increase epidural space or cerebrospinal fluid pressures through their mass effect. Illustration by Gary J. Nelson. Reproduced with permission from Neal and Rathmell, Complications in Regional Anesthesia and Pain Medicine.[117]

TABLE 7. Recommendations: Blood Pressure Control During Neuraxial Anesthesia

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

- Local anesthetics, adjuvants, and their combination have variable effects on SCBF. Reduction of SCBF in the presence of local anesthetics and adjuvants typically mirrors reduction in metabolic demand secondary to spinal cord anesthesia. There is no evidence that either intravenous or intrathecal epinephrine or phenylephrine adversely affect SCBF (Class I).
- Our understanding of the LLA of SCBF has evolved recently, based on inferences gained from cerebral LLA studies. Rather than the previously accepted cerebral LLA at a MAP of 50 mm Hg in humans, many experts now believe the cerebral LLA in unanesthetized adults is 60 to 65 mm Hg MAP. There is wide variability of LLA among subjects. Preexisting hypertension seems to be a poor predictor of LLA except at the extremes of hypertension, for example, systolic pressure >160 mm Hg (Class II).
- Case reports attest to an extremely small subset of patients who have sustained cerebral or spinal ischemia associated with periods of severe or prolonged low blood pressure. These rare events stand in stark contrast to the common perioperative occurrence of relative hypotension that does not result in spinal cord ischemia. Presumably, injury does not manifest in most patients because of a physiologic reserve that exists between the LLA and blood pressure thresholds below which neurologic injury occurs (Class III).
- When the LLA of SCBF is approached, specific patient conditions may increase the risk of injury. Such conditions include reduced blood oxygen carrying capacity, impairment of SCBF from obstructing anatomic lesions, and/or increased spinal cord CSF pressure (Class I).
- In the absence of compelling reasons to manage a patient otherwise, we recommend that blood pressures during neuraxial anesthesia be maintained in normal ranges or at least within 20% to 30% of baseline MAP. When MAP goes below these parameters, we recommend that it not be allowed to persist at those levels. Although these recommended parameters are arbitrary, they are inferred based on large population studies that have linked both degree and duration of hypotension to perioperative cerebral, renal, or myocardial injury (Class II).
- When neuraxial anesthesia or analgesia is followed by unexpectedly prolonged sensory or motor blockade, recrudescence of weakness or sensory changes after initial block resolution, or neural blockade outside of the expected distribution of the intended procedure, the anesthesiologist must rule out reversible causes in an expedient manner. At the physician's judgment, this may entail a reduction or discontinuation of local anesthetic infusion and reexamination of the patient within an hour or immediate neuroimaging to exclude a compressive process (hematoma or abscess). If imaging is ordered, MRI is preferable to CT, but the diagnosis should not be delayed if only CT is available. However, if CT rules out a compressive lesion, subsequent MRI will be necessary if spinal cord ischemia is suspected (Class I).
- If imaging rules out an operable mass lesion and spinal cord ischemia is suspected, practitioners should ensure at least normal blood pressure or consider inducing high-normal-range blood pressure. The efficacy of CSF pressure modulation via lumbar drains in anesthesia/interventional pain medicine–related spinal cord ischemia is unknown, but the technique is widely used to treat surgery-related spinal ischemia and seems safe in the setting of ischemic spinal cord injury (Class III).
- The role of corticosteroids in anesthesia-related injuries is unknown. Corticosteroids may have a beneficial effect after direct spinal cord trauma resulting from interventional procedures. However, the potential benefits for these patients should be balanced against the associated risk of corticosteroid-associated hyperglycemia, that is, hyperglycemia worsens brain (and presumably, spinal cord) ischemic injury. We do not recommend the use of corticosteroids for ischemic spinal cord injury. Definitive diagnosis and treatment are best determined in consultation with neurology or neurosurgery colleagues (Class III).

presentations associated with normal clinical settings. Known risk factors for anesthetic-related CES are supernormal doses of intrathecal local anesthetic and/or the maldistribution of local anesthetic spread within the intrathecal space. In recent years, reported cases of CES have been associated with previously undiagnosed spinal stenosis.[25,26,28,51] In theory, a tight spinal canal may lead to pressure-induced spinal cord ischemia or limit normal local anesthetic distribution within the intrathecal sac, thereby exposing the cauda equina to high drug concentrations. Either of these conditions could promote local anesthetic neurotoxicity and could be exacerbated by additional compromise of the spinal canal, as may occur with non-neutral surgical positioning. In addition to these pathophysiologic explanations for CES, there seems to exist a subset of patients who suffer CES after receiving a standard neuraxial anesthetic. The advisory panel speculates that these patients might represent an extremely rare subset of patients who are predisposed to neurotoxicity from clinically appropriate doses of local anesthetic and/or who develop neural inflammation in response to the local anesthetic, adjuvant, needle trauma, surgical positioning, or factors unrelated to the anesthetic.[13] Table 9 presents our recommendations regarding CES, which include risk-to-benefit consideration of neuraxial anesthesia in patients with known severe lumbar spinal stenosis, and to avoid exceeding the maximum recommended dose of intrathecal local anesthetic in the setting of a failed, partial, or maldistributed spinal anesthetic.

Local Anesthetic Neurotoxicity

Controversy remains as to whether transient neurologic symptoms (TNS) after spinal anesthesia are a forme fruste of local anesthetic neurotoxicity. Regardless, since the 2008 advisory, further clinical experience has come forth concerning TNS and intrathecal 2-chloroprocaine (2-CP).[131,132] These studies suggest that the risk of TNS is very low when using 40 to 50 mg intrathecal 2-CP. Spinal 2-CP remains off-label in the United States; in 2013, a 1% 2-CP solution was approved for intrathecal use in Europe. Although the risk of TNS from 2-CP is low, there are insufficient data for the advisory panel to make recommendations with regard to 2-CP and CES. Indeed, 1 patient who received 2-CP in a recent study developed a transient case of incomplete CES that was confirmed by positive nerve conduction study and electromyography.[132]

Arachnoiditis

New to this iteration of the practice advisory is a discussion regarding arachnoiditis. This poorly understood diffuse inflammatory reaction of the meninges is classically associated with nonanesthetic conditions, such as infection, trauma, contrast media, or multiple back surgeries. Cases of arachnoiditis that stem directly from a neuraxial anesthetic, if they exist, are extremely rare and most likely related to an idiosyncratic reaction to an unknown provocation. Nevertheless, concern has recently been

TABLE 8. Recommendations: Transforaminal Injection Techniques

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

- To avoid direct injection into critical structures, final position of an immobile needle during transforaminal injection should be confirmed by injecting contrast medium under real-time fluoroscopy and/or digital subtraction imaging, using adequate radiologic views, before injecting any substance that may be hazardous to the patient (Class III).
- Because of the significantly higher risk of catastrophic neurologic injuries associated with cervical transforaminal injections, particulate steroids should not be used in therapeutic cervical transforaminal injections (Class III).
- Although the risk of neurologic injury is markedly lower when performed at lumbar levels, a nonparticulate steroid (eg, dexamethasone) should be used for the initial injection in lumbar transforaminal epidural injections (Class III).
- Particulate steroids can be considered under some circumstances for lumbar transforaminal injections, for example, after failure to respond to treatment with a nonparticulate steroid (Class III).

raised regarding the possibility of antiseptic solutions, particularly chlorhexidine/alcohol mixtures, causing arachnoiditis. The evidence for these concerns is circumstantial at best. Conversely, a retrospective cohort study of more than 12,000 patients reported no increased risk in neuraxial complications with the use of chlorhexidine as the skin disinfectant.[60] Furthermore, an in vitro study found chlorhexidine at clinically used concentrations no more cytotoxic that povidone-iodine and calculated that, if allowed to dry, any residual chlorhexidine carried by the block needle tip from skin to subarachnoid space would be diluted 1:145,000.[133] Based on the superiority of chlorhexidine as an antiseptic agent, the advisory panel stands with other national organizations in recommending it as the skin disinfectant of choice before neuraxial procedures.[7,27,134] Table 9 summarizes our recommendations, which include allowing chlorhexidine/alcohol mixtures to fully dry (2–3 minutes) before starting the procedure and maintaining complete physical separation of chlorhexidine (or any disinfectant solution) or its applicator devices from aseptic equipment so as to avoid drip or splash contamination of needles, syringes, or drugs.[13]

Procedures on Anesthetized or Deeply Sedated Patients

One of the more controversial recommendations from our previous advisory concerns performing regional anesthetics or interventional pain medicine procedures on patients receiving general anesthesia or who are "deeply sedated to the point of being unable to recognize and/or report any sensation that the physician would interpret as atypical during block placement."[1,4] This topic is a good example of how groups of equally qualified experts can analyze the same limited data set and arrive at different advices, as is the case with North American and European interpretations of this topic. In the interim since our last advisory, a number of large registries from the United States and Europe[30,56,135] have reaffirmed our previous recommendation that placing peripheral and neuraxial nerve blocks in anesthetized children seems not to increase injury above baseline risk estimates (which are derived mostly from studies of awake adults). Similarly, a report from the ASA Closed Claims study pointed to an apparent increased injury rate in those patients who underwent cervical interventional pain medicine procedures while anesthetized or deeply sedated.[124] We believe that this report also reaffirms our previous advice not to routinely perform regional anesthetic or interventional pain medicine procedures in anesthetized or deeply sedated adult patients. Despite the controversy surrounding this topic, the panel views wakefulness as yet another monitor of patient well-being during procedural interventions and as such suggests that wakefulness could be considered a component of vigilant patient care, just as ultrasound guidance, PNS, and expert observation are.[13] Recommendations for performing procedures on anesthetized or deeply sedated patients are presented in Table 10.

ANATOMY AND PATHOPHYSIOLOGY OF PNI

The pathophysiology and etiology of PNI associated with regional anesthetic techniques are exquisitely complex topics. Yet understanding these mechanisms is crucial if anesthesiologists are to develop risk avoidance strategies. Since the 2008 practice advisory,[4] further studies have added to our understanding of how peripheral nerve microanatomy influences PNI. Similar knowledge gains have occurred regarding the relative roles of nerve localization and monitoring technologies. Although the next section of this article will summarize existing and new knowledge

TABLE 9. Recommendations: CES, Local Anesthetic Neurotoxicity, and Arachnoiditis

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

- Initial dosing or redosing of subarachnoid local anesthetic in excess of the maximum recommended dose may increase the risk of spinal cord or spinal nerve root neurotoxicity and should be avoided. In addition, maldistribution (usually sacral) of local anesthetic spread should be ruled out before redosing single-injection or continuous subarachnoid blocks (Class I).
- The risks and benefits of neuraxial techniques should be considered in patients known to have moderate-to-severe spinal stenosis, especially if within the vertebral territory of the intended injection (Class II).
- The incidence of TNS after 40 to 50 mg intrathecal 2-chloroprocaine seems to be remarkably low. The number of 2-chloroprocaine spinal anesthetics reported in the literature is insufficient to determine the risk for CES or other manifestations of neurotoxicity (Class III).
- Physically and temporally separate disinfectant use from block trays and instruments during neuraxial procedures. Allow the solution to completely dry on skin before needle placement (2–3 min). Care should be taken to avoid needle or catheter contamination from chlorhexidine spraying or dripping, or from applicator device disposal, onto aseptic work surfaces (Class II).

TABLE 10. Recommendations: Performing Neuraxial Techniques in Anesthetized or Deeply Sedated* Patients

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

- **Monitoring and Prevention:** There are *no data to support the concept that ultrasound guidance of needle placement reduces the risk of neuraxial injury* in patients under general anesthesia or deep sedation (Class II).
- **Adult Neuraxis:** Warning signs such as paresthesia or pain on injection of local anesthetic inconsistently herald needle contact with the spinal cord. Nevertheless, some patients do report warning signs of needle-to-neuraxis proximity. General anesthesia or deep sedation removes any ability for the patient to recognize and report warning signs. This suggests that neuraxial regional anesthesia *or interventional pain medicine procedures* should be performed rarely in adult patients whose sensorium is compromised by general anesthesia or deep sedation. *Adult patients with specific conditions (eg, developmental delay, multiple bone trauma) may be appropriate exceptions to this recommendation after consideration of risk vs benefit (Class III)*.
- **Pediatric Neuraxis:** The benefit of ensuring a cooperative and immobile infant or child *likely outweighs* the risk of performing neuraxial regional anesthesia in pediatric patients during general anesthesia or deep sedation. The overall risk of neuraxial anesthesia should be weighed against its expected benefit *(Class I)*.

Recommendations contained within Table 10 have been modified from our 2008 advisory.[1] Significant changes are in *italics*.

**Anesthetized* refers to patients under general anesthesia. *Deep sedation* is defined as the patient being sedated to the point of being unable to recognize and/or report any sensation that the physician would interpret as atypical during block placement.

related to nerve injury pathophysiology, readers who desire a more complete understanding of this complicated topic are referred to the detailed supporting article contained within this series.[10]

Anatomic Considerations

Anesthesiologists are increasingly aware of the importance of peripheral nerve microanatomy as a key determinant of PNI risk. Nerve axons are bundled as fascicles and enveloped within the perineurium, which consists of layers of tightly fitting perineurial cells that prevent diffusion of potentially toxic substances into the fascicle and also partially protect against mechanical injury. Multiple fascicles are surrounded by a permeable epineurium, which contains the fascicles plus various amounts of interfascicular connective tissues that occupies an ever-increasing proportion of the nerve's cross-sectional area as the nerve extends proximally to distally. This relative abundance of distal connective tissue explains why intraneural, but extrafascicular, needle tip placement is more likely to reside in a noncritical (ie, nonfascicular) portion of the nerve. Thus, neural microanatomy seems to correlate with ultrasound-enabled clinical observations that block needles were intraneural (subepineurium, but extraperineurium) more often than was previously assumed, but that this unanticipated occurrence was not associated with clinical evidence of PNI in most patients.[136]

Pathophysiology of PNI

The traditional mechanisms of PNI have been described in animal models as mechanical, injection, ischemic, and/or neurotoxic.

TABLE 11. Recommendations: Needle Tip Location, Choice of Local Anesthetic, and Nerve Localization Techniques

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

Needle Tip Location, Choice of Local Anesthetic, and Paresthesia

- Intraneural needle insertion does not invariably lead to functional nerve injury (Level 3)
- Intrafascicular needle insertion and injection should be avoided because it can cause histological and/or functional nerve injury (Level 2)
- Paresthesia during needle advancement or on injection of local anesthetic is not entirely predictive of PNI (Level 3)

Nerve Localization Techniques

- There are no human data to support the superiority of 1 nerve localization technique over another with regard to reducing the likelihood of PNI (Level 3)
- *Peripheral Nerve Stimulation*
  - Presence of an evoked motor response at a current of <0.5 (0.1 ms) indicates intimate needle-nerve relationship, needle-nerve contact, or an intraneural needle placement (Level 2)
  - Absence of a motor response at current of up to 1.8 mA does not exclude needle-nerve contact or intraneural needle placement (Level 3)
- *Injection Pressure* Monitoring
  - Animal data have linked high injection pressures to subsequent fascicular injury, but there are no human data that confirm or refute the effectiveness of injection pressure monitoring for limiting PNI (Level 2)
  - Injection pressure monitoring can detect needle-nerve contact for interscalene brachial plexus block (Level 3)
  - The common practice of subjectively assessing injection pressure by "hand feel" is inaccurate (Level 3)
- *Ultrasound*
  - Ultrasound can detect intraneural injection (Level 2)
  - Current ultrasound technology does not have adequate resolution to discern between an interfascicular and intrafascicular injection (Level 2)
  - Adequate images of needle-nerve interface are not consistently obtained by all operators and in all patients (Level 2)

Levels of evidence are based on the 2011 Oxford construct.[18]

Forceful needle-to-nerve contact and/or injection into the nerve are believed to set in motion a series of events that might lead to ischemia or neurotoxicity. Needle trauma to or rupture of the perineurium is believed to negate the fascicle's protective environment, which then becomes a crucial contributory factor in determining the likelihood and severity of subsequent PNI. Direct application of (otherwise innocuous) local anesthetic to denuded axons can cause acute inflammatory reactions or neurotoxicity. Such insults are magnified in the setting of a disrupted perineurium[137,138] and prolonged exposure to the local anesthetic (as might occur with vasoconstrictive adjuvants, which reduce drug clearance). If the needle does not completely disrupt the perineurium, injection can transiently elevate intraneural pressure and lead to ischemia. Bleeding around the nerve or microhematoma within the nerve can also lead to ischemia. Lastly, nonspecific inflammatory responses can affect single or multiple nerves and at sites proximate to or distant from the surgical site. Such inflammatory changes have been observed during surgical nerve bypass procedures for permanent phrenic nerve injuries associated with interscalene block.[139]

Etiology of PNI

The etiology of PNI continues to evoke explanations that include anesthetic, surgical, patient-related, or a combination of factors thereof. The evidence for the significance of these factors is summarized in Table 4.

Anesthetic Risk Factors

Recent large studies fail to link peripheral nerve block as an independent risk factor for perioperative nerve injury either in the general operative setting[73] or in total joint arthroplasties.[70–72] Nevertheless, PNI does occur as a consequence of anesthetic techniques. Controversy continues regarding the concept of *intentional* intraneural injection for the purpose of achieving more rapid onset of denser peripheral nerve blockade. Published reports of intentional intraneural injection have noted no nerve injuries, albeit in patient numbers too small to prove safety.[140,141] Similarly, several small clinical studies have also reported no PNI despite *unintentional* intraneural injection.[136,142] Nevertheless, the advisory panel interprets the majority of animal and human PNI studies as supporting the concept that anesthesiologists should not purposefully seek needle-to-nerve contact[143] or intentional intraneural injection.

Surgical Risk Factors

Most surgical injuries are thought to occur from traction, stretch, transection, or compression injuries. These factors were reviewed in the previous section on surgically related neurologic complications.

Patient Risk Factors

Factors that place patients at an increased risk for anesthesia-related PNIs include metabolic, hereditary, toxic, and entrapment neuropathies and other preexisting neurologic injuries/conditions. Diabetic neuropathy is of particular concern because it seems to increase PNI at least 10-fold as compared with the general population.[26] A large general surgical population study identified peripheral vascular disease, smoking, vasculitis, and hypertension as independent risk factors for perioperative nerve injury.[73]

The Role of Nerve Localization and Monitoring Techniques

Paresthesia

A single randomized clinical trial did not support the elicitation of paresthesia as a risk factor for PNI.[80] The absence of a paresthesia does not reliably exclude the possibility of needle-to-nerve contact nor does it prevent PNI. Nevertheless, severe paresthesia that occurs with needle advancement or injection should prompt the cessation of either maneuver, and repositioning of the needle should be considered.

Peripheral Nerve Stimulation

Peripheral nerve stimulation is characterized by low sensitivity, but high specificity, for needle-to-nerve contact. When a motor response occurs at a low current output, such as 0.2 mA or lower, one cannot reliably discern if the needle tip is abutting the nerve or is subepineurial.[10,144] Conversely, current output greater than 0.5 mA is generally associated with extraneural needle placement,[141,145] although reports exist of intraneural needle tip placement at currents approaching 2.0 mA.

Injection Pressure Monitoring

Interest continues in the controversial practice of injection pressure monitoring. The clinical usefulness of this monitoring modality remains poorly defined. Avoidance of high resistance to injection seems to be a reasonable strategy during peripheral nerve blockade because studies consistently show that low opening pressures (<15 psi) are associated with injection into non-neural tissues. However, injection pressure monitoring seems to be most valuable as a negative predictor of PNI, that is, low injection pressure correlates with no PNI, but high injection pressure is not consistently linked to PNI. Unfortunately, anesthesiologists cannot reliably discern injection pressure based on syringe feel alone.[146,147] With regard to direct pressure monitoring systems, studies suggest that the technique cannot reliably detect intraneural intrafascicular injection and that needle-to-nerve contact and intrafascicular injection can be indistinguishable from each other.[148–150]

Ultrasound Guidance

Ultrasound guidance has not been associated with a reduction of PONS or long-term PNI.[21,22,33] The inability of ultrasound to reduce nerve injury may stem from technical and/or training limitations in discerning nerve from surrounding tissues (insufficient resolution to distinguish fascicles from connective tissue) or it may be related to anesthesiologists attempting to place the needle as close to the nerve as possible, thereby potentially increasing the risk for unintended subepineurial injection. Recent studies suggest that injecting local anesthetic adjacent to the brachial plexus, rather than within the fascial sheath, results in equivalent neural blockade.[151]

In summary, PNI is a diverse and complicated entity that may be associated with anesthetic, surgical, patient-related, or a combination of risk factors. In recent years, ultrasound studies have demonstrated that anesthesiologists place block needles within the nerve much more frequently than previously imagined and that most of these occurrences are not associated with PNI. The practice advisory panel interprets the weight of animal and human evidence to support the practice of avoiding needle placement that abuts or enters the nerve. Although there is no evidence that PNS, ultrasound, or pressure monitoring can prevent PNI, the panel believes it reasonable to consider using several of these modalities in combination when appropriate. Our advice is tempered by our limited knowledge of those factors that most influence PNI and recognition that those factors vary with the specific nerve involved, the peripheral block performed, and with unique patient and surgical factors. Recommendations regarding nerve localization techniques are presented in Table 11.

PATIENTS WITH PREEXISTING NEUROLOGIC DISEASE

The "double-crush" theory was first proposed by Upton and McComas[152] in 1973. The theory maintains that patients with preexisting neurologic compromise anywhere along the neural pathway may be at increased susceptibility for subsequent nerve injury from a secondary low-grade insult such as might occur during the perioperative period from surgery or anesthetic causes. Moreover, the resultant nerve damage may exceed the additive effects of 2 low-grade injuries[153] (Fig. 2). Preexisting neurologic conditions, many of them subclinical, might set the stage for subsequent double-crush scenarios, including such broad etiologies as mechanical, ischemic, toxic, metabolic, and autoimmune conditions. Preexisting neurological conditions have historically led to recommendations not to perform regional anesthetics.[154] The intent of our practice advisory was to analyze and summarize current evidence so that clinicians and their patients can make better informed decisions when presented with the conundrum of whether or not to offer regional anesthetic or interventional pain medicine procedures to patients with preexisting neurologic disease.

Although new information on the issue of performing regional anesthetic techniques in patients with preexisting neurologic disease is limited, this evidence reinforces our previous recommendations regarding patients with diabetes mellitus and spinal stenosis. Furthermore, there is a substantial amount of new information on postsurgical inflammatory neuropathies (PSINs). More detailed discussion on the topic of performing blocks in

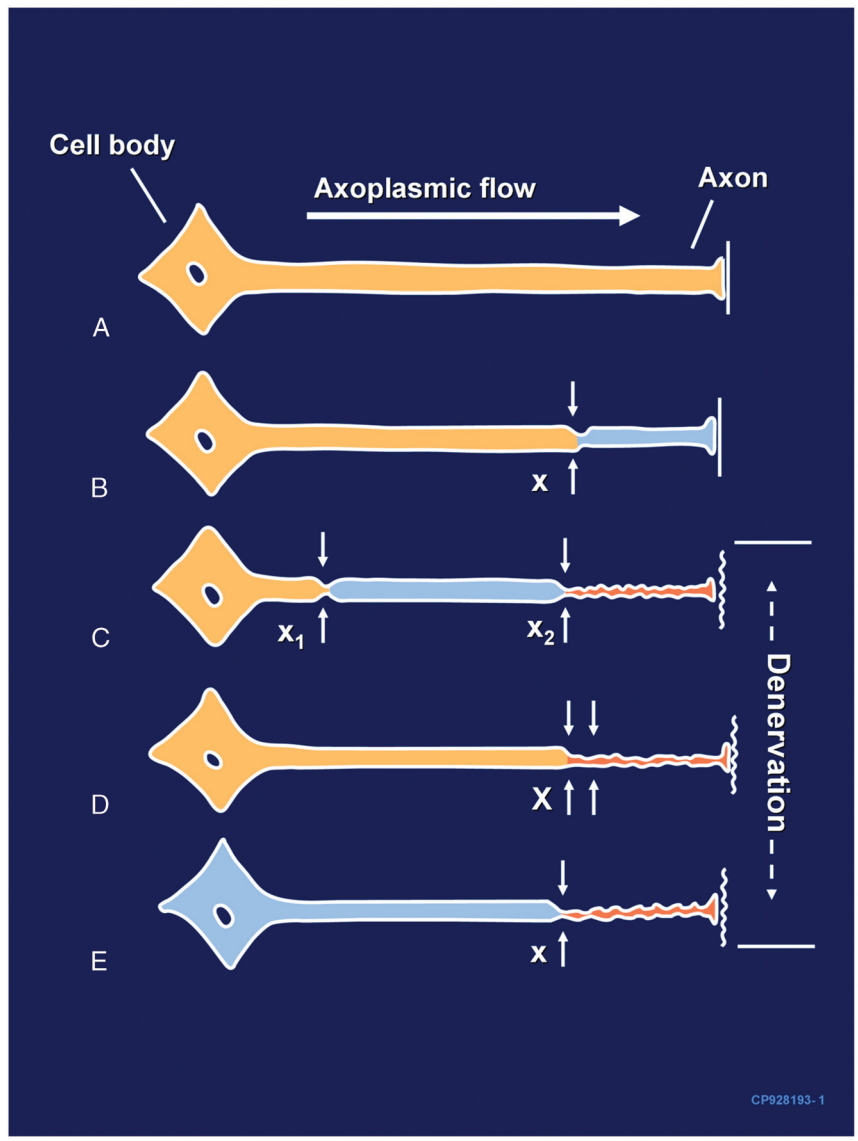

FIGURE 2. Neural lesions resulting in denervation. Axoplasmic flow is indicated by the degree of shading. Complete loss of axoplasmic flow results in denervation (C, D, E). A, Normal neuron. B, Mild neuronal injury at a single site (x) is insufficient to cause denervation distal to the insult. C, Mild neuronal injury at 2 separate sites (x1 and x2) may cause distal denervation (ie, "double crush"). D, Severe neuronal injury at a single site (X) may also cause distal denervation. E, Axon with a diffuse preexisting underlying disease process (toxic, metabolic, ischemic) may have impaired axonal flow throughout the neuron, which may or may not be symptomatic, but predisposes the axon to distal denervation after a single minor neural insult at x (ie, "double crush"). By permission of Mayo Foundation for Medical Education and Research.

patients with preexisting neurologic disease is contained in the supporting article by Kopp et al.[16]

Preexisting Peripheral Nervous System Disorders

Peripheral neuropathies are either hereditary or acquired. The most common inherited disorders are from the collective category of Charcot-Marie-Tooth (CMT) disease, which affects approximately 1 in 2500 humans. A few case reports and small case series describe the use of either peripheral or central regional anesthetic techniques in CMT patients without apparent worsening of their underlying condition. However, clinical evidence is too sparse to allow for definitive recommendations other than if a regional technique is chosen; extra precautions should be taken to minimize other surgical or anesthetic risk factors. Most patients with preexisting peripheral nervous system disease have acquired peripheral neuropathies such as diabetes mellitus or chemotherapy-induced neuropathies.

Diabetic Polyneuropathy

Diabetes mellitus is associated with several types of neuropathies, but distal symmetric sensorimotor polyneuropathy (diabetic polyneuropathy or DPN) is most common and is present in up to 50% of long-standing diabetic patients. Although animal studies[155,156] consistently report that diabetic nerve fibers are more sensitive to the blocking effects of local anesthetics and may have increased susceptibility to local anesthetic neurotoxicity, it is unclear if these findings are clinically relevant in humans. A small number of clinical studies attest to higher peripheral nerve block success rates in diabetic patients,[157] but such increased sensitivity to local anesthetics may not necessarily reflect increased susceptibility to neurotoxicity. However, a single-institution study reported that 0.4% (95% CI, 0.1%–1.3%) of patients with sensorimotor neuropathy or DPN who underwent spinal anesthesia subsequently developed new or progressive postoperative neurologic deficits, which is a higher incidence than that observed in the institution's general surgical population.[49] Although this finding does not absolutely link spinal anesthesia to increased risk in patients with DPN, it does suggest that the anesthetic may have been a contributing factor. Another area of concern in patients with DPN involves nerve localization technique; diabetic nerves are less sensitive to electrical stimulation, which theoretically increases the risk of intraneural needle placement when localizing nerves using a PNS.[158] Although ultrasound guidance has not decreased the rate of PONS in the general population, it is possible that the advantages of ultrasound guidance—facilitating avoidance of intentional needle-nerve contact and reducing local anesthetic volume—may eventually prove beneficial in at-risk populations such as diabetic patients.[21] In summary, patients with DPN may be more susceptible to double-crush injury, but current clinical evidence is suggestive rather than definitive. Nevertheless, we recommend that, in profoundly symptomatic patients, consideration be given to limiting local anesthetic concentration and/or dose, avoidance of adjuvant epinephrine,[159] and ultrasound guidance to maintain needle tip distance from the nerve.

Chemotherapy-Induced Neuropathy

Approximately 30% to 40% of patients who receive neurotoxic chemotherapeutic agents (eg, cisplatin, vincristine, paclitaxel) develop peripheral neuropathy. The risk of nerve injury is increased further in those patients with preexisting neuropathic changes from diabetes mellitus or alcoholism. Many of these chemotherapy-induced neuropathies are subclinical. A note of concern pertinent to these patients was raised by an isolated case report of severe brachial plexopathy after peripheral nerve blockade in a patient with subclinical chemotherapy-induced neuropathy.[160]

Inflammatory Neuropathies

The inflammatory neuropathies include Guillain-Barré syndrome (GBS) and recently highlighted postsurgical inflammatory neuropathies (PSIN). Most case reports of GBS come from (usually successful) use of neuraxial blockade in obstetric patients. However, major concerns include the potential for autonomic instability and consequent exaggerated responses to neuraxial blockade and reactivation of previously dormant GBS symptoms, both of which have been reported.[16] There are too few data to make recommendations on GBS and concurrent regional anesthetic techniques other than to suggest that decisions be made on an individualized basis that accounts for risk and benefit.

Postsurgical Inflammatory Neuropathies

There is growing awareness of inflammatory etiologies for perioperative nerve injuries, including Parsonage-Turner syndrome,[161] lumbosacral radiculoplexus neuropathies,[162] and PSIN.[163,164] Distinguishing features of these neuropathies include their delayed appearance (within 30 days of surgery, although some may be apparent immediately), which is usually followed by a period of normal recovery. Clinical presentation also includes signs and symptoms outside of the expected location of anesthetic blockade or surgery and a period of intense pain out of proportion to what would be expected from the surgery, which then resolves, only to be followed by weakness. Postsurgical inflammatory neuropathy is thought to be an immune-mediated idiopathic response to a physiologic stress, such as infection, vaccination, or surgery.[164] The associated neurologic deficits may be focal, multifocal, or diffuse. The greatest risk of PSIN is surgeons and anesthesiologists not considering its diagnosis and, in so doing, delaying potentially useful therapies. When patients present with this constellation of symptoms, urgent neurological consultation is warranted. Although the natural history without treatment is one of probable slow recovery, once diagnosed, many neurologists recommend suppressing the immune response with prolonged high-dose steroids or immunoglobulin to minimize the immune-mediated nerve injury, although such therapies have not been proven. In contradistinction from much perioperative nerve injury, most patients with PSIN improve with treatment if diagnosed early.

Preexisting Central Nervous System Disorders

As with preexisting peripheral nervous system disease, anesthesiologists historically were reluctant to offer regional anesthetic–based techniques to their patients with preexisting CNS diseases.[154] Although modern data are limited, most studies of the general surgical population[50] and obstetrics[165,166] have not found that regional techniques place most patients with active disease at risk for new or worsening symptoms. Despite these reassuring findings, the decision to perform neuraxial anesthetic or interventional pain medicine procedures in patients with preexisting CNS disease still demands risk-to-benefit consideration.

Multiple Sclerosis

The focal demyelination that characterizes multiple sclerosis (MS) contributes to its classic "waxing and waning" pattern. When coupled with known perioperative stressors that can worsen the disease process, such as hyperpyrexia, infection, and/or emotional stress, it is often difficult to sort out the causes for perioperative progression or new onset of MS-related symptoms. Although classically considered a CNS disease, some portion of patients (from 5% to 47%)[167,168] also have peripheral demyelination. The clinical significance of peripheral MS is unclear because there are very few case reports that link MS to injury after peripheral nerve blockade.[169] Conversely, there are case series that support the

general safety of neuraxial anesthesia in parturients with MS.[165,170] Importantly, the obstetric model may not be ideal because MS patients have diminished frequency of relapse during pregnancy but an increased rate postpartum. To maximize safety in obstetric patients, it is recommended that the dose and concentration of local anesthetic be limited. Epidural anesthesia is considered safer than spinal anesthesia because it does not deposit local anesthetic directly adjacent to the CNS (ie, the spinal cord).

Postpolio Syndrome

Postpolio syndrome (PPS) is the most prevalent motor neuron disease in North America. The largest series (n = 79) of PPS patients to receive neuraxial anesthesia documented no worsening of symptoms.[50] Nevertheless, the paucity of data on these patients suggests that the risk and benefit of a neuraxial technique be balanced against that of general anesthesia.

Amyotrophic Lateral Sclerosis

The greatest perioperative risks of amyotrophic lateral sclerosis (ALS) are respiratory and/or neurologic deterioration. A few case reports attest to the apparent safety of neuraxial or peripheral blockade in ALS patients,[16] but these reports are insufficient for general recommendations. As with other CNS preexisting diseases, the risk and benefit of regional techniques should be balanced against those of general anesthesia.

Spinal Canal Pathology

Emerging concerns regarding patients with spinal stenosis were discussed in the section on neuraxial pathophysiology.[13] With regard to previous spine surgery, a recent publication reported no evidence that these patients were at risk for developing new or progressive neurologic deficits when they underwent spinal anesthesia.[58] Although previous spinal surgery should not be considered a contraindication to neuraxial anesthetic or interventional pain medicine techniques, consideration might be given to preprocedure imaging to better define relevant anatomy, deformity, and/or surgical implants.[58]

Neural Tube Defects

Congenital neural tube defects may present at birth as open spinal dysraphisms (eg, meningocele or meningomyelocele) or closed spinal dysraphisms, which range from isolated defects of posterior vertebral column closure (spina bifida occulta) or more serious malformations such as diastematomyelia (split cord malformations), tethered spinal cord syndrome, or dural ectasia (lumbosacral widening or caudad displacement of the dural sac). A few case reports have described successful spinal or epidural anesthesia in parturients who previously underwent surgical correction of open spinal dysraphisms. These cases were characterized by extensive cranial spread of a dense local anesthetic block, with limited caudad spread below the site of surgical correction. Thus, if the decision is made to provide neuraxial anesthesia in this subset of patients, it is recommended that the block needle is inserted cephalad to the original lesion.

The closed spinal dysraphisms are challenging because the proceduralist or patient may not always be aware of the defect. Failure of a single vertebral arch to fuse (isolated spinal bifida occulta) is common in the general population (10%–24%).[171] It is recommended that needle insertion occur above the level of spinal abnormality, assuming its presence is known. A total of 11 cases of successful epidural anesthetics using normal doses of local anesthetic have been reported in isolated spina bifida patients.[16] In contrast, patients with complex spina bifida should not receive neuraxial anesthesia. This recommendation is based on reports of neurologic complications in patients who underwent a variety of neuraxial techniques; in some of those cases, the defect was unrecognized before the procedure. Patients with complex spina bifida often have associated conditions, such as cutaneous manifestations over the level of abnormality, involvement of more than 1 lamina, or associated bowel, bladder, or neurologic symptoms. If the presence of a neural tube defect is known or suspected, the underlying neuroanatomy should be documented with radiographic imaging before considering a neuraxial technique. We recommend that complex closed spinal dysraphisms be considered a contraindication to neuraxial techniques. In patients with spina bifida occulta, neuraxial techniques may be considered after appropriate risk (technical difficulties, dural puncture, or atypical local anesthetic spread) is balanced against perceived benefit.

Recommendations for performing neuraxial or peripheral anesthesia/analgesia procedures in patients with preexisting neurologic disease are presented in Table 12.

DIAGNOSIS AND TREATMENT

Since our 2008 advisory,[4,5] new information has evolved concerning postoperative inflammatory neuropathies. We have added new information on acute interventions that may possibly improve neurologic outcome, both acutely and in relation to long-term management of the neuropathic pain that occasionally results from these injuries. We have updated our previous algorithm that contains a structured approach to diagnosis and initial management (Fig. 3). Although this advisory focuses on nonhemorrhagic and noninfectious neurologic complications, these entities will be briefly noted throughout this section for both completeness and perspective. Readers are encouraged to refer to the ASRA practice advisories on these topics for details[7,8] and should seek the most up-to-date versions of these works. Summary articles are available on the ASRA Web site (www.asra.com).

Timely Recognition of Perioperative Nerve Injury

Early recognition and appropriate stratification of suspected perioperative nerve injury into those that require emergent imaging and/or neurologic evaluation are of paramount importance to afford patients the best opportunity for full or partial recovery, especially in the case of neuraxial injuries. Nonetheless, our current advisory[15] notes multiple barriers to appropriate recognition of perioperative nerve injury, including such factors as neurologic deficits being masked by sedation, concurrent analgesics, or continuous catheter use; the absence of ambulatory patient follow-up; or delayed recognition of sensorimotor deficits until after hospital discharge, which has been reported to occur in up to 90% of patients undergoing lower extremity arthroplasty.[70,71] Delayed recognition is more likely to be associated with nonoperative causes of nerve injury, such as immobilization, dressing compression, infection, or inflammation. Such delays also confound the patient's perception of onset. In the "blur" that accompanies typical perioperative events, patients can incorrectly report their symptoms as presenting immediately after surgery despite objective documentation of onset at 48 hours, as for example with perioperative ulnar nerve injury.[172] The complexity of perioperative recognition, the absolute imperative in some cases to diagnose and treat emergently, and operators' unique understanding of the expected consequences of their procedure, all speak to the advisability of direct, candid, and timely conversation between the anesthesiologist or pain physician and the neurologic consultant.[15]

Diagnosis and Treatment of Neuraxial Complications

Certain signs and symptoms after neuraxial blockade should raise suspicion for perioperative nerve injury. Weakness that is

TABLE 12. Recommendations: Regional Anesthesia in Patients With Preexisting Neurologic Disease

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

Peripheral Nervous System Disorders

Hereditary Peripheral Neuropathies

- Patients with CMT disease and hereditary neuropathy with liability to pressure palsy may have clinical or subclinical evidence of a preexisting peripheral neuropathy due to neural compromise from the disease state (Class I).
- Anecdotal case reports and small case series suggest that both peripheral and neuraxial regional techniques may be used in patients with stable CMT or hereditary neuropathy with liability to pressure palsy disease states without worsening their neurologic symptoms. However, a careful discussion regarding the potential risks and benefits of performing regional anesthesia in patients with preexisting neural compromise is strongly recommended (Class III).

Acquired Peripheral Neuropathies

- Patients with diabetic peripheral neuropathy or previous exposure to chemotherapy (eg, cisplatin or vincristine) may have clinical or subclinical evidence of a preexisting peripheral neuropathy caused by neural compromise from the disease state (Class I).
- An abundance of animal data and limited clinical data support the concern that diabetic nerves are more sensitive to local anesthetics and perhaps more susceptible to injury. Therefore, peripheral and neuraxial blockade may theoretically increase the risk of new or progressive neurologic deficits in patients with diabetic peripheral neuropathy (Class II).
- When regional anesthesia is thought to be appropriate in patients with acquired peripheral neuropathy (eg, diabetic peripheral neuropathy or chemotherapy-induced neuropathy), consideration should be given to modify the anesthetic technique (ie, decreasing the concentration of local anesthetic, reducing the total dose of local anesthetic, eliminating or reducing the concentration of vasoconstrictors such as epinephrine) to minimize the potential additive risk (Class II).
- The use of ultrasound guidance may facilitate (a) perineural needle placement and (b) a reduction in the total dose (volume) of local anesthetic administered. However, clinical data demonstrating a reduction in neurologic injury with ultrasound guidance are currently lacking (Class II).

Inflammatory Neuropathies

- Patients with inflammatory neuropathies such as GBS and PSIN are at risk of new or worsening neurologic deficits during the postoperative period regardless of anesthetic technique (Class II).
- Neural compromise secondary to acute neuronal inflammation may be a relative contraindication to regional anesthesia. However, the existing literature can neither support nor refute this claim. Therefore, the decision to perform neuraxial or peripheral nerve blockade in patients with inflammatory neuropathies should be made on an individual basis after a thorough discussion of the potential risks and benefits with the patient (Class III).

CNS Disorders

- Patients with CNS disorders (eg, MS, PPS, ALS) may have clinical or subclinical evidence of a preexisting neurologic deficit caused by neural compromise from the disease state. Furthermore, it is not uncommon for patients with CNS disorders to experience worsening of their neurologic symptoms during the postoperative period regardless of the anesthetic technique (Class I).
- Anecdotal case reports and small case series suggest that neuraxial anesthesia and analgesia may be used in patients with stable neurologic symptoms without worsening their neurologic deficits. However, *definitive* evidence supporting this practice is lacking. Therefore, a careful discussion regarding the potential risks and benefits of performing regional anesthesia in patients with preexisting neural compromise is strongly recommended (Class II).

Spinal Canal Pathology

Previous Spine Surgery

- Prior spine surgery is not a contraindication to the performance of neuraxial anesthesia or analgesia. However, before performing a regional technique, a review of the patient's radiologic imaging or the use of fluoroscopy could be useful to identify the optimal approach to the neuraxis (Class I).
- Under most clinical circumstances, spinal anesthesia may be (a) technically easier to perform and (b) more reliable (ie, higher success rates) than epidural techniques in patients who have previously undergone spine surgery. Patients undergoing neuraxial anesthesia or analgesia after previous spine surgery do not seem to be at higher risk of new or progressive neurologic deficits (Class II).

Neural Tube Defects

- Neural tube defects encompass a wide range of spinal cord malformations, including both open (eg, meningocele, meningomyelocele) and closed (eg, spina bifida occulta, tethered spinal cord syndrome, diastematomyelia, dural ectasia) spinal dysraphisms. Patients with neural tube defects may have clinical or subclinical evidence of a preexisting neurologic deficit caused by neural compromise from the disease state (Class I).
- Because of the wide range and severity of possible spinal cord and vertebral column malformations, patients with neural tube defects should undergo radiographic imaging to fully evaluate and define the extent of their disease state before considering neuraxial anesthesia or analgesia (Class II).
- Anecdotal case reports and small case series suggest that the performance of neuraxial anesthesia and analgesia in patients with complex closed spinal dysraphisms (ie, tethered spinal cord syndrome or diastematomyelia) may result in new or progressive neurologic symptoms. However, *definitive* evidence suggesting an increased risk of neurologic complications is lacking (Class II).
- Anecdotal case reports and small case series suggest that neuraxial anesthesia and analgesia may be used in patients with *isolated* spina bifida occulta (without associated tethered spinal cord syndrome or diastematomyelia) without an increased risk of neurologic injury. However, *definitive* evidence supporting this practice is lacking. Therefore, a careful discussion regarding the potential risks (technical difficulties, unpredictable local anesthetic spread, inadvertent dural puncture, and neural injury) and benefits of performing regional anesthesia in patients with *isolated* spina bifida occulta is strongly recommended (Class II).

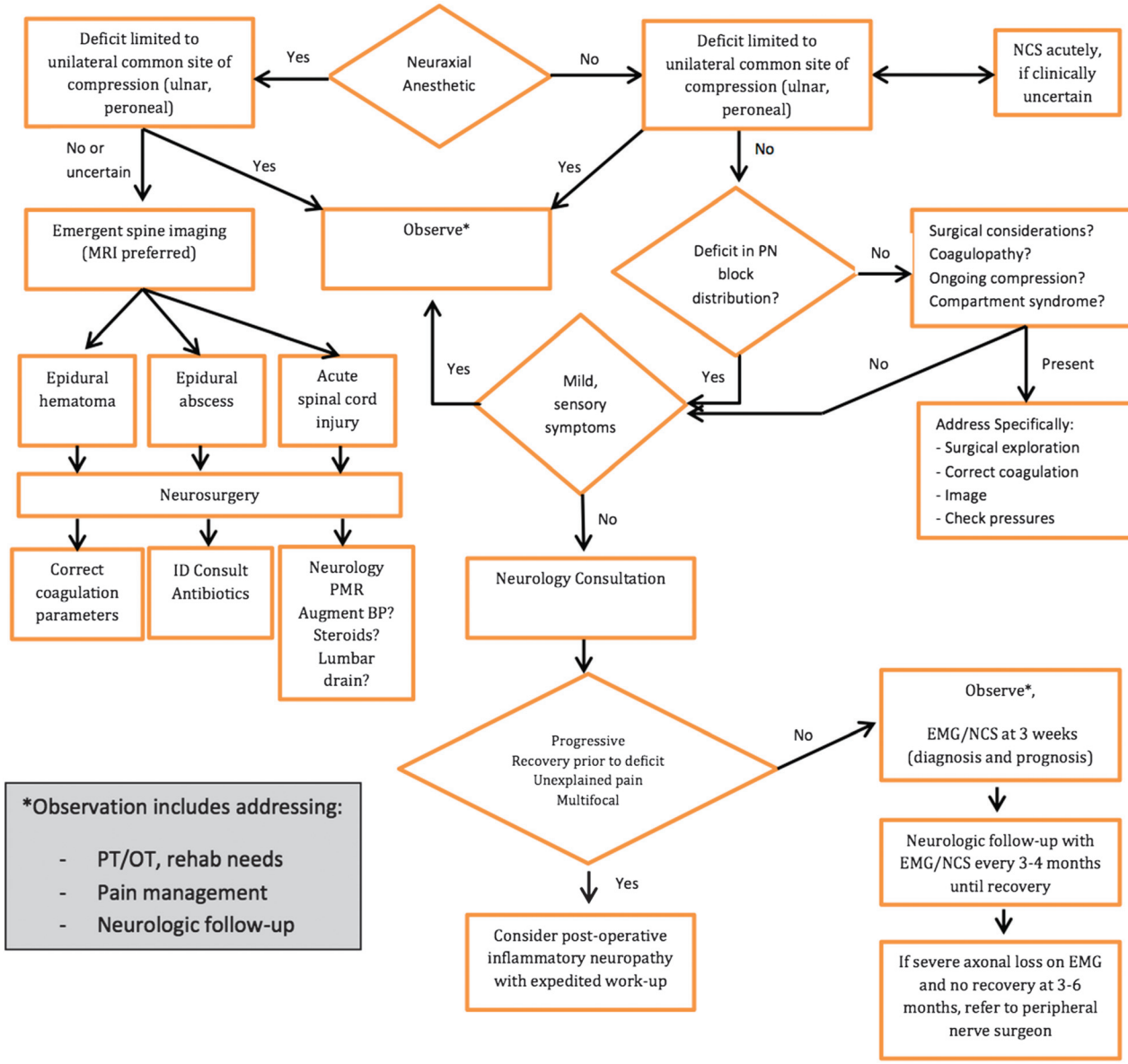

FIGURE 3. Algorithm for the diagnosis and initial therapy of perioperative nerve injuries. PN indicates peripheral nerve; NCS, nerve conduction studies; EMG, electromyography; PMR, physical medicine rehabilitation specialty consultation; BP, blood pressure. From Watson and Huntoon.[15] Used with permission.

more intense than expected, recurrent after initial resolution, progressive, and/or in an area inconsistent with the block (eg, lower leg or foot weakness associated with a thoracic epidural) can be the first presenting symptoms of a significant neuraxial injury.[36,173–175] Back pain is observed less frequently, whereas bowel or bladder symptoms are late. For those mass lesions amendable to emergent surgical decompression, full (40%–66%) or partial recovery is possible if decompression occurs within 8 to 12 hours of symptom onset, although a recent study challenges this assumption.[61] The severity of neurologic deficit at the time of intervention also predicts outcome.[176–178] Frequently noted in medicolegal claims[36] is the failure of anesthesiologists to recognize and begin management of a neuraxial complication in a timely manner—all too often, neurologic deficits are wrongly attributed to the block itself. Inappropriate delays are all the more likely when unenlightened surgical or nursing personnel manage the patient in the absence of anesthesiologist expertise. When injury is suspected, magnetic resonance imaging (MRI) differentiates soft tissues, identifies coexisting spinal canal pathology, and locates an aberrantly placed catheter more effectively than does computerized tomography (CT). However, in the absence of immediately available MRI, an emergent CT scan can identify those space-occupying compressive processes most amenable to emergent surgical decompression (ie, spinal abscess or hematoma).

Table 13 presents the characteristics of neuraxial injury presentation that may aid differential diagnosis. Epidural hematoma is associated temporally with needle/catheter placement or catheter removal and in 75% of cases will have a fulminant presentation within 24 hours.[177] Conversely, spinal epidural abscess or meningitis may have an insidious presentation—a delay of several days

TABLE 13. Differential Diagnosis of Neuraxis Injuries Associated With Anesthetic or Pain Medicine Techniques

	Epidural Abscess	Spinal Hematoma	Anterior Spinal Artery Syndrome	Direct Spinal Cord Trauma
Age of patient	Any age	50% older than 65 y	Any age, but mostly elderly	Any age, but often younger
Previous history	Infection*	Anticoagulants	Arteriosclerosis, abnormal blood pressure	Difficult spinal anatomy
Onset	1–3 d	Sudden	Sudden	Sudden or occult
Generalized symptoms	Fever, malaise, back pain	Sharp, transient back pain and leg pain	None	Paresthesia, especially with injection, or none
Sensory involvement	None or paresthesias	Variable	Minor, patchy–sparing posterior columns (proprioception)	Dermatomal or diffuse paresthesia
Motor involvement	Flaccid paralysis, later spastic	Flaccid paralysis	Flaccid paralysis	Possible weakness or none
Segmental reflexes	Exacerbated*–later obtunded	Abolished	Abolished acutely–later signal change anterior two thirds of cord	Variable
CT scan/MRI	Signs of extradural compression	Signs of extradural compression	Normal acutely	Edema or hemorrhage, needle track
Laboratory data	Rise in inflammatory markers	Clotting abnormality	Normal	Normal

Modified from Wedel and Horlocker.[179] Used with permission.
*Infrequent findings.

after the procedure, followed by indolent fever and back pain, followed by rapid progression to paralysis. Accurate diagnosis and therapy are important because spinal epidural abscess/meningitis have a 15% mortality; earlier diagnosis is also associated with less severe neurologic deficits.[180] Anterior spinal artery syndrome may be heralded by back pain at the level of infarction and bilateral radicular discomfort in 75% of cases, with typically rapid progression to paraplegia or tetraplegia that spares the posterior columns (vibration and proprioception).[181] Complete recovery is extremely rare. Direct spinal cord trauma from needles or catheters may present with unilateral or bilateral symptoms, depending on the anatomical lesion site. If the only symptom after suspected direct trauma is a persistent paresthesia that is nonprogressive and improving, observation alone may be warranted. However, more widespread sensory symptoms (ie, nondermatomal) or motor involvement should prompt MRI and possible neurologic consultation.

In summary, early recognition and appropriate intervention can improve outcome in those patients who have suffered a hemorrhagic, infectious, or inflammatory insult. Unfortunately, the same cannot be said for ischemic, local anesthetic neurotoxic, and/or direct mechanical injury causes. Recommendations for the diagnosis and treatment of neuraxial injuries are presented in Tables 14 and 15.

Diagnosis and Treatment of Peripheral Nerve Complications

Similar to neuraxial injuries, the diagnosis and treatment of PNIs should be approached urgently to rule out potentially correctable lesions, such as from extrinsic or intrinsic compression

TABLE 14. Recommendations: Diagnosis of Perioperative Nerve Injury

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

Neuraxial Injury

- In the setting of neuraxial anesthesia, any concern of spinal cord dysfunction requires emergent neuroimaging (Level I).
- Magnetic resonance imaging is the preferred imaging modality. However, imaging should not be delayed to arrange MRI or to get neurologic consultation. Computerized tomography or CT myelography are acceptable as initial imaging to exclude a compressive lesion (Level I).
- Diagnosis of a compressive lesion (epidural hematoma or spinal epidural abscess) within or near the neuraxis demands emergent neurosurgical consultation for consideration of decompression (Level I).

Peripheral Nerve Injury

- Neurologic consultation is recommended for complete nerve injuries (complete absence of nerve function), incomplete injuries with moderate to severe functional limitations, or progressive neurologic dysfunction (Level I).
- An inflammatory postsurgical neuropathy should be considered if there are multifocal, progressive deficits, unexplained excessive pain despite standard perioperative analgesia and neurologic deficits developing after a period of return to neurologic baseline postoperatively. Neurologic consultation should be considered (Level II).
- Electrodiagnostic studies (EMG and nerve conduction studies) may help confirm neuropraxia with conduction block or define preexisting disease when performed acutely. Axonal loss (prognostic) and the extent of a perioperative neurogenic injury will be better clarified by electrodiagnostic studies performed 3 wk after injury (Level I).

Levels of evidence are based on the 2011 Oxford construct.[18]
EMG indicates electromyography.

TABLE 15. Recommendations: Treatment of Perioperative Nerve Injury

These recommendations are intended to encourage optimal patient care but cannot ensure the avoidance of adverse outcomes. As with any practice advisory recommendation, these are subject to revision as knowledge advances regarding specific complications.

- Outcomes for compressive lesions (epidural hematoma or spinal epidural abscess) are dependent on the severity of neurologic impairment and the duration of symptoms at the time of neurosurgical decompression. Most experts agree that neurologic recovery is improved with early decompression (<8–12 h from symptom onset in epidural hematoma and <36 h from symptom onset for spinal epidural abscess) and when the preoperative neurologic deficits are milder in severity (Level I).
- Neuropathic pain is reasonably treated pharmacologically (Level I).
- Functional deficits from neurological injuries should be rehabilitated in concert with rehabilitation specialists (Level II).
- Nerve lesions that fail to resolve 3–5 mo after initial neurologic evaluation should prompt consideration of consultation with a peripheral nerve neurosurgeon (Level II).
- If imaging rules out an operable mass lesion and spinal cord ischemia is suspected, practitioners should ensure at least normal blood pressure or consider inducing high-normal-range blood pressure. The efficacy of CSF pressure modulation via lumbar drains in anesthesia/interventional pain medicine–related spinal cord ischemia is unknown, but the technique is widely used to treat surgical spine ischemia and seems safe in the setting of ischemic spinal cord injury (Class III).
- The role of corticosteroids in anesthesia-related injuries is unknown. Corticosteroids may have a beneficial effect after direct spinal cord trauma and possibly trauma resulting from interventional procedures. However, the potential benefits for these patients should be balanced against the associated risk of corticosteroid-associated hyperglycemia, that is, hyperglycemia worsens brain (and presumably, spinal cord) ischemic injury. We do not recommend the use of corticosteroids for ischemic spinal cord injury. Definitive diagnosis and treatment are best determined in consultation with neurology or neurosurgery colleagues (Class III).

Levels of evidence are based on the 2011 Oxford construct.[18]

(casts, dressings, compartment syndrome, visible hematoma, or occult perineural microhematoma). If a hematoma is suspected, urgent imaging or ultrasonography should be considered. Acute surgical injury should also be ruled out by engaging the surgeon in candid discussion regarding the possibility of nerve transection, excessive traction, or wayward ligatures. Indeed, 1 review reported that more than 90% of surgically explored iatrogenic nerve injuries were linked to intraoperative causes.[182] The goal of timely consultation is to alleviate potentially correctable causes or nonsurgical or anesthesia-related etiologies, such as stroke. Once the need for immediate treatment has been ruled out, the diagnosis of PNI can proceed as directed by initial presenting symptoms (Fig. 3). Pure sensory deficits that occur within the territory of the peripheral block[74] or a classic compression point, for example, common peroneal nerve compression at the fibular head, can be observed and are expected to resolve within days to weeks. However, neurologic consultation should be considered when the deficit involves motor function, is progressive, is characterized by recrudescence of neural blockade, or is difficult to localize and/or reconcile with the expected distribution of the anesthetic block or surgery. Electrophysiologic studies for more severe or unclear cases are typically delayed for 2 to 3 weeks, when signs of Wallerian degeneration first appear. However, early electrophysiologic studies may we worthwhile to define preexisting pathology. Bilateral studies may be indicated if occult conditions are suspected to affect the nonoperative side. Such decisions are best made in consultation with a neurologist. When no or incomplete improvement has taken place by 3 to 5 months, consideration should be given for referral to a peripheral nerve surgeon. Recommendations for the diagnosis and treatment of PNIs can be found in Tables 14 and 15.

Postsurgical Inflammatory Neuropathies

Postsurgical inflammatory neuropathies were discussed previously in the preexisting neurologic disease section. When patients present with this symptom complex in the postsurgical period, urgent neurologic consultation is warranted.

Management of Chronic Pain After Perioperative Nerve Injury

A subset of patients who sustain perioperative nerve injury will develop chronic neuropathic pain. The pain medicine physician is often called on to provide long-term symptomatic management of these patients and to assume coordination of patient education, expectation, and physical therapy. New to this advisory are evidence-based recommendations for the care of these challenging patients, some of whom may have unanswered questions or unrealistic expectations consequent to suboptimal communication with various practitioners during the immediate postoperative episode.

Postsurgical neuropathic pain syndromes may result from surgical injury, such as intercostal neuritis after thoracotomy, or may be consequent to neural blocks administered during the perioperative period. There are several considerations for when it might be appropriate to refer patients with persistent postsurgical pain to a pain medicine specialist—severe pain out of proportion to that expected from a specific surgical procedure; pain that limits patient function; or pain that is progressive, multifocal, and/or difficult to localize. Other signs that should prompt early referral are those consistent with chronic regional pain syndrome, such as neurologic impairment in an area remote from the regional block, surgery, or compression or physical signs such as allodynia, edema, or hyperhidrosis. Readers are referred to the supporting article's[15] detailed recommendations regarding stepwise pharmacologic therapies for these patients, as well as reasonable indications for the use of diagnostic nerve blocks, such as stellate ganglion block. The evidence for neuromodulation therapy is less conclusive; the European Federation of Neurological Societies supports the use of spinal cord stimulation for chronic regional pain syndrome,[183] although there are no supporting studies specific to postsurgical neuropathic pain.

In summary, the diagnosis and treatment of neuraxial injuries demands emergent stratification of those injuries that may be amenable to surgical decompression. Although the management of PNIs is less urgent (particularly when sensory predominant), practitioners are reminded that severe, progressive, or difficult-to-localize deficits demand urgent neurologic consultation to exclude potentially treatable causes such as from compressive etiologies. If

a treatable cause is excluded, there is little that the physician can do to change the course of these injuries. However, pain physicians have a useful role to play in coordinating education, expectation management, and pain modulation in those patients who develop chronic neuropathic pain from their injury.

CONCLUSIONS

The Second ASRA Practice Advisory on Neurologic Complications Associated With Regional Anesthesia and Pain Medicine provides a number of updates to the 2008 advisory. New information has been presented on the incidence of nerve injury inherent to common elective orthopedic surgeries. The advisory contains updated information regarding the pathophysiology of neuraxial and peripheral nerve injury. New or expanded information is presented, particularly with regard to spinal canal pathology, blood pressure control during neuraxial anesthetics, neurotoxicity-related neuraxial injuries, transforaminal pain medicine procedures, and the advisability of performing procedures in anesthetized or deeply sedated patients. The advisory also expands recommendations related to the diagnosis and treatment of these disorders.

Our final conclusion is very similar to that made in 2008: "Neurologic complications associated with regional anesthesia and pain medicine are rare—particularly those complications that do not involve hematoma or infection. Understanding the pathophysiology and risk factors associated with neuraxial and peripheral nerve injury may allow anesthesiologists to minimize the number of adverse neurologic outcomes. Unfortunately, even with flawless care of otherwise healthy patients by well-trained physicians, these complications are neither completely predictable nor preventable. This practice advisory offers a number of recommendations specific to common clinical scenarios encountered in everyday practice."[4]

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APPENDIX 1. Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence

Levels of Evidence for Treatment Benefits/Does This Intervention Help?	
Level 1	Systematic review of randomized trials or *n*-of-1 trials
Level 2	Randomized trial or observational study with dramatic effect
Level 3	Nonrandomized controlled cohort/follow-up study
Level 4	Case series or case-control studies or historically controlled studies
Level 5	Mechanism-based reasoning

From the Oxford Centre for Evidence-Based Medicine.[18]

APPENDIX 2. Strength of Recommendations

Classification	
Class I	Animal and/or human evidence and/or general agreement of expert opinion supports the effectiveness and usefulness of the recommendation.
Class II	The weight of conflicting evidence and/or the weight of expert opinion supports the usefulness of the recommendation.
Class III	The usefulness of the recommendation is limited by absent or conflicting evidence and/or divergent expert opinion.

This classification system is significantly modified from the American College of Cardiology/American Heart Association construct for classifying strength of evidence.[19]