

# Perioperative Nerve Injury after Total Knee Arthroplasty

## Regional Anesthesia Risk during a 20-Year Cohort Study

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### ABSTRACT

**Background:** Perioperative nerve injury (PNI) is one of the most debilitating complications after total knee arthroplasty (TKA). Although regional anesthesia (RA) techniques reduce pain and improve functional outcomes after TKA, they may also contribute to PNI. The objective of this study was to test the hypothesis that PNI risk differs among patients according to RA use during TKA.

**Methods:** All patients aged at least 18 yr who underwent elective TKA from January 1988 to July 2007 were retrospectively identified. The primary outcome variable was the presence of a new PNI documented within 3 months of the procedural date. Age, sex, body mass index, type of procedure, tourniquet time, type of anesthesia, and use of peripheral nerve blockade were evaluated as potential risk factors for PNI using multivariable logistic regression.

**Results:** Ninety-seven cases of PNI were identified among 12,329 patients. Overall incidence of PNI was 0.79% (95% CI, 0.64–0.96%). PNI was not associated with peripheral nerve blockade (odds ratio [OR], 0.97) or type of anesthesia (OR, 1.10 [neuraxial vs. general]; OR, 1.82 [combined vs. general]). Risk for PNI decreased with age (OR, 0.68 [per decade];  $P < 0.001$ ) but increased with tourniquet time (OR, 1.28 [per 30-min increase];  $P = 0.003$ ) and bilateral procedures (OR, 2.51;  $P < 0.001$ ). Patients with PNI who underwent peripheral nerve blockade were less likely to have complete neurologic recovery (OR, 0.37;  $P = 0.03$ ).

**Conclusions:** Risk for PNI after TKA was unchanged by the use of RA techniques. This finding supports the notion that

### What We Already Know about This Topic

- Peripheral nerve blockade improves analgesia after total knee arthroplasty, but whether it increases peripheral nerve injury in this setting is not known.

### What This Article Tells Us That Is New

- In a review of more than 12,000 total knee arthroplasty patients during 20 yr, use of peripheral nerve blockade was not associated with peripheral nerve injury. However, patients with peripheral nerve injury were less likely to recover completely if they had received peripheral nerve blockade.

the known benefits of RA for patients undergoing TKA can be achieved without increasing risk of neurologic injury. However, in rare situations when PNI occurs, complete recovery may be less likely if it develops after peripheral nerve blockade.

PERIOPERATIVE nerve injury (PNI) is one of the most debilitating complications of surgery that commonly results in functional impairment, chronic pain, and decreased quality of life.<sup>1–3</sup> Large retrospective epidemiologic studies have estimated the overall incidence of PNI at 0.03–0.05%.<sup>1,2,4</sup> Although the majority of these injuries resolve over time,<sup>5</sup> it is important for anesthesia providers to recognize risk factors that may predispose patients to PNI. Several procedural and patient-related characteristics have been implicated in PNI.<sup>2,5–7</sup> Specifically, orthopedic surgical procedures may place patients at higher risk for PNI,<sup>4</sup> with the incidence of neurologic dysfunction after total knee arthroplasty (TKA) approaching 10%.<sup>8–13</sup>

Regional anesthesia (RA) techniques are commonly used to provide intraoperative and perioperative analgesia for patients undergoing TKA. Although RA has been shown to improve functional outcomes and facilitate early hospital discharge after TKA,<sup>14</sup> its use may increase the risk of PNI from direct needle- or catheter-induced mechanical trauma, local anesthetic toxicity, or by blunting the protective reflexes of an anesthetized extremity. The incidence of neurologic complications after RA for lower extremity procedures is esti-

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mated at 0.03–1.5%,<sup>15–19</sup> with central neuraxial techniques having a lower estimated risk than peripheral techniques.<sup>4,18</sup>

Previous studies examining PNI have included patients undergoing a wide range of surgical procedures or they have collected data from numerous institutions with varying surgical practices.<sup>2,4,16,17,20</sup> This variation in study methodology may confound the interpretation of surgical, anesthetic, and patient-related risk factors for PNI. Furthermore, the lack of a standardized definition for PNI and the restricted time frame in which many studies assess PNI (*i.e.*, short follow-up periods) limit the widespread application of these findings to the general population.<sup>4,16,17</sup> Therefore, the objective of this single-institution, large scale, single procedural cohort study was to test the hypothesis that risk for PNI differs among patients during elective TKA based on RA status. By using a homogeneous surgical population (*i.e.*, TKA) with extended postoperative follow-up, we assessed the interaction between the risk for PNI imposed by RA techniques and that imposed by the surgery itself.

## Materials and Methods

After Mayo Clinic Institutional Review Board approval and written informed consent were obtained, all patients aged at least 18 yr who underwent elective TKA at Mayo Clinic from January 1, 1988, to July 1, 2007, were retrospectively identified using the Mayo Clinic Total Joint Registry. The Mayo Clinic Total Joint Registry is a previously validated<sup>21</sup> and comprehensive repository of data collected for each joint replacement surgery performed at Mayo Clinic since 1969. Data included within the registry has been prospectively defined and is collected by manual chart review, written patient questionnaire, and follow-up telephone surveys conducted by full-time research assistants unaware of study hypotheses. Study inclusion was restricted to the first elective TKA performed at Mayo Clinic for any given patient identified within the registry. Patients who denied research authorization were excluded according to state government statute (Minnesota). Patients were also excluded if they were younger than 18 yr, underwent a “staged” bilateral procedure (*i.e.*, right and left TKA performed during the same hospitalization but on different dates), or if a matched anesthesia record (name, date of birth, surgical date) was not identified within the Mayo Clinic Department of Anesthesiology Quality Database.

Patient demographics (sex, date of birth, height, weight), date of surgery, side of surgery (right, left, bilateral), surgeon, total tourniquet time, and type of surgery (primary, revision) were recorded from the Mayo Clinic Total Joint Registry. Each patient’s primary anesthetic was categorized as (1) general anesthesia, (2) neuraxial anesthesia (spinal or epidural), or (3) combined general/neuraxial anesthesia. The use of supplemental peripheral nerve blockade was also documented and categorized as (1) femoral nerve blockade, (2) psoas compartment blockade, (3) fascia iliaca blockade, (4) sciatic nerve blockade, (5) combined femoral/sciatic nerve

blockade, or (6) combined psoas compartment/sciatic nerve blockade. All data pertaining to the patient’s anesthetic care were collected from the Mayo Clinic Department of Anesthesiology Quality Database.

The primary outcome variable was the presence of a new sensory or sensorimotor deficit documented within 3 months of the surgical date. Potential cases of PNI were identified using a comprehensive list of complications documented within the Mayo Clinic Total Joint Registry. Specifically, neurologic complications were coded as either a “nerve-related complication” or a “peroneal/sciatic nerve palsy” based on documentation by the surgical service, the Department of Anesthesiology, or the Acute Pain Service within the medical record. All cases of PNI were subsequently verified (or excluded) after manual chart review by one of the authors (H.P.S.). Patients with preexisting sensory or motor deficits (*e.g.*, diabetic peripheral neuropathy, multiple sclerosis) or deficits first appearing more than 3 months after surgery were excluded. Sensory deficits were defined as any new subjective or objective evidence of numbness, tingling, decreased sensation, paresthesia, or dysesthesia without evidence of motor dysfunction. Sensorimotor deficits were defined as the presence of any new subjective or objective weakness, nerve palsy, or neurapraxia with an associated sensory deficit in the same anatomic distribution.

Although the data collection methods of the Mayo Clinic Total Joint Registry have been previously validated,<sup>21</sup> additional validation was performed to confirm the reliability of the registry to capture PNI. The names and medical record numbers of 40 patients with known PNI after joint replacement surgery were prospectively collected during the past 10 yr by one of the authors (J.R.H.). The Mayo Clinic Total Joint Registry was queried and appropriately coded all 40 patients as experiencing a “nerve-related complication” or a “peroneal/sciatic nerve palsy” after surgery, suggesting a high degree of sensitivity in capturing the proposed clinical endpoint (*i.e.*, PNI).

All cases of PNI were observed until complete resolution or the date of last documented follow-up. The clinical course of each PNI was recorded, including: (1) date of onset, (2) terminology used to describe the deficit (numbness, weakness, neuropathy, neurapraxia, nerve palsy, nerve injury, paresthesia, foot drop, other), (3) presence of neurologic deficit at hospital discharge, (4) diagnostic evaluation by neurology consultation and/or electromyography study, (5) date of neurologic recovery, (6) date of last follow-up, (7) time to recovery (less than 1 month, 1–3, 3–6, 6–12 months, or more than 12 months), and (8) degree of neurologic recovery (complete [returned to baseline neurologic status], partial [deficit improved, but symptoms still exist], or none [deficit unchanged from initial description]).

## Statistical Analysis

The frequency of perioperative neurologic complications was summarized using point estimates along with corresponding

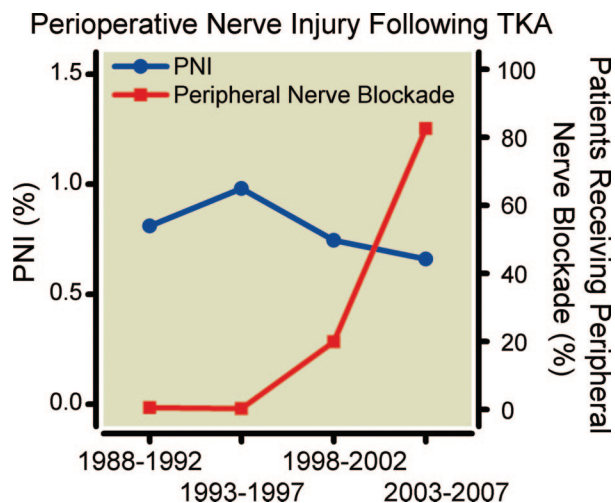
95% CIs calculated using the Poisson approximation to the binomial distribution. Age, sex, body mass index, type of procedure (unilateral primary, unilateral revision, and bilateral), tourniquet time, type of anesthesia (general, neuraxial, combined), and the use of peripheral nerve blockade were evaluated as potential risk factors for PNI using multivariable logistic regression. Age, body mass index, and tourniquet time were analyzed as continuous variables; other variables were analyzed as nominal variables. For bilateral procedures, the longest of the two tourniquet times was used in the analysis. In all cases, two-tailed *P* values less than or equal to 0.05 were considered statistically significant. Unless otherwise indicated, data are presented as mean  $\pm$  SD for continuous variables and frequency percentages for categorical variables. All analyses were performed using SAS (version 9.1; SAS Institute, Inc., Cary, NC).

## Results

A total of 13,252 patients underwent 19,058 elective TKA procedures during the 20-yr study period. After excluding 923 patients who denied research authorization or met one or more exclusion criteria, the first TKA of 12,329 patients was included for study analysis. The majority (56%) of patients undergoing TKA were female. Mean patient age was  $69 \pm 10$  yr. Overall, 69.7% of TKA surgical procedures were unilateral primary; 15.5%, unilateral revision; and 14.8%, bilateral. Intraoperative anesthesia included general anesthesia in 44%, neuraxial anesthesia in 45%, and combined neuraxial/general anesthesia in 8% of patients. Peripheral nerve blockade was performed in 3,883 patients (31%) for supplemental postoperative analgesia.

A total of 173 potential cases of PNI were initially identified from the Mayo Clinic Total Joint Registry. After manual chart review, 76 of these cases did not meet inclusion criteria for PNI. Therefore, a total of 97 cases of PNI were included for study analysis. The overall incidence of PNI after TKA was 0.79% (95% CI, 0.64–0.96%). Because the use of peripheral nerve blockade has become more common during the past decade, the 20-yr study period was divided into quartiles to assess the incidence of PNI over time (fig. 1). Peripheral nerve blockade was performed in 0.5, 0.2, 19.8, and 82.5% of TKA patients during the designated time periods, respectively, 1988–1992, 1993–1997, 1998–2002, and 2003–2007 ( $P < 0.001$ ). Despite a higher percentage of patients receiving peripheral nerve blockade from 2003–2007, incidence rates for PNI did not differ significantly over time ( $P = 0.36$ ). The incidence of PNI was significantly higher among patients undergoing bilateral procedures (1.70%; 95% CI, 1.15–2.41%) compared with those undergoing unilateral primary (0.65%; 95% CI, 0.49–0.85%) or unilateral revision surgical procedures (0.52%; 95% CI, 0.25–0.96%).

Patient and surgical characteristics and the incidence of PNI within patient subgroups (sex, age, type of anesthesia, peripheral nerve blockade) are listed in table 1. After multivariable logistic regression, age (OR, 0.70 [per decade];  $P < 0.001$ ) and tourniquet time (OR, 1.28 [per 30-min incre-



**Fig. 1.** Incidence of perioperative nerve injury (PNI) after total knee arthroplasty (TKA) and the proportion of patients receiving peripheral nerve blockade during 20-yr study period.

ment];  $P = 0.003$ ) were found to be associated with risk for PNI (table 2). Peripheral nerve blockade was not correlated with risk for PNI (OR, 0.97). Type of intraoperative anesthesia was also not associated with PNI (OR, 1.10 [neuraxial *vs.* general anesthesia]; OR, 1.82 [combined general/neuraxial *vs.* general anesthesia]). There were no sex differences in the incidence of PNI (OR, 1.11 [female *vs.* male]).

The characteristics and clinical course of all PNIs are summarized in table 3. Most cases of PNI (73 [75%] of 97) were combined sensorimotor deficits. The remaining 24 cases (25%) of PNI were limited to sensory deficits without associated motor dysfunction. The majority of sensorimotor nerve injuries (66 [90%] of 73) were documented during patient hospitalization. In contrast, only 5 (21%) of 24 patients experiencing isolated sensory deficits had documentation of the neurologic deficit before hospital dismissal.

Median (interquartile range) length of follow-up was 5.1 (2.5–9.5) years with all patients observed for a minimum of 1 yr. Overall, of the 97 cases of PNI, 60 patients (62%) had complete neurologic recovery, 35 patients (36%) had partial recovery, and 2 patients (2%) had no improvement in their neurologic symptoms 2.5 yr after surgery. Six months after surgery, 47 patients (48%) achieved maximal neurologic recovery, with 33 reporting complete recovery. Twelve months after surgery, an additional 28 patients (29%) achieved maximal neurologic recovery, with 17 reporting complete recovery. Twenty patients (21%) required more than 1 yr to achieve maximal neurologic recovery, with 10 reporting complete recovery. There was no difference in the time to resolution of sensory neurologic deficits compared to the resolution of sensorimotor deficits. However, patients with an isolated sensory deficit were more likely to have complete neurologic recovery compared with patients with sensorimotor deficits (73 *vs.* 57%, respectively;  $P < 0.0001$ ).

Twenty-five patients undergoing peripheral nerve blockade had PNI. Seven patients (28%) had injuries in a similar

**Table 1.** PNI Incidence after TKA by Patient and Surgical Characteristics (N = 12,329)

Characteristics	Unilateral Primary		Unilateral Revision		Bilateral	
	n	PNI, No. (%)	n	PNI, No. (%)	n	PNI, No. (%)
Total	8,590	56 (0.65)	1,911	10 (0.52)	1,828	31 (1.70)
Sex	—	—	—	—	—	—
Male	3,649	19 (0.52)	851	3 (0.35)	892	18 (2.02)
Female	4,941	37 (0.75)	1,060	7 (0.66)	936	13 (1.39)
Age group, yr	—	—	—	—	—	—
18–49	368	7 (1.90)	80	0	46	1 (2.17)
50–59	962	13 (1.35)	241	0	225	4 (1.78)
60–69	2,746	20 (0.73)	592	5 (0.84)	716	13 (1.82)
70–79	3,461	13 (0.38)	756	4 (0.53)	699	13 (1.86)
≥80	1,053	3 (0.28)	242	1 (0.41)	142	0
Type of anesthesia	—	—	—	—	—	—
General	3,998	25 (0.63)	1,054	7 (0.66)	846	12 (1.42)
Neuraxial	4,328	27 (0.62)	778	2 (0.26)	839	16 (1.91)
Combined	264	4 (1.52)	79	1 (1.27)	143	3 (2.10)
Peripheral nerve blockade	—	—	—	—	—	—
No	5,415	35 (0.65)	1,370	9 (0.66)	1,661	27 (1.63)
Yes	3,175	21 (0.66)	541	1 (0.18)	167	3 (1.80)
Date range	—	—	—	—	—	—
1988–1992	1,300	3 (0.23)	364	0	681	16 (2.35)
1993–1997	1,920	18 (0.94)	473	4 (0.85)	565	7 (1.24)
1998–2002	2,255	14 (0.62)	500	5 (1.00)	330	4 (1.21)
2003–2007	3,115	21 (0.67)	574	1 (0.17)	252	4 (1.59)

PNI = perioperative nerve injury; TKA = total knee arthroplasty.

anatomic distribution to the peripheral nerve block (e.g., proximal sciatic nerve injury after proximal sciatic nerve blockade). Ten patients (40%) had neurologic injury in a distribution that may have been related to the nerve block (e.g., isolated peroneal nerve injury after proximal sciatic

nerve blockade). Eight patients (32%) had a neurologic deficit in a distribution unrelated to the peripheral nerve block (e.g., peroneal nerve injury after femoral nerve blockade). Nineteen patients (76%) developed sensorimotor neurologic deficits, 6 (24%) developed sensory deficits only.

**Table 2.** Patient and Procedural Risk Factors for Perioperative Nerve Injury

Risk Factors	OR	95% CI	P Value
Age	0.70	0.59–0.83	<0.001
Sex	—	—	0.439
Male	1.00	—	—
Female	1.18	0.78–1.78	—
Body mass index	1.02	0.95–1.09	0.657
Type of surgery	—	—	0.002
Unilateral primary	1.00	—	—
Unilateral revision	0.73	0.36–1.45	—
Bilateral	2.14	1.33–3.44	—
Type of anesthesia	—	—	0.267
General	1.00	—	—
Central/neuraxial	1.15	0.75–1.77	—
Combined	1.89	0.87–4.11	—
Tourniquet time	1.28	1.09–1.50	0.003
Lower extremity block	—	—	0.383
No	1.00	—	—
Yes	1.24	0.76–2.03	—

Results are from a multivariable logistic regression analysis predicting perioperative nerve injury. Age, body mass index, and tourniquet time are modeled as continuous variables with odds ratios (ORs) presented for each decade age increases, 5 kg/m<sup>2</sup> increases in body mass index, and 30 min increases in tourniquet time. The analysis includes only patients with complete data for all risk factors (N = 11,645).

Complete neurologic recovery may be less likely in patients that underwent peripheral nerve blockade (OR, 0.37; 95% CI, 0.15–0.94; P = 0.03). Of the 25 patients that had PNI after peripheral nerve blockade, 11 (44%) had complete neurologic recovery, and 14 (56%) had partial recovery. Six months after surgery, 5 patients (25%) achieved maximal neurologic recovery, all having reported complete recovery. Twelve months after surgery, an additional 8 patients (72%) achieved maximal neurologic recovery, with six reporting complete recovery. Two patients (8%) required more than 1 yr to achieve their maximal neurologic recovery, neither of which had complete recovery. There was no difference in the time to resolution of sensory or sensorimotor neurologic deficits in PNI patients that received peripheral nerve blockade.

**Discussion**

TKA is one of the most commonly performed orthopedic procedures in the United States, representing the greatest single Medicare procedural expenditure.<sup>22,23</sup> Despite these surgical volumes, the American Academy of Orthopedic Surgeons estimates that the number of TKAs will continue to increase by 300% per year through the year 2030. This tremendous growth in surgical volume is largely attributed to the aging “baby boom” population.<sup>24</sup> Unfortunately, PNI is



**Table 3.** Characteristics and Clinical Course of Perioperative Nerve Injury

Characteristics	Unilateral	Unilateral	Bilateral	Overall
	Primary (n = 56) No. (%)	Revision (n = 10) No. (%)	(n = 31) No. (%)	(n = 97) No. (%)
Type of peripheral nerve blockade	—	—	—	—
None	35 (62)	9 (90)	28 (91)	72 (75)
Femoral block only*	6 (11)	0	2 (6)	8 (8)
Femoral and sciatic block†	14 (25)	1 (10)	1 (3)	16 (16)
Psoas compartment and sciatic block‡	1 (2)	0	0	1 (1)
Type of nerve injury	—	—	—	—
Sensory	15 (27)	5 (50)	4 (13)	24 (25)
Sensorimotor	41 (73)	5 (50)	27 (87)	73 (75)
Neurologic deficit documented prior to hospital discharge	—	—	—	—
No	16 (29)	5 (50)	5 (16)	26 (27)
Yes	40 (71)	5 (50)	26 (84)	71 (73)
Neurology consultation obtained	—	—	—	—
No	40 (71)	8 (80)	18 (58)	66 (68)
Yes	16 (29)	2 (20)	13 (42)	31 (32)
Electromyography obtained	—	—	—	—
No	35 (62)	7 (70)	15 (48)	57 (59)
Yes	21 (38)	3 (30)	16 (52)	40 (41)
Degree of neurologic recovery	—	—	—	—
None	0	1 (10)	1 (3)	2 (2)
Partial	20 (36)	2 (20)	13 (42)	35 (36)
Complete	36 (64)	7 (70)	17 (55)	60 (62)

\* Continuous = 7, single injection = 1 (unilateral primary). † All femoral nerve blocks were continuous; all sciatic nerve blocks were single injection. ‡ All psoas compartment blocks were continuous; all sciatic nerve blocks were single injection.

also associated with TKA—occurring in 0.01–10% of patients.<sup>8–13</sup> Numerous surgical and patient-related risk factors, including a preoperative valgus deformity or flexion contracture, preexisting neurologic deficits, rheumatoid arthritis, prolonged tourniquet inflation times, constrictive postoperative dressing, and RA techniques have all been implicated as potential risk factors for PNI.<sup>8,10,15</sup> However, this single institution, large scale, single procedural cohort study found that only age, type of surgical procedure, and total tourniquet time were associated with increased risk for PNI after TKA. Type of anesthesia, specifically neuraxial anesthesia or peripheral nerve blockade, was not associated with PNI in patients undergoing TKA. However, patients undergoing peripheral nerve blockade and experiencing PNI may be less likely to have complete neurologic recovery than patients not undergoing RA.

Several studies have attempted to quantify the incidence of PNI after orthopedic surgery. Auroy *et al.*<sup>16,17</sup> reported results from more than 250,000 RAs, including spinal, epidural, peripheral, and intravenous regional techniques. The overall incidence of any neurologic injury (including peripheral neuropathy, cauda equina syndrome, neurologic injury, radiculopathy, or paraplegia) was approximately 4 per 10,000 (0.04%) after all types of RA. However, the incidence varied according to the type of neurologic deficit, RA type, and the type of surgical procedure. Although these studies have reported results on a large number of patients undergoing RA, clinical outcomes were collected using self-reporting surveys from a small, voluntary proportion of French anes-

thesiologists (15 and 6% in 1997 and 2002, respectively).<sup>16,17</sup> This methodology leaves to chance the possibility of underreporting, response bias, and a lack of standardization between anesthesia and surgical practices across several institutions. Furthermore, Auroy *et al.*<sup>16,17</sup> included a variety of surgical procedures. These differences in study methodology may account, in part, for the seemingly higher incidence of PNI identified in the current study of 79 per 10,000 (0.79%) in patients undergoing TKA at a single institution. Welch *et al.*<sup>4</sup> reported a 10-yr retrospective review of more than 380,000 consecutive patients undergoing all types of surgical procedures and anesthetics from a single institution. They reported the overall incidence of PNI at 0.03%, including a 0.05% incidence among orthopedic patients. Furthermore, they found that the use of general or epidural anesthesia increased the risk of postoperative neuropathy. However, there was no difference with the use of peripheral nerve blockade. It is important to note that the authors sought information on peripheral neuropathies that were identified only during the first 48 hours after surgery. Because the use of prolonged (*i.e.*, more than 48 hours) postoperative continuous RA techniques may obscure symptoms of PNI, this study design may have also increased the risk of underreporting overall PNI frequency.

The incidence of neurologic complications after peripheral nerve blockade has also been reported by Capdevila *et al.*<sup>20</sup> In that investigation, neurologic complications associated with 1,416 continuous peripheral nerve catheters were prospectively examined in a multicenter study design. Rela-

tively high rates of persistent hypoesthesia (3%), weakness (2.2%), and persistent paresthesia (1.5%) were identified. Three neural lesions (0.2%) were noted after continuous femoral nerve blockade with subsequent resolution ranging from 36 hours to 10 weeks. Data collection was limited to 5 days postoperatively with the exception of those patients in whom a prolonged neurologic deficit was already documented. Some cases of PNI may not become apparent until several days or even weeks after a surgical event.<sup>8,9,11,25</sup> Therefore, complete case ascertainment cannot be assured. Finally, the multicenter study design may have once again introduced a lack of standardization in anesthesia and surgical practices, both of which are limitations not seen within a single-center study design.

Although most experts agree that the overall incidence of neurologic complications is quite low, estimated rates of nerve injury should be interpreted in the context of a study's limitations. Surveys that use physician self-reports introduce reporting bias, whereas short-term data collection (e.g., 48 hours after surgery) could fail to recognize late-onset deficits, introducing a timing bias. Furthermore, because of the assumed low complication rate, large numbers of patients are needed to capture the true incidence reliably. Lastly, data capture methods that rely on patient referral to neurology or pain medicine specialists run the risk of identifying only those patients with several neurologic deficits. Together, these limitations make it difficult to assemble a cohort of patients experiencing PNI after undergoing a single surgical procedure.

In the current study, we identified an overall PNI incidence of 0.79%, a value similar to previously reported prospective rates of nerve injury.<sup>26</sup> This result may suggest that, despite a retrospective study design, our methodology and ability to identify all possible cases of PNI was robust. Although we found that the use of RA techniques (neuraxial anesthesia or peripheral nerve blockade) did not increase PNI risk, we cannot speculate whether an association exists between RA and PNI in those cases that developed a postoperative neurologic deficit and underwent RA. However, in 32% of PNI cases that underwent a peripheral nerve block, the neurologic deficit was in a distribution anatomically unrelated to the block. In the remaining 68% of patients, the peripheral nerve block was in an anatomic distribution that was congruent with the location of the nerve injury. Overall, the majority (62%) of neurologic deficits completely resolved during the median follow-up of 5.1 yr, with an additional 36% of patients reporting partial recovery. Our observed proportion of PNIs with complete recovery is similar to that previously reported in patients undergoing TKA.<sup>8,12,27,28</sup> It should be noted that a smaller proportion of PNI patients that underwent peripheral nerve blockade (44%) had complete neurologic recovery compared with PNI patients that did not receive a peripheral nerve blockade (68%). While we cannot make any formal conclusions about the association of PNI severity and peripheral nerve block-

ade, it is possible that complete recovery may be less likely when a neurologic deficit develops in the setting of peripheral nerve blockade.

The current study found that age, bilateral procedures, and total tourniquet time were associated with risk for PNI. These associations are consistent with a previous report by Horlocker *et al.*<sup>5</sup> While younger patients may be more likely to undergo bilateral procedures, no association was found between age and bilateral surgical procedures. The greater risk for PNI associated with increased tourniquet inflation times may be exacerbated in patients undergoing bilateral procedures, but no association was found between tourniquet time and bilateral surgical procedures. Each of the above variables was independently associated with risk for PNI.

It is important to recognize the limitations of the current study. First, the retrospective nature of data collection introduces the possibility of missing transient, yet clinically significant, events that may not have been documented by the surgical team in hospital dismissal summaries or outpatient clinic notes. Therefore, even trained abstractors will not be able to identify those events that were either clinically present and not documented by the surgeon or anesthesiologist or documented more than 3 months after surgery but occurring during the immediate postoperative period. It is possible that transient neurologic events (*i.e.*, short-term deficits) may have been underreported within the current study as well. Finally, while a single center study design may strengthen internal validity, external validity may be limited compared to a multicenter design.

In summary, the use of RA techniques (neuraxial anesthesia or peripheral nerve blockade) does not increase the risk for PNI. Therefore, the known functional and clinical benefits of RA for patients undergoing TKA<sup>14</sup> can be achieved without increasing the risk of neurologic injury. If a PNI does occur, most patients will experience complete or partial recovery of their neurologic deficit within 12 months of surgery. However, complete recovery may be less likely in the rare instance when a neurologic deficit develops in the setting of peripheral nerve blockade.

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