Good News

But Why Is the Incidence of Postoperative Ischemic Optic Neuropathy Falling?

Michael M. Todd, M.D.

THE first description of postoperative visual loss (POVL) in Medline is from 1950.[1] Cases appeared sporadically over the next 30 to 40 yr (fig. 1), mostly related to opthalmalogic procedures, cardiac surgery, and a miscellany of other operations. Some were due to direct eye injuries, but some were due to ischemic optic neuropathy (ION), most commonly reported in association with massive intraoperative hemorrhage and hypotension or radical head and neck surgery. Then, in the early 1990s, cases of ION began to appear after prone spine surgeries. Along with the rapid growth in instrumented spine procedures, the yearly number of publications accelerated dramatically (fig. 1). Some of these publications advanced unsupported theories as to cause and equally unsupported recommendations regarding prevention. In response, the American Society of Anesthesiologists (ASA) made a concerted effort to gather objective information by establishing the POVL Registry in 1999. Over the next few years, information was accumulated that began to shed some light on the problem. For example, case data in the registry effectively eliminated "pressure on the globe" as a major cause of POVL, established the important role of case duration, and raised questions about the specific roles of blood loss, transfusion, hypotension, anemia, *etc.*, strongly supporting a belief in a complex multivariate etiology.[2] Based on this, the ASA published its first Practice Advisory regarding POVL in 2006.[3] Working with data in the registry, the POVL Study Group conducted a multicenter case-matching study intended to better examine risk factors for ION.[4] As expected, multiple factors were found to differ between patients with and without ION, but only six could be identified as independent risk factors in a multivariate model: male sex, obesity, the use of a Wilson frame for positioning, case duration, estimated blood loss (EBL), and the fraction of colloids given as part of non–blood fluid management. Many of these items were incorporated into an updated ASA Practice Advisory in 2012.[5]

"...since 1998 to 2000, the incidence of postoperative ION [ischemic optic neuropathy following prone spine surgery] has fallen by almost 60%.... But why has this occurred?"

In this issue of the Journal, Rubin *et al.*[6] looked at long-term trends in the incidence of ION after spine fusion surgery. Using data from the Nationwide Inpatient Sample (NIS), they provide two key pieces of new information. First, they confirmed that male sex, obesity, and transfusion (which *may be* a surrogate for blood loss) are risk factors, and they added age to the list. Second—and certainly of far greater importance—they showed that, since 1998 to 2000, the incidence of postoperative ION has fallen by almost 60%, from approximately 1.63/10,000 to 0.6/10,000 in 2010 to 2012.

Since this is a new finding, rigorous confirmatory data are lacking, but there are other consistent observations. For example, the number of cases reported yearly to the ASA POVL registry has been decreasing progressively from a peak in 2000 to 2002 (Karen Posner, Ph.D., University of Washington, Seattle, Washington, personal communication, February 2016). Yearly malpractice claims for POVL for one

Image: ©Thinkstock.

Corresponding article on page XXX.

Accepted for publication April 28, 2016.

From the Department of Anesthesia, University of Iowa Carver College of Medicine, Iowa City, Iowa.

 Anesthesiology 2016; 125:00-00

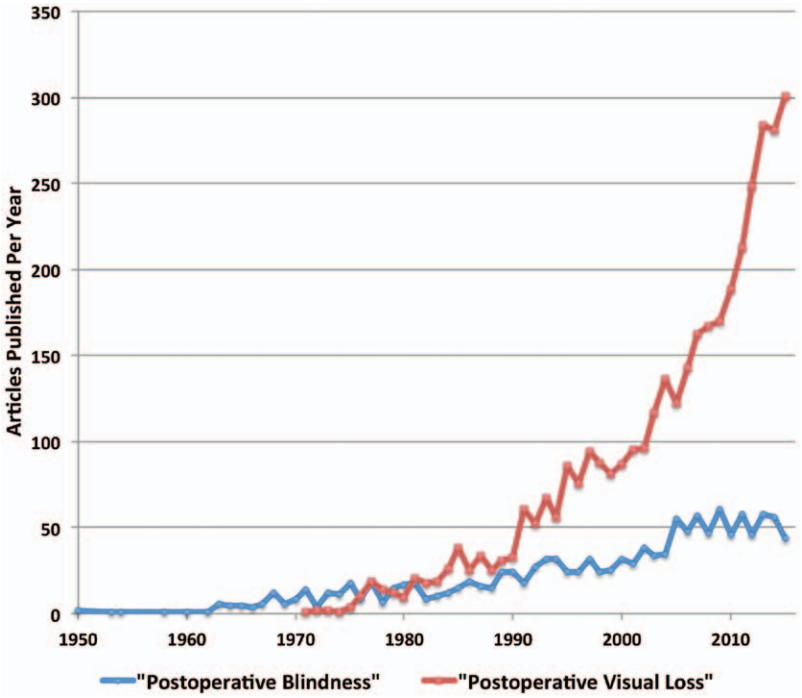

Fig. 1. Publications per year retrieved from Medline using the search terms "postoperative blindness" and "postoperative visual loss."

large national insurer (Preferred Physicians Medical, USA) peaked between 1997 and 2004 and have been dropping since (with only one case filed since 2008; Steven Sanford, personal communication, April 2016).

This is great news for us and our patients! But why has this occurred? Is it due to the conscious efforts of anesthesiologists and surgeons to prevent ION or is it an unintended consequence of changes in either our patients or in the conduct of anesthesia and surgery? While we would all like to believe that it was due to our well-focused efforts, a careful consideration of many factors suggest that it is more likely to be due to the latter (or at least a combination of the two).

A better understanding of WHY the incidence has decreased can help us understand WHY the event occurs at all. In other words, further considerations of known risks (*e.g.*, age, sex, and obesity)—and their changes over time—may provide mechanistic insights and/or allow us to better focus on a narrower range of factors. I'd therefore like to look at these risks individually.

Patient Characteristics: Age, Sex, and Obesity

It is reasonable to conclude that *patient* risk factors are *not* improving; our patients are not getting younger or smaller, and there is nothing to suggest a major change in the sex of spine surgery patients. The aging of our surgical population is well known. For example, the average age of patients undergoing major spine surgery at The University of Iowa, Iowa City, Iowa, has *increased* by over 8 yr since 1996. Data from NIS show that over the data range evaluated by Rubin *et al.* and in the same spinal fusion population, age increased by 5 yr, the incidence of obesity increased substantially, and there was only a tiny change in sex ratio (a 3% drop in the fraction of males).* Supplementary information from the American College of Surgeons National Surgical Quality Improvement Program database for spine fusion surgery—albeit over a shorter time period—also supports these findings (information provided by Dr. Y. Gao, Department of Orthopedics, University of Iowa).

Surgical Factors: Positioning, Case Duration, Blood Loss, and Fluid Management

The POVL group demonstrated that the use of a Wilson frame was associated with the highest "risk ratio" of any of the six factors, presumably due to higher intraabdominal and venous pressures secondary to abdominal compression and perhaps a tendency toward a more head-down posture. While no objective data are available, an informal e-mail survey of more than a dozen senior members of the U.S. neuroanesthesia community strongly indicates that the use of the Wilson frame, at least for major spine fusions, has nearly disappeared in the last decade, having largely been replaced by OSI/Jackson tables. Positioning on the OSI/Jackson table results in less abdominal compression and, frequently, a more neutral head (or even head-up) position.

*As part of this assessment, this author contacted the senior author of Rubin *et al.* (Dr. Roth) and asked him to provide additional data from Nationwide Inpatient Sample, specifically related to the changes over time in patient ages and the incidence of obesity and transfusions.

If, as suggested,[4] venous pressure plays an important role in ION, this change alone may be playing a major role.

The NIS database does not contain case duration data and, to the best of my knowledge, no other national source of case duration information exists. I was able to retrieve deidentified duration information from our Departmental billing database for adult patients back to 1996, focusing on the same current procedural terminology–coded procedures as studied by Rubin *et al.* As expected—and as reported by Rubin *et al.*—case numbers for 2013 to 2015 were three times greater than those for 1996 to 1998 (1042 *vs.* 347). Average case duration for these two 3-yr periods decreased by 18 min (P = 0.031), and the fraction of cases lasting greater than or equal to 6 h decreased from 54% in 1996 to 1998 to 43% in 2013 to 2015 (P = 0.0003)—although surprisingly, the fraction of cases lasting more than 8 h did not change (18%). If these data are representative of national practice, it is possible that some changes in operative times may be an important factor, but also suggest that the relationship between case duration and the incidence of ION is both complex and highly nonlinear.

The POVL group identified EBL as a risk factor, while Rubin *et al.* showed an association between transfusion and ION. Neither NIS nor the National Surgical Quality Improvement Program tracks operative EBL over time, but the progressive adoption of minimally invasive techniques[7,8] and the growing use of antifibrinolytics such as tranexamic acid might be expected to decrease EBL[9,10]—we just don't know. At our institution, overall incidence and volume of blood transfused has fallen over time—but surprisingly NIS data (see footnote 1) show that the fraction of patients transfused has actually increased (although volume data are not available). Whether "transfusion" is a surrogate for EBL (as suggested by Rubin *et al.*) and whether other (unrecorded) changes in transfusion practice are playing a role are unknown. The data do suggest that transfusion *per se* cannot explain the changes in ION.

One last factor shown by the POVL group to be relevant is the colloid fraction of total nonblood fluids. Again, like EBL, no longitudinal data exist to determine if changes have occurred. However, colloid use was quantitatively the smallest risk factor identified by the POVL group, so even a huge change in practice would be expected to have a minimal impact.

Conclusions

As noted, the observed reductions in the incidence of ION are unlikely to be due to changes in our patients (age, sex, or body mass index) and hence must be related to how we are practicing. The largest changes are *probably* due to changes in surgical positioning along with a possible reduction in operative times. Did these changes occur specifically in response to our recognition of ION? Probably not. For example, the onset of the decrease in ION incidence appears to have predated the appearance of objective information and practice advisories, although general awareness of the problem, driven by the rapidly expanding literature, may have played some role. In addition, other unrecognized factors may be operating. The risk factors defined by the POVL Study Group are limited by the relatively small sample size (and the huge sample used by Rubin *et al.* probably explains why they—but not the POVL Study Group—were able to identify age as a risk factor). For example, hypotension could not be identified by the POVL group as a factor—and yet ischemic injury to any organ is influenced by perfusion pressure. Given the large number of published articles anecdotally suggesting a link between blood pressure and ION, it is possible that anesthesiologists have become more compulsive about blood pressure management in these patients.

Caveat

It would be a mistake to assume that "this problem has been beaten." Cases of devastating postoperative blindness after prone spine surgery continue to appear, if for no other reason than that the number of surgeries performed has increased, and, as noted by the authors, the incidence of retinal artery occlusion has not changed. Further progress will depend on continuing research—both clinical and laboratory—into causative mechanisms. For example, we still do not understand why ION occurs in only a small fraction of patients, even when they are matched for known risks; the POVL Study Group showed that even in patients at highest risk (obese males undergoing very long operations on a Wilson frame with large EBLs), the predicted incidence of ION is only on the order of 2 to 3%. What is different about these patients *versus* the 97 to 98% of similar patients having similar operations who do not develop ION? Only by solving this dilemma can we completely eliminate this problem, and hopefully, the observations of Rubin *et al.* will aid us in focusing our efforts.

Competing Interests

The author is not supported by, nor maintains any financial interest in, any commercial activity that may be associated with the topic of this article.

Correspondence

Address correspondence to Dr. Michael M. Todd: michael-todd@uiowa.edu

References

1. Curtillet E, Portier P: Un cas d'amaurose post-operatoire [Postoperative amaurosis]. Afr. Fr. Chir 1950; 1:51–3
2. Lee LA, Roth S, Posner KL, Cheney FW, Caplan RA, Newman NJ, Domino KB; The American Society of Anesthesiologists: Postoperative Visual Loss Registry: Analysis of 93 spine surgery cases with postoperative visual loss. Anesthesiology 2006; 105:652–9
3. American Society of Anesthesiologists: Practice advisory for perioperative visual loss associated with spine surgery: A report by the American Society of Anesthesiologists Task

Force on perioperative blindness. ANESTHESIOLOGY 2006; 104:1319–28

4. The Postoperative Visual Loss Study Group: Risk factors associated with ischemic optic neuropathy after spinal fusion surgery. ANESTHESIOLOGY 2012; 116:15–24
5. American Society of Anesthesiologists: Practice Advisory for perioperative visual loss associated with spine surgery: An updated report by the American Society of Anesthesiologists Task Force on perioperative visual loss. ANESTHESIOLOGY 2012; 116:274–85
6. Rubin DS, Parakati I, Lee LA, Moss HE, Joslin CE, Roth S: Perioperative visual loss in spine fusion surgery: Ischemic optic neuropathy in the United States from 1999 to 2011 in the Nationwide Inpatient Sample. ANESTHESIOLOGY 2016; XX:XX–XX
7. Banczerowski P, Czigléczki G, Papp Z, Veres R, Rappaport HZ, Vajda J: Minimally invasive spine surgery: Systematic review. Neurosurg Rev 2015; 38:11–26; discussion 26
8. Phan K, Rao PJ, Kam AC, Mobbs RJ: Minimally invasive *versus* open transforaminal lumbar interbody fusion for treatment of degenerative lumbar disease: Systematic review and meta-analysis. Eur Spine J 2015; 24:1017–30
9. Wang M, Zheng XF, Jiang LS: Efficacy and safety of antifibrinolytic agents in reducing perioperative blood loss and transfusion requirements in scoliosis surgery: A systematic review and meta-analysis. PLoS One 2015; 10:e0137886
10. Cheriyan T, Maier SP II, Bianco K, Slobodyanyuk K, Rattenni RN, Lafage V, Schwab FJ, Lonner BS, Errico TJ: Efficacy of tranexamic acid on surgical bleeding in spine surgery: A meta-analysis. Spine J 2015; 15:752–61

Perioperative Visual Loss in Spine Fusion Surgery

Ischemic Optic Neuropathy in the United States from 1998 to 2012 in the Nationwide Inpatient Sample

Daniel S. Rubin, M.D., Isaac Parakati, B.S., Lorri A. Lee, M.D., Heather E. Moss, M.D., Ph.D., Charlotte E. Joslin, O.D., Ph.D., Steven Roth, M.D., F.A.R.V.O.

ABSTRACT

Background: Perioperative ischemic optic neuropathy (ION) causes visual loss in spinal fusion. Previous case–control studies are limited by study size and lack of a random sample. The purpose of this study was to study trends in ION incidence in spinal fusion and risk factors in a large nationwide administrative hospital database.

Methods: In the Nationwide Inpatient Sample for 1998 to 2012, procedure codes for posterior thoracic, lumbar, or sacral spine fusion and diagnostic codes for ION were identified. ION was studied over five 3-yr periods (1998 to 2000, 2001 to 2003, 2004 to 2006, 2007 to 2009, and 2010 to 2012). National estimates were obtained using trend weights in a statistical survey procedure. Univariate and Poisson logistic regression assessed trends and risk factors.

Results: The nationally estimated volume of thoracic, lumbar, and sacral spinal fusion from 1998 to 2012 was 2,511,073. ION was estimated to develop in 257 patients (1.02/10,000). The incidence rate ratio (IRR) for ION significantly decreased between 1998 and 2012 (IRR, 0.72 per 3 yr; 95% CI, 0.58 to 0.88; $P = 0.002$). There was no significant change in the incidence of retinal artery occlusion. Factors significantly associated with ION were age (IRR, 1.24 per 10 yr of age; 95% CI, 1.05 to 1.45; $P = 0.009$), transfusion (IRR, 2.72; 95% CI, 1.38 to 5.37; $P = 0.004$), and obesity (IRR, 2.49; 95% CI, 1.09 to 5.66; $P = 0.030$). Female sex was protective (IRR, 0.30; 95% CI, 0.16 to 0.56; $P = 0.0002$).

Conclusions: Perioperative ION in spinal fusion significantly decreased from 1998 to 2012 by about 2.7-fold. Aging, male sex, transfusion, and obesity significantly increased the risk. **(ANESTHESIOLOGY 2016; 125:00-00)**

PERIOPERATIVE visual loss (POVL) in spinal fusion surgery is a rare but devastating complication, most commonly due to ischemic optic neuropathy (ION), although other known causes include retinal arterial occlusion (RAO) and cortical blindness. Patients who undergo spinal fusion or cardiac surgery are at the greatest risk for the development of ION.[1] As the utilization of spinal fusion in the United States is the highest in the world,[2] it is imperative to uncover the risk factors for and determine how to prevent rare but serious complications such as ION. In a case–control study of 80 subjects with ION after spinal fusion in the American Society of Anesthesiologists (ASA) Postoperative Visual Loss Registry *versus* unaffected control patients from 17 North American medical centers, we showed that

What We Already Know about This Topic

- Perioperative ischemic optic neuropathy causes visual loss in spinal fusion. The purpose of this study was to determine trends in ischemic optic neuropathy incidence in spinal fusion and risk factors in a large nationwide administrative hospital database.

What This Article Tells Us That Is New

- In the Nationwide Inpatient Sample for 1998 to 2012, procedure codes for spine surgery and diagnostic codes for ischemic optic neuropathy were identified. It was found that perioperative ischemic optic neuropathy in spinal fusion significantly decreased from 1998 to 2012 by about 2.7-fold. Aging, male sex, transfusion, and obesity significantly increased the risk.

This article is featured in "This Month in Anesthesiology," page 1A. Corresponding article on page XXX. This work was presented in part at the Annual Meeting of the American Society of Anesthesiologists in San Diego, California, October 2015, and at the Annual Meeting of the American Academy of Neurology in Vancouver, BC, Canada, April 2016.

Submitted for publication December 28, 2015. Accepted for publication May 23, 2016. From the Department of Anesthesia and Critical Care, University of Chicago Medicine, Chicago, Illinois (D.S.R.); College of the University of Chicago, Chicago, Illinois (I.P.); Department of Anesthesiology (L.A.L.) and Neuroanesthesia (L.A.L.), Vanderbilt University, Nashville, Tennessee; Departments of Ophthalmology and Visual Sciences (H.E.M., C.E.J., S.R.), Neurology and Rehabilitation (H.E.M.), and Anesthesiology (S.R.), College of Medicine, University of Illinois at Chicago, Chicago, Illinois; Division of Epidemiology and Biostatistics, School of Public Health, University of Illinois at Chicago, Chicago, Illinois (C.E.J.); and Department of Anesthesia and Critical Care (S.R.) and The Center for Health and the Social Sciences (S.R.), University of Chicago Medicine, Chicago, Illinois. Current position: Department of Biostatistics, Emory University, Atlanta, Georgia (I.P.).

 Anesthesiology 2016; 125:00-00

the risk factors for ION included male sex, obesity, the use of a Wilson frame for surgical positioning, anesthesia duration, higher estimated blood loss, and percent colloid of nonblood replacement during the procedure.[3]

The incidence of POVL in spine surgery has been approximated at 1 to 10/10,000.[4,5] Estimates differ widely depending upon size of the study and the data source, *e.g.*, administrative data, single *versus* multiple institutions, inclusion of all spine surgery, fusions alone, anatomical locations of the surgery, and year of the study, among other factors.[3] Although few anesthesiologists and surgeons were familiar with POVL in the 1980s and 1990s, the increasing publication of case reports in the literature,[6] publicity associated with the ASA POVL Registry,[7,8] and other studies of POVL in the 2000s[9–12] appear to have increased awareness of this complication. Nonetheless, in a survey by the Anesthesia Patient Safety Foundation, 87% of anesthesiologists opined that most surgeons do not recognize the risk of perioperative ION, and 52% believed the same for anesthesia professionals.[13] There have been other efforts to heighten awareness of POVL in spine surgery among anesthesiologists and surgeons. These included two ASA Advisories on Postoperative Visual Loss, first in 2006 and the other in 2012,[14,15] and a Consensus Statement on Postoperative Visual Loss from the Anesthesia Patient Safety Foundation.[13]

Based upon clinical observations, we hypothesized that the incidence of ION in spinal surgery has been decreasing. We also theorized that examination of spinal fusion ION cases in a large, randomly collected database close to the current time would provide new data on pre- and perioperative risk factors. Accordingly, there were two main goals of the current study: (1) to evaluate the incidence trends of ION associated with spinal fusion, and specifically, to determine if the incidence has decreased and (2) to use a large nationwide database to identify risk factors for development of ION in spine fusion surgery.

Materials and Methods

As there were no patient identifiers, the University of Chicago and University of Illinois Institutional Review Boards deemed the study "exempt." We studied discharge data in the Nationwide Inpatient Sample (NIS) from 1998 to 2012. The database is maintained by the Healthcare Cost and Utilization Project under the Agency for Healthcare Research and Quality (AHRQ). The hospital discharge record includes patient demographics, diagnoses (principal and less than 14 secondary), procedures (principal and less than 14 secondary), charges (in dollars), length of stay (in days), discharge status, outcomes, and medical diagnoses.[1,16] Diagnoses and procedures are coded using the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM).

The NIS is roughly a 20% stratified sample of nonfederal U.S. inpatient hospital discharges and is derived from routine hospital discharge data. In 2012, the sampling was redesigned to improve the accuracy of national estimates; sampling is from all participating hospitals rather than a sample of hospitals. AHRQ provided updated discharge weights on its Internet site for the 1998 to 2012 NIS to ensure accurate weighting of the sample and enable analysis across multiple years.[17] We, thus, used these "trend weights" in the "survey" function of Stata (Stata Corp., USA) for all patient-level analysis.

Quality control and reliability of the NIS have been examined each year since 2000. National estimates of essential healthcare parameters in the NIS were precise and accurate compared with the American Hospital Association Annual Survey, National Hospital Discharge Survey, and Medicare Inpatient data.[18]

Data Classification

As previously reported,[3] ICD-9-CM codes for primary procedure of posterior thoracic, lumbar, or sacral spine fusion in the NIS from 1998 to 2012 were studied, excluding anterior approach to the spine (table 1). Since most ION cases after spinal fusion involve the thoracic and lower vertebrae,[7] cervical spine fusion was excluded. To ensure complete coverage of relevant procedure codes, ICD-9-CM codes were confirmed against Current Procedural Technology procedure spinal fusion codes using Encoder Pro.com (Optum, USA). Patients discharged with a principal or secondary diagnostic ICD-9-CM code of ION (377.41) were considered to have developed ION during the hospitalization. For comparison of incidence trends, we also identified patients with a diagnosis of retinal artery occlusion (RAO, 362.3; 362.30-0.34, table 1).

Patient and Surgical Characteristics

Patient characteristics analyzed included age (years, continuous variable), sex, length of hospital stay (days), and yearly inflation-adjusted total hospital charges (both as continuous variables), type of admission (elective, urgent, emergent), discharge status (home, nursing facility, died, *etc.*), and race. Medical diagnoses (ICD-9 codes are in table 2) studied were atherosclerosis, coronary artery disease, carotid artery stenosis, diabetes mellitus, hypertension, obesity, peripheral vascular disease, and smoking. Hospital conditions included anemia and transfusion. Stroke was included as postoperative, acute, embolic, and thrombotic.

Analysis

Stata v14.0-MP was used to analyze data. We utilized AHRQ trend weights in the survey function in Stata for all estimates and regressions. Missing data points were noted for race, type of admission, and discharge status. Missing data for race are reported as "unknown" in the regression analysis. Type of admission and discharge status were not included in the regression analysis, and no observations were otherwise excluded due to missing data. To calculate incidence of ION and RAO, we divided the study into 3-yr periods (1998 to 2000, 2001 to 2003, 2004 to 2006, 2007 to 2009,

Table 1. ICD-9-CM and Corresponding CPT Procedure Codes for Spinal Fusion and ICD-9-CM Diagnosis Code for Ischemic Optic Neuropathy in the Nationwide Inpatient Sample

Description	ICD-9-CM Code	CPT
Diagnosis		
Ischemic Optic Neuropathy (ION)	377.41	
Retinal Artery Occlusion (RAO)	362.3	
	362.30–4	
Procedures		
Dorsal And Dorsolumbar Fusion Of The Posterior Column, Posterior Technique	81.05	22610, 22612, 22614, 22800, 22802, 22804, 22851
Lumbar And Lumbosacral Fusion Of The Posterior Column, Lateral Transverse Process Technique	81.07	22612, 22614, 22630, 22632, 22633, 22634, 22800, 22842, 22851
Lumbar And Lumbosacral Fusion Of The Anterior Column, Posterior Technique	81.08	0195T, 0196T, 0309T, 22586, 22612, 22514, 22630, 22632, 22633, 22634, 22800, 27279, 27280
Refusion Of Dorsal And Dorsolumbar Spine, Posterior Column, Posterior Technique	81.35	22610, 22612, 22614, 22800, 22802, 22804, 22851
Refusion Of Lumbar And Lumbosacral Spine, Posterior Column, Lateral Transverse Process Technique	81.37	22612, 22614, 22630, 22632, 22800, 22842, 22851
Refusion Of Lumbar And Lumbosacral Spine, Anterior Column, Posterior Technique	81.38	0195T, 0196T, 0309T, 22586, 22612, 22614, 22630, 22632, 22800

To ensure complete coverage of relevant procedure codes, ICD-9-CM procedure codes for posterior approach for thoracic, lumbar, or sacral spinal fusion were confirmed against a list of all Current Procedural Technology (CPT) procedure spinal fusion codes using Encoder Pro.com (Optum, USA).

ICD-9-CM = *International Classification of Diseases, Ninth Revision, Clinical Modification*.

Table 2. ICD-9-CM Codes for Patient Characteristics

Patient Characteristics	ICD-9-CM
Atherosclerosis	440.x
Coronary artery disease	414.0x
Carotid artery stenosis	433.1x
Diabetes mellitus	250.0x
Hypertension	401.x
Obesity	278.0x
Peripheral vascular disease	443.x
Smoking	V15.82, 305.1
Anemia	280.x, 285.2x
Transfusion	99.00, 99.04
Stroke	997.02, 434.91, 434.11, 434.01

An "x" at the end of *Internal Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) code signifies that multiple suffix codes were used to search for associated conditions.

and 2010 to 2012). This enabled the numerator (cases per time period) to reach the threshold for reporting (more than 10), while the denominator was the number of spinal fusion procedures per time period. (AHRQ prohibits data reporting of any data cell, where n is less than or equal to 10.) To study if age was a risk factor, 10-yr age groups were studied, *i.e.*, 18 to 30, 31 to 40 years, *etc*.

Patient characteristics in spinal fusion groups with or without ION for 1998 to 2012 were tabulated using the national estimates. Univariate analysis, followed by multivariate Poisson regressions, assessed risk factors in the discharges from 1998 to 2012.[19] A Poisson model was used because it was deemed appropriate for modeling count data. $P < 0.2$ was the minimum criterion for inclusion of variables in the subsequent multiple Poisson regression, and $P < 0.05$ in the multiple Poisson regression model indicated a significant risk factor. Results are reported as incidence rate ratios (IRRs). The variance inflation factor examined for collinearity.[20] Pearson goodness-of-fit test assessed fit of the model.

Results

There were an estimated 2,511,073 discharges in the United States from 1998 to 2012 with procedure codes for posterior thoracic, lumbar, and sacral spinal fusion. The national estimates (table 3) for ION were 257 (1.02/10,000), and for RAO, 224 (0.89/10,000). The volume of procedures per 3 yr increased nearly threefold from 262,279 in 1998 to 2000 to 733,454 in 2010 to 2012 (table 3), but ION in spine fusion (fig. 1) decreased significantly ($P = 0.002$) from 1.63/10,000 in 1998 to 2000 to 0.60/10,000 in 2010 to 2012. There was no significant change in incidence of RAO during the study period (fig. 1).

Table 4 shows the characteristics in the national estimates of those who sustained ION and those who did not. ION patients were older, and males predominated among ION patients. At least 20% of the race information was not provided. Mean total inflation-adjusted charges for the hospitalization and length of hospital stay were higher for ION than for nonaffected. A higher proportion of ION patients had a blood transfusion (ION, 29.6%; non-ION, 14.0%); the percent of patients with obesity was greater in those with ION (17.1%) than in nonaffected ones (9.8%). Mean number of vascular factors was similar for the two groups; stroke was infrequent, but with higher percent in ION cases.

Poisson multivariate analysis models considered 3-yr interval incidence, age (10-yr intervals), sex, transfusion, obesity, and stroke (those factors with $P < 0.2$ in univariate analysis, table 5, were entered into the model).

Table 3. National Estimates of ION and RAO in Thoracic, Lumbar, and Sacral Spine Fusion from 1998 to 2012 in the NIS

Year	Spinal Fusion Cases (n)	ION among Spinal Fusion Cases, n (95% CI)	ION per 10,000 Spinal Fusions (95% CI)	RAO among Spinal Fusion Cases, n (95% CI)	RAO per 10,000 Spinal Fusions (95% CI)
1998–2000	262,279	43 (15–72)	1.63 (0.57–2.75)	23 (2–45)	0.88 (0.076–1.72)
2001–2003	399,773	52 (19–84)	1.30 (0.48–2.10)	33 (7–60)	0.83 (0.18–1.50)
2004–2006	492,133	69 (32–105)	1.40 (0.65–2.13)	34 (8–61)	0.69 (0.16–1.24)
2007–2009	623,434	49 (11–87)	0.79 (0.18–1.40)	67 (26–104)	1.07 (0.42–1.67)
2010–2012	733,454	44 (13–74)	0.60 (0.18–1.01)	66 (29–104)	0.90 (0.40–1.42)
Total	2,511,073	257 (182–331)	1.02 (0.72–1.32)	224 (151–296)	0.89 (0.60–1.18]

Ischemic optic neuropathy (ION) in posterior spinal fusion procedures decreased significantly between 1998 and 2012; however, retinal artery occlusion (RAO) remained unchanged. To calculate incidence of ION and RAO per 10,000 cases, time was divided into 3-yr periods (1998–2000, 2001–2003, 2004–2006, 2007–2009, and 2010–2012). This enabled numerator (ION or RAO cases per time period) to reach the threshold for reporting (> 10), while the denominator was the number of spinal fusion procedures per time period. Estimates from the Nationwide Inpatient Sample (NIS) were created using the trend weights and stratum variables from the NIS and the survey function of Stata (Stata Corp., USA).

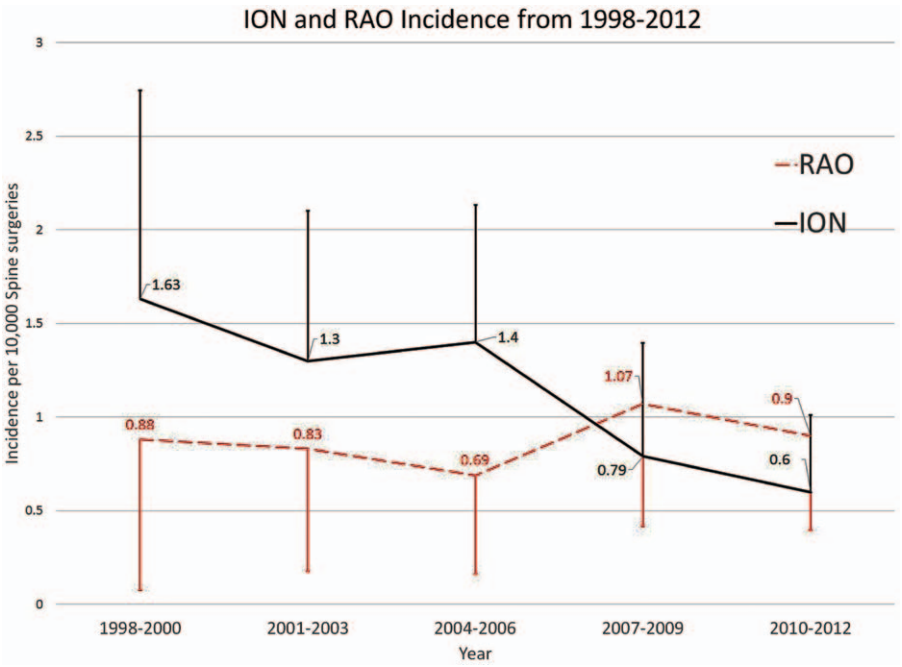

Fig. 1. The y-axis shows the 3-yr incidence of ischemic optic neuropathy (ION) and retinal artery occlusion (RAO) per time period (x-axis), using national estimates from the Nationwide Inpatient Sample. The data are shown as incidence point estimates ± 95% CIs. Three-year periods were used, as Agency for Health Research and Quality does not allow reporting results less than 10. The incidence of ION, but not RAO, significantly decreased over time.

Atherosclerosis, carotid artery stenosis, peripheral vascular disease, and race other than white, Hispanic, or Asian/Pacific Islander had insufficient sample size, and therefore, risk with these parameters could not be calculated accurately. In the final model (table 6), the IRR for ION decreased from 1998 to 2012 (IRR, 0.72 per 3-yr period; 95% CI, 0.58 to 0.88; P = 0.002). Factors significantly associated with ION were increasing age (IRR, 1.24 per 10 yr of age; 95% CI, 1.05 to 1.45; P = 0.009), blood transfusion (IRR, 2.72; 95% CI, 1.38 to 5.37; P = 0.004), and obesity (IRR, 2.49; 95% CI, 1.09 to 5.66; P = 0.030). Being female was protective (IRR, 0.30; 95% CI, 0.16 to 0.56; P < 0.000). The Poisson regression showed good fit, as Pearson goodness-of-fit test was not significant at the 5% level. Furthermore, lack of collinearity in the model was suggested by variance inflation factor less than 10 for all covariates.

Discussion

POVL after spine fusion surgery continues to be a devastating complication, with ION the most frequent cause of visual loss in this surgical cohort. Encouragingly, this study illustrated significantly decreasing ION in spinal fusion; incidence in 2010 to 2012 was about one third than in 1998 to 2000. The lack of change in incidence of RAO suggests that the mechanisms of these disorders are different; moreover, the RAO results serve as an inherent control, further confirming the validity of the results.

Table 4. Characteristics for All Spinal Fusion Patients and for Those Specifically with Ischemic Optic Neuropathy in the NIS 1998 to 2012, Based upon Population Estimates

	Ischemic Optic Neuropathy	Unaffected
All patients: number of discharges	257	2,510,816
Age (yr): all patients, mean (95% CI)	60.0 (56.9–63.1)	56.1 (55.8–56.3)
Length of stay (d), mean (95% CI)	7.4 (6.1–8.7)	4.9 (4.8–5.0)
Total hospital charges, mean (95% CI)	132,504 (103,544–161,465)	95,347 (92,150–98,545)
Sex		
Male (%)	179 (69.6)	1,122,459 (44.7)
Female (%)	78 (30.4)	1,387,191 (55.2)
Type of admission		
Elective (%)	153 (60)	1,870707 (75)
Nonelective (%)	34 (13)	254,576 (10)
Unknown	70 (27)	385,533 (15)
Discharge status		
Routine (%)	122 (≥ 45.9)	1,650,983 (65.7)
Various transfers (%)	95 (≥ 35.7)	493,573 (19.7)
Home health care (%)	39 (≥ 14.7)	354,058 (14.1)
Other (%)	0 (0)	8,304 (0.3)
Unknown	0 (0)	459 (0.02)
Race		
White (%)	181 (≥ 81.9)	1,675,794 (66.9)
Black (%)	≤ 10 (≤ 4.5)	129,545 (5.2)
Hispanic (%)	≤ 10 (≤ 4.5)	116,325 (4.6)
Asian or Pacific Islander (%)	≤ 10 (≤ 4.5)	19,461 (0.8)
Other (%)	≤ 10 (≤ 4.5)	53,763 (0.3)
Unknown	67 (26.1)	515,927 (20.5)
Transfusion (%)	76 (29.6)	350,464 (14.0)
Obesity (%)	44 (17.1)	247,176 (9.8)
Mean number of vascular factors listed below (95% CI)	1.07 (0.77–1.35)	0.91 (0.90–0.93)
Stroke (%)	≤ 10 (≤ 3.9)	3967 (0.2)
Hypertension (%)	125 (48.6)	1,073,017 (42.7)
Diabetes mellitus (%)	43 (16.7)	332,748 (13.3)
Atherosclerosis (%)	≤ 10 (≤ 3.9)	38,635 (0.3)
Peripheral vascular disease	≤ 10 (≤ 3.9)	31,265 (1.2)
Coronary artery disease (%)	34 (13.2)	215,690 (8.6)
Smoking (%)	57 (22.2)	584,316 (23.3)
Carotid artery stenosis (%)	0 (0.0)	5,996 (0.2)

Results are nationwide estimates using Nationwide Inpatient Sample (NIS) weighting and the Stata survey function. Numbers are presented as count estimates or mean (%) and mean (95% CI) when indicated. Results with n < 10 could not be reported. See Materials and Methods for diagnostic codes used to identify characteristics. Spinal fusion cases were lumbar, thoracic, or sacral, using a posterior surgical approach. Total charges (not including professional fees) were inflation adjusted to 2012 dollars using Bureau of Labor Statistics (http://www.bls.gov/data/).

We cannot determine the mechanism of this trend in ION. A possible cause is changes in surgical and anesthesia practice, perhaps driven by the heightened awareness generated by the literature, advisories, and consensus statements. However, there are other possible trends that cannot be assessed by our study, such as changes in surgical patient selection, intraoperative positioning, and postoperative management.

The mechanism of perioperative ION, particularly posterior ION, remains elusive, but retrospective studies have revealed associated factors. A case–control study from a single institution examined 126,666 general anesthetic records and found 17 patients with perioperative ION; a subpopulation underwent spine fusion. They could not identify differences in intraoperative hemodynamic parameters between ION patients and the matched controls, suggesting either that patient-specific characteristics may be involved or that the number of cases identified yielded insufficient study power.[12] Subsequently, a case–control study compared perioperative data between 80 spinal fusion cases with ION from the ASA POVL Registry and 315 unaffected control patients undergoing similar procedures from 17 North American institutions. Male sex, obesity, Wilson frame use, longer anesthetic duration, greater estimated blood loss, and a lower percentage of colloid in nonblood fluid administration were significant and independent risk factors for ION.[3]

In this study, using NIS data, we identified four factors, increasing age, male sex, blood transfusion, and obesity, that

Table 5. Univariate Analysis for ION for Spinal Fusion in the Nationwide Inpatient Sample 1998 to 2012

	Incidence Risk Ratio	95% CI	*P* Value
ION 3-yr interval (continuous)	0.72	0.58–0.88	0.002
Retinal artery occlusion 3-yr interval (continuous)	1.04	0.83–1.31	0.737
10-yr age (continuous)	1.23	1.03–1.46	0.022
Sex (male = 0, female = 1)	0.30	0.16–0.56	0.0002
Race (reference: white)			
Hispanic	0.323	0.04–2.59	0.287
Asian or Pacific Islander	2.70	0.33–21.7	0.352
Unknown	1.16	0.59–2.29	0.662
Other	—		
Transfusion	2.72	1.37–5.40	0.004
Obesity	2.41	1.06–5.48	0.036
Vascular factors			
Stroke	7.38	0.89–61.27	0.064
Hypertension	1.11	0.58–2.16	0.748
Diabetes mellitus (%)	1.07	0.48–2.40	0.87
Atherosclerosis	—		
Peripheral vascular disease	—		
Coronary artery disease	1.00	0.43–2.32	0.995
Smoking	1.05	0.54–2.05	0.89
Carotid artery stenosis	—		

Univariate regression using a Poisson regression shows a decrease in ischemic optic neuropathy (ION) for female sex and procedures performed closer to 2012. Increase in ION counts is observed with older patients, obese patients, and those receiving a blood transfusion. A similar Poisson regression with retinal artery occlusion showed no change in the rate during the same time period. Data coding is indicated in the left column of the table. Dashes indicate not enough data available for regression analysis or no ION cases containing that characteristic.

Table 6. Multivariate Analysis for ION for Spinal Fusion in the Nationwide Inpatient Sample from 1998 to 2012

	Incidence Risk Ratio	95% CI	Poisson Regression *P* Value	VIF	Pearson Goodness-of-Fit (*P* Value)
ION, 3-yr interval (continuous)	0.72	0.58–0.88	0.002	1.03	0.9999
Sex (male = 0, female = 1)	0.30	0.16–0.56	0.0002	1.02	
Age (per 10 yr)	1.24	1.05–1.45	0.009	1.04	
Transfusion	2.72	1.38–5.37	0.004	1.02	
Obesity	2.49	1.09–5.66	0.030	1.02	
Stroke	7.27	0.87–60.48	0.067	1.00	

Surgery closer to 2012 and female sex decreased risk for ischemic optic neuropathy (ION), and increasing age, transfusion, and obesity increased risk. Values from univariate analysis (table 5) with $P < 0.2$ were entered into the multivariate regression model using the Poisson regression. Variance inflation factor (VIF) values <10 indicated lack of collinearity. We cannot reject the hypothesis that the data are Poisson distributed because the Pearson goodness-of-fit test is not significant at the 5% level.

were associated with the development of perioperative ION in a multivariate model. While the NIS database does not provide intraoperative data, we demonstrated that two of the factors overlapped with the earlier case–control study: male sex and obesity. Transfusion may be a surrogate for blood loss.

The strengths of this study included a large database, the size of which exceeded that examined in our previous case–control study.[3] In the 2012 case–control study, the 80 patients with ION had been anonymously submitted by medical practitioners, quality improvement administrative personnel, and patients. Biased sampling technique or incorrectly entered data could not be ruled out, and some data points were missing in the records.[3] For the unaffected controls, the study used a much smaller sampling of hospitals compared to the NIS; hospitals from which the affected patients were derived was anonymous; hence, it is not known if the sampling was representative of all patients in the United States who underwent the procedure. But, the NIS has the advantage of providing a randomized sampling of discharges from hospitals.

Why men were at higher risk for ION remains unclear since there are no known anatomic variations between the male and female visual pathways. An influence of female hormones including estrogen could play a role.[21] Acute venous congestion of the head and neck secondary to patient position is a possible mechanism for ischemic damage to the optic nerve, which corresponds well with one of the theories on ION pathogenesis.[22] Anatomic differences between men and women, which may become evident when they are positioned on the Wilson frame, may play a role in causing

greater interstitial fluid accumulation in men that may predispose to a higher incidence of ION. It is possible that obese men are more likely to lose greater amounts of blood and require more fluid during spine surgery.

A new finding was that age was a risk factor for ION in spinal fusion. There was a 24% increase in incidence risk ratio per 10 yr of age. It may be related to older patients requiring more complex surgery or to increased vulnerability of the optic nerve to physiologic insults associated with major spine surgery, as the optic nerve undergoes significant degeneration with age.[23] We found no influence of diabetes mellitus, hypertension, coronary artery disease, number of vascular risk factors, or smoking on the risk of developing ION. Stroke (none were postoperative stroke) was not significant in the multivariate analysis. However, sample sizes of affected patients were small and could have influenced these results. Due to missing data, it is not possible to assess the impact of any possible racial disparities on the results.

Our study demonstrated longer length of stay and higher hospital charges in patients who sustained ION. While these patients typically undergo more in-hospital diagnostic procedures, and/or treatment of ION, we cannot definitively conclude that longer stay and higher charged were caused by ION. Patients who are older and undergo more complex surgery, *e.g.*, greater number of spine levels fused, and hence sustain longer hospital stays, could also be the same patients who are at risk of ION. However, we were unable to study the effect of number of levels fused as these data were only sparsely present in the database.

In addition to understanding the risk factors associated with ION, there has been a coordinated and concerted effort to increase awareness and help guide patient management. In 2006 (and revised in 2012, but the latter cannot be related to the results in this study), the ASA produced practice advisory statements to help educate and guide practice for spine fusion surgery.[15] We cannot determine from the current study what role, if any, these advisory statements have had on the changing incidence of ION. One notable change in spine surgery has been the increasing use of "minimally invasive" surgical techniques.[24] These have been shown to result in less blood and fluid requirements compared to the traditional "open" approach.[24,25] Although it would have been relevant to study the impact of this change on ION incidence, there was no specific procedure code for the "minimally invasive" procedure before 2013.[26]

There are limitations to this study. The NIS database relies on the accuracy of diagnosis and coding. Verification of each individual case and the associated medical diagnoses are not possible as the discharge records are deidentified. Currently, there are not enough data in the literature to assess the accuracy of coding in NIS for uncommon complications such as ION and RAO.[27] Both over- and undercoding are possible. Also, it is not possible to rule out if changes in coding frequency of ION or of the spinal fusion procedure codes are involved in the incidence data results. The coding discharge information depends upon entry of the data by professional coders; however, the accuracy of the information in turn depends upon the diagnoses recorded by physicians and the procedure description provided by the surgeon. To avoid confounding issues with procedure coding, a wide range of codes for posterior spinal fusion was used and compared to Current Procedural Technology codes, which are more commonly used for procedure coding in the United States for billing purposes. However, given the nationwide scope of the NIS, systematic bias in this coding appears improbable. Some cases of ION may have been preexisting which would lead to a false elevation of the incidence. The severity of injury using the NIS cannot be quantified, and the type of ION (anterior *vs.* posterior) cannot be differentiated. The NIS only identifies diagnosed cases of ION but does not stratify the extent of loss of vision. NIS data lack longitudinal information (*i.e.*, a single individual cannot be tracked across multiple hospitalizations or for follow-up after surgery). NIS does not contain intraoperative data such as anesthetic technique, length of surgery, surgical positioning, blood loss, or volume of fluids infused.[16]

Definitive conclusions concerning changes in intraoperative technique and practice cannot be made from this study. This area remains challenging to appropriately study in the clinical setting since rates of ION are low and deliberately manipulating intraoperative variables in a randomized controlled design would be difficult if not unethical. Despite the continual and dramatic increase in spinal fusion utilization, the rates of ION after spine fusion in our study have declined significantly between 1998 and 2012. Further study of large multicenter databases that contain more pertinent intraoperative data may allow assessment of whether perioperative surgical and anesthetic practice has been modified consistent with the recommendations of the national practice advisories.

Acknowledgments

The authors are grateful to Ms. Elaine Hrinyo, C.P.C., Billing Manager, Department of Anesthesia and Critical Care, University of Chicago Medicine, Chicago, Illinois, for assistance with Current Procedural Technology codes, and the Encoder program.

Research Support

Supported by National Institutes of Health (Bethesda, Maryland) grants RO1 EY10343 (to Dr. Roth), UL1 RR024999 (to the University of Chicago Institute for Translational Medicine, Chicago, Illinois), K23 EY024345 (to Dr. Moss), core grant P30 EY001792 (to the Department of Ophthalmology, University of Illinois at Chicago, Chicago, Illinois), and an unrestricted grant from Research to Prevent Blindness (New York, New York) to the Department of Ophthalmology and Visual Sciences, University of Illinois at Chicago.

Competing Interests

Drs. Roth and Lee have served as expert witnesses in cases of perioperative eye injuries on behalf of patients, physicians, and hospitals. The other authors declare no competing interests.

Correspondence

Address correspondence to Dr. Roth: Department of Anesthesiology, University of Illinois Medical Center, 1740 West Taylor, MC515, Chicago, Illinois 60612. rothgas@uic.edu.

References

1. Shen Y, Drum M, Roth S: The prevalence of perioperative visual loss in the United States: A 10-year study from 1996 to 2005 of spinal, orthopedic, cardiac, and general surgery. Anesth Analg 2009; 109:1534–45
2. Deyo RA, Mirza SK, Martin BI, Kreuter W, Goodman DC, Jarvik JG: Trends, major medical complications, and charges associated with surgery for lumbar spinal stenosis in older adults. JAMA 2010; 303:1259–65
3. Lee LA, Roth S, Todd MM, Posner KL, Polissar NL, Neradilek MB, Torner J, Newman NJ, Domino KB; The Postoperative Visual Loss Study Group: Risk factors associated with ischemic optic neuropathy after spinal fusion surgery. Anesthesiology 2012; 116:15–24
4. Stevens WR, Glazer PA, Kelley SD, Lietman TM, Bradford DS: Ophthalmic complications after spinal surgery. Spine (Phila Pa 1976) 1997; 22:1319–24
5. Roth S: Postoperative Blindness, Miller's Anesthesia. Edited by Miller RD. New York, Elsevier, 2015, pp 2821–41
6. Buono LM, Foroozan R: Perioperative posterior ischemic optic neuropathy: Review of the literature. Surv Ophthalmol 2005; 50:15–26
7. Lee LA, Roth S, Posner KL, Cheney FW, Caplan RA, Newman NJ, Domino KB: The American Society of Anesthesiologists Postoperative Visual Loss Registry: Analysis of 93 spine surgery cases with postoperative visual loss. Anesthesiology 2006; 105:652–9; quiz 867–8
8. Roth S, Barach P: Postoperative visual loss: Still no answers–Yet. Anesthesiology 2001; 95:575–7
9. Nuttall GA, Garrity JA, Dearani JA, Abel MD, Schroeder DR, Mullany CJ: Risk factors for ischemic optic neuropathy after cardiopulmonary bypass: A matched case/control study. Anesth Analg 2001; 93:1410–6, table of contents
10. Newman NJ: Perioperative visual loss after nonocular surgeries. Am J Ophthalmol 2008; 145:604–10
11. Patil CG, Lad EM, Lad SP, Ho C, Boakye M: Visual loss after spine surgery: A population-based study. Spine (Phila Pa 1976) 2008; 33:1491–6
12. Holy SE, Tsai JH, McAllister RK, Smith KH: Perioperative ischemic optic neuropathy: A case control analysis of 126,666 surgical procedures at a single institution. Anesthesiology 2009; 110:246–53
13. Lee LA, Stoelting RK: APSF-Sponsored Conference on Perioperative Visual Loss Develops Consensus Conclusions. Anesthesia Patient Safety Foundation Newsletter, Winter, 2013
14. Apfelbaum JL, Roth S, Connis RT, Domino KB, Lee LA, Nickinovich DG, Warner MA: Practice advisory for perioperative visual loss associated with spine surgery: An updated report by the American Society of Anesthesiologists Task Force on perioperative visual loss. Anesthesiology 2012; 116:274–85
15. Arens JF, Connis RT, Domino KB, Lee LA, Miller NR, Mirza SK, Newman NJ, Nickinovich DG, Roth S, Savino PJ, Warner MA, Weinstein PH: Practice advisory for perioperative visual loss associated with spine surgery: A report by the American Society of Anesthesiologists Task Force on perioperative blindness. Anesthesiology 2006; 104:1319–28
16. Shen Y, Silverstein JC, Roth S: In-hospital complications and mortality after elective spinal fusion surgery in the United States: A study of the nationwide inpatient sample from 2001 to 2005. J Neurosurg Anesthesiol 2009; 21:21–30
17. Agency for Healthcare Research and Quality: Overview of the National (Nationwide) Inpatient Sample (NIS). Rockville, 2015. Available at: hcupnet.ahrq.gov. Accessed May 3, 2016
18. Whalen DR, Elixhauser A: 2004 HCUP Nationwide Inpatient Sample (NIS) Comparison Report, HCUP Methods Series Report #2007-03. Rockville, U.S. Agency for Healthcare Research and Quality, 2007
19. Hidalgo B, Goodman M: Multivariate or multivariable regression? Am J Public Health 2013; 103:39–40
20. Murray DM, Pals SL, Blitstein JL, Alfano CM, Lehman J: Design and analysis of group-randomized trials in cancer: A review of current practices. J Natl Cancer Inst 2008; 100:483–91
21. Engler-Chiurazzi EB, Singh M, Simpkins JW: From the 90's to now: A brief historical perspective on more than two decades of estrogen neuroprotection. Brain Res 2016; 1633:96–100
22. Levin LA, Danesh-Meyer HV: Hypothesis: A venous etiology for nonarteritic anterior ischemic optic neuropathy. Arch Ophthalmol 2008; 126:1582–5
23. Girkin CA, McGwin G Jr, Sinai MJ, Sekhar GC, Fingeret M, Wollstein G, Varma R, Greenfield D, Liebmann J, Araie M, Tomita G, Maeda N, Garway-Heath DF: Variation in optic nerve and macular structure with age and race with spectral-domain optical coherence tomography. Ophthalmology 2011; 118:2403–8
24. Smith ZA, Fessler RG: Paradigm changes in spine surgery: Evolution of minimally invasive techniques. Nat Rev Neurol 2012; 8:443–50
25. Phan K, Rao PJ, Kam AC, Mobbs RJ: Minimally invasive *versus* open transforaminal lumbar interbody fusion for treatment of degenerative lumbar disease: Systematic review and meta-analysis. Eur Spine J 2015; 24:1017–30
26. Garber T, Ledonio CG, Polly DW Jr: How much work effort is involved in minimally invasive sacroiliac joint fusion? Int J Spine Surg 2015; 9:58
27. Grauer JN, Leopold SS: Editorial: Large database studies—What they can do, what they cannot do, and which ones we will publish. Clin Orthop Relat Res 2015; 473:1537–9