

## Perioperative Peripheral Nerve Injuries

### A Retrospective Study of 380,680 Cases during a 10-year Period at a Single Institution

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**CME** This article has been selected for the ANESTHESIOLOGY CME Program. Learning objectives and disclosure and ordering information can be found in the CME section at the front of this issue.

**Background:** Peripheral nerve injuries represent a notable source of anesthetic complications and can be debilitating. The objective of this study was to identify associations with peripheral nerve injury in a broad surgical population cared for in the last decade.

**Methods:** At a tertiary care university hospital, the quality assurance, closed claims, and institution-wide billing code databases were searched for peripheral nerve injuries over a 10-yr period. Each reported case was individually reviewed to determine whether a perioperative injury occurred, defined as a new sensory and/or motor deficit. The location and type of the injury were also identified. Nerve complications as a result of the surgical procedure itself were excluded, and an expert review panel assisted in the adjudication of unclear cases. Patient preoperative characteristics, anesthetic modality, and surgical specialty were evaluated for associations.

**Results:** Of all patients undergoing 380,680 anesthetics during a 10-yr period, 185 patients were initially identified as having nerve injuries, and after review, 112 met our definition of a perioperative nerve injury (frequency = 0.03%). Hypertension, tobacco use, and diabetes mellitus were significantly associated with perioperative peripheral nerve injuries. General and epidural anesthesia were associated with nerve injuries. Significant associations were also found with the following surgical specialties: Neurosurgery, cardiac surgery, general surgery, and orthopedic surgery.

**Conclusions:** To our knowledge, this is the largest number of consecutive patients ever reviewed for all types of perioperative peripheral nerve injuries. More importantly, this is the first

study to identify associations of nerve injuries with hypertension, anesthetic modality, and surgical specialty.

PERIOPERATIVE peripheral nerve injury represents a notable source of anesthetic complications and can be very debilitating.<sup>1-3</sup> In the most recent American Society of Anesthesiologists (ASA) closed claims analysis, nerve injuries comprise 15-16% of the claims.<sup>1,2</sup> The fact that this percentage was relatively unchanged between studies performed almost a decade apart underscores the need for a more comprehensive understanding of risk factors for this persistent problem.<sup>2</sup>

The etiology of perioperative peripheral nerve injury can be a result of a variety of factors. It is believed that such injuries can sometimes be associated with patient comorbidities, positioning, and surgical conditions.<sup>4</sup> Occasionally, direct trauma from peripheral nerve blocks and neuraxial techniques can cause injury. The most likely pathologic mechanisms of injury include stretch, compression, ischemia, and metabolic/environmental abnormalities.<sup>4,5</sup> Some preexisting risk factors and intraoperative conditions have been demonstrated in well-designed studies. Previous studies, however, have focused on specific comorbidities and types of neuropathy, such as laboring patients,<sup>6</sup> orthopedic procedures,<sup>7</sup> the lithotomy position,<sup>8,9</sup> and ulnar nerve injury.<sup>10,11</sup> Furthermore, perioperative neuropathy associations between patient variables and common comorbidities have been conflicting among studies, including diabetes,<sup>7,8,11,12</sup> tobacco use,<sup>8,9,11</sup> vascular disease,<sup>8,9,11</sup> extremes in weight,<sup>6,8,9,11,13</sup> gender,<sup>2,8-11,13</sup> and age.<sup>6,8,9,11-13</sup> Despite being a common comorbidity associated with neuropathy in medical patients,<sup>14</sup> hypertension has never been studied as an independent risk factor in the surgical setting. Recent data in a more current and broader surgical population, encompassing both upper and lower extremity nerve injuries in all anesthetic modalities, is lacking. In addition, the association of nerve injury with certain surgical specialties has never been evaluated.

The goals of the present study were as follows: To determine whether injury is associated with preexisting patient characteristics, to determine whether injury is associated with the type of anesthetic technique or surgical specialty, and to determine the 10-yr frequency of perioperative peripheral neuropathies. This was accomplished by reviewing the quality assurance (QA), closed claims (CC), and institution-wide billing code databases for peripheral nerve

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**Fig. 1.** The Quality Assurance (QA) database was one of the three databases searched for perioperative peripheral nerve injuries. The voluntary reporting system allows reports of complications in the operating room (OR) or postanesthesia care unit (PACU) period from predefined pick lists, including “New Peripheral Nerve Injury.” CNS = central nervous system.

injuries for all patients who underwent anesthetic management over a 10-yr period at our institution.

**Materials and Methods**

We defined a perioperative peripheral nerve injury as a new (within 48 h) sensory and/or motor deficit in any patient who had been sedated or anesthetized. Injuries as a result of the surgical procedure itself were excluded. Nerve injuries were identified in a retrospective manner using three distinct databases at a large, tertiary care university hospital from May 1997 to May 2007.

After obtaining institutional review board (University of Michigan, Ann Arbor, Michigan) approval, we first searched the Department of Anesthesiology’s QA database. The QA database has been in place at our institution for over 10 yr and contains voluntary reports of complications by the anesthesiology residents, faculty anesthesiologists, and certified registered nurse anesthetists. QA events are used for research and internal review, as they are discussed weekly during Morbidity and Mortality conferences. A potential peripheral nerve injury was identified by one of three ways in the QA system. First, under “OR/PACU Events,” “New Peripheral Nerve Injury” can be selected from a predefined pick list (fig. 1). Second, under “Inpatient Post-op Visit,” “Peripheral neurologic deficit within 48 hours post-op”

can be selected from a predefined pick list (fig. 2). Third, under “Comments,” the free text was searched for the words “neuropathy,” “nerve,” “weakness,” “numbness,” “tingling,” “sensory,” or “motor.”

The second database searched was the departmental CC database. Over the last 10 yr, a record has been kept of claims filed against the Department of Anesthesiology. The free text of the initial complaint, full allegation, and key issues were searched for the words “neuropathy,” “nerve,” “weakness,” “numbness,” “tingling,” “sensory,” or “motor.”

The third and final database searched was the institution-wide outpatient and inpatient medical diagnoses and billing codes database. Specifically, the Current Procedural Terminology (CPT) codes searched for outpatient visits were 953.0–953.9 (Injury to nerve roots and spinal plexus), 955.0–955.9 (Injury to peripheral nerve[s] of shoulder girdle and upper limb), and 956.0–956.6 (Injury to peripheral nerve(s) of pelvic girdle and lower limb). The *International Classification of Diseases, 9th Edition* codes searched for inpatient visits were 955.0–955.9 (Injury to peripheral nerve(s) of shoulder girdle and upper limb) and 956.0–956.6 (Injury to peripheral nerve(s) of pelvic girdle and lower limb). The medical registration numbers of patients identified through this method were cross-referenced with our institution’s perioperative clinical information sys-

**Fig. 2.** The Quality Assurance (QA) database is a voluntary reporting system that allows reports of complications in the postoperative period from predefined pick lists, including “Peripheral neurologic deficit within 48 hours post-op.” Areas also exist for free text entry of postoperative events. CNS = central nervous system; MI = myocardial infarction; OR = operating room; PACU = postanesthesia care unit.

tem (Centricity, General Electric Healthcare, Waukesha, WI) to identify patients who had a peripheral nerve injury diagnosed by the billing codes and also underwent anesthetic management during the specified 10-yr period. From these three separate databases, duplicate cases, *i.e.*, the same patients with the same date of anesthetic care, were eliminated.

Potential cases of nerve injury were reviewed by the authors using additional information from the CC database, QA database, and patients' electronic medical record. This review determined whether a peripheral nerve injury actually occurred, according to the following definition: A new sensory and/or motor deficit that appears within 48 h of a procedure involving anesthetic care, and that most likely is not a result of the surgery itself. To clarify, the patient must have developed the complaint within 48 h of the surgery, but the injury itself could have been diagnosed either in the electronic medical record or by the billing codes at any point in time after the surgery.

A review panel was formed consisting of faculty anesthesiologists from the University of Michigan (CMB, PG, GAM); specifically, CMB and PG completed fellowship training in pain, GAM completed fellowship training in neuroanesthesia, and both CMB and GAM have done original research on topics related to the peripheral nervous system.<sup>15,16</sup> This panel adjudicated cases in which it was difficult to determine whether the injury met our definition of peripheral nerve injury. Agreement from two of the three members of the panel was necessary to make a decision. If there was a disagreement about the case, a group discussion took place and a consensus was reached.

Next, perioperative data were collected from the routine clinical documentation entered by anesthesiology residents, faculty anesthesiologists, and certified registered nurse anesthetists in the QA database. Entries are chosen from a predefined pick list. The following patient variables were searched: ASA status, age, sex, hypertension, coronary artery disease, tobacco use, renal disease, and diabetes mellitus. The following anesthetic variables were searched: Anesthetic modality and anesthetic procedures, including peripheral nerve blocks, epidurals, and spinals. The surgical specialty was also identified for each case. Surgical specialty listed was the primary service and did not account for any secondary surgical services involved. Finally, the location of the injury (upper extremity, lower extremity, or both) and nature of the neuropathy (motor, sensory, or both) was then identified from the QA database and/or the patient's medical records.

### Statistics

Statistical analysis was performed using SPSS version 15 (SPSS Inc., Chicago, IL). For analysis, all cases were divided according to the presence or absence of neuropathy. Associations were then investigated for preexisting

comorbidities, anesthetic techniques, and surgical service using hazard ratios (HRs) with 95% confidence intervals (CI). The databases by which the injuries were identified were noted for each of the positive neuropathy cases, along with the location (upper extremity, lower extremity, or both) and characteristics (motor only, sensory only, or both motor and sensory) of the neuropathy. Associations were made among anesthesia technique and location of the neuropathy, surgical service and the location of the neuropathy, database reported and if the neuropathy was either sensory or motor only, or if it was both sensory and motor. Specific ages were only available for patients who developed a neuropathy. The mean age is reported as a continuous variable. ASA status was collapsed into a binomial variable for ease of interpretation; ASA Class 1 or 2 and ASA Class 3, 4, or 5.

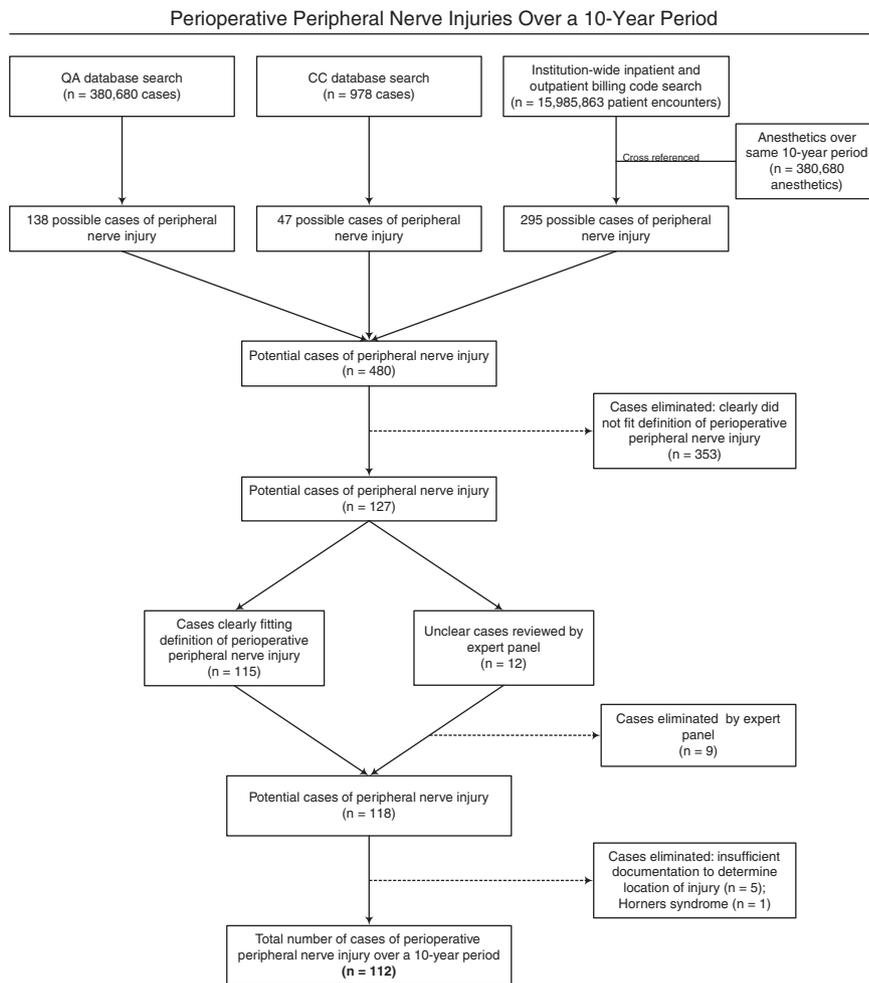
### Results

A total of 380,680 surgeries occurred under anesthetic management over a 10-yr period at our institution. The aforementioned three databases yielded 480 cases of potential perioperative peripheral nerve injuries (fig. 3). Of those, 138 were identified from the QA database, 47 from the CC database, and 295 from the billing code database. The QA database contained 380,680 cases involving anesthetic care during the specified 10-yr interval. The number of cases searched from the CC database was 978. The medical diagnoses database contained 15,985,863 total patient encounters or single medical diagnoses, and 2,933,544 individual patients with the medical diagnosis over the 10-yr period. These patients were cross-referenced with the 380,680 patients in the perioperative clinical information system, resulting in the previously mentioned 295 cases.

Of the 480 possible cases, 359 cases were eliminated because they did not fit the definition of perioperative peripheral nerve injury. Cases that were eliminated involved resolving epidural or spinal anesthetics, resolving peripheral nerve blocks, high spinals, central neurologic events, preexisting neurologic deficits that were unchanged, Horner's syndrome, incomplete documentation, or nerve damage clearly from the surgical procedure itself.

Of the remaining 121 cases, 109 clearly fit the definition of a perioperative peripheral nerve injury. The additional 12 cases were individually assessed by the expert review panel. The panel identified an additional three cases for a total of 112 perioperative peripheral nerve injuries out of 380,680 cases. The mean patient age was 46 yr. The youngest patient was 13 yr old and the oldest 86 yr old. Men made up 54% of the cases and women 46% of the cases. In the group that developed neuropathy, there was no significant difference in the

**Fig. 3.** Perioperative peripheral nerve injuries were identified by searching three separate large databases. The Quality Assurance (QA) and Closed Claims (CC) databases are specific to the Department of Anesthesiology and were searched for possible cases of nerve injury. The institution-wide inpatient and outpatient billing code database includes all patient encounters throughout the institution over the same time period as the anesthetics in the QA and CC databases. Billing codes associated with peripheral nerve injury were selected and cross-referenced against patients who had anesthetics over the study period. The cases identified through the three methods were hand-reviewed. Many cases clearly did not fit the definition for perioperative peripheral nerve injury associated with anesthesia and/or positioning and were excluded. Of the remaining cases, 12 were unclear and reviewed by an expert panel. Nine of the 12 patients were eliminated because of lack of clear documentation supporting a peripheral nerve injury. One case of Horner's syndrome postoperatively was also eliminated, as it did not fit the definition of perioperative peripheral nerve injury described in the Methods section. The total number of perioperative peripheral nerve injuries identified over a 10-yr period at our institution was 112 out of a possible 380,680 cases (0.03%).



number of ASA Class 1 and 2 patients (28%) when compared with the ASA Class 3, 4, and 5 patients (34%).

Three medical conditions were found to be associated with injury: Hypertension (HR 2.2; 95% CI 1.5–3.3), tobacco use (HR 2.1; CI 1.3–3.4), and diabetes mellitus (HR 2.4; CI 1.4–4.1) (table 1). Coronary artery disease and renal disease were not associated with injury. General (HR 2.8; CI 1.7–4.6) and epidural anesthesia (HR 4.1; CI 2.7–6.3) were found to have associations with injury. No associations were found with spinal anesthesia and peripheral nerve blocks (table 2). There were no

**Table 1.** Preexisting Patient Characteristics and Associations with Peripheral Nerve Injury

Patient Characteristic	No Neuropathy (n = 380,568)	Neuropathy (n = 112)	HR (95% CIs)
Diabetes mellitus	26,168 (6.9%)	17 (15%)	2.4 (1.4–4.1)
Hypertension	76,142 (20%)	40 (34%)	2.2 (1.5–3.3)
Tobacco use	37,057 (9.7%)	21 (19%)	2.1 (1.3–3.4)
Renal disease	18,433 (4.8%)	10 (8.5%)	1.9 (1.0–3.6)
Coronary artery disease	28,964 (7.6%)	14 (12%)	1.7 (1.0–3.0)

Five preexisting patient characteristics were searched for associations with perioperative peripheral nerve injuries. Hypertension, tobacco use, and diabetes mellitus were associated with perioperative peripheral nerve injury. Bold indicates significant values. HR = hazard ratio; n = number of cases.

cases of peripheral nerve injury that involved monitored anesthetic care. Fifteen different surgical services were searched (table 3), and four were found to be associated with injury: Neurosurgery (HR 2.7; CI 1.4–5.2), cardiac surgery (HR 2.6; CI 1.3–5.7), general surgery (HR 2.0; CI 1.3–3.3), and orthopedic surgery (HR 2.0; CI 1.3–3.2).

The locations of the injuries were identified and are displayed in table 4. Sixty-five were upper extremity and 45 were lower extremity injuries. Two patients had both upper and lower extremity injuries from a single case.

**Table 2.** Anesthetic Technique and Associations with Peripheral Nerve Injury

Anesthetic Technique	No Neuropathy (n = 380,568)	Neuropathy (n = 112)	HR (95% CIs)
<b>Epidural</b>	<b>28,436 (7.5%)</b>	<b>28 (25%)</b>	<b>4.1 (2.7–6.3)</b>
<b>General</b>	<b>254,352 (67%)</b>	<b>95 (85%)</b>	<b>2.8 (1.7–4.6)</b>
PNB	6,681 (1.8%)	4 (3.6%)	2.1 (0.8–5.6)
MAC	58,798 (16%)	0 (0%)	0.8 (0.8–0.8)
Spinal	20,478 (5.4%)	1 (0.8%)	0.2 (0.0–1.1)

Five anesthetic techniques were searched for associations with perioperative peripheral nerve injuries. General and epidural anesthetics were associated with perioperative peripheral nerve injury. Bold indicates significant values. HR = hazard ratio; MAC = monitored anesthesia care; n = number of cases; PNB = peripheral nerve block.

**Table 3. Associations between Surgical Service Peripheral Nerve Injury**

Surgical Service	No Neuropathy (n = 380,568)	Neuropathy (n = 112)	HR (95% CIs)
<b>Neurosurgery (n = 13,446)</b>	<b>13,436 (3.5%)</b>	<b>10 (8.9%)</b>	<b>2.7 (1.4–5.1)</b>
<b>Cardiac (n = 10,353)</b>	<b>10,345 (2.7%)</b>	<b>8 (7.1%)</b>	<b>2.8 (1.3–5.7)</b>
<b>General (n = 36,762)</b>	<b>36,740 (9.7%)</b>	<b>20 (18%)</b>	<b>2.0 (1.3–3.3)</b>
<b>Orthopedics (n = 43,699)</b>	<b>43,676 (12%)</b>	<b>23 (21%)</b>	<b>2.0 (1.3–3.2)</b>
Transplant (n = 6,850)	6,846 (1.8%)	4 (2.7%)	1.5 (0.5–4.7)
Vascular (n = 7,260)	7,256 (1.9%)	4 (3.6%)	1.9 (0.7–5.2)
Thoracic (n = 6,897)	6,894 (1.8%)	3 (2.7%)	1.5 (0.5–4.7)
Cardiology (n = 5,147)	5,145 (1.4%)	2 (1.8%)	1.3 (0.3–5.4)
GYN (n = 17,189)	17,183 (4.5%)	6 (5.4%)	1.2 (0.5–2.8)
OB (n = 28,572)	28,563 (7.5%)	9 (8.0%)	1.1 (0.5–2.1)
Burn (n = 1,696)	1,696 (0.4%)	0 (0%)	1.0 (1.0–1.0)
Psychiatry (n = 7,311)	7,311 (1.9%)	0 (0%)	1.0 (1.0–1.0)
Radiology (n = 3,048)	3,048 (0.8%)	0 (0%)	1.0 (1.0–1.0)
Trauma (n = 5,313)	5,313 (1.4%)	0 (0%)	1.0 (1.0–1.0)
Pulmonary (n = 513)	513 (0.1%)	0 (0%)	1.0 (1.0–1.0)
Oncology (n = 10,866)	10,863 (2.9%)	3 (2.7%)	0.9 (0.3–3.0)
Ophthly (n = 30,417)	30,417 (8.0%)	0 (0%)	0.9 (0.9–0.9)
Urology (n = 58,342)	58,326 (15%)	14 (13%)	0.9 (0.5–1.4)
OMFS (n = 4,127)	4,126 (1.1%)	1 (0.9%)	0.8 (0.1–5.9)
Plastic (n = 17,520)	17,518 (4.6%)	2 (1.8%)	0.4 (0.1–1.5)
ENT (n = 38,290)	38,287 (10%)	3 (2.7%)	0.2 (0.1–0.8)

All surgical services were searched for associations with perioperative peripheral nerve injuries. Neurosurgery, cardiac surgery, general surgery, and orthopedic surgery were associated with perioperative peripheral nerve injury. Bold indicates significant values. ENT = otolaryngology; GYN = gynecology; HR = hazard ratio; OB = obstetrics; OMFS = oral maxillofacial surgery; Ophthly = ophthalmology; n = number of cases.

Neuraxial techniques (epidurals and spinals) were more commonly associated with lower extremity injuries, as compared with all other techniques (71% vs. 31%, respectively; odds ratio 5.7 [2.2–14.7]). The number of upper extremity injuries between cardiac surgery and other surgical services was not significantly different (75% vs. 58%, respectively).

The type of the neuropathy was identified as sensory, motor, or both (table 5). Sixteen were motor injuries, 67 were sensory injuries, and 27 were both motor and sensory injuries. Two cases could not be determined, but were repeatedly described as a “plexopathy.” Patients in the CC database were more likely to have a motor component to their neuropathy, as compared with those identified in the QA database (69% vs. 39%, respectively;  $P = 0.029$ ).

The 10-yr frequency of perioperative peripheral nerve injuries was 112 of 380,680 cases, or 0.03%.

**Table 4. Location of Peripheral Nerve Injury**

Location of Injury	Number of Cases
Upper extremity	65
Lower extremity	45
Both upper and lower extremity	2

The locations of the perioperative nerve injuries were determined from the electronic medical records. Upper extremity injuries were more prevalent than lower extremity injuries. Two patients had both upper and lower extremity injuries from a single case.

**Table 5. Type of Peripheral Nerve Injury**

Type of Injury	Number of Cases
Sensory	67
Motor	16
Both motor and sensory	27
Not determined	2*

The type of the perioperative nerve injuries was determined from the electronic medical records. Sensory neuropathies were more prevalent than motor neuropathies or combined sensory and motor neuropathies.

\* Not determined cases were documented as plexopathies.

## Discussion

Our results demonstrate significant associations between perioperative nerve injury and diabetes mellitus, tobacco use, and hypertension. Diabetes is a known cause of chronic neuropathy and vascular disease, and it was originally described as a potential cause of perioperative neuropathy in case reports.<sup>17,18</sup> It was found to be a risk factor in the development of ulnar neuropathy and lower extremity neuropathy in the lithotomy position,<sup>8,11</sup> but was also shown to not be associated with injury in patients undergoing total knee arthroplasty.<sup>7,12</sup> Conflicting results have also been found for tobacco use, which proved to be an independent risk factor for lithotomy-associated lower extremity neuropathy,<sup>8</sup> but not for ulnar nerve neuropathy.<sup>9,11</sup> The associations found in our study support some of the previous findings, but in a more generalized population involving all anesthetic techniques. Moreover, this is the first study to associate hypertension specifically with perioperative peripheral nerve injury. No previous study has evaluated whether or not this common chronic medical condition is a risk factor for injury. Hypertension is a chronic disease process that affects blood flow, and thus may leave the nerve more susceptible to injury. There could be other reasons why hypertensive patients have more nerve injury, including a propensity for hemodynamic instability or the predisposition for other comorbidities associated with peripheral nerve injury. Interestingly, the finding that diabetes, smoking, and hypertension are associated with perioperative neuropathies parallels the association with peripheral neuropathy in medical patients.<sup>14,19–21</sup>

We selected particular variables from the QA pre-defined pick lists because of suggested associations with neuropathies,<sup>7–12,14,19,20,22,23</sup> or because they were disease states that chronically disrupt blood flow. As mentioned, ischemia and infarct are mechanisms of localized injury to the peripheral nerves of an anesthetized patient. Since the disruption of the blood supply to the nerves is integral to the mechanism of injury,<sup>5</sup> one can hypothesize that patients with already compromised vasculature will be more susceptible to perioperative injury as well. Thus, a chronically dysfunctional nerve, such as that of a diabetic, may be more susceptible to injury from acute ischemic or mechanical insult.<sup>10,22</sup> In support of

an ischemic etiology, the use of pneumatic tourniquets has been associated with perioperative neuropathy in two previous studies.<sup>7,12</sup>

We found significant associations with the techniques of general and epidural anesthesia. No associations were found with peripheral nerve blocks, monitored anesthetic care, or spinal anesthesia. Given the low number of injuries with these anesthesia techniques, however, it is difficult to draw any significant conclusions. Peripheral nerve blocks were trending towards, but did not reach, significant association with injury. These results stand in contrast to recent data showing a higher incidence of injury with peripheral nerve blocks (3%) than central neuraxial anesthesia (0.014%).<sup>24</sup> Also, a previous study of CC data revealed that general anesthesia is less frequently associated with nerve injury than regional anesthesia.<sup>1</sup> In the present study, there were no cases of injury associated with monitored anesthesia care. Our findings that general and epidural anesthetics are associated with injury are somewhat surprising given the recent incidence data, but these studies have varied widely in their methods. Thus, it is reasonable to consider each anesthetic technique with its own particular opportunities for risk. The lack of association with monitored anesthetic care deserves mention and is not unexpected, as conscious patients should retain more of their protective reflexes and be able to reposition themselves. In addition, sedation cases are usually shorter. Other studies, however, have reported cases of injury with sedation,<sup>8,11</sup> and an easy explanation for the difference may be depth of sedation, length of case, and perioperative positioning.

This is the first study of associations between particular surgical services and perioperative neuropathy. It has been well established that cardiac surgery has a high incidence of nerve injury,<sup>25</sup> which we confirmed. Potential mechanisms for the association with cardiac surgery include the median sternotomy leading to brachial plexus injuries, as well as the hypothermia and hemodynamic changes during bypass.<sup>26</sup> In addition, general surgery, orthopedic surgery, and neurosurgery were also found to be associated with injury, which has not previously been reported. The frequency of prone positioning involved in orthopedics and neurosurgery may have caused nerve injury, but our study design does not allow confirmation of this hypothesis. We are further investigating prone positioning in an ongoing study. It is notable that services that regularly position their patients in a prolonged lithotomy position (*i.e.*, urology and gynecology) were not associated with nerve injury, although lithotomy position for longer than 2 h has been shown to be a major risk factor for injury.<sup>8</sup> In addition, obstetrics was not associated with more nerve injuries, which is surprising, given the higher incidence of postpartum peripheral nerve injuries of 0.92%.<sup>6</sup>

The distribution of the location of injuries in our study was consistent with previous work (table 4). Upper

extremity injuries were more common than lower extremity injuries, which was also shown in a previous CC study.<sup>2</sup> Associations between neuraxial techniques and lower extremity neuropathy have also been reported,<sup>1</sup> and was significant in the present study. Cardiac surgery has been linked with more upper extremity injuries because of a variety of reasons, including internal jugular vein cannulation, internal mammary artery dissection, and stretching of brachial plexus with retraction, in addition to those discussed above.<sup>27,28</sup> While not a statistically significant result, cardiac surgery patients tended to have higher rates of upper extremity neuropathy as compared with other surgical patients in the neuropathy group (75% *vs.* 58%, respectively).

More than half of the injuries identified were primarily sensory symptoms (67 of 112, table 5). Interestingly, the patients identified through the CC database were significantly more likely to have a motor component (motor or both motor and sensory) to their injury, as compared with patients identified through the QA system. These findings indicate that patients with a motor component to their injury are more likely to pursue legal measures. It is not surprising that patients would deem a neuropathy in which there was a loss of physical function to be more significant.

The frequency of perioperative peripheral nerve injuries in 380,680 consecutive surgical patients over a 10-yr period was 0.03%. To our knowledge, this is the largest number of consecutive patients ever reviewed for all types of perioperative peripheral nerve injuries. Our result is also lower than previously reported. Parks *et al.*<sup>29</sup> reported in 1973 an incidence of 0.14% based on a retrospective review of 50,000 general surgery patients, excluding those who received central neuraxial anesthesia and peripheral nerve blocks. Blitt *et al.*<sup>30</sup> included all anesthetic techniques and found an incidence of injury of 0.11% in 81,000 procedures between 1987 and 1993. Warner *et al.*<sup>8,9,11</sup> reviewed much larger numbers of patients but focused exclusively on ulnar neuropathy and lower extremity neuropathy in the lithotomy position, stating the incidence to be 0.037% and 0.028%–1.5%, with the 1.5% incidence derived from a prospective study.

The wide range in ages in the current study demonstrates the broad scope of this problem. Specifically, six nerve injuries occurred in children, a population that has been largely excluded in previous studies. Recommendations have been made for the positioning of children, based mainly on anatomic and physiologic differences between adults and children.<sup>31</sup> Unlike previous studies,<sup>1,2,8</sup> there was no association found between men and nerve injury. ASA status does not seem to be associated with neuropathies.

There has been limited scientific evidence to guide the prevention of this complication, especially regarding positioning. The ASA practice advisory for the prevention

of perioperative peripheral neuropathies recommends a preoperative assessment to determine whether the position can be tolerated, various considerations for each position, a postoperative assessment to lead to early recognition of peripheral neuropathies, and better documentation. Better documentation can help the practitioner focus on certain aspects of positioning and also provide information that can be later used for refinements in patient care.<sup>32</sup> We believe that anesthetic documentation of positioning should be improved in all patients, as past investigations have shown it to be inadequate.<sup>33</sup> This is an area of perioperative anesthetic care that needs further research, as multiple closed claims analysis still judge anesthetic care, positioning, and padding inadequate in a significant percentage of cases.<sup>1,33</sup>

### Limitations

This study has several limitations. The capture of perioperative peripheral nerve injuries will be incomplete when reviewing data in a retrospective manner, as evident by our discrepancies of cases in the three methods of retrospective review. The analysis of the QA database relies on self-reporting, and complications tend to be underreported. Thus, we expect the actual incidence to be higher because of the self-reporting nature of the QA database. Although there are limitations inherent to a retrospective methodology, we have attempted to minimize them by employing three different databases. It is important to note, however, that the primary goal of the current study was to identify associations and risk factors for perioperative peripheral nerve injury, rather than the precise incidence. It is unclear whether a decreased capture rate of injury would have biased the associations identified.

Another area of limitation pertains to exactly which patient and surgery characteristics were available in the QA database. We are currently investigating more variables from our electronic medical records system, as over the last 5 yr the preoperative and intraoperative data capture has expanded significantly. The QA system also did not allow us to identify the location of the injury in every case. Yet another limitation is the very definition of the perioperative peripheral nerve injury: A new sensory and/or motor complaint that appears within 48 h of a procedure involving anesthetic care. The definition was formulated in this manner based on a structured, predefined pick list in the QA system and applied to other methods of identifying cases. In previous studies, however, it has been shown that appearance of peripheral nerve injuries can be delayed for weeks after anesthesia and surgery.<sup>2,11</sup> Whereas narrowing the definition to the first 48 h postoperatively may miss some cases of injury, it may target those that occurred perioperatively and limit those that occurred postoperatively, such as from lying in bed during a long hospital stay.<sup>34</sup> Finally, the results of this study may be limited in their general-

izability, given the fact that it is from a single large tertiary care university hospital. As with most retrospective studies, these patients were not followed long-term, so it is unknown whether these injuries persisted, and to what degree of severity and consequence to the patient.

### Conclusion

By a retrospective review of three distinct databases over a 10-yr period, hypertension was newly identified as being significantly associated with a higher risk of perioperative peripheral nerve injuries, in addition to diabetes and tobacco use. Four surgical services, general anesthesia and epidural anesthesia were also uniquely noted to have associations. Future prospective studies are warranted to better understand the risk factors associated with and methods for prevention of this potentially devastating complication.

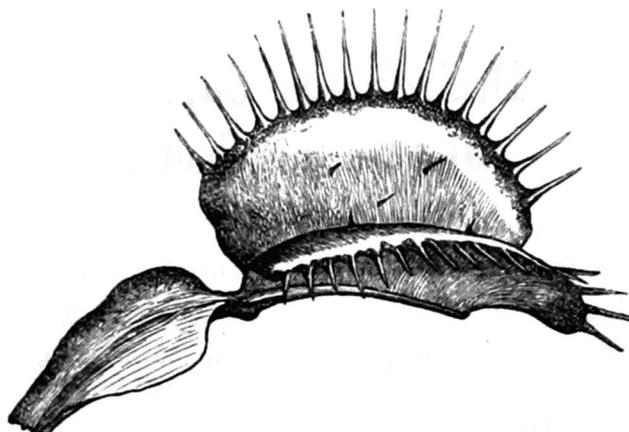
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## ■ ANESTHESIOLOGY REFLECTIONS

### Darwin Etherizes Venus Flytraps



In his 1875 text *Insectivorous Plants*, naturalist Charles Darwin noted that the "plant, commonly called Venus' fly-trap, from the rapidity and force of its movements, is one of the most wonderful in the world." While investigating anesthetics' effects on the botanical carnivore's leaf-closing, he tried chloroform and then ether vapors. Using a 2-oz. vessel, the naturalist determined that the flytrap's leaf required 24 hr to recover sensibility from 20 min exposure to "15 minims" of ether, but only 52 min to recover from 3 min exposure to "10 drops" in a larger bottle. Darwin conceded that he did not know whether "the larger doses of . . . ether, which caused the leaves to close slowly, acted on the sensitive filaments or on the leaf itself. . . ." His son George provided the illustration above of an unclosed leaf of *Dionaea muscipula*, whose Latin name actually means "Venus mousetrap." (Copyright © the American Society of Anesthesiologists, Inc. This image appears in the *Anesthesiology Reflections* online collection available at [www.anesthesiology.org](http://www.anesthesiology.org).)

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