Neurological Complications After Regional Anesthesia: Contemporary Estimates of Risk

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BACKGROUND: Regional anesthesia (RA) provides excellent anesthesia and analgesia for many surgical procedures. Anesthesiologists and patients must understand the risks in addition to the benefits of RA to make an informed choice of anesthetic technique. Many studies that have investigated neurological complications after RA are dated, and do not reflect the increasing indications and applications of RA nor the advances in training and techniques. In this brief narrative review we collate the contemporary investigations of neurological complications after the most common RA techniques.

METHODS: We reviewed all 32 studies published between January 1, 1995 and December 31, 2005 where the primary intent was to investigate neurological complications of RA.

RESULTS: The sample size of the studies that investigated neurological complications after central and peripheral (PNB) nerve blockade ranged from 4185 to 1,260,000 and 20 to 10,309 blocks, respectively. The rate of neuropathy after spinal and epidural anesthesia was 3.78:10,000 (95% CI: 1.06–13.50:10,000) and 2.19:10,000 (95% CI: 0.88–5.44:10,000), respectively. For common PNB techniques, the rate of neuropathy after interscalene brachial plexus block, axillary brachial plexus block, and femoral nerve block was 2.84:100 (95% CI 1.33–5.98:100), 1.48:100 (95% CI: 0.52–4.11:100), and 0.34:100 (95% CI: 0.04–2.81:100), respectively. The rate of permanent neurological injury after spinal and epidural anesthesia ranged from 0–4.2:10,000 and 0–7.6:10,000, respectively. Only one case of permanent neuropathy was reported among 16 studies of neurological complications after PNB.

CONCLUSIONS: Our review suggests that the rate of neurological complications after central nerve blockade is <4:10,000, or 0.04%. The rate of neuropathy after PNB is <3:100, or 3%. However, permanent neurological injury after RA is rare in contemporary anesthetic practice.

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Regional anesthesia (RA) is associated with multiple benefits compared to general anesthesia, including reduced morbidity and mortality (1–5), superior postoperative analgesia (6–11), and enhanced cost effectiveness (12). However rare, neurological injury after RA can be distressing to patients and their families. Many of the studies that have addressed the incidence of neurological injury after RA are decades old and focused on neuraxial blockade (13–21). These dated studies may not reflect technical advances in central (CNB) and peripheral (PNB) nerve blockade. Although formal postgraduate training programs (22), consensus conference recommendations (23), new block techniques (24–30), and new local anesthetics (31) may enhance the safety of RA, the increasing prevalence of risk factors for nerve injury [e.g., obesity (32), diabetes (33), potent anticoagulants (23)] and the increasing use of continuous catheter-based PNB may alter the rate of neurological complications. The American Society of Anesthesiologists Closed Claims Project provides the most contemporary and comprehensive collection of adverse events associated with RA practice in the United States (34); however, the lack of a denominator prevents the calculation of the incidence of complications. Because nerve injury after RA is uncommon, prohibitively large numbers of patients are required for study in cohort to capture the incidence of neurological complications. Much of the available literature is restricted to retrospective reviews and surveys of anesthesiologists, both of which may be limited by under-reporting of complications. The objective of this brief narrative review is to gather and consolidate recent studies of neurological complications after RA to assist anesthesiologists and patients alike to more accurately understand risks.

METHODS

A MEDLINE search was performed using the medical subject heading (MeSH) words "anesthesia, spinal," "anesthesia, epidural," and "nerve block," each

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limited to the MeSH subheading "adverse effects." Search results were then cross-referenced with each of the MeSH heading words "nervous system diseases" and "postoperative complications." Final search results were limited to English language studies published within the past 10 yr (between January 1, 1995 and December 31, 2005). Only studies in which the stated objective was to investigate neurological complications of RA were considered for the present review. Studies focused on the pediatric population were excluded. The reference sections of all relevant publications were examined to capture any additional material suited for the present review. For CNB, only studies with a minimum sample of 1000 spinal or epidural anesthetics were included. The quality of evidence for each study was graded (highest to lowest: I–III) according to the criteria described by Harris et al. (Appendix) (35).

Only adverse neurological sequelae reportedly related to or associated with the regional anesthetic are addressed in this review. Local anesthetic toxicity (characterized by seizures), transient neurological symptoms (characterized by temporary severe radicular back pain upon resolution of spinal anesthesia) (36), and epidural hematoma and abscess are discussed in detail elsewhere (37–42) and are not addressed in this review.

The rate of neurological injury reported by cohort studies is herein expressed as "incidence," and the rate of neurological injury described by case–control studies and surveys is expressed as "frequency." Because the clinical presentation of neuropathic symptoms can vary after nerve blockade (21,43), and because the timing of assessment varied between and within each study reviewed, the highest reported rate for each complication is recorded below (henceforth termed "rate of occurrence"). The rate of each neurological complication after CNB is expressed as *n*:10,000, and the rate of neuropathy after PNB is expressed as *n*:100. For the purpose of this review, permanent nerve injury is defined as neurological deficit lasting more than 12 mo (henceforth termed "rate of permanent injury").

Confidence intervals (CI) were calculated for each complication cited in the source studies according to the method described by Zar (44). We used a meta-analysis random effects general linear model to determine aggregate estimates of the rate of occurrence and corresponding 95% CI for each complication pooled from all applicable source studies. The statistical model used was Poisson regression with γ-distributed random effects. For each complication, the Cochran Q test was applied to determine the heterogeneity between the source studies. Significance was considered at $P < 0.05$. All statistical analyses were performed using Comprehensive Meta-Analysis Version 2.0 statistical software (Biostat, Englewood, NJ).

RESULTS

Our MEDLINE search method yielded 235 results, of which 32 studies met our inclusion criteria. The quality of evidence score (Appendix) (35) for all 32 studies included in this review was grade II-2. Tables 1 and 2 list the rates and 95% CI for neurological complications associated with the most common CNB and PNB techniques, respectively. To summarize the data listed in Tables 1 and 2, the aggregate estimated rate of occurrence and corresponding 95% CI for each complication calculated using a random effects model are presented in Tables 3 and 4. For most of the complications considered herein, we found significant heterogeneity among the source studies (Tables 3 and 4). Figures 1 and 2 demonstrate the disparity between the aggregate estimated rates of occurrence of neurological complications after the various CNB and PNB techniques, respectively.

Neuraxial Blockade

The largest contemporary comprehensive study of neurological complications after CNB was published by Moen et al. (51) in 2004. The large, albeit approximate, number of CNBs (1,260,000 spinal and 450,000 epidural anesthetics) captured reflects the long study period (1990–99) as well as the authors' efforts to accumulate data from multiple sources, including a postal survey to anesthesiologists, the national Swedish database for mandatory reporting of adverse events, and that country's predominant manufacturer of neuraxial local anesthetics. The next largest study was conducted by Aromaa et al. (46) in 1997. These authors collected all claims of neurological complications associated with CNB that were reported by patients to Finland's legislated no-fault patient compensation insurance program between 1987 and 1993, and retrospectively estimated the total number of CNBs administered in that country (550,000 spinal and 170,000 epidural anesthetics) over the same time period. Scott and Tunstall (50) performed a prospective survey that captured 14,856 obstetrical spinal anesthetics and 108,133 obstetrical epidural anesthetics performed between 1990 and 1991 in 79 obstetrical units across the United Kingdom. The next two largest comprehensive studies of neurological complications after CNB were performed by Auroy et al. (45,47) These two widely cited studies prospectively surveyed hundreds of practicing anesthesiologists in France to determine the frequency of major complications associated with all RA techniques. In addition to gathering the most extensive data on complications after PNB, Auroy et al. included 40,640 spinal and 30,413 epidural anesthetics performed in 1994 (47) and 41,079 spinal and 35,293 epidural anesthetics performed in 1998–1999 (45).

Moen et al. (51) reported that the overall frequency of severe neurological complications after spinal anesthesia was approximately 0.4:10,000. Auroy et al.

Table 1. Neurological Complications After Neuraxial Blockade

Neurological complication	Study design	Number of occurrences	Number of blocks performed	Rate of occurrence (n = 10,000)	Number of permanent injuries	Rate of permanent injury (n = 10,000)	Remarks
Spinal anesthesia							
Radiculopathy/peripheral neuropathy							
Auroy 2002 (45)	P	11	41,079[a]	2.68 (1.51–4.79)	?	—	Most cases resolved by 3 wk.
Aromaa 1997 (46)	R	25	550,000[b]	0.45 (0.31–0.66)	7	0.13 (0.06–0.26)	
Auroy 1997 (47)	P	43	40,640	10.58 (7.87–14.25)	?	—	
Horlocker 1997 (48)	R	6	4,767	12.59 (5.90–27.37)	2	4.20 (1.30–15.14)	4 cases resolved by 1 wk; 2 cases resolved by 24 mo.
Dahlgren 1995 (49)	P, R	3	8,501	3.53 (1.28–10.31)	3	3.53 (1.28–10.31)	
Scott 1995 (40)	P	8	14,856	5.39 (2.77–10.61)	0	0 (0.02–2.48)	Obstetrical population. All cases resolved by 12 wk.
Cauda equina syndrome							
Moen 2004 (51)	R	20	1,260,000[b,c]	0.16 (0.10–0.24)	20	0.16 (0.10–0.24)	20 cases include 2 continuous catheters.
Auroy 2002 (45)	P	3	41,079[a]	0.73 (0.27–2.13)	?	—	
Aromaa 1997 (46)	R	1	550,000[b]	0.02 (undef–0.10)	1	0.02 (undef–0.10)	
Auroy 1997 (47)	P	5	40,640	1.23 (0.54–2.87)	?	—	
Intracranial event							
Moen 2004 (51)	R	2	1,260,000[b,c]	0.02 (undef–0.06)	?	—	Intracranial subdural hematoma (n = 2).
Auroy 2002 (45)	P	0	41,079[a]	0 (0–0.73)	0	0 (0–0.73)	
Paraplegia							
Moen 2004 (51)	R	1	1,260,000[b,c]	0.01 (undef–0.04)	1	0.01 (undef–0.04)	
Auroy 2002 (45)	P	0	41,079[a]	0 (undef–0.90)	0	0 (undef–0.90)	
Aromaa 1997 (46)	R	5	550,000[b]	0.09 (0.04–0.21)	5	0.09 (0.04–0.21)	
Auroy 1997 (47)	P	0	40,640	0 (undef–0.91)	0	0 (undef–0.91)	
Epidural anesthesia							
Radiculopathy/peripheral neuropathy							
Horlocker 2003 (52)	R	0	4,298	0 (0.06–8.58)	0	0 (0.06–8.58)	Denominator includes 4,298 epidurals placed under GA.
Auroy 2002 (45)	P	0	35,293[d]	0 (undef–1.05)	0	0 (undef–1.05)	
Paech 1998 (53)	P	1	10,995	0.91 (0.22–5.07)	?	—	Obstetrical population.
Aromaa 1997 (46)	R	5	170,000[b]	0.29 (0.13–0.69)	1	0.06 (0.01–0.33)	
Auroy 1997 (47)	P	11	30,413	3.62 (2.04–6.47)	?	—	
Giebler 1997 (54)	P, R	10	4,185	23.89 (13.12–43.89)	0	0 (0.06–8.81)	Denominator includes 4,185 thoracic epidurals. All cases resolved by 3 wk.
Dahlgren 1995 (49)	P, R	7	9,232	7.58 (3.74–15.61)	7	7.58 (3.74–15.61)	
Holdcroft 1995 (55)	P	1	13,007	0.77 (0.19–4.28)	?	—	Obstetrical population.
Scott 1995 (50)	P	38	108,133	3.51 (2.56–4.82)	0	0 (undef–0.34)	Obstetrical population. All cases resolved by 12 wk.
Cauda equina syndrome							
Moen 2004 (51)	R	12	450,000[b,e]	0.27 (0.15–0.47)	12	0.27 (0.15–0.47)	12 cases include 4 CSEs.
Auroy 2002 (45)	P	0	35,293[d]	0 (undef–1.05)	0	0 (undef–1.05)	
Aromaa 1997 (46)	R	1	170,000[b]	0.06 (0.01–0.33)	1	0.06 (0.01–0.33)	
Auroy 1997 (47)	P	0	30,413	0 (undef–1.21)	0	0 (undef–1.21)	
Intracranial event							
Moen 2004 (51)	R	3	450,000[b,e]	0.07 (0.02–0.19)	?	—	Intracranial subdural hematoma (n = 3).
Auroy 2002 (45)	P	0	35,293[d]	0 (undef–1.05)	0	0 (undef–1.05)	
Paraplegia							
Moen 2004 (51)	R	3	450,000[b,e]	0.07 (0.02–0.18)	3	0.07 (0.02–0.18)	
Auroy 2002 (45)	P	0	35,293[d]	0 (undef–1.05)	0	0 (undef–1.05)	
Aromaa 1997 (46)	R	1	170,000[b]	0.06 (0.01–0.33)	1	0.06 (0.01–0.33)	

Continues

Table 1. (continued)

Neurological complication	Study design	Number of occurrences	Number of blocks performed	Rate of occurrence (n = 10,000)	Number of permanent injuries	Rate of permanent injury (n = 10,000)	Remarks
Paraplegia							
Moen 2004 (51)	R	3	450,000[b,e]	0.07 (0.02–0.18)	3	0.07 (0.02–0.18)	
Auroy 2002 (45)	P	0	35,293[d]	0 (undef–1.05)	0	0 (undef–1.05)	
Aromaa 1997 (46)	R	1	170,000[b]	0.06 (0.01–0.33)	1	0.06 (0.01–0.33)	
Auroy 1997 (47)	P	1	30,413	0.33 (0.08–1.83)	1	0.33 (0.08–1.83)	Associated with prolonged hypotension

95% confidence intervals appear in parentheses.

P = Prospective; R = Retrospective; undef = undefined; CSE = combined spinal-epidural; GA = general anesthesia; ? = Insufficient data.

[a] Denominator includes 5640 obstetrical spinal anesthetics.

[b] Denominator is approximate.

[c] Denominator includes 50,000 obstetrical spinal anesthetics.

[d] Denominator includes 29,732 obstetrical epidural anesthetics.

[e] Denominator includes 205,000 obstetrical epidural anesthetics.

noted the overall incidence of serious or major neurological complications after spinal anesthesia to be considerably higher, specifically, 11.8:10,000 in 1994 (47) and in 3.7:10,000 in 1998–1999 (45). At least one reason for this difference is the authors' definition of "severe" (51); and "serious" (47); or "major" (45); neurological complications, that is, Auroy et al. (45,47) included radiculopathy and peripheral neuropathy as complications, whereas Moen et al. (51) did not. After epidural anesthesia, Moen et al. (51) determined the frequency of "severe" neurological complications to be approximately 1.6:10,000, whereas Auroy et al. found the overall incidence of "serious" or "major" neurological complications to be 3.9:10,000 in 1994 (47) and 0.3:10,000 in 1998–1999 (45). For all CNB studies, the present review suggests that spinal anesthesia carries a higher risk of radiculopathy or peripheral neuropathy (3.78:10,000; 95% CI: 1.06–13.50:10,000) compared to epidural anesthesia (2.19:10,000; 95% CI: 0.88–5.44:10,000) (Table 3). The rate of permanent neurological injury ranged from 0–4.2:10,000 and 0–7.6:10,000 after spinal and epidural anesthesia, respectively (Table 1).

Peripheral Nerve Blockade

There are a limited number of contemporary prospective studies in the literature examining the risk of neurological injury after PNB. Most of the available data involves upper extremity, rather than lower extremity, PNB, which reflects the preference for brachial plexus blockade in contemporary RA practice (71). In the two large prospective studies performed by Auroy et al., eight cases of neurological injury were identified among 21,278 PNBs (3.8:10,000) in 1997 (47) and 12 cases among 43,946 PNBs (2.7:10,000) in 1998–1999 (45). In the latter study, neurological symptoms were still present 6 mo after the PNB in 7 of the 12 cases of reported peripheral neuropathy (45). Unfortunately, however, neither of these two studies provides sufficient detail to determine the overall frequency of permanent neurological deficit. For all PNB studies, the present review suggests that interscalene block carries the highest risk of transient neurological deficit, specifically, 2.84:100 (95% CI: 1.33–5.98:100) (Table 4). Among the 16 studies in which complications were sought 12 mo after PNB, only one case of permanent neuropathy was reported (69) (Table 2).

DISCUSSION

As the practice of RA continues to gain popularity both in Europe (72) and North America (71), knowledge of the risks of neurological injury associated with the most common RA techniques is imperative. Historically, nerve injury after CNB is rare. In the 1950–1960s, several large scale studies of neurological complications after CNB were published underscoring the safety of spinal and epidural anesthesia (13–21). In the classic prospective study examining complications of spinal anesthesia, Vandam and Dripps (17) found 71 cases of transient neurological deficit after 10,098 spinal anesthetics. All but 1 of the 71 of these cases resolved, whereas the single case of permanent nerve injury was subsequently deemed unrelated to the spinal anesthetic (14). Dawkins (18) published the classic review of neurological complications after 32,718 epidural anesthetics and reported the frequency of transient and permanent nerve injury to be 0.1% and 0.02%, respectively. It is noteworthy that the incidence of permanent neurological deficit after CNB reported by Dahlgren and Tornebrandt (49) is considerably higher compared to most other studies presently reviewed (Table 1). At least one reason for this discrepancy may be that Dahlgren and Tornebrandt reported all neurological complications (including very mild sensory deficit) suffered by patients of all age groups (including children) and both genders who underwent a wide variety of operations and were often administered continuous epidural infusions postoperatively (49). By contrast, most other studies reviewed included, in all (50,53,55) or in part (45,51,73), young healthy women undergoing obstetrical spinal or epidural anesthesia. In fact, Moen et al. (51) calculated the frequency of severe neurological

Table 2. Neuropathy After Peripheral Nerve Blockade

Author/Year	Study design	Number of occurrences	Number of blocks performed	Rate of occurrence (n = 100)	Number of permanent injuries	Rate of permanent injury (n = 100)	Remarks
Brachial plexus blockade							
Interscalene block							
Candido 2005 (56)	P	31	693	4.47 (3.17–6.28)	0	0 (0.00–0.53)	All cases resolved by 12 wk.
Capdevila 2005 (57)	P	0	256[a]	0 (0.01–1.42)	0	0 (0.01–1.42)	
Borgeat 2003 (24)	P	56	700[a]	8.00 (6.14–10.16)	0	0 (0.00–0.52)	All cases resolved by 6 mo.
Auroy 2002 (45)	P	1	3,459	0.03 (0.01–0.16)	?	—	
Weber 2002 (58)	R	2	218	0.92 (0.28–3.26)	0	0 (0.01–1.67)	
Borgeat 2001 (59)	P	74	520	14.23 (11.49–17.50)	?	—	73 cases resolved by 9 mo. Denominator includes single-injections (n = 286) and continuous catheters (n = 234).
Fanelli 1999 (60)	P	7	171	4.09 (2.03–8.21)	0	0 (0.01–2.12)	All cases resolved by 12 wk.
Supraclavicular block							
Auroy 2002 (45)	P	0	1,899	0 (0.00–0.19)	0	0 (0.00–0.19)	
Axillary block							
Capdevila 2005 (57)	P	0	126[a]	0 (0.02–2.86)	0	0 (0.02–2.86)	
Bergman 2003 (61)	R	2	405[a]	0.49 (0.15–1.77)	?	—	
Auroy 2002 (45)	P	2	11,024	0.02 (0.00–0.07)	?	—	
Hebl 2001 (62)	R	6	100	6.00 (2.83–12.48)	?	—	Axillary block in 100 patients with preexisting ulnar neuropathy. Worsened ulnar neuropathy (n = 6) but no new non–ulnar neuropathy.
Urban 2000 (63)	P	29	131	22.14 (15.89–30.00)	0	0 (0.02–2.76)	All cases resolved by 12 wk.
Fanelli 1999 (60)	P	17	1,650	1.03 (0.65–1.64)	0	0 (0.00–0.27)	All cases resolved by 12 wk.
Horlocker 1999 (64)	R	7	1,614	0.43 (0.21–0.89)	0	0 (0.00–0.23)	Repeated axillary blocks among 607 patients (median 2 blocks per patient within a 13-wk interval). All cases resolved by 20 wk.
Pearce 1996 (65)	P	25	200	12.50 (8.62–17.81)	0	0 (0.01–1.82)	Patient self-report questionnaire. All cases resolved by 6 wk.
Cooper 1995 (66)	P	127	1,149	11.05 (9.37–13.00)	0	0 (0.00–0.32)	Patient self-report questionnaire. All cases resolved by 10 wk.
Stan 1995 (67)	P	2	996	0.20 (0.06–0.72)	0	0 (0.00–0.37)	All cases resolved by 4 wk.
Midhumeral block							
Auroy 2002 (45)	P	1	7,402	0.01 (0.00–0.08)	?	—	
Carles 2001 (27)	P	0	1,468	0 (0.00–0.25)	0	0 (0.00–0.25)	
Lumbar plexus blockade							
Lumbar plexus block							
Capdevila 2005 (57)	P	0	20[a]	0 (0.12–16.11)	0	0 (0.12–16.11)	
Auroy 2002 (45)	P	0	394	0 (0.01–0.93)	0	0 (0.01–0.93)	
Macaire 2002 (68)	R	2	4,319	0.05 (0.01–0.17)	0	0 (0.00–0.09)	
Femoral nerve block							
Capdevila 2005 (57)	P	3	683[a]	0.44 (0.16–1.28)	0	0 (0.00–0.54)	All cases resolved by 10 wk.
Auroy 2002 (45)	P	3	10,309	0.03 (0.01–0.09)	?	—	
Cuvillon 2001 (69)	P	1	211[a]	0.47 (0.01–2.60)	1	0.47 (0.01–2.60)	1 case partial recovery by 12 mo.

Continues

Table 2. (continued)

Author/Year	Study design	Number of occurrences	Number of blocks performed	Rate of occurrence (n = 100)	Number of permanent injuries	Rate of permanent injury (n = 100)	Remarks
Fanelli 1999 (60)	P	45	2,175	2.07 (1.55–2.76)	0	0 (0.00–0.17)	Denominator reported as combined femoral-sciatic block. 44 cases resolved by 12 wk; 1 case resolved by 25 wk.
Sacral plexus blockade							
Sciatic nerve block							
Capdevila 2005 (57)	P	0	32[a]	0 (0.08–10.58)	0	0 (0.08–10.58)	
Auroy 2002 (45)	P	2	8,507	0.02 (0.01–0.08)	?	—	
Fanelli 1999 (60)	P	45	2,175	2.07 (1.55–2.76)	0	0 (0.00–0.17)	Denominator reported as combined femoral-sciatic block. 44 cases resolved by 12 wk; 1 case resolved by 25 wk.
Popliteal nerve block							
Capdevila 2005 (57)	P	0	167[a]	0 (0.02–2.17)	0	0 (0.02–2.17)	
Borgeat 2004 (25)	P	0	500	0 (0.01–0.73)	0	0 (0.01–0.73)	Denominator includes single-injections (n = 263) and continuous catheters (n = 237).
Auroy 2002 (45)	P	3	952	0.32 (0.11–0.92)	?	—	
Provenzano 2002 (70)	R	0	467	0 (0.01–0.79)	0	0 (0.01–0.79)	

95% confidence intervals appear in parentheses.

P = Prospective; R = Retrospective; ? = Insufficient data.

[a] Continuous catheter technique.

Table 3. Aggregate Estimated Rate of Occurrence of Neurological Complications After Neuraxial Blockade

	Estimated rate of occurrence (n = 10,000)	Lower CI (n = 10,000)	Upper CI (n = 10,000)	Heterogeneity (Q value)	
Spinal anesthesia					
Radiculopathy/neuropathy (6 studies)	3.78	1.06	13.50	168.70	$P < 0.01$
Cauda equina syndrome (4 studies)	0.11	0.03	0.37	20.59	$P < 0.01$
Intracranial event (2 studies)	0.03	0.00	0.20	1.66	NS
Paraplegia (4 studies)	0.06	0.02	0.20	5.38	NS
Epidural anesthesia					
Radiculopathy/neuropathy (9 studies)	2.19	0.88	5.44	142.30	$P < 0.01$
Cauda equina syndrome (4 studies)	0.23	0.14	0.39	2.30	NS
Intracranial event (2 studies)	0.07	0.03	0.21	0.24	NS
Paraplegia (4 studies)	0.09	0.04	0.22	2.23	NS

The estimated rate of occurrence was calculated using a random effects general linear model (see text).

CI = 95% confidence interval; NS = nonsignificant (nonsignificance indicates the absence of heterogeneity between studies).

Table 4. Aggregate Estimated Rate of Occurrence of Neuropathy After Peripheral Nerve Blockade

	Estimated rate of occurrence (n = 100)	Lower CI (n = 100)	Upper CI (n = 100)	Heterogeneity (Q value)	
Brachial plexus blockade					
Interscalene block (7 studies)	2.84	1.33	5.98	90.71	$P < 0.01$
Supraclavicular block (1 study)	0.03	0.00	0.42	NA	NA
Axillary block (10 studies)	1.48	0.52	4.11	315.57	$P < 0.01$
Midhumeral block (2 studies)	0.02	0.00	0.09	0.28	NS
Lumbar plexus blockade					
Lumbar plexus block (3 studies)	0.19	0.02	1.93	6.18	$P < 0.05$
Femoral nerve block (4 studies)	0.34	0.04	2.81	57.51	$P < 0.01$
Sacral plexus blockade					
Sciatic nerve block (3 studies)	0.41	0.02	9.96	38.71	$P < 0.01$
Popliteal nerve block (4 studies)	0.24	0.10	0.61	0.96	NS

The estimated rate of occurrence was calculated using a random effects general linear model (see text).

CI = 95% confidence interval; NA = not applicable; NS = nonsignificant (nonsignificance indicates the absence of heterogeneity between studies).

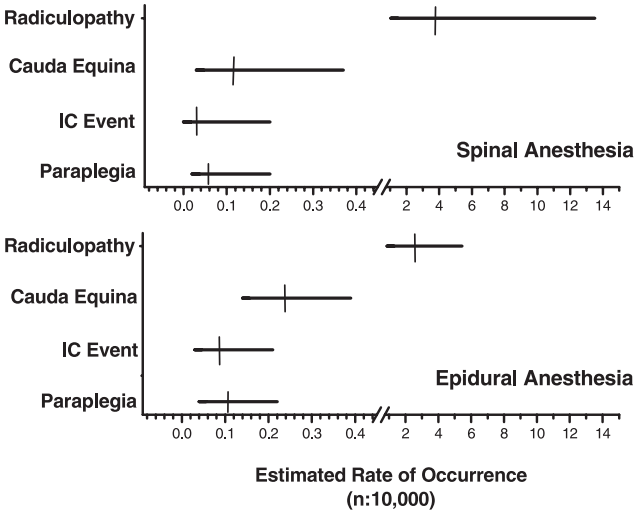

Figure 1. Aggregate estimated rate of occurrence and corresponding 95% confidence intervals (CI) for neurological complications after neuraxial blockade techniques. The short vertical bar indicates the estimated rate of occurrence for each specified complication. The ends of the horizontal bar represent the upper and lower values of the 95% CI, respectively, calculated using a random effects linear model. IC = Intracranial.

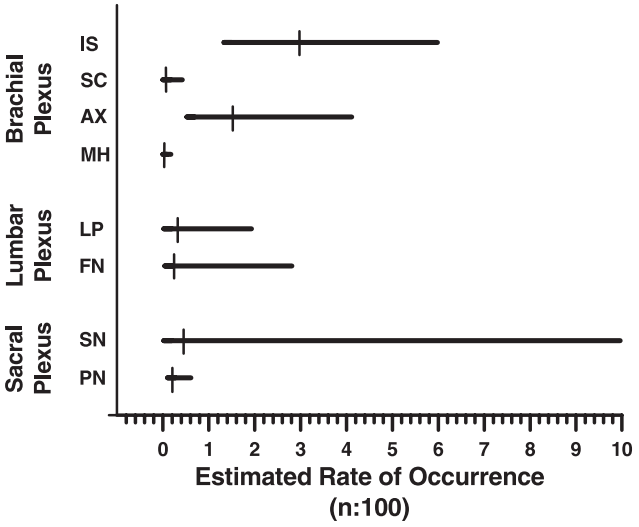

Figure 2. Aggregate estimated rate of occurrence and corresponding 95% confidence intervals (CI) for neuropathy after peripheral nerve blockade techniques. The short vertical bar indicates the estimated rate of occurrence for each specified complication. The ends of the horizontal bar represent the upper and lower values of the 95% CI, respectively, calculated using a random effects linear model. IS = Interscalene Block; SC = Supraclavicular Block; AX = Axillary Block; MH = Midhumeral Block; LP = Lumbar Plexus Block; FN = Femoral Nerve Block; SN = Sciatic Nerve Block; PN = Popliteal Block.

complications after epidural anesthesia to be 2.8:10,000 when the obstetrical population is omitted, as opposed to 0.4:10,000 for obstetrical epidural anesthesia. Excluding obstetrics, Auroy et al. (45) similarly found the incidence of major neurological complications related to CNB to be 3.4:10,000 compared to 0.6:10,000 for the obstetric population. Another reason for the relatively high number of neurological complications reported by Dahlgren and Tornebrandt (49) may be the questionable association between the CNB and subsequent neurological symptoms as 1 of the 3 and each of the 7 cases of neuropathy after spinal and epidural blockade, respectively, may have been caused by surgery, patient positioning, or intercurrent disease (33,49).

Although there is a limited number of contemporary large scale studies examining neurological complications after PNB available for review, there are even fewer available for historical comparison with our present findings. In 1985, Winchell and Wolfe (74) prospectively followed 854 consecutive patients who underwent brachial plexus blockade for upper extremity surgery and found a 0.4% incidence of postoperative neuropathy and no cases of permanent neurological deficit. Weeks et al. (75) followed 834 patients who underwent axillary brachial plexus blockade and found that four patients (0.5%) suffered persistent pain unrelated to the surgical site when assessed at 2 yr postoperatively. Finally, in an observational study examining 242 consecutive axillary and 266 consecutive interscalene brachial plexus blocks for upper extremity surgery, Urban and Urquhart (76) determined the incidence of neurological deficit to be 5% and 3%, respectively, at 2 wk postoperatively, with only one patient in each group (0.4%) experiencing persistent deficit beyond 4 wk.

The heterogeneity and quality of the available source studies included in an article such as this calls for caution when interpreting the validity of our risk estimates. Differences in sample size, patient populations, comorbidities, and surgical procedures undermine faithful comparisons of neurological complications reported in each study. Moreover, the presentation, investigation, and diagnosis of anesthesia-related nerve injury is complex (77,78) and inconsistent among studies, likely resulting in underreporting in some studies and over-reporting in others. For example, identification of neurological complications likely varied depending on direct anesthesia follow-up (24,25,53,54,56,57,59,60,63,69), surgeon referral (49), voluntary reporting by anesthesiologists (45,47,50,51,55,68), retrospective chart review (48,52,58,62,64,70,73), or patient self-reporting (46,58,59), the latter associated with a relatively higher rate of neurological symptoms after nerve blockade.

The time at which assessment or follow-up occurred surely affected the incidence of complications as neurological symptoms after CNB and PNB diminish with time. In some studies, one or more anesthesiologists (24,45,47,49,53,55–57,59,67), neurologists (47,49,54,55), or surgeons (24,49,55,56) undertook diagnosis, whereas in most other studies it is unclear who, if anyone, was charged with diagnosing the etiology of nerve injury. Finally, none of the

studies presently reviewed were of prospective controlled design. Rather, the largest of the source studies reviewed relied, in all or in part, on self-reporting from anesthesia providers (45–47,50,51). The significant potential for under-reporting of anesthesia-related complications is the predominant limitation when self-reporting is sought from anesthesiologists (79). Although the tendency for under-reporting may be greater in voluntary self-reporting systems [e.g., Auroy et al. (45,47)] (80), mandatory self-reporting [e.g., Moen et al. (51)] does not guarantee that all adverse events will be reported either (79). Nonetheless, voluntary or mandatory self-reporting is one of the only practical means to capture rare (approximate incidence 1:10,000–1:100,000) occurrences (79). A more reliable and valid method to capture the true incidence of rare neurological complications would be an international, multicenter, prospective, standardized trial (79), the logistics of which can be highly impractical. For extremely rare events (approximate incidence 1:1,000,000), such as paraplegia after CNB, preemptive risk modeling would be ideal, but this strategy is still premature in our specialty (79). At present, collating and adjusting the reported rates of neurological complications and calculating CI (81) are likely our best means to quantify and estimate the incidence of such rare occurrences.

In summary, our review suggests that the rate of neurological complications after CNB is <4:10,000, or 0.04%. The rate of neuropathy after PNB is <3:100, or 3%. However, permanent neurological injury after RA is rare in contemporary anesthetic practice. The rate of neurological complications presented in this article may be under-estimated, because much of the source data relied on self-reporting from anesthesia providers rather than prospective controlled trials.

Appendix: Quality of Evidence (35)

Grade I	Evidence obtained from at least one properly randomized controlled trial.
Grade II-1	Evidence obtained from well-designed controlled trials without randomization.
Grade II-2	Evidence obtained from well-designed cohort or case-control analytic studies, preferably from more than one center or research group.
Grade II-3	Evidence obtained from multiple time series with or without the intervention. Dramatic results in uncontrolled experiments (such as the results of the introduction of penicillin treatment in the 1940s) could also be regarded as this type of evidence.
Grade III	Opinions of respected authorities, based on clinical experience, descriptive studies and case reports, or reports of expert committees.

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