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Perioperative Comparative Effectiveness of Anesthetic Technique in Orthopedic Patients

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Abstract

Background—The impact of anesthetic technique on perioperative outcomes remains controversial. We studied a large national sample of primary joint arthroplasty recipients and hypothesized that neuraxial anesthesia favorably influences perioperative outcomes.

Methods—Data from approximately 400 hospitals between 2006 and 2010 were accessed. Patients who underwent primary hip or knee arthroplasty were identified and subgrouped by anesthesia technique: general, neuraxial, and combined neuraxial–general. Demographics, postoperative complications, 30-day mortality, length of stay, and patient cost were analyzed and compared. Multivariable analyses were conducted to identify the independent impact of choice of anesthetic on outcomes.

Results—Of 528,495 entries of patients undergoing primary hip or knee arthroplasty, information on anesthesia type was available for 382,236 (71.4%) records. Eleven percent were performed under neuraxial, 14.2% under combined neuraxial– general, and 74.8% under general anesthesia. Average age and comorbidity burden differed modestly between groups. When neuraxial anesthesia was used, 30-day mortality was significantly lower (0.10, 0.10, and 0.18%; $P < 0.001$), as was the incidence of prolonged (>75th percentile) length of stay, increased cost, and

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in-hospital complications. In the multivariable regression, neuraxial anesthesia was associated with the most favorable complication risk profile. Thirty-day mortality remained significantly higher in the general compared with the neuraxial or neuraxial–general group for total knee arthroplasty (adjusted odds ratio [OR] of 1.83, 95% CI 1.08–3.1, *P* = 0.02; OR of 1.70, 95% CI 1.06–2.74, *P* = 0.02, respectively).

Conclusions—The utilization of neuraxial *versus* general anesthesia for primary joint arthroplasty is associated with superior perioperative outcomes. More research is needed to study potential mechanisms for these findings.

Over the last decades, intense controversy has persisted among clinicians over the potential impact of the type of anesthesia on perioperative outcomes.[1,2] The patient population at the forefront of this debate has included hip and knee arthroplasty (total hip arthroplasty [THA] and total knee arthroplasty [TKA]) recipients, both because their procedures are highly suitable for neuraxial techniques and because of the magnitude of the overall impact this growing group of patients has on medical and economic parts of the healthcare system. Indeed, the number of total hip and knee arthroplasties performed annually in the United States has been steadily increasing and is expected to surpass four million by the year 2030.[3] Providing adequate data to guide evidence-based practice has been difficult thus far, because large, randomized controlled trials have not seemed feasible given the number of patients needed to study relatively low incidence outcomes and the limitations on external validity posed by such an approach.[4] Although a number of authors propose that neuraxial anesthesia in orthopedic patients may be associated with decreased rates of thromboembolic phenomena, a reduction in intraoperative blood loss and operating room time, these claims are based on publications of relatively small single institutional trials and meta-analyses burdened by inclusion of historic data, thus posing limitations associated with small sample sizes and widespread applicability of results representing current practice. Furthermore, because of the inclusion of data from specific institutions and patient populations, the utilization of different types of anesthesia among orthopedic patients in a nationally representative sample remains unknown.

Therefore, we used a large national database to (1) identify the utilization of different types of anesthesia among hip and knee arthroplasty recipients and (2) analyze whether the type of anesthesia is associated with differences in perioperative outcomes. We have recently used the same database to study the need for critical care utilization among hip and knee arthroplasty recipients and have found that patients undergoing these procedures under neuraxial compared with general anesthesia had lower odds for the utilization of such resources.[5] In another study, we determined the differences in demographics and perioperative outcomes associated with neuraxial *versus* general anesthesia in a select group of patients undergoing simultaneous bilateral TKA.[6] However, these previous studies did not address the specific question of the impact of the type of anesthesia on any other perioperative outcomes on a broader population receiving joint arthroplasties. We hypothesized that patients undergoing primary total hip and knee arthroplasty under neuraxial anesthesia would represent a minority among patients, although having more favorable perioperative outcomes.

Materials and Methods

Data Source

Data collected between 2006 and 2010 were obtained from Premier Perspective, Inc. (Charlotte, NC), an administrative database containing information on discharges from approximately 400 acute care hospitals located throughout the United States.[**] Data included are compliant with the Health Insurance Portability and Accountability Act[7] and therefore this project was exempt from requirements for consent by our institutional review board. The vendor of the database carries out a rigorous data validation and quality assurance process before data are being incorporated in the Premier data warehouse. The validation process involves a seven-step integrity analysis, followed by approximately 100 sampling and statistical validity and integrity assurance crosschecks.[**]

Study Sample

All patient records with an International Classification of Diseases-9th revision-Clinical Modification (ICD-9-CM) procedure code for primary lower extremity joint arthroplasty between 2006 and 2010 were identified using codes for primary hip (81.51) and knee (81.54) replacement. Using billing data, we separated entries into groups of patients, who underwent their procedure under general, neuraxial, or combined neuraxial–general anesthesia. Those without indication of type of anesthesia were included as missing. To ensure that this step would not skew results, sensitivity analyses were performed by (1) including and (2) excluding patients with missing entry for all analyses.[8] No significant difference in results was seen.

Demographic Variables

We compared the characteristics of patients undergoing surgery under the different types of anesthesia. Patient- and healthcare system–related characteristics were analyzed. Patient demographics included age, sex, race (white, black, Hispanic, other), admission type (emergent, elective, urgent, and others), and payor (commercial, Medicaid, Medicare, Uninsured). Healthcare system–related parameters included hospital size (bed size of <299, 300–499, >500), geographic location (rural, urban), and teaching status (teaching, nonteaching). The prevalence of comorbidities and overall comorbidity burden was assessed using the method described by Deyo *et al*.[9] Procedure-specific variables included the type of surgery (total knee or hip arthroplasty) and surgical pathology (osteoarthritis, rheumatoid arthritis, trauma, and other [infectious, internal derangements]) and were based on ICD-9 diagnosis codes and/or billing records.

Complication Variables

For each group, the proportions of patients suffering from major complications were computed by identifying cases that had ICD-9-CM diagnosis codes listed consistent with such diagnosis (appendix 1). Systemic complications analyzed included pulmonary embolism, cerebral infarction, pulmonary compromise, acute myocardial infarction, cardiac complications (except myocardial infarction), pneumonia, other infectious complications, acute renal failure, and gastrointestinal complications. The incidence of 30-day mortality was directly provided from Premier. Furthermore, the incidence of the need for blood product transfusion and mechanical ventilation was recorded using ICD-9 and billing codes (appendix 1). Differences in length of hospital stay and patient costs were analyzed as continuous and as binary variables with dichotomization at the 75th percentile. Entries above the 75th percentile were categorized as prolonged hospitalization and increased cost.

Statistical Analysis

The study goal was to analyze whether the type of anesthesia is associated with differences in perioperative outcomes. All statistical analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC). The weighting procedure developed by Centers for Medicare & Medicaid Services and made available by Premier was used to derive nationally

[**]Premier Inc.: Premier Perspective Database. Available at: https://www.premierinc.com/quality-safety/tools-services/. Accessed April 1, 2013.

representative estimates from the available data.** To facilitate analysis of weighted data, SAS procedures SURVEYMEANS, SURVEYFREQ, SURVEYREG, and SURVEYLOGISTIC were used for descriptive analyses and modeling efforts.

Univariate Analysis

Weighted means and percentages were described for continuous and categorical variables, respectively. For variables that had a skewed distribution, median and interquartile range was estimated. For other variables, 95% CI was shown as a measure of variability. Chi-square test was performed to evaluate the association of two categorical variables. One-way ANOVA F test was used to compare means for continuous variables between more than two groups. Percentage of missing data for all covariates, stratified by anesthesia type, was determined.

Multivariate Regression Analysis

Multivariate analysis was performed for THA and TKA separately. Binary outcomes of incidence of complications, 30-day mortality, need for blood product transfusion, mechanical ventilation, prolonged length of hospital stay, and increased patient cost as defined above were considered. All variables that were deemed clinically important were considered and those with *P* values less than 0.2 in the univariate analyses were included in the final multivariate regressions. Deyo index was used as a continuous variable. "Missing" data were modeled as a separate category in each analysis.

For each outcome, weighted logistic regression was used to evaluate its association with the type of anesthesia while controlling for age, sex, race, admission type, payor type, hospital size, hospital location, hospital teaching status, surgical pathology, and comorbidity burden. We used Bonferroni correction to correct the *P* values for the two comparisons (general *vs.* neuraxial and general *vs*. combined neuraxial–general) within the regression for each outcome. 95% CIs were also reported, corresponding to the same adjustments and the same corrections.[10] The conventional threshold of statistical significance (*i.e*., two-sided *P* value <0.05) was used to determine significance of variables.

Model Diagnostic

Multicollinearity was evaluated by estimating the variance inflation factor. The conventional criterion for absence of multicollinearity (*i.e.*, variance inflation factor <10) was used. A test of model discrimination using the *C*-statistic and a test of model calibration using the Hosmer-Lemeshow test were performed for each model.[11] Although *C*-statistic values of greater than 0.7 are considered indicative of acceptable discrimination[12] and nonsignificant *P* values for the Hosmer-Lemeshow test were considered reflective of a well-calibrated model, caution needs to be taken when interpreting significant *P* values for the Hosmer-Lemeshow test in the setting of large sample sized studies.[13] In this context, it has been suggested that even models with significant *P* value could claim adequate calibration. In addition, it has been demonstrated that perhaps a low *C*-statistic is not necessarily a result of a weak model, but, in fact, a consequence of patient entries simply becoming more alike.[14] Therefore, caution against overreliance on the *C*-statistics is recommended.

Results

We identified 528,495 hospitalizations during which a primary total hip or knee arthroplasty was performed. For 71.4% (n = 382,236) of those admissions, an entry for the type of anesthesia was available: 11.1% (n = 40,036) were performed under neuraxial, 14.2% (n = 49,396) under combined neuraxial–general, and 74.8% (n = 292,804) under general anesthesia, respectively.

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Table 1 shows the patient- and healthcare system–related demographics of patients by anesthesia type used for the combined cohort of THA and TKA patients. Appendix 2 shows demographic information stratified by type of procedure. Aside from the anesthesia type variable, missing data were limited to the categories of race, admission type, and payor type (16, 0.26, and 3%, respectively). Modest differences were found in the average age of patients undergoing their surgery under neuraxial, combined neuraxial–general, and general anesthesia (66.9 [95% CI 66.8–67.0] years, 66.5 [95% CI 66.4–66.6], 65.7 [95% CI 65.6–65.7] years, respectively [$P < 0.001$]). Overall comorbidity burden between groups differed only slightly (table 1). More than 50% of patients were covered by Medicare across all anesthesia types. Most surgeries were performed at urban, nonteaching hospitals. The prevalence of a number of comorbidities is shown in Table 2.

Thirty-day mortality was significantly lower among neuraxial and combined neuraxial–general groups compared with those undergoing surgery under general anesthesia (0.10, 0.10, and 0.18%; $P < 0.001$). Incidence rates of in-hospital complications were generally lower among the neuraxial and combined neuraxial–general *versus* the general groups (see Table 3 for complication incidence of THA and TKA combined; see appendix 3 stratified by THA *vs*. TKA), including for pulmonary embolism, pulmonary compromise, pneumonia, cerebrovascular events, and acute renal failure. No differences in the rate of acute myocardial infarction (0.24% *vs*. 0.26% *vs*. 0.28%; $P = 0.47$) and other nonmyocardial infarction cardiac complications (6.20% *vs*. 6.61% *vs*. 6.42%; $P = 0.07$) were seen between groups. Transfusion requirements and median (interquartile range) were lowest in the neuraxial *versus* combined neuraxial–general and general group (15.15% *vs*. 15.56% *vs*. 18.53%; $P < 0.001$). Median length of hospital stays (interquartile range) were 2.6 (2.2–3.2) days *versus* 2.6 (2.2–3.1) days *versus* 2.7 (2.2–3.5) days, respectively ($P < 0.001$). The incidence of prolonged length of stay (>75th percentile) was lower in the neuraxial and combined neuraxial–general groups than in the general anesthesia group (28.7, 27.4, and 35.4%; $P < 0.001$). Median patient cost (interquartile range) was higher in the neuraxial and combined neuraxial–general groups than in the general anesthesia group (15,366 [12,733–18,240] USD *vs*. 14,859 [12,607–17,676] *vs*. 14,780 [12,120–18,500] USD; $P < 0.001$); however, the incidence of increased cost (>75th percentile) was lower in the neuraxial and combined neuraxial–general than in the general anesthesia group (21.4, 18.3, and 23.4%, $P < 0.001$).

When controlling for covariates, general anesthesia was associated with higher odds for most systemic complications and resource utilization compared with neuraxial or combined neuraxial–general for both THA and TKA (Tables 4 and 5).

For patients receiving general anesthesia, the odds ratios (adjusted 95% CI, *P* value) for prolonged length of stay and increased patient costs were 1.32 ([1.25–1.39], $P < 0.001$) and 1.02 ([0.96–1.08], $P = 0.87$) for THA, and 1.29 ([1.24–1.33], $P < 0.001$) and 1.10 ([1.06–1.15], $P < 0.001$) for TKA compared with neuraxial anesthesia, respectively. When comparing these outcomes to combined neuraxial–general, the odds associated with general anesthesia were 1.55 ([1.47–1.63], $P < 0.001$) and 1.34 ([1.26–1.41], $P < 0.001$) for THA and 1.37 ([1.33–1.42], $P < 0.001$) and 1.28 ([1.23–1.33], $P < 0.001$) for TKA, respectively.

Multicollinearity was found absent (all variance inflation factor in the range of 1–8). The *C*-statistics for THA-related models were all above the 0.7 range except for the outcome of prolonged length of stay. Models for TKA analysis were associated with values less than 0.7 more frequently as shown in Table 5. This may be explained by higher homogeneity of the sample for these outcomes, and thus may not represent inadequate discrimination. As expected, the Hosmer-Lemeshow test for some outcomes had significant *P* values, but given the large sample size, we are not deeming these models suspect of bad calibration.

Discussion

In this study comparing perioperative outcomes after primary hip and knee arthroplasty in a large nationwide sample, we were able to determine that the utilization of neuraxial anesthesia was independently associated with better outcomes compared with general anesthesia. The addition of neuraxial to general anesthesia was also associated with improvements in many outcomes, suggesting that neuraxial anesthesia represents a positive modifier in reducing perioperative complications.

These findings are important especially when viewed in the context of perioperative comparative effectiveness research, which seeks to compare various competing medical interventions and their impact on patient outcomes in a real-world setting, *i.e.*, a wide range of practices.[4]

A number of attempts have been made in the past to determine the impact of various anesthetic techniques on outcomes but have been limited by a number of factors. In a recent publication based on the same data source used here, we concluded that the use of neuraxial anesthesia was associated with lower odds for the need of postoperative critical care services in hip and knee arthroplasty patients, but with the narrow focus of this previous analysis, the impact on other outcomes remained elusive.[5] A meta-analysis by Rodgers *et al*.[2] included 9,559 patients undergoing a variety of procedures from 141 trials. Although the authors found an overall benefit with neuraxial anesthesia compared with general anesthesia in regard to mortality and serious complications, they acknowledged that their study lacked sufficient power for appropriate subgroup analysis and estimation of the effect size of outcome benefits found.[2] Thus, although the orthopedic subgroup comprised one third of patients (36%), no conclusions on the differential impact could be drawn. Similarly, an analysis of administrative data collected from 1994 to 2004 in Canada including 259,037 patients undergoing various procedures was able to identify a small 30-day mortality benefit of epidural anesthesia and analgesia over general anesthesia among all patients (1.7% *vs*. 2.0%; relative risk 0.89, 95% CI 0.81–0.98; $P = 0.02$). Again, no significant findings could be found for patients undergoing individual procedures, and no analysis of perioperative complications other than the need for mechanical ventilation, which was nonsignificant between groups, was pursued.[15]

A subsequent meta-analysis focusing on the impact of the type of anesthesia on outcomes in the setting of elective hip and knee arthroplasty found beneficial effects of neuraxial anesthesia *versus* general anesthesia in respect to the incidence of thromboembolism, surgical time, and blood loss.[16,17] However, these studies have been criticized because of their relatively small sample sizes, the inclusion of patients from mostly single institutional, academic, and often specialized centers, the analysis of limited outcomes, the inclusion of studies that do not reflect current medical practice, or the influence of publication bias. Furthermore, it must be mentioned that the beneficial impact of neuraxial anesthesia on outcomes has been disputed by others using similarly limited data to back their conclusions.[18–20]

The utilization of large databases to address questions of comparative effectiveness of various anesthetic techniques has recently gained popularity and is increasingly providing valuable information on the topic.[21,22] Examining the impact of the type of anesthesia in a cohort limited to hip fracture patients in New York, Neuman *et al*.[22] discovered beneficial effects of regional *versus* general anesthesia in respect to mortality and pulmonary complications. However, given the unique morbidity of this specific patient subpopulation, the ability to extrapolate these results to other orthopedic patient groups is limited.

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In our study of a large nationwide sample including patients from a variety of practice settings and hospitals, we found evidence of a beneficial effect of neuraxial anesthesia in regard to a wide range of outcomes. Interestingly, these benefits were observed despite the fact that the neuraxial group was on average older compared with the general anesthesia patient group. This is especially important because advanced age has been previously shown to be a major predictor of perioperative complications in the orthopedic patient population.[23] The mechanism by which these benefits are conferred may not be fully understood but may include alterations in coagulation parameters and blood flow, beneficial effects on respiratory mechanics, and overall perioperative stress response.[24]

We found that the utilization of neuraxial anesthesia (with or without general) in our sample was applied only in a minority of patients. Reasons for this distribution have to remain speculative but may include physician and patient preference, level of experience and familiarity with the techniques involved, and institutional approaches to perioperative anticoagulation. Despite these factors, examples of successful institutional conversions from primarily general anesthesia to using neuraxial techniques have been described along with marked improvements in outcomes.[25] Furthermore, given the beneficial impacts on outcome found in this and other studies, the potential overall impact of higher utilization of neuraxial anesthesia is important for two reasons: First, as evidenced by our data, the proportional utilization of neuraxial anesthesia (with or without general) in the time period between 2006 and 2010 is approximately 24% and has therefore the potential for growth. Second, the number of hip and knee arthroplasties performed is expected to increase markedly from currently one million to more than four million within one generation.[3]

The question whether the performance of neuraxial anesthesia itself or the avoidance of general anesthesia is responsible for observed outcome benefits remains a topic of debate.[2] Although our data may not be entirely conclusive, in this study, we were able to study a group of patients who received a combination of both modes of anesthesia. Interestingly, the odds for many of the outcomes fell between that of general-only and neuraxial-only approaches. This observation suggests that neuraxial anesthesia may by itself confer a positive modifiable effect. However, it is important to note that some outcomes remained unaffected by the choice of anesthesia.

In addition, the search for ideal measures of model calibration and discrimination continues.[26] It is clear that some measure of model performance in both categories of calibration and discrimination should be used. However, over-reliance on any particular measure or a related cutoff (*e.g.*, 0.7 for *C*-statistic and *P* value <0.05 for Hosmer-Lemeshow test) should be considered with caution in deeming a model of inadequate value.[14]

Our study is subject to limitations inherent to the analysis of secondary data from large administrative databases. First, detailed clinical information (*i.e.*, blood loss, intraoperative details) cannot be captured and therefore the impact of such factors on outcome cannot be taken into consideration. In this context, details on anticoagulation practices or cardioprotective measures are not considered here. However, it must be mentioned that by using a large, nationwide sample, this study evaluated outcomes under realistic and noninvestigational conditions, thus presenting results from a “real-world” setting. Second, complications were only captured if they occurred during the index admission where surgery was performed, not taking into account postdischarge events. However, we did analyze and report 30-day mortality data because this information is provided. Third, the definition of comorbidities, surgical pathology, and complications is based on the ICD-9 coding system and thus may be burdened with coding bias despite quality checks used by Premier, Inc. This may be especially the case when diagnosis codes are listed as secondary entries.

However, in the database used, there is no limitation in the numbers of diagnoses listed and we used all available for our analyses. Nevertheless, the true incidence of comorbidities and complications may be underestimated because of noncapture by the specific ICD-9-CM codes used (appendix 1). However, all groups should be equally exposed to any potential bias within the same data collection construct and comparative analysis is therefore less affected by this influence.

Furthermore, we did not study the incidence of complications associated directly with the use of the types of anesthesia, such as the incidence of postdural puncture headaches, epidural and spinal hematomas and neuropraxias, damage to oropharyngeal structures during the intubation process, or failure to intubate. However, it is well accepted that morbidity associated with anesthetic procedures *per se* is low and unlikely a factor associated with the choice of a particular technique. Although this does not mean that a particular technique may be contra-indicated or less desirable in particular patient populations, *i.e.*, anticoagulated patients and those with previous spine fusion when considering neuraxial and those with severe pulmonary compromise when contemplating general anesthesia.

In addition, this study does not address the impact of peripheral nerve blocks on perioperative events, which feasibly may have a beneficial impact on pain control and thus potentially outcomes.

Finally, it has to be mentioned that this specific dataset of hip and knee arthroplasty patients was used for the study to identify risk factors for the need for critical care services. Although the current study is addressing a different issue, some overlap in queries may exist. In particular, we had studied the impact of the type of anesthesia on the need for such services.[5] Given this overlap, we have to point out that in light of the increasing use of databases for perioperative research and multiple publications resulting from such work, it is of utmost importance that researchers disclose any potential impact this approach might have and address concerns of experiment-wide statistical error caused by multiple analyses of the same datasets.[27] In this context, we would like to mention that we are currently working on projects that use different samples from the same database.

In conclusion, our analysis of this large nationwide sample provides evidence of the superior comparative effectiveness of neuraxial versus general anesthesia in the setting of primary hip and knee arthroplasty. Multiple outcomes including perioperative complications and length of hospital stay are positively affected by the choice of neuraxial *versus* general anesthesia. Many outcome benefits were reduced, but still significant when combining general with neuraxial anesthesia. Our data therefore offer evidence of benefit associated with neuraxial anesthesia and support further research to study the mechanisms by which beneficial effects may be exerted.

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References

1. O'Hara DA, Duff A, Berlin JA, Poses RM, Lawrence VA, Huber EC, Noveck H, Strom BL, Carson JL. The effect of anesthetic technique on postoperative outcomes in hip fracture repair. Anesthesiology. 2000; 92:947–57. [PubMed: 10754613]

2. Rodgers A, Walker N, Schug S, McKee A, Kehlet H, van Zundert A, Sage D, Futter M, Saville G, Clark T, MacMahon S. Reduction of postoperative mortality and morbidity with epidural or spinal anaesthesia: Results from overview of randomised trials. BMJ. 2000; 321:1493. [PubMed: 11118174]
3. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007; 89:780–5. [PubMed: 17403800]
4. Memtsoudis SG, Besculides MC. Perioperative comparative effectiveness research. Best Pract Res Clin Anaesthesiol. 2011; 25:535–47. [PubMed: 22099919]
5. Memtsoudis SG, Sun X, Chiu YL, Nurok M, Stundner O, Pastores SM, Mazumdar M. Utilization of critical care services among patients undergoing total hip and knee arthroplasty: Epidemiology and risk factors. Anesthesiology. 2012; 117:107–16. [PubMed: 22634871]
6. Stundner O, Chiu YL, Sun X, Mazumdar M, Fleischut P, Poultsides L, Gerner P, Fritsch G, Memtsoudis SG. Comparative perioperative outcomes associated with neuraxial versus general anesthesia for simultaneous bilateral total knee arthroplasty. Reg Anesth Pain Med. 2012; 37:638–44. [PubMed: 23080348]
7. US Department of Health and Human Services. Office for Civil Rights, HIPAA Compliance Assistance. OCR Privacy Brief: Summary of the HIPAA Privacy Rule. Washington, DC: 2003.
8. Groenwold RH, Donders AR, Roes KC, Harrell FE Jr, Moons KG. Dealing with missing outcome data in randomized trials and observational studies. Am J Epidemiol. 2012; 175:210–7. [PubMed: 22262640]
9. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. J Clin Epidemiol. 1992; 45:613–9. [PubMed: 1607900]
10. Bland JM, Altman DG. Multiple significance tests: The Bonferroni method. BMJ. 1995; 310:170. [PubMed: 7833759]
11. Hosmer DW, Lemeshow SA. Goodness-of-fit test for the multiple logistic regression model. Commun Stat. 1980; A10:1043–69.
12. Hosmer, DW.; Lemeshow, S. Applied Logistic Regression. 2. New York: John Wiley & Son Inc; 2000. p. 162
13. Kramer AA, Zimmerman JE. Assessing the calibration of mortality benchmarks in critical care: The Hosmer-Lemeshow test revisited. Crit Care Med. 2007; 35:2052–6. [PubMed: 17568333]
14. Merkow RP, Hall BL, Cohen ME, Dimick JB, Wang E, Chow WB, Ko CY, Bilimoria KY. Relevance of the c-statistic when evaluating risk-adjustment models in surgery. J Am Coll Surg. 2012; 214:822–30. [PubMed: 22440055]
15. Wijeysundera DN, Beattie WS, Austin PC, Hux JE, Laupacis A. Epidural anaesthesia and survival after intermediate-to-high risk non-cardiac surgery: A population-based cohort study. Lancet. 2008; 372:562–9. [PubMed: 18692893]
16. Mauermann WJ, Shilling AM, Zuo Z. A comparison of neuraxial block versus general anesthesia for elective total hip replacement: A meta-analysis. Anesth Analg. 2006; 103:1018–25. [PubMed: 17000823]
17. Hu S, Zhang ZY, Hua YQ, Li J, Cai ZD. A comparison of regional and general anaesthesia for total replacement of the hip or knee: A meta-analysis. J Bone Joint Surg Br. 2009; 91:935–42. [PubMed: 19567860]
18. Brueckner S, Reinke U, Roth-Isigkeit A, Eleftheriadis S, Schmucker P, Siemens HJ. Comparison of general and spinal anesthesia and their influence on hemostatic markers in patients undergoing total hip arthroplasty. J Clin Anesth. 2003; 15:433–40. [PubMed: 14652120]
19. Planès A, Vochelle N, Fagola M, Feret J, Bellaud M. Prevention of deep vein thrombosis after total hip replacement. The effect of low-molecular-weight heparin with spinal and general anaesthesia. J Bone Joint Surg Br. 1991; 73:418–22. [PubMed: 1670442]
20. Mitchell D, Friedman RJ, Baker JD 3rd, Cooke JE, Darcy MD, Miller MC 3rd. Prevention of thromboembolic disease following total knee arthroplasty. Epidural versus general anesthesia. Clin Orthop Relat Res. 1991; 269:109–12. [PubMed: 1864027]

21. Memtsoudis SG, Ma Y, Swamidoss CP, Edwards AM, Mazumdar M, Liguori GA. Factors influencing unexpected disposition after orthopedic ambulatory surgery. J Clin Anesth. 2012; 24:89–95. [PubMed: 22305625]
22. Neuman MD, Silber JH, Elkassabany NM, Ludwig JM, Fleisher LA. Comparative effectiveness of regional versus general anesthesia for hip fracture surgery in adults. Anesthesiology. 2012; 117:72–92. [PubMed: 22713634]
23. Memtsoudis SG, Della Valle AG, Besculides MC, Esposito M, Koulouvaris P, Salvati EA. Risk factors for perioperative mortality after lower extremity arthroplasty: A population-based study of 6,901,324 patient discharges. J Arthroplasty. 2010; 25:19–26. [PubMed: 19106028]
24. Kehlet, H. Modification of responses to surgery by neural blockade. In: Cousins, M.; Bridenbaugh, P., editors. Clinical Implications, Neural Blockade in Clinical Anesthesia and Management of Pain. 2. Philadelphia: J B Lippincott; 1988. p. 145-88.
25. Sharrock NE, Cazan MG, Hargett MJ, Williams-Russo P, Wilson PD Jr. Changes in mortality after total hip and knee arthroplasty over a ten-year period. Anesth Analg. 1995; 80:242–8. [PubMed: 7818108]
26. Steyerberg EW, Vickers AJ, Cook NR, Gerds T, Gonen M, Obuchowski N, Pencina MJ, Kattan MW. Assessing the performance of prediction models: A framework for traditional and novel measures. Epidemiology. 2010; 21:128–38. [PubMed: 20010215]
27. Eisenach JC. Note of editorial concern. Anesthesiology. 2011; 115:463. [PubMed: 21716090]

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What We Already Know about This Topic

- Several small studies have suggested better outcomes when lower extremity joint replacement surgery is performed with neuraxial anesthesia, but how well these results can be generalized to a broad population is uncertain

What This Article Tells Us That Is New

- In a review of nearly 400,000 patients undergoing total hip or knee arthroplasty, major morbidity and mortality were significantly lower in those receiving neuraxial anesthesia

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Table 1

Patient and Healthcare System–related Characteristics by Anesthesia Type

Variable	Category	Neuraxial % (N)	Neuraxial/General % (N)	General % (N)	Missing % (N)	*P* Value[†]
Procedure type	Total hip arthroplasty	28.95 (11,610)	30.2 (15,261)	33.1 (98,122)	31.4 (47,474)	<0.001
	Total knee arthroplasty	71.1 (28,426)	69.8 (34,135)	66.9 (194,682)	68.6 (98,785)	
Age group (yr)	≤44	2.0 (775)	2.5 (1,340)	3.2 (9,932)	2.5 (3,737)	<0.001
	45–54	11.4 (4,555)	11.6 (5,819)	13.4 (39,710)	11.7 (17,154)	
	55–64	26.9 (11,022)	27.6 (13,647)	28.0 (82,683)	27.3 (40,312)	
	65–74	33.1 (13,114)	32.7 (16,204)	31.5 (91,866)	31.9 (46,696)	
	≥75	26.6 (10,570)	25.6 (12,386)	23.9 (68,613)	26.6 (38,360)	
Sex	Female	60.9 (24,385)	60.7 (29,950)	61.3 (179,501)	61.6 (90,040)	0.03
Race	White	81.1 (31,783)	82.1 (40,962)	72.9 (221,496)	62.8 (98,907)	<0.001
	Black	4.4 (1,707)	5.6 (3,065)	7.5 (23,866)	4.9 (7,524)	
	Other	1.6 (624)	1.5 (681)	3.0 (7,324)	2.6 (3,304)	
	Missing	12.9 (5,922)	10.8 (4,688)	16.6 (40,118)	29.8 (36,524)	
Admission type	Emergent	0.9 (321)	2.5 (1,011)	3.3 (8,857)	1.5 (2,203)	<0.001
	Urgent	3.6 (1,343)	3.7 (2,512)	3.8 (11,769)	4.2 (5,380)	
	Routine	95.4 (38,315)	93.6 (45,771)	92.3 (270,740)	94.2 (138,465)	
	Other	0.03 (12)	<0.01 (<10)	0.2 (387)	0.03 (54)	
	Missing	0.09 (45)	0.2 (100)	0.5 (1,051)	0.1 (157)	
Payor	Commercial	37.0 (14,626)	38.1 (18,672)	39.6 (117,264)	37.9 (55,658)	<0.001
	Medicaid	1.6 (680)	1.9 (980)	2.8 (8,248)	2.2 (2,993)	
	Medicare	58.0 (23,186)	57.1 (28,296)	54.2 (156,977)	56.7 (82,596)	
	Uninsured	0.3 (148)	0.4 (190)	0.6 (1,670)	0.4 (605)	
	Missing	3.2 (1,396)	2.6 (1,258)	2.9 (8,645)	2.8 (4,407)	
Hospital size (bed number)	≤299	46.9 (15,698)	29.8 (13,367)	36.5 (94,828)	35.5 (46,749)	<0.001
	300–499	40.5 (15,797)	56.1 (24,654)	38.7 (105,928)	45.3 (61,140)	
	≥500	12.6 (8,541)	14.1 (11,375)	24.8 (92,048)	19.2 (38,370)	
Hospital location	Rural	5.2 (4,497)	4.5 (5,677)	4.3 (26,555)	5.3 (14,669)	<0.001
	Urban	94.8 (35,539)	95.5 (43,719)	95.7 (35,539)	94.7 (131,590)	
Hospital teaching status	Nonteaching	85.0 (27,354)	86.8 (36,269)	75.2 (162,895)	78.5 (85,192)	<0.001

Variable	Category	Neuraxial % (N)	Neuraxial/General % (N)	General % (N)	Missing % (N)	*P* Value†
	Teaching	15.0 (12,682)	13.2 (13,127)	24.8 (129,909)	21.5 (61,067)	
Surgical pathology	Rheumatoid arthritis	2.9 (1,223)	3.4 (1,685)	3.3 (9,822)	3.0 (4,425)	<0.001
	Osteoarthritis	97.0 (38,842)	96.8 (47,721)	95.1 (278,560)	96.6 (141,012)	<0.001
	Infectious arthritis	0.04 (20)	0.04 (23)	0.1 (140)	0.04 (64)	0.78
	Internal derangement	0.8 (326)	0.7 (324)	0.9 (2,520)	0.8 (1,084)	<0.001
	Trauma	2.5 (1,008)	2.5 (1,268)	3.5 (9,929)	2.7 (4,152)	<0.001
		Neuraxial Mean (95% CI)	Neuraxial/General Mean (95% CI)	General Mean (95% CI)	Missing Mean (95% CI)	*P* Value††
	Deyo index	0.60 (0.59–0.61)	0.62 (0.61–0.63)	0.63 (0.63–0.64)	0.60 (0.59–0.60)	<0.001

† *P* value is to test the null hypothesis of no incidence difference among neuraxial, general, and neuraxial/general (chi-square test).

†† *P* value is to test the null hypothesis of no mean difference among neuraxial, general, and neuraxial/general (ANOVA F test).

Table 2

Preexisting Comorbidities

Comorbidity	Neuraxial % (N)	Neuraxial/General % (N)	General % (N)	Missing % (N)	*P* Value†
Myocardial infarction	3.7 (1,526)	3.8 (1,952)	3.5 (10,462)	3.6 (5,490)	0.007
Peripheral vascular disease	1.8 (679)	1.7 (872)	1.7 (5,107)	1.8 (2,573)	0.71
Cerebrovascular disease	0.2 (95)	0.2 (106)	0.2 (708)	0.2 (325)	0.32
Dementia	0.1 (53)	0.1 (50)	0.1 (246)	0.1 (154)	0.21
COPD	14.1 (5,754)	14.6 (7,400)	14.2 (41,976)	13.9 (20,420)	0.008
Rheumatic disease	3.6 (1,476)	4.1 (2,035)	4.0 (11,861)	3.6 (5,301)	<0.001
Mild liver disease	0.2 (69)	0.2 (111)	0.3 (819)	0.2 (331)	<0.001
Severe liver disease	<0.1 (4)	<0.1 (20)	0.1 (173)	<0.1 (65)	0.003
Uncomplicated diabetes	16.9 (6,694)	16.9 (8,519)	18.0 (52,440)	16.7 (24,442)	<0.001
Complicated diabetes	1.1 (486)	1.0 (503)	1.1 (3,186)	1.0 (1,524)	0.03
Renal disease	0.1 (23)	0.1 (30)	0.1 (151)	<0.1 (61)	0.57
AIDS	<0.1 (6)	<0.1 (21)	0.1 (153)	<0.1 (46)	<0.001
Paraplegia	<0.1 (3)	<0.1 (5)	<0.1 (31)	<0.1 (14)	0.82
Cancer	1.5 (655)	1.8 (898)	1.8 (5,175)	1.7 (2,595)	0.03

† *P* value is to test the null hypothesis of no prevalence difference among neuraxial, general, and neuraxial/general (chi-square test).

AIDS = acquired immune deficiency syndrome; COPD = chronic obstructive pulmonary disease.

Table 3

Incidences of Various Complications by Anesthesia Type

	Neuraxial % (N)	Neuraxial/General % (N)	General % (N)	Missing % (N)	*P* Value[†]
Systemic complications					
Pulmonary embolism	0.35 (129)	0.34 (172)	0.44 (1,307)	0.38 (567)	0.001
Cerebrovascular event	0.07 (28)	0.12 (58)	0.13 (374)	0.11 (146)	0.006
Pulmonary compromise	0.37 (141)	0.61 (310)	0.81 (2,234)	0.55 (816)	<0.001
Cardiac (nonmyocardial infarction)	6.20 (2,564)	6.61 (3,287)	6.42 (18,644)	6.32 (9,409)	0.07
Pneumonia	0.69 (295)	0.83 (435)	0.94 (2,669)	0.80 (1,157)	<0.001
All infections	3.11 (1,301)	3.87 (1,943)	4.50 (12,507)	4.22 (5,795)	<0.001
Acute renal failure	1.10 (456)	1.43 (731)	1.75 (4,935)	1.24 (1,821)	<0.001
Gastrointestinal complication	0.70 (285)	0.72 (366)	0.77 (2,294)	0.77 (1,122)	0.26
Acute myocardial infarction	0.24 (102)	0.26 (126)	0.28 (787)	0.26 (373)	0.47
Resource utilization					
Mechanical ventilation	0.39 (192)	0.49 (279)	0.72 (2,022)	0.94 (1,303)	<0.001
Blood product transfusion	15.15 (6,646)	15.56 (8,628)	18.53 (54,700)	22.41 (30,204)	<0.001
Mortality					
30-Day mortality	0.10 (42)	0.10 (54)	0.18 (493)	0.13 (209)	<0.001

[†] *P* value is to test the null hypothesis of no difference in incidence among neuraxial, general, and neuraxial/general (chi-square test).

Table 4

Results from the Multivariable Regression Analysis for Total Hip Arthroplasty

	Total Hip Arthroplasty			
	General vs. Neuraxial		General vs. Neuraxial/General	
	Odds Ratio (Adjusted 95% CI)	**Adjusted *P* Value**	**Odds Ratio (Adjusted 95% CI)**	**Adjusted *P* Value**
Systemic complications				
Pulmonary embolism	1.26 (0.68–2.31)	0.8079	1.29 (0.78–2.15)	0.5252
Cerebrovascular event	3.15 (1.11–8.92)	0.0271	1.27 (0.69–2.33)	0.7513
Pulmonary compromise	3.34 (2.10–5.32)	<0.0001	1.41 (1.07–1.86)	0.0105
Cardiac complications (nonmyocardial infarction)	1.13 (1.02–1.25)	0.0171	1.01 (0.92–1.11)	>0.9999
Pneumonia	1.51 (1.13–2.01)	0.0029	1.14 (0.90–1.43)	0.4221
All infections	1.45 (1.27–1.65)	<0.0001	1.17 (1.05–1.30)	0.0028
Acute renal failure	1.70 (1.35–2.13)	<0.0001	1.31 (1.10–1.57)	0.0014
Gastrointestinal complication	1.22 (0.93–1.60)	0.1939	1.28 (1.01–1.64)	0.0439
Acute myocardial infarction	1.11 (0.71–1.73)	1.0000	1.27 (0.81–1.97)	0.4623
Resource utilization				
Mechanical ventilation	1.57 (1.10–2.22)	0.0085	1.49 (1.09–2.04)	0.0091
Blood product transfusion	1.14 (1.07–1.22)	<0.0001	1.40 (1.33–1.49)	<0.0001
Mortality				
30-Day mortality	1.28 (0.70–2.37)	0.7192	1.55 (0.88–2.70)	0.1609

This table displays the results of the multivariable regression analysis for various complications and outcomes comparing general *vs*. neuraxial (reference) and general *vs*. combined neuraxial–general (reference) anesthesia for patients receiving total hip arthroplasty. For each outcome, weighted logistic regression was used to evaluate its association with the type of anesthesia while controlling for age, sex, race, admission type, payor type, hospital size, hospital location, hospital teaching status, surgical pathology, and comorbidity burden.

Table 5

Results from the Multivariable Regression Analysis for Total Knee Arthroplasty

	Total Knee Arthroplasty			
	General *vs.* Neuraxial		General *vs.* Neuraxial/General	
	Odds Ratio (Adjusted 95% CI)	Adjusted *P* Value	Odds Ratio (Adjusted 95% CI)	Adjusted *P* Value
Systemic complications				
Pulmonary embolism*	1.24 (0.97–1.59)	0.1029	1.28 (1.02–1.6)	0.0281
Cerebrovascular event*	1.58 (0.90–2.78)	0.1397	1.09 (0.71–1.66)	>0.9999
Pulmonary compromise	1.83 (1.43–2.35)	<0.0001	1.23 (1.02–1.48)	0.0248
Cardiac complications (nonmyocardial infarction)	1.09 (1.02–1.16)	0.0086	1.00 (0.95–1.07)	>0.9999
Pneumonia*	1.27 (1.05–1.53)	0.0083	1.05 (0.90–1.23)	0.9761
All infections*	1.38 (1.26–1.52)	<0.0001	1.12 (1.04–1.21)	0.0017
Acute renal failure	1.44 (1.24–1.67)	<0.0001	1.11 (0.98–1.25)	0.1342
Gastrointestinal complication*	1.04 (0.86–1.27)	>0.9999	0.96 (0.80–1.15)	>0.9999
Acute myocardial infarction	1.10 (0.78–1.54)	>0.9999	0.93 (0.70–1.23)	>0.9999
Resource utilization				
Mechanical ventilation	1.72 (1.35–2.18)	<0.0001	1.32 (1.09–1.60)	0.0021
Blood product transfusion*	1.23 (1.17–1.28)	<0.0001	1.01 (0.97–1.05)	>0.9999
Mortality				
30-Day mortality	1.83 (1.08–3.1)	0.0211	1.70 (1.06–2.74)	0.0228

This table displays the results of the multivariable regression analysis for various complications and outcomes comparing general (G) *vs.* neuraxial (N) (reference) and general (G) *vs.* combined neuraxial-general (N+G) (reference) anesthesia for patients receiving total knee arthroplasty. For each outcome, weighted logistic regression was used to evaluate its association with the type of anesthesia while controlling for age, sex, race, admission type, payor type, hospital size, hospital location, hospital teaching status, surgical pathology, and comorbidity burden. (**C*-statistic <0.7).

Appendix 1

ICD-9-CM Diagnosis Codes and Billing Codes for Major Complications

Complications	ICD-9-CM Diagnosis Codes/Billing Codes
Device-related complication	996.xx
Hematoma	998.1
Wound dehiscence	998.3
Wound infection	998.5x
Pulmonary embolism	415.1
Acute respiratory distress syndrome	518.5
Deep vein thrombosis	451.1, 451.2, 451.8, 451.9, 453.2, 453.4, 453.8, 453.9
Cerebrovascular event	433.01, 433.11, 433.21,433.31, 433.81, 433.91, 434.01, 434.11, 434.91, 997.02
Pulmonary compromise	514, 518.4, 518.5, 518.81, 518.82
Cardiac (nonmyocardial infarction)	426.0, 427.41, 427.42, 429.4, 997.1, 427.4, 427.3, 427.31, 427.32
Pneumonia	481, 482.00–482.99, 483,485, 486, 507.0, 997.31, 997.39
Wound complication	998.3, 998.30, 998.31, 998.32, 997.4, 997.5, 998.33, 998.83, 998.12, 998.13, 998.6, 998.51, 729.92
All infections	590.1, 590.10, 590.11, 590.8, 590.81, 590.2, 590.9, 595.0, 595.9, 599.0, 567.0 480, 480.0, 480.1, 480.2, 480.8, 480.9, 481, 482.0, 482.1, 482.2, 482.3, 482.30, 482.31, 482.32, 482.39, 482.4, 482.40, 482.41, 482.42, 482.49, 482.5, 482.8, 482.81, 482.82, 482.83, 482.84, 482.89, 482.9, 483, 483.0, 483.1, 483.8, 485, 486, 487, 997.31, 038, 038.0, 038.1, 038.10, 038.11, 038.12, 038.19, 038.2, 038.3, 038.4, 038.40, 038.41, 038.42, 038.43, 038.44, 038.49, 038.8, 038.9, 790.7, 998.0, 958.4, 998.5, 998.59, 998.89, 785, 785.50, 785.52, 785.59, 999.39, 999.31, 999.3
Acute renal failure	584, 584.5, 584.9
Gastrointestinal complication	997.4, 560.1, 560.81, 560.9, 536.2, 537.3
Acute myocardial infarction	410.XX
Mechanical ventilation	93.90, 96.7, 96.70, 96.71, 96.72, (CPT Code) 94002, 94656, 94003, 94657
Blood transfusion	99.0, 99.01, 99.02, 99.03, 99.04, 99.05, 99.06, 99.07, 99.08, 99.09, (HCPCS codes) P9010, P9011, P9012, P9016, P9017, P9019, P9020, P9021, P9022, P9023, P9031, P9032, P9033, P9034, P9035, P9036, P9037, P9038, P9039, P9040

CPT = Current Procedural Terminology; HCPCS = Healthcare Common Procedure Coding System; ICD-9-CM = International Classification of Diseases-9th Revision-Clinical Modification.

Appendix 2

Patient- and Healthcare System–related Characteristics by Type of Surgery (Hip Arthroplasty, Knee Arthroplasty) and Anesthesia Type

		Hip Arthroplasty					Knee Arthroplasty				
Variable	**Category**	**Neuraxial % (N)**	**Neuraxial/General % (N)**	**General % (N)**	**Missing % (N)**	***P* Value[†]**	**Neuraxial % (N)**	**Neuraxial/General % (N)**	**General % (N)**	**Missing % (N)**	***P* Value[†]**
Age group (yr)	≤44	3.8 (446)	5.0 (831)	5.8 (6,031)	4.5 (2,187)	<0.001	1.2 (329)	1.5 (509)	1.9 (3,901)	1.6 (1,550)	<0.001
	45–54	14 (1,642)	14.6 (2,278)	15.5 (15,642)	14.2 (6,699)		10.4 (2,913)	10.3 (3,541)	12.3 (24,068)	10.6 (10,455)	
	55–64	25.3 (3,031)	25.5 (3,871)	25.5 (25,450)	25.8 (12,319)		27.6 (7,991)	28.5 (9,776)	29.2 (57,233)	28.1 (27,993)	
	65–74	29 (3,338)	28.6 (4,352)	27.4 (26,744)	27.9 (13,314)		34.7 (9,776)	34.4 (11,852)	33.5 (65,122)	33.7 (33,382)	
	≥75	27.9 (3,153)	26.3 (3,929)	25.8 (24,255)	27.5 (12,955)		26.1 (7,417)	25.3 (8,457)	23.1 (44,358)	26.1 (25,405)	
Sex	Female	57.1 (6,659)	56.3 (8,504)	56.4 (55,037)	56.7 (26,893)	0.41	62.5 (17,726)	62.7 (21,446)	63.8 (124,464)	63.8 (63,147)	<0.001
	Male	42.9 (4,951)	43.7 (6,757)	43.6 (43,085)	43.3 (20,581)		37.5 (10,700)	37.3 (12,689)	36.2 (70,218)	36.2 (35,638)	
Race	White	82 (9,280)	85.6 (13,134)	74.4 (76,049)	64.2 (32,348)	<0.001	80.7 (22,503)	80.6 (27,828)	72.2 (145,447)	62.1 (66,559)	<0.001
	Black	3.9 (435)	5.3 (917)	7.2 (7,693)	4.3 (2,173)		4.6 (1,272)	5.7 (2,148)	7.6 (16,173)	5.1 (5,351)	
	Other	0.9 (105)	1.4 (182)	2.2 (1,740)	1.7 (687)		1.9 (519)	1.6 (499)	3.5 (5,584)	3.0 (2,617)	
	Missing	13.2 (1,790)	7.7 (1,028)	16.3 (12,640)	29.8 (12,266)		12.8 (4,132)	12.1 (,3660)	16.8 (27,478)	29.8 (24,258)	
Admission type	Emergent	2.1 (237)	4.9 (638)	5.2 (4,684)	3.5 (1,647)	<0.001	0.4 (84)	1.4 (373)	2.4 (4,173)	0.6 (556)	<0.001
	Urgent	2.3 (266)	3.2 (561)	4.2 (4,295)	3.5 (1,552)		4.1 (1,077)	3.9 (1,951)	3.5 (7,474)	4.5 (3,828)	
	Routine	95.4 (11,088)	91.6 (14,030)	90.1 (88,774)	92.9 (44,202)		95.4 (27,227)	94.5 (31,741)	93.4 (181,966)	94.8 (94,263)	
	Other	0.1 (11)	<0.1 (2)	0.1 (100)	0.1 (33)		<0.1 (1)	0.0 (0)	0.2 (287)	<0.1 (21)	
	Missing	0.1 (8)	0.2 (30)	0.4 (269)	0.1 (40)		0.1 (37)	0.2 (70)	0.5 (782)	0.1 (117)	
Payor	Commercial	39.1 (4,525)	40.3 (6,132)	41.6 (41,782)	40.5 (19,215)	<0.001	36.1 (10,101)	37.1 (12,540)	38.7 (75,482)	36.6 (36,443)	<0.001
	Medicaid	1.7 (236)	2.3 (381)	3 (2,939)	2.4 (1,053)		1.5 (444)	1.7 (599)	2.6 (5,309)	2.2 (1,940)	
	Medicare	56 (6,444)	54.3 (8,274)	52.3 (50,177)	54.3 (25,726)		58.8 (16,742)	58.3 (20,022)	55.2 (106,800)	57.8 (56,870)	
	Uninsured	0.7 (77)	0.8 (114)	0.9 (852)	0.7 (337)		0.2 (71)	0.2 (76)	0.4 (818)	0.3 (268)	
	Missing	2.6 (328)	2.4 (360)	2.3 (2,372)	2.1 (1,143)		3.4 (1,068)	2.7 (898)	3.1 (6,273)	3.1 (3,264)	
Hospital size (bed number)	≤299	48.8 (4,617)	26.1 (3,498)	35.4 (30,513)	35.6 (14,446)	<0.001	46.1 (11,081)	31.4 (9,869)	37 (64,315)	35.4 (32,303)	<0.001
	300–499	39.4 (4,686)	58.8 (7,612)	38.4 (34,832)	42.5 (19,232)		40.9 (11,111)	54.9 (17,042)	38.8 (71,096)	46.6 (41,908)	
	≥500	11.8 (2,307)	15.1 (4,151)	26.2 (32,777)	21.9 (13,796)		12.9 (6,234)	13.6 (7,224)	24.2 (59,271)	18 (24,574)	
Hospital location	Rural	4.8 (1,233)	4.0 (1,521)	3.9 (8,162)	4.6 (4,277)	<0.001	5.3 (3,264)	4.8 (4,156)	4.4 (18,393)	5.6 (10,392)	<0.001
	Urban	95.2 (10,377)	96.0 (13,740)	96.1 (89,960)	95.4 (43,197)		94.7 (25,162)	95.2 (29,979)	95.6 (176,289)	94.4 (88,393)	
Hospital teaching status	Nonteaching	84.7 (7,822)	84.7 (10,627)	73.2 (51,855)	76.2 (26,129)	<0.001	85.1 (19,532)	87.7 (25,642)	76.2 (111,040)	79.5 (59,063)	<0.001

		Hip Arthroplasty					Knee Arthroplasty				
Variable	**Category**	**Neuraxial % (N)**	**Neuraxial/General % (N)**	**General % (N)**	**Missing % (N)**	***P* Value**[†]	**Neuraxial % (N)**	**Neuraxial/General % (N)**	**General % (N)**	**Missing % (N)**	***P* Value**[†]
	Teaching	15.3 (3,788)	15.3 (4,634)	26.8 (46,267)	23.8 (21,345)		14.9 (8,894)	12.3 (8,493)	23.8 (83,642)	20.5 (39,722)	
Surgical pathology	Rheumatoid arthritis	2.8 (341)	3.2 (485)	3.3 (3,221)	2.8 (1,353)	0.029	3.0 (882)	3.5 (1,200)	3.3 (6,601)	3.1 (3,072)	0.0037
	Osteoathritis	93.4 (10,835)	92.6 (14,041)	89.5 (87,929)	92.3 (43,764)	<0.001	98.5 (28,007)	98.7 (33,680)	97.9 (190,631)	98.5 (97,248)	<0.001
	Infectious arthritis	0.1 (8)	0.1 (11)	0.1 (54)	<0.1 (30)	0.91	<0.1 (12)	<0.1 (12)	<0.1 (86)	<0.1 (34)	0.5076
	Internal derangeent	0.1 (11)	<0.1 (8)	0.1 (84)	0.1 (28)	0.18	1 (315)	1.0 (316)	1.3 (2,436)	1.1 (1,056)	<0.001
	Trauma	4.8 (554)	4.3 (701)	7.0 (6,531)	5.5 (2,698)	<0.001	1.5 (454)	1.7 (567)	1.8 (3,398)	1.4 (1,454)	0.0302
		Neuraxial Mean (95% CI)	Neuraxial/General Mean (95% CI)	General Mean (95% CI)	Missing Mean (95% CI)	*P* Value[††]	Neuraxial Mean (95% CI)	Neuraxial/General Mean (95% CI)	General Mean (95% CI)	Missing Mean (95% CI)	*P* Value[††]
	Deyo Index	0.51 (0.49–0.52)	0.53 (0.51–0.54)	0.55 (0.55–0.56)	0.52 (0.51–0.53)	<0.001	0.64 (0.63–0.65)	0.66 (0.65–0.67)	0.67 (0.67–0.68)	0.64 (0.63–0.64)	<0.001

[†] *P* value is to test the null hypothesis of no incidence difference among neuraxial, general, and neuraxial/general (chi-square test).

[††] *P* value is to test the null hypothesis of no mean difference among neuraxial, general, and neuraxial/general (ANOVA F test).

Appendix 3

Incidences of Various Complications by Type of Surgery (Hip Arthroplasty, Knee Arthroplasty) and Anesthesia Type

	Hip Arthroplasty				Knee Arthroplasty			
Variable	**Neuraxial % (N)**	**Neuraxial/General % (N)**	**General % (N)**	***P* Value†**	**Neuraxial % (N)**	**Neuraxial/General % (N)**	**General % (N)**	***P* Value†**
Pulmonary embolism	0.2 (19)	0.2 (26)	0.3 (244)	0.1438	0.4 (110)	0.4 (146)	0.5 (1,063)	0.0028
Cerebrovascular event	0.1 (7)	0.1 (18)	0.2 (162)	0.0171	0.1 (21)	0.1 (40)	0.1 (212)	0.2331
Pulmonary compromise	0.3 (30)	0.6 (94)	1.0 (856)	<0.0001	0.4 (111)	0.6 (216)	0.7 (1,378)	<0.0001
Cardiac (nonmyocardial infarction)	6.1 (736)	6.6 (1,014)	6.8 (6,435)	0.0681	6.2 (1,828)	6.6 (2,273)	6.2 (12,209)	0.0594
Pneumonia	0.7 (86)	0.9 (143)	1.1 (1,040)	<0.0001	0.7 (209)	0.8 (292)	0.9 (1,629)	0.0445
All infections	3.6 (424)	4.4 (664)	5.4 (4,997)	<0.0001	2.9 (877)	3.7 (1,279)	4.0 (7,510)	<0.0001
Acute renal failure	1.1 (136)	1.5 (225)	2.1 (1,925)	<0.0001	1.1 (320)	1.4 (506)	1.6 (3,010)	<0.0001
Gastrointestinal complication	0.8 (97)	0.8 (121)	1.0 (988)	0.0144	0.7 (188)	0.7 (245)	0.7 (1,306)	0.7261
Acute myocardial infarction	0.3 (37)	0.2 (36)	0.3 (310)	0.1355	0.2 (65)	0.3 (90)	0.2 (477)	0.6682
Mechanical ventilation	0.4 (61)	0.4 (73)	0.8 (710)	<0.0001	0.4 (131)	0.5 (206)	0.7 (1,312)	<0.0001
Blood product transfusion	20.3 (2,498)	16.4 (2,860)	23.1 (22,352)	<0.0001	13.1 (4,148)	15.2 (5,768)	16.3 (32,348)	<0.0001
30-Day mortality	0.2 (18)	0.1 (22)	0.3 (243)	0.0041	0.1 (24)	0.1 (32)	0.1 (250)	0.0041

† *P* value is to test the null hypothesis of no difference in incidence among neuraxial, general, and neuraxial/general (chi-square test).