The Incidence of Perioperative Stroke: Estimate Using State and National Databases and Systematic Review

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Background and Purpose: Perioperative stroke remains a devastating complication after surgical procedures, due to hemodynamic and inflammatory changes that increase the risk of strokes within 30 days following surgery. We aimed to assess the incidence of perioperative strokes in patients undergoing various surgical procedures and reach a national estimate.

Methods: A retrospective cohort study was conducted using California State Inpatient Databases, State Emergency Department Databases, State Ambulatory Surgery and Services Databases, and the National Inpatient Sample (NIS) during the period 2008 to 2011 from the Healthcare Cost and Utilization Project. A systematic review was conducted using PubMed, Embase, and Web of Science databases to obtain published articles that reported the incidence of perioperative stroke in various surgical procedures.

Results: Analysis of 3,694,410 surgical encounters from the state of California (mean±standard deviation age: 52.4±21.1 years) yielded an overall rate of perioperative stroke of 0.32% (n=11,759). The incidence of perioperative strokes was highest following neurological (1.25%), vascular (1.07%), and cardiac (0.98%) surgeries. The NIS database contained a total of 48,672,974 weighted hospitalizations and yielded a rate of perioperative stroke of 0.42% (n=204,549). The systematic review completed yielded 187 articles, which had an overall sample size of 184,922 and an incidence of perioperative stroke ranging from 0% to 13.86%. It is estimated that in any given year, there would be approximately 40,000 to 55,000 (0.33% to 0.46%) perioperative strokes nationally.

Conclusions: Our findings support further strategies to identify and stratify patients undergoing surgical procedures with a high incidence of perioperative strokes to improve patient counseling and a future potential treatment plan.

Keywords: Stroke; Postoperative complications; Incidence; Surgery; Perioperative period
Introduction

Perioperative stroke, a new neurological deficit that occurs during or within 30 days of surgery,\(^1\) is a devastating complication because it is associated with significant clinical burden and mortality.\(^1,2\) The vast majority of these strokes are ischemic, and about 1% to 4% are hemorrhagic.\(^2,4,5\) The majority of the strokes (50%) occur within the first postoperative day.\(^3,6\)

The incidence of perioperative stroke varies among different types of surgical procedures, as it ranges approximately from 1.9% to 9.7% in high-risk cardiovascular surgeries, e.g., coronary artery bypass grafting (CABG) surgeries have a perioperative stroke rate of 3% to 5%\(^7\) compared to 0.1% to 1.9% in non-cardiovascular, non-neurological and minor vascular surgeries.\(^1,3,8\) This variation in incidence is attributed to the surgical procedure itself as well as the associated risk factors and comorbidities.\(^2\) The incidence of perioperative stroke has not changed over the past two decades despite an improvement in medical and surgical care.\(^2,9\)

The primary objective of the present study was to estimate the national incidence of perioperative strokes in patients undergoing various surgical procedures. We achieved this objective through analysis of a state-wide database and stratifying included patients according to their comorbidities and demographic variables, including age, sex, and ethnicity. We further estimated the incidence of perioperative stroke with results from the National Inpatient Sample (NIS) database. Finally, we performed a systematic review for all published studies reporting the incidence of perioperative stroke following various surgical procedures; this review has helped to solidify the calculated estimate we have reached using our databases. We expect the results of the study to improve the recognition and diagnosis of perioperative stroke and patient safety, which will help us estimate the financial cost and burden of perioperative stroke, as well as, pave the road for optimizing therapeutic and preventive measures that could be implemented to minimize the incidence of perioperative stroke.

Methods

Data source

Informed consent was not required by the The Institutional Review Board (IRB) at our institution for this retrospective cohort analysis. Data were obtained from the Healthcare Cost and Utilization Project (HCUP) including State Inpatient Databases (SID), State Emergency Department Databases (SEDD), and State Ambulatory Surgery and Services Databases (SASD) for the state of California, and NIS during the 2008 to 2011 period. The SID, SEDD, and SASD contain the universe of the inpatient, emergency department (ED) and outpatient unit discharge abstracts and a set of clinical and nonclinical information on about 97% of patients discharged from different medical facilities in California. We chose the California state databases as they contain present on admission (POA) indicator; which is defined as the conditions present when the inpatient admission occurs.\(^10\) The POA indicator helps to differentiate strokes occurring in patients as a complication following surgery from those presented on admission with a stroke or history of stroke. The NIS contains data from all-payer inpatient health care in the United States, yielding national estimates of hospital inpatient stays.

Patient and surgical procedure selection

Patients in this study were those who underwent any surgical procedure from 2008 to 2011; this period was chosen because 2008 was one of the first years where the SID adopted using the POA indicators. The years 2010 and 2011 were chosen in Table 1 because claims databases tend to be very granular and improve yearly; therefore, presenting the most 2 recent years seemed most suited. Most patients undergoing any surgical procedure that did not require intubation and general anesthesia were excluded. Patients were identified according to their primary diagnosis, surgical procedure and comorbid risk factors using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD–9–CM) and the Clinical Classification Software (CCS) which is a uniform and standardized coding system, that collapses the vast multitude of codes found in the ICD–9 into a smaller number of clinically meaningful categories. Each specific surgical subcategory in Table 2 reflects one ICD–9 code for one or more surgical procedure and intervention, the specific surgical procedure(s) for each subcategory are shown in Supplementary Table 1. The ICD–9 codes for the five subcategories were selected according to the combined highest procedure frequency, stroke number, and stroke incidence. Supplementary Tables 2–4 show the highest 100 surgical subcategories according to procedure frequency, stroke number, and stroke incidence respectively. Any results showing single digit number of cases were replaced by *** to maintain patient privacy.

Covariates

The patients were identified into different categories according to hospital-level covariables, including age, sex, ethnicity, and specific comorbidities. Surgical procedures were stratified into 15 surgical categories according to the system involved. The age sub-groups were separated starting from 0 to 17 years, and from 18 to 25 years and every 5 years after that. Patients who suffered from perioperative stroke were identified according to the presence of at least one ICD–9 codes shown in Supplementary Table 5.
Outcomes
The primary outcome of the present study is strokes that occurred within 30 days of surgical procedures that require intubation and general anesthesia.

Systematic review
A systematic review was conducted on the incidence of perioperative stroke after surgical procedures. It complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The search criteria, inclusion and exclusion criteria, detailed data extraction information, and PRISMA flowchart, are found in Supplementary Material, Supplementary Table 6, and Supplementary Figure 1.

Statistical analysis
Dataset construction and analysis were done using the SAS program version 9.4 (SAS Institute Inc., Cary, NC, USA). Data in each year from 2008 to 2011 were merged into a shared database. Patient records were linked and tracked using VisitLink and DaysToEvents variables provided by HCUP. For patients

| Table 1. The incidence of perioperative stroke during 2010 to 2011 for both genders according to different age groups and races |
|-----------------------------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
| Variable                                | Male (n=2,537,251)                          | Female (n=48,672,974)                        | Overall (n=2,537,251)                       |
|                                        | 2010                                        | 2011                                        | 2010                                        | 2011                                        | 2008–2011                                    |
| Age group (yr)                          | 2010                                        | 2011                                        | 2010                                        | 2011                                        | 2008–2011                                    |
| 0–17                                    | 24 (0.20)                                   | 23 (0.21)                                   | 20 (0.23)                                   | 14 (0.17)                                   | 196 (0.15)                                  | 3,479 (0.06)                                |
| 18–25                                   | 12 (0.13)                                   | 18 (0.19)                                   | 13 (0.13)                                   | 11 (0.11)                                   | 121 (0.04)                                  | 1,845 (0.04)                                |
| 26–30                                   | 14 (0.19)                                   | * (0.112)                                   | 16 (0.19)                                   | 15 (0.18)                                   | 127 (0.05)                                  | 1,672 (0.05)                                |
| 31–35                                   | 19 (0.23)                                   | 17 (0.20)                                   | * (0.09)                                    | 10 (0.11)                                   | 122 (0.04)                                  | 2,082 (0.06)                                |
| 36–40                                   | 27 (0.25)                                   | 23 (0.225)                                  | 20 (0.17)                                   | 13 (0.11)                                   | 180 (0.08)                                  | 3,184 (0.12)                                |
| 41–45                                   | 43 (0.28)                                   | 36 (0.24)                                   | 30 (0.20)                                   | 49 (0.33)                                   | 322 (0.16)                                  | 4,725 (0.22)                                |
| 46–50                                   | 71 (0.31)                                   | 75 (0.33)                                   | 66 (0.30)                                   | 51 (0.24)                                   | 489 (0.19)                                  | 8,020 (0.29)                                |
| 51–55                                   | 95 (0.32)                                   | 85 (0.28)                                   | 77 (0.28)                                   | 91 (0.33)                                   | 717 (0.27)                                  | 11,730 (0.36)                               |
| 56–60                                   | 147 (0.43)                                  | 127 (0.36)                                  | 121 (0.39)                                  | 106 (0.34)                                  | 975 (0.34)                                  | 15,541 (0.44)                               |
| 61–65                                   | 171 (0.48)                                  | 157 (0.43)                                  | 128 (0.37)                                  | 142 (0.40)                                  | 1,167 (0.39)                                | 19,856 (0.53)                               |
| 66–70                                   | 200 (0.58)                                  | 170 (0.48)                                  | 173 (0.49)                                  | 177 (0.49)                                  | 1,390 (0.47)                                | 21,832 (0.58)                               |
| 71–75                                   | 201 (0.66)                                  | 196 (0.64)                                  | 193 (0.59)                                  | 191 (0.58)                                  | 1,501 (0.56)                                | 22,723 (0.69)                               |
| 76–80                                   | 195 (0.74)                                  | 218 (0.83)                                  | 210 (0.69)                                  | 220 (0.73)                                  | 1,681 (0.68)                                | 23,068 (0.79)                               |
| 81–85                                   | 150 (0.75)                                  | 173 (0.88)                                  | 203 (0.76)                                  | 202 (0.79)                                  | 1,455 (0.75)                                | 19,372 (0.87)                               |
| 86–90                                   | 109 (0.84)                                  | 107 (0.82)                                  | 157 (0.82)                                  | 176 (0.91)                                  | 1,067 (0.82)                                | 11,272 (0.89)                               |
| 91–95                                   | 20 (0.95)                                   | 20 (0.86)                                   | 39 (0.82)                                   | 37 (0.75)                                   | 220 (0.79)                                  | 3,328 (0.68)                                |
| 96–100                                   | * (1.92)                                    | * (0.47)                                    | * (0.94)                                    | * (0.66)                                    | 25 (0.68)                                   | 495 (0.68)                                  |
| Total†                                  | 1,502 (0.48)                                 | 1,454 (0.46)                                | 1,481 (0.45)                                | 1,510 (0.46)                                | 11,755 (0.32)                               | 174,287 (0.35)                              |
| Race                                    |                                             |                                             |                                             |                                             |                                             |                                             |
| White                                   | 874 (0.46)                                  | 827 (0.44)                                  | 881 (0.44)                                  | 883 (0.45)                                  | 6,889 (0.35)                                | 107,795 (0.38)                              |
| Black                                    | 98 (0.52)                                   | 90 (0.47)                                   | 101 (0.45)                                  | 118 (0.51)                                  | 813 (0.35)                                  | 20,008 (0.39)                               |
| Hispanic                                 | 296 (0.47)                                  | 272 (0.42)                                  | 264 (0.41)                                  | 282 (0.42)                                  | 2,162 (0.26)                                | 11,417 (0.24)                               |
| Asian or Pacific Islander                | 155 (0.83)                                  | 173 (0.89)                                  | 161 (0.76)                                  | 148 (0.69)                                  | 1,181 (0.45)                                | 3,922 (0.34)                                |
| Native American                         | 0 (0)                                      | 0 (0)                                      | 0 (0)                                      | * (1.04)                                    | * (0.23)                                    | 864 (0.31)                                  |
| Other                                    | 33 (0.58)                                   | 44 (0.68)                                   | 25 (0.48)                                   | 42 (0.68)                                   | 275 (0.38)                                  | 4,763 (0.32)                                |
| Total†                                   | 1,456 (0.49)                                 | 1,406 (0.47)                                | 1,432 (0.45)                                | 1,475 (0.47)                                | 11,327 (0.33)                               | 148,788 (0.36)                              |

Values are presented as number (%). The overall incidence during 2008 to 2011 for the same age groups and races for California state (State Inpatient Databases [SID], State Emergency Department Databases [SEDD], and State Ambulatory Surgery and Services Databases [SASD] databases; n=2,537,251) and National Inpatient Sample (NIS) databases (n=48,672,974).

*Any results showing numbers less than 10 patients to maintain patient privacy; †In the data obtained, some patients had the age and race information reported as missing, which resulted in different totals in both categories.
### Table 2. The incidence of perioperative stroke for the state of California in different surgical categories

| Surgical category                                      | Male          | Female         | Overall (2008–2011) |
|--------------------------------------------------------|---------------|----------------|---------------------|
|                                                        | 2010          | 2011           | 2010                | 2011                |                 |
| Neurosurgery                                           | 225 (1.34)    | 216 (1.31)     | 190 (1.42)          | 188 (1.50)          | 1,594 (1.25)    |
| Ventricular shunt to extracranial site                 | *(1.85)*      | *(2.99)*       | *(8.00)*            | *(10.31)*           | *(23.56)*       |
| Craniotomy and craniectomy; reopening of craniotomy site | *(6.25)*      | *(4.65)*       | *(12.82)*           | *(0)*               | *(18.54)*       |
| Other incision of brain                                | 14 (4.08)     | 29 (7.32)      | 14 (5.74)           | 14 (5.24)           | 138 (5.25)      |
| Other craniectomy                                      | *(4.55)*      | 12 (8.05)      | *(6.20)*            | *(2.13)*            | *(46.46)*       |
| Incision of cerebral meninges                          | 65 (3.62)     | 47 (2.60)      | 34 (3.90)           | 36 (4.12)           | 357 (3.27)      |
| Cardiac                                                | 446 (0.90)    | 434 (0.92)     | 292 (1.24)          | 320 (1.43)          | 2,871 (0.98)    |
| Insertion of implantable heart assist system           | *(4.44)*      | *(3.45)*       | *(11.11)*           | *(11.76)*           | *(27.57)*       |
| Open heart valvuloplasty of aortic valve without replacement | *(3.97)*      | *(4.67)*       | *(8.00)*            | *(6.41)*            | *(31.42)*       |
| Open and other replacement of aortic valve with tissue graft | 65 (2.49)    | 60 (2.21)      | 41 (2.79)           | 46 (3.03)           | 416 (2.61)      |
| Implant of pulsation balloon                           | 24 (1.98)     | 29 (2.25)      | 14 (2.55)           | *(1.33)*            | 151 (2.18)      |
| (Aorto)coronary bypass of three coronary arteries       | 47 (1.83)     | 43 (1.75)      | 17 (2.32)           | 16 (2.25)           | 238 (1.78)      |
| Vascular                                               | 369 (0.91)    | 367 (0.91)     | 443 (1.28)          | 431 (1.26)          | 3,170 (1.07)    |
| Endovascular removal of obstruction from head and neck vessel(s) | 27 (17.88)   | 25 (18.25)     | 34 (26.56)          | 36 (24.49)          | 171 (18.47)     |
| Extracranial–intracranial vascular bypass             | *(20.69)*     | *(0.09)*       | *(15.00)*           | *(10.58)*           | *(60.13.82)*    |
| Clipping of aneurysm                                   | 17 (8.37)     | 21 (11.23)     | 51 (10.30)          | 47 (9.44)           | 294 (10.29)     |
| Endarterectomy; other vessels of head and neck         | 56 (1.45)     | 59 (1.59)      | 49 (1.86)           | 57 (2.31)           | 433 (1.59)      |
| Percutaneous transluminal coronary angioplasty         | 111 (0.39)    | 109 (0.41)     | 81 (0.63)           | 103 (0.86)          | 761 (0.46)      |
| Organ transplant                                       | 10 (1.72)     | 10 (1.63)      | *(2.56)*            | *(11.94)*           | *(31.35)*       |
| Heart transplantation                                  | *(3.47)*      | *(4.29)*       | *(1.79)*            | *(7.94)*            | *(31.51)*       |
| Combined heart-lung transplantation                    | 0 (0)         | 0 (0)          | 0 (0)               | 0 (0)               | *(3.3)*         |
| Bilateral lung transplantation                         | *(1.82)*      | *(1.69)*       | *(4.17)*            | *(1.82)*            | *(1.58)*        |
| Other transplant of liver                             | *(1.25)*      | *(0.60)*       | *(3.19)*            | *(1.97)*            | *(31.48)*       |
| Pancreatic transplant, not otherwise specified         | 0 (0)         | 0 (0)          | 0 (0)               | 0 (0)               | *(1.79)*        |
| Respiratory/Thoracic                                   | 61 (0.43)     | 48 (0.33)      | 54 (0.42)           | 68 (0.52)           | 428 (0.39)      |
| Reopening of recent thoracotomy site                   | 0 (0)         | 0 (0)          | *(13.33)*           | *(7.14)*            | *(2.78)*        |
| Other and unspecified pneumonectomy                    | *(3.03)*      | *(0.0)*        | *(2.98)*            | *(3.92)*            | *(1.55)*        |
| Other lobectomy of lung                               | *(0.55)*      | *(0.45)*       | *(0.75)*            | *(0.38)*            | *(37.057)       |
| Decortication of lung                                 | *(0.39)*      | *(0.39)*       | *(0.44)*            | *(0.48)*            | *(15.48)*       |
| Thoracoscopic excision of lesion or tissue of lung     | *(0.44)*      | *(0.27)*       | *(0.36)*            | *(0.54)*            | *(31.037)*      |
| Endocrine                                              | 12 (0.45)     | 13 (0.52)      | 22 (0.29)           | 14 (0.20)           | 109 (0.25)      |
| Partial excision of pituitary gland, transfrontal approach | *(12.50)*    | *(6.06)*       | *(21.43)*           | *(9.52)*            | *(25.10.16)*    |
| Partial excision of pineal gland                      | 0 (0)         | *(33.33)*      | *(16.67)*           | 0 (0)               | *(3.13)*        |
| Division of thyroid isthmus                            | 0 (0)         | 0 (0)          | *(33.33)*           | 0 (0)               | *(3.77)*        |
| Unilateral adrenalectomy                              | *(0.57)*      | 0 (0)          | *(0.40)*            | *(0.38)*            | *(0.33)*        |
| Complete thyroidectomy                                 | *(0.14)*      | 0 (0)          | *(0.03)*            | *(0.04)*            | *(0.04)*        |
| Gastrointestinal                                       | 153 (0.23)    | 119 (0.18)     | 168 (0.20)          | 178 (0.21)          | 1,193 (0.19)    |
| Open total intra-abdominal colectomy                   | *(0.40)*      | *(0.36)*       | *(1.44)*            | *(0.77)*            | *(17.98)*       |
| Open and other left hemicolectomy                      | *(0.56)*      | *(1.11)*       | *(1.03)*            | *(0.79)*            | *(56.083)*      |
| Exploratory laparotomy                                 | *(0.35)*      | *(0.38)*       | *(0.81)*            | *(0.98)*            | *(28.064)*      |
| Other partial resection of small intestine             | 13 (0.56)     | 14 (0.61)      | 16 (0.58)           | 21 (0.73)           | 121 (0.61)      |
| Cholecystectomy                                        | 13 (0.61)     | *(0.34)*       | *(0.29)*            | *(0.15)*            | *(57.32)*       |
| Surgical category                                      | Male 2010 | Female 2010 | Male 2011 | Female 2011 | Overall (2008–2011) |
|-------------------------------------------------------|-----------|-------------|-----------|-------------|---------------------|
| **Ophthalmic**                                        |           |             |           |             |                     |
| Other removal or destruction of corneal lesion        | * (25)   | * (0.09)    | * (0.13)  | 0 (0)       | 12 (0.15)           |
| Other extracapsular extraction of lens                | 0 (0)     | 0 (0)       | 0 (0)     | 0 (0)       | * (4.17)            |
| Other repair of retinal detachment                    | * (10.00)| 0 (0)       | 0 (0)     | 0 (0)       | * (2.78)            |
| Other operations on vitreous                          | 0 (0)     | 0 (0)       | 0 (0)     | 0 (0)       | * (1.67)            |
| Suture of corneal laceration                          | 0 (0)     | 0 (0)       | 0 (0)     | 0 (0)       | * (0.36)            |
| **Blood/Lymphatic**                                   |           |             |           |             |                     |
| Total splenectomy                                     | * (0.19) | * (0.56)    | * (0.96)  | * (0.68)    | 23 (0.56)           |
| Radical excision of periaortic lymph nodes            | 0 (0)     | 0 (0)       | * (0.64)  | (0)         | * (0.55)            |
| Biopsy of lymphatic structure                         | * (0.031)| * (0.20)    | * (0.24)  | * (0.38)    | 36 (0.34)           |
| Radical neck dissection, unilateral                   | * (0.45) | * (0.15)    | 0 (0)     | * (0.61)    | 10 (0.24)           |
| Excision of axillary lymph node                       | 0 (0)     | 0 (0)       | 0 (0)     | * (0.05)    | * (0.02)            |
| **Musculoskeletal**                                   |           |             |           |             |                     |
| Amputation above knee                                 | * (0.60) | * (0.58)    | * (1.50)  | * (1.29)    | 53 (1.06)           |
| Atlas-axis spinal fusion                              | * (1.37) | * (0.78)    | * (0.60)  | * (0.61)    | 11 (0.92)           |
| Other amputation below knee                           | * (0.50) | 13 (0.87)   | 11 (1.72) | * (0.92)    | 66 (0.75)           |
| Partial hip replacement                               | 21 (0.77)| 22 (0.82)   | 51 (0.80) | 36 (0.57)   | 250 (0.68)          |
| Open reduction of fracture with internal fixation; femur| 19 (0.45)| 28 (0.66)   | 39 (0.47) | 38 (0.46)   | 275 (0.54)          |
| **Urology**                                           |           |             |           |             |                     |
| Nephroureterectomy                                    | * (0.24) | * (0.30)    | * (0.35)  | * (0.25)    | 45 (0.27)           |
| Percutaneous nephrostomy without fragmentation        | * (0.25) | * (0.40)    | * (0.37)  | * (0.33)    | 41 (0.41)           |
| Radical cystectomy                                    | * (0.46) | * (0.47)    | * (0.92)  | 0 (0)       | 14 (0.46)           |
| Other transurethral excision or destruction of lesion or tissue of bladder | * (0.16) | * (0.22)    | * (0.65)  | 0 (0)       | 28 (0.28)           |
| Control of (postoperative) hemorrhage of bladder      | * (0.82) | * (3.57)    | 0 (0)     | 0 (0)       | * (0.96)            |
| **Reproductive male**                                 |           |             |           |             |                     |
| Other transurethral prostatectomy                      | * (0.08) | 11 (0.20)   | 0 (0)     | 0 (0)       | 33 (0.13)           |
| Control of (postoperative) hemorrhage of prostate      | * (1.69) | * (0.81)    | 0 (0)     | 0 (0)       | * (0.89)            |
| Radical prostatectomy                                  | * (0.05) | * (0.07)    | 0 (0)     | 0 (0)       | 12 (0.04)           |
| Unilateral orchiectomy                                | 0 (0)     | * (0.31)    | 0 (0)     | 0 (0)       | * (0.7)             |
| Removal of both testes at same operative episode       | 0 (0)     | 0 (0)       | 0 (0)     | 0 (0)       | * (0.56)            |
| **OBGYN**                                             |           |             |           |             |                     |
| Low cervical cesarean section                         | 0 (0)     | 0 (0)       | 11 (0.01) | 10 (0.01)   | 41 (0.01)           |
| Other and unspecified total abdominal hysterectomy     | 0 (0)     | 0 (0)       | * (0.06)  | * (0.02)    | 27 (0.04)           |
| Other removal of both ovaries and tubes at same operative episode | 0 (0) | 0 (0) | 0 (0) | * (0.13) | * (0.11) |
| Laparoscopic total abdominal hysterectomy              | 0 (0)     | 0 (0)       | * (0.03)  | * (0.04)    | * (0.03)            |
| Classical cesarean section                            | 0 (0)     | 0 (0)       | * (0.12)  | 0 (0)       | * (0.6)             |
| Breast and skin                                       | * (0.19) | * (0.19)    | * (0.05)  | 11 (0.10)   | 52 (0.08)           |
| Fat graft of skin and subcutaneous tissue             | 0 (0)     | * (3.23)    | 0 (0)     | * (2.17)    | * (2.06)            |
| Bilateral simple mastectomy                            | 0 (0)     | 0 (0)       | 0 (0)     | * (0.34)    | * (0.8)             |
| Removal of implant of breast                          | 0 (0)     | 0 (0)       | 0 (0)     | 0 (0)       | * (0.8)             |
| Other free skin graft to other sites                  | * (0.27) | * (0.17)    | * (0.47)  | * (0.15)    | 15 (0.21)           |
| Homograft to skin                                     | * (0.56) | 0 (0)       | 0 (0)     | 0 (0)       | * (0.34)            |
with multiple admissions and surgeries, only the first record was considered for analysis. The cases that were lacking values for age, gender, and race were not excluded in our final dataset as they composed a sizable portion of the data. Descriptive data characteristics were presented as mean±standard deviation or as a number of cases with their percentages.

CCS codes available on the HCUP website were used to group surgical procedures into different categories. ICD-9 procedural codes were used for surgical subgroup analysis. We created an array that searches through every record’s diagnoses variable 2 to 25 with negative POA variable. The negative POA variable helps us differentiate between cases of stroke developing during the inpatient hospital stay and cases of stroke that was present at the time of admission, and therefore, eliminating the latter. We performed univariate analyses using an unpaired t-test for continuous variables and Pearson’s chi-square test for categorical variables.

The HCUP uses databases as samples used to represent a larger universe. To generate a national estimate using the NIS database, a process called data weighting must be performed on the discharge or hospital weights from unweighted counts, which was performed and stratified using the strata variable provided by HCUP. NIS databases do not contain the POA variable, which made it impossible to identify cases of stroke that happened before the studied surgical admission.

### Results

#### Patient characteristics

**California state database**

A total of 3,694,410 patients who underwent various surgical procedures during 2008 to 2011 were identified from the SID, SASD, and SEDD. In the present dataset, 63.21% of the cases were females (n=2,267,321) with cases missing values for gender (n=107,537, 2.91%), the largest age and racial groups were those between 61 to 65 years of age 8.21% (n=300,779) and white 58.44% (n=1,991,270) with cases missing values for age (n=31,294, 0.85%) and race (n=287,191, 7.77%). Patients who suffered from a perioperative stroke were older (67.6±16.7 years vs. 52.4±21.1 years) and more likely to be females (50.9%, P<0.01). However, the incidence of perioperative stroke was higher in males (0.44% vs. 0.26%) because of the high number of obstetrics and gynecology (OBGYN) surgeries that had a low to tal incidence of perioperative stroke (Table 2). The most prevalent comorbidities in patients from this dataset were hypertension (n=1,445,794, 39.13%), iron deficiency anemia (n=571,964, 15.48%), and uncomplicated diabetes (n=457,844, 12.39%).

**NIS database**

From the NIS database, a total of 48,672,974 weighted hospitalizations were obtained during 2008 to 2011, 58.0% of the cases were females (n=27,984,592), and the largest age and racial groups were those between 0 to 17 years of age 11.71% (n=5,701,621) and white 69.1% (n=28,643,738), while cases missing values for race comprised a proportion of the cohort, we were not able to obtain the number of those missing cases after data weighting. The patients who suffered from a perioperative stroke were older (67.6±16.7 years vs. 52.4±21.1 years) and more likely to be females (50.9%, P<0.01). However, the incidence of perioperative stroke was higher in males (0.44% vs. 0.26%) because of the high number of obstetrics and gynecology (OBGYN) surgeries that had a low total incidence of perioperative stroke (Table 2). The most prevalent comorbidities in patients from this dataset were hypertension (n=1,445,794, 39.13%), iron deficiency anemia (n=571,964, 15.48%), and uncomplicated diabetes (n=457,844, 12.39%).

### Systematic review

The systematic review performed, without a meta-analysis, yielded 187 papers, with a total cohort of 184,922 patients. The highest three countries that had the most published papers
in our search were United State (58 papers, 75,456 patients),
Italy (23 papers, 15,703 patients), and Germany (21 papers,
11,814 patients). From the 58 papers published in the United
States, there were 57 papers on cardiovascular procedures and
one paper on noncardiovascular procedures.

Incidence of perioperative stroke

**California state database results**
The 30-day stroke incidence was 0.32% (n=11,759) in all surgi-
cical procedures in this database. The majority of patients suf-
fered from perioperative stroke during the same surgical hospi-
talization (86.38%, n=10,157), while the rest (13.62%, n
=1,602) occurred as a readmission within the 30-day postop-
erative period after discharge, or as a visit to the ED or as a
visit to an observation unit in an outpatient setting.

The incidence of perioperative stroke in the state of Califor-
nia during 2010 to 2011 for each gender according to different
age groups and races, as well as the overall incidence through
2008 to 2011 for age and race using the dataset for the state
of California and the NIS are shown in Table 1. For incidence
calculation and comparison between the two genders in Table
1, OBGYN and male reproductive surgeries were excluded, re-
sulting in 2,537,251 patients in 2008 to 2011. The incidence of
perioperative stroke rises significantly after the age of 40 in
both genders (Table 1). However, the incidence was markedly
higher in patients younger than 17 years old—compared to the
following older age groups—in both genders in 2010 to 2011
with an incidence of 0.15% (n=196) in that age group. Among
race groups, perioperative stroke was highest among Asian and
Pacific Islander in both genders in 2010 to 2011 with an inci-
dence of 0.45% (n=1,181).

Surgical procedures with the highest incidence of periopera-
tive strokes in the state of California for different age groups
during 2008 to 2011 are shown in Figure 1. It shows that neu-
rosurgical and cardiac procedures have the highest periopera-
tive stroke incidence in age groups between 65 to 95 years old,
neurosurgery peaking at 2.19% in the age group of 86 to 90
years and cardiac surgery peaking at 2.5% in the age group of
91 to 95 years. Meanwhile, organ transplant procedures were
the highest in almost all age groups younger than 65 years,
peaking at 4.17% in the age group of 36 to 40 years. The inci-
dence of perioperative stroke in all surgical procedures peaked
at 0.82% in the age group of 86 to 90 years, while it had an
apparent increase starting at the age of 40.

The incidence of perioperative stroke in the state of Califor-
nia during 2010 to 2011 according to the surgical procedure
for each gender, as well as the overall incidence during 2008 to
2011, are shown in Table 2. The surgical categories with the
highest overall incidence of perioperative stroke were organ
transplant surgeries 1.9% (n=74) followed by neurosurgeries
1.25% (n=1,594) and vascular surgeries 1.07% (n=3,170).

The incidence of perioperative stroke in patients with different
comorbidities in the state of California during 2008 to 2011, as

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![Figure 1](https://example.com/figure1.png)  
**Figure 1.** The overall Incidence of perioperative stroke according to different age groups and the highest three surgical categories in each age group.
**Figure 2.** Associated comorbidities in patients who suffered from a perioperative stroke in the state of California during 2008 to 2011. (A) The association between the number of comorbidities and the incidence of perioperative stroke, as well as the prevalence of the count of comorbidities in patients who suffered from a perioperative stroke. (B) The incidence of perioperative stroke with different comorbidities and the prevalence of those comorbidities in patients who suffered from a perioperative stroke.
well as the prevalence of those comorbidities in patients who suffered from a perioperative stroke, are shown in Figure 2. Correlation between the number of comorbidities and the incidence of perioperative stroke is shown in Figure 2A, as patients who had increasing numbers of comorbidities, had a higher incidence of perioperative stroke. It also shows that 56.5% of patients who suffered from perioperative stroke had one comorbidity or less. Specific comorbidities shown in Figure 2B, demonstrate that patients who had paralysis or other neurologic disorders had the highest incidence of perioperative stroke that ranges between 5.18% to 5.81% and 1.64% to 1.84% respectively. It also shows that hypertension (68.03%, n=8,000), fluid and electrolyte disorders (39.10%, n=4,598), and paralysis (29.08%, n=3,419) were the most prevalent comorbidities in patients who suffered from a perioperative stroke.

**NIS database results**

The overall incidence of inpatient perioperative stroke from the NIS is 0.42% (n=204,549), results from the NIS in Table 1 shows a similar pattern to the California state database with slightly higher incidences in age groups older than 40. However, the youngest age group (0 to 17 years) did not show a significantly higher incidence of perioperative stroke incidence compared to the older age groups.

**Systematic review**

From our systematic review, 187 articles were qualified for data extraction and yielded an overall cohort sample size of 184,922 as shown in Table 3, detailed information about the search results can be found in Supplementary Material and Supplementary Table 6.

Studies that provided information about perioperative strokes occurring in cardiovascular and non-cardiovascular procedures, comprised a cohort of 145,714 and 39,208 patients and the perioperative stroke incidence and stroke number ranged from 0% to 13.86% (n=0–214; total=2,342) and 0% to 1.05% (n=0–123; total=233), respectively.

**Estimation**

In the state of California during the year 2011, our databases showed that there had been 911,126 surgical procedures performed, and had an incidence of perioperative stroke of 0.33%. Nationally during the same year, the NIS showed that there had been 11,934,162 surgical procedures performed, and had a 0.46% incidence of perioperative stroke. Using our databases from the state of California and the NIS, it can be estimated that in any given year there would be approximately 40,000 to 55,000 perioperative strokes nationally, and its incidence would be close to 0.33% to 0.46% and that constitutes of approximately 6.25% of all strokes that happen in the USA every year.12

In the state of California during the year 2011 as well, our databases showed that there had been 11,534 CABG and 6,301 carotid endarterectomies (CEAs) performed and had an incidence of perioperative stroke of 1.53% and 1.56%, respectively. Nationally during the same year, the NIS showed that there had been 163,864 CABG and 98,626 CEA surgeries performed and had an incidence of perioperative stroke of 1.76% and 3.04% respectively. In the systematic review performed, studies that reported the incidence of perioperative stroke in CABG and CEA in the United States ranged from 0% to 7.69% in 14 papers (cohort=27,173 patients) and 0% to 4.16% in 22 papers (cohort=32,116) respectively. It can be estimated that in any given year, there would be approximately 2,500 to 3,000 and 1,000 to 3000 perioperative strokes nationally that result from CABG and CEA, respectively.

**Discussion**

Our study identifies the incidence of perioperative stroke according to the surgical procedure performed as well as gender, age, and race of patients using various databases from the HCUP from 2008 to 2011. A systematic review of the literature was also performed to identify the incidences of perioperative stroke in the United States and other countries published between the years 1980 to 2017. Most perioperative strokes from

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**Table 3. Characteristics of systematic review results according to surgical procedure type**

| Surgery                  | Sample size | No. of studies | No. of strokes |
|--------------------------|-------------|----------------|---------------|
| Non-cardiovascular*      | 39,208      | 10             | 233           |
| Cardiovascular           | 145,714     | 178            | 2,342         |
| Cardiac surgeries        | 78,233      | 82             | 1,555         |
| CAGB                     | 56,414      | 49             | 1,035         |
| Valvular heart surgery   | 4,100       | 12             | 86            |
| Surgical ablation for atrial fibrillation | 1,814      | 6             | 14            |
| Other cardiac surgery    | 15,905      | 15             | 420           |
| Carotid surgeries        | 64,879      | 87             | 756           |
| Carotid artery stenting  | 3,984       | 12             | 76            |
| CEA                      | 59,528      | 70             | 651           |
| Other carotid surgeries  | 1,367       | 5              | 22            |
| Aortic surgeries         | 787         | 6              | 22            |
| Other peripheral vascular surgeries | 1,815  | 3 | 9 |
| All surgeries            | 184,922     | 188            | 2,575         |

CABG, coronary artery bypass grafting; CEA, carotid endarterectomy. *Detailed list can be found in Supplementary Table 6.
the HCUP in the present study (86.3%) occurred during the same surgical hospitalization in agreement with other studies that reported the occurrence of perioperative stroke during the first postoperative week. The NIS database during 2008 to 2011 included 48,672,974 weighted hospitalizations, resulted in an overall incidence of perioperative stroke of 0.42%. Results from the state of California and NIS showed similar results according to the incidence of perioperative stroke. There have been no noticeable trends over the incidence of perioperative stroke during the years our data was obtained from, although the incidence of stroke in the general population has been decreasing over the past 20 years due to improvement in blood pressure control and a decrease in smoking prevalence.

The results reported from the analysis of our data are consistent with other previous studies, which reported that the overall incidence of perioperative stroke in various surgical procedures ranged between 0.2% and 0.7%. Female gender and advanced age have been consistently reported as a risk factor for perioperative stroke; as our California population cohort showed that patients who suffered from perioperative stroke were older (67.6±16.7 years vs. 52.4±21.1 years). The overall incidence of perioperative stroke started increasing after the 4th decade significantly (Figure 1). However, the higher incidence of perioperative stroke in the age group of 0 to 17 years can be explained by the increased rates of certain surgical procedures in pediatrics. Congenital defects that involve the heart and central nervous system would put this age group under surgical procedures that have an increased risk for perioperative stroke.

Our systematic review showed that the incidence and number of perioperative stroke to be higher in Cardiovascular procedures than non-cardiovascular procedures ranging from 0% to 13.86% (n=0–214; 177 papers) and 0% to 1.05% (n=0–123; 10 papers), respectively. In cardiovascular procedures, most literature had a focus on CEA, CABG, and valvular procedures, with no specific trend or change in the incidence of perioperative stroke in the United States in these or any other surgical procedures over time. Somatosensory evoked potential is mainly used in CEAs to detect and diagnose perioperative strokes. Many studies reported that the incidence of perioperative stroke in procedures like CABG and valvular heart surgeries had higher incidences than carotid surgeries, this could mean that intraoperative monitoring might need to be broadened to include further surgical procedures in order to prevent and manage perioperative strokes.

The different incidences in each surgical procedures can be accounted for various pathophysiologic pathways. Surgical procedures can cause hemodynamic and inflammatory changes that increase the risk of stroke. It has been estimated that embolic events cause more than 60% of perioperative strokes, followed by unknown causes (13.9%), a synergistic effect from hypotension, hypoperfusion and formation of microemboli together (10%), hypoperfusion (9%), hemorrhagic strokes (1%), and the remaining 20% is distributed between other minor and unknown causes.

Surgery also has been known to amplify the inflammatory pathways which can initiate or exacerbate cerebral ischemic injury. Perioperative hemorrhagic strokes have been linked to sudden surges of cerebral perfusion; revascularization procedures; for example, can lead to cerebral hyperperfusion syndrome that causes acute neurological deficits. Solid organ transplant surgeries have been previously reported to be associated with different neurological complications; stroke specifically was found to be the most common neurologic complication within the first 30 days after transplant, especially in liver, heart, and lung transplant surgeries. Zierer et al. explained that there are fundamental factors that contribute to the high incidence of perioperative stroke after heart transplant surgeries, which include prolonged cardiopulmonary bypass and metabolic changes secondary to hepatic failure. Perioperative strokes that occur after neurosurgeries have been linked to local changes and alterations to the physiological regulation of brain vascular circulation, autoregulation, and vasomotoricity. These changes vary according to the nature of different tumoral, vascular, infectious or traumatic conditions, different localization, and different surgical technique used in the procedure.

Strengths and limitations
This study was conducted using claims databases obtained from the HCUP; as they allow the analysis of a large number of patients and facilitates multi-state and national analysis and comparison. A major strength of this study is its large cohort size, with sufficient cases in each sex, age, and race groups to allow generalizability and population analysis. Furthermore, the usage of POA enables us to differentiate between strokes that occurred as a postoperative complication and patients presenting with strokes.

However, some of the limitations of using claims databases from HCUP include that it depends on proper ICD-9 coding for each diagnosis, as well as its inconsistency and overlapping of the codes of specific procedures that could affect the analysis and results. Although the usage of the POA indicator helps us differentiate between strokes that occurred before the time of admission, there is a possibility that some of the strokes might have happened after admission and before the surgical procedure. Furthermore, the lack of POA in the NIS database can attribute to the slightly higher incidences of perioperative stroke.
than in the state of California (Table 1) as some of those strokes may have happened at the time of admission and before surgery. The presence of paralysis and other neurologic disorders as the most prevalent comorbidities (Figure 2B) might also indicate that those patients had these comorbidities from a previous medical condition such as a previous stroke. Some limitations of our systematic review include that the incidence of perioperative stroke may have varied in various studies, which may be caused by different diagnostic protocols for strokes in each hospital or healthcare facility. Comorbidities that increase the risk of perioperative strokes such as hypertension, diabetes, and older age may have been more prevalent in some studies more than others and affected the variance of the systematic review.

Conclusions

Further prospective studies are needed in surgical procedures with a relatively high incidence of perioperative stroke to identify further strategies and stratify patients at high risk before the surgical procedures to improve patient counseling and a future potential treatment plan. Perioperative stroke is an underrecognized complication that accounts for about 6% for all strokes that happen in the United States annually.

Supplementary materials

Supplementary materials related to this article can be found online at https://doi.org/10.5853/jos.2019.00304.

Disclosure

The authors have no financial conflicts of interest.

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Supplementary Material

Search criteria and strategy
An electronic search of PubMed, Embase, and Web of Science was performed to retrieve published articles related to postoperative s that were published from January 1970 through December 2017. The search was completed by combining keywords for stroke (stroke OR Cerebrovascular accident OR CVA OR Cerebral ischemia OR Brain ischemia) with surgery-specific key terms (postoperative OR perioperative OR post-operative OR peri-operative OR postprocedural OR post-procedural OR postsurgical OR post-surgical OR postoperative care OR post-operative care OR surgical patient OR postoperative complication OR post-operative complication). For Pubmed, the terms (prospective studies[mesh:noexp] OR prospective[tiab]) were used to specify prospective studies only. The search criteria and inclusion/exclusion criteria were created in a way to minimize bias commonly encountered in observational studies. The Quality Assessment of Diagnostic Accuracy Studies, version 2, was performed to evaluate for bias and to determine whether the chosen studies were relevant to the review question.

Inclusion & exclusion criteria for study selection
The inclusion criteria included the following: (1) all prospective studies, (2) incident postoperative stroke that was identified using criteria for the study, (3) studies inclusive of postoperative neurological outcomes within 30 days postoperative, (4) reported quantitative data, (5) studies published in English, (6) studies that included an abstract, and (7) studies done on 100 patients or more.

Data extraction
Two authors (R.A. and E.J.) independently reviewed all the titles and abstracts of the articles from the electronic search to identify those that satisfied all the inclusion criteria, and a third researcher (K.A.) settled any disagreements. Simultaneously, an Excel spreadsheet was constructed by each author outlining the articles to be excluded—the reason why a study was eliminated was indicated by a number corresponding to the inclusion criteria that was not met. A third author reconciled inclusion/exclusion disagreements and assembled a final list of studies for this review. The following data were extracted from each study: author name and year, sample size, the incidence of perioperative stroke, number of strokes.

Search results
A search was conducted on December 18, 2017 using the terms mentioned and resulted with total 4,035 references, 870 duplicates were removed from the three databases using endnote, leaving 3,166 potential references. Looking further into the abstracts of the references, 2,830 articles were excluded after title/abstract screening; 484 were not prospective studies, 1,578 the incidence of perioperative stroke and neurologic outcome was not identified within 30 days, 335 had a sample size of fewer than 100 patients, six studies were not performed on humans and 427 were more duplicated studies found, leaving 336 articles.

After full-text screen, 187 articles were qualified for data extraction. The overall sample size is 184,922 patients that had an incidence of perioperative stroke ranging from 0% to 13.86%. Studies that provided information about perioperative strokes occurring in cardiovascular and non-cardiovascular procedures, comprised of a total cohort of 145,714 and 39,208. The highest three countries that had the most published papers in our search were United State (58 papers; 75,456 patients), Italy (23 papers; 15,703 patients), and Germany (21 papers; 11,814 patients). From the 58 papers published in the United States, there were 57 papers on cardiovascular procedures and one paper on noncardiovascular procedures.
**Supplementary Table 1.** Surgical subcategories used and the surgical procedures they include

| Surgical subcategory                                           | ICD-9 code | Surgical procedure(s)                                                                 |
|---------------------------------------------------------------|------------|--------------------------------------------------------------------------------------|
| Ventricular shunt to extracranial site                       | 0231       | Ventricle to nasopharynx shunt, ventriculomastoid anastomosis                        |
| Craniotomy and craniectomy; reopening of craniotomy site     | 0123       |                                                                                      |
| Other incision of brain                                       | 0139       | Amygdalohippocampotomy, drainage of intracerebral hematoma, incision of brain NOS     |
|                                                               |            | Excludes: division of cortical adhesions                                              |
| Other craniectomy                                             | 0124       | Cranial (decompression, exploration, trephination), craniotomy NOS, craniotomy        |
|                                                               |            | with removal of (epidural abscess, extradural hematoma, foreign body of skull)        |
|                                                               |            | Excludes: removal of foreign body with incision into brain                           |
| Incision of cerebral meninges                                 | 0131       | Drainage of (intracranial hygroma, subarachnoid abscess (cerebral), subdural empyema)|
| Insertion of implantable heart assist system                  | 3766       | Axial flow heart assist system, diagonal pump heart assist system, left ventricular   |
|                                                               |            | assist device, pulsatile heart assist system, right ventricular assist device,        |
|                                                               |            | rotary pump heart assist system, transportable implantable heart assist system,       |
|                                                               |            | ventricular assist device not otherwise specified                                    |
|                                                               |            | Excludes: implant of pulsation balloon, implantation of total internal biventricular   |
|                                                               |            | heart replacement system (artificial heart), insertion of percutaneous external heart  |
|                                                               |            | assist device                                                                        |
| Open heart valvuloplasty of aortic valve without replacement  | 3511       |                                                                                      |
| Open and other replacement of aortic valve with tissue graft  | 3521       | Repair of aortic valve with tissue graft (autograft, heterograft, homograft)         |
| Implant of pulsation balloon                                  | 3761       |                                                                                      |
| (Aorto)coronary bypass of three coronary arteries             | 3613       |                                                                                      |
| Endovascular removal of obstruction from head and neck vessel(s) | 3974       | Endovascular embolectomy, endovascular thrombectomy of pre-cerebral and cerebral      |
|                                                               |            | vessels, mechanical embolectomy or thrombectomy                                       |
|                                                               |            | Excludes: endarterectomy of intracranial vessels and other vessels of head and neck,|
|                                                               |            | occlusive endovascular repair of head or neck vessels, open embolectomy or           |
|                                                               |            | thrombectomy                                                                         |
| Extracranial–intracranial vascular bypass                    | 3928       |                                                                                      |
| Clipping of aneurysm                                          | 3951       | Excludes: clipping of arteriovenous fistula                                           |
| Endarterectomy; other vessels of head and neck               | 3812       | Extirpation of matter from: right/left common carotid artery, right/left internal   |
|                                                               |            | carotid artery, right/left external carotid artery, right/left vertebral artery,     |
|                                                               |            | facial artery, right/left temporal artery, right/left thyroid artery                   |
| Percutaneous transluminal coronary angioplasty                | 0066       | Balloon angioplasty of coronary artery, coronary atherectomy, percutaneous coronary   |
|                                                               |            | angioplasty NOS                                                                         |
| Heart transplantation                                         | 3751       |                                                                                      |
| Combined heart–lung transplantation                          | 336        |                                                                                      |
| Bilateral lung transplantation                                | 3352       | Double-lung transplantation, en bloc transplantation                                   |
| Other transplant of liver                                    | 5059       | Exclude: auxiliary hepatic transplantation leaving patient's own liver in situ         |
| Pancreatic transplant NOS                                     | 5280       |                                                                                      |
| Reopening of recent thoracotomy site                         | 3403       |                                                                                      |
| Other and unspecified pneumonectomy                          | 3259       | Excludes: thoracoscopic pneumonectomy                                                 |
| Other lobectomy of lung                                      | 3249       | Excludes: thoracoscopic lobectomy of lung                                             |
| Decortication of lung                                        | 3451       | Excludes: thoracoscopic decortication of lung                                         |
| Thoracoscopic excision of lesion or tissue of lung            | 3220       | Thoracoscopic wedge resection                                                         |
| Partial excision of pituitary gland, transfrontal approach   | 0761       | Cryohypophysectomy, partial transfrontal approach, division of hypophyseal stalk      |
|                                                               |            | transfrontal approach, division of hypophyseal stalk transfrontal approach, excision   |
|                                                               |            | of lesion of pituitary (hypophysis) transfrontal approach, hypophysectomy subtotal     |
|                                                               |            | transfrontal approach, infundibulomegaly hypophyseal transfrontal approach            |
|                                                               |            | Excludes: biopsy of pituitary gland transfrontal approach                             |
| Partial excision of pineal gland                             | 0753       | Excludes: biopsy of pineal gland                                                     |
| Division of thyroid isthmus                                  | 0619       | Transection of thyroid isthmus                                                        |
| Unilateral adrenalectomy                                     | 0722       | Adrenalectomy NOS                                                                    |
|                                                               |            | Excludes: excision of remaining adrenal gland                                         |

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### Supplementary Table 1. Continued

| Surgical subcategory                                      | ICD-9 code | Surgical procedure(s)                                                                 |
|-----------------------------------------------------------|------------|---------------------------------------------------------------------------------------|
| Complete thyroidectomy                                     | 064        | Excludes: complete substernal thyroidectomy                                           |
| Open total intra-abdominal colectomy                      | 4582       | -                                                                                     |
| Open and other left hemicolectomy                         | 4575       | Excludes: proctosigmoidectomy, second stage Mikulicz operation                        |
| Exploratory laparotomy                                     | 5411       | Excludes: exploration incidental to intra-abdominal surgery                            |
| Other partial resection of small intestine                 | 4562       | Duodenectomy, ileectomy, jejunectomy                                                   |
|                                                           |            | Excludes: duodenectomy with synchronous pancreatotomy, resection of cecum and terminal ileum |
| Cholecystectomy                                            | 5122       | Excludes: laparoscopic cholecystectomy                                                 |
| Other removal or destruction of corneal lesion             | 1149       | Excision of cornea NOS                                                                |
|                                                           |            | Excludes: biopsy of cornea                                                            |
| Other extracapsular extraction of lens                     | 1359       | Exclude: extracapsular extraction of lens by temporal inferior route                   |
| Other repair of retinal detachment                         | 1459       | Exclude: repair of retinal detachment with diathermy, cryotherapy, xenon arc photocoagulation, laser photocoagulation, photoacogulation of unspecified type |
| Other operations on vitreous                               | 1479       | Exclude: open sky technique, removal of vitreous, anterior approach, aspiration of vitreous by posterior sclerotomy, mechanical vitrectomy by anterior/posterior approach, injection of vitreous substitute |
| Suture of corneal laceration                               | 1151       | -                                                                                    |
| Total splenectomy                                          | 415        | Splenectomy NOS                                                                       |
| Radical excision of peri-aortic lymph nodes                | 4052       | -                                                                                    |
| Biopsy of lymphatic structure                              | 4011       | -                                                                                    |
| Radical neck dissection, unilateral                        | 4041       | -                                                                                    |
| Excision of axillary lymph node                            | 4023       | -                                                                                    |
| Amputation above knee                                      | 8417       | Amputation of leg through femur, amputation of thigh, conversion of below-knee amputation into above-knee amputation, supracondylar above-knee amputation |
| Atlas-axis spinal fusion                                   | 8101       | Craniovascular fusion by (anterior, transoral, or posterior technique), C1-C2 fusion by (anterior, transoral, or posterior technique), occiput C2 fusion by (anterior, transoral, or posterior technique) |
| Other amputation below knee                                | 8415       | Amputation of leg through tibia and fibula NOS                                        |
| Partial hip replacement                                    | 8152       | Bipolar endoprosthesis                                                                |
| Open reduction of fracture with internal fixation; femur    | 7935       | Excludes: that for separation of epiphysis                                            |
| Nephroureterectomy                                         | 5551       | Nephroureterectomy with bladder cuff, total nephrectomy (unilateral) Excludes: removal of transplanted kidney |
| Percutaneous nephrostomy without fragmentation             | 5503       | Nephrostolithotomy (nephroscopic), percutaneous removal of kidney stone(s) by: (basket extraction, forceps extraction [nephroscopic]), pyelolithotomy (nephroscopic), with placement of catheter down ureter Excludes: percutaneous removal by fragmentation, repeat nephroscopic removal during current episode |
| Radical cystectomy                                          | 5771       | Pelvic exenteration in male, removal of bladder, prostate, seminal vesicles, and fat, removal of bladder, urethra, and fat in a female Excludes: that as part of pelvic exenteration in female |
| Other transurethral excision or destruction of lesion or tissue of bladder | 5749 | Endoscopic resection of bladder lesion Excludes: transurethral biopsy of bladder, transurethral fistulectomy |
| Control of (postoperative) hemorrhage of bladder           | 5793       | -                                                                                    |
| Other transurethral prostatectomy                          | 6029       | Excision of median bar by transurethral approach, transurethral electrovaporization of prostate, transurethral enucleative procedure, transurethral prostatectomy NOS, transurethral resection of prostate |
| Control of (postoperative) hemorrhage of prostate          | 6094       | Coagulation of prostatic bed, cystoscopy for control of prostatic hemorrhage           |
| Radical prostatectomy                                      | 605        | Prostatovesiculectomy, radical prostatectomy by any approach Excludes: cystoprostatectomy |
| Unilateral orchidectomy                                    | 623        | Orchidectomy (with epididymectomy) NOS                                                |
### Supplementary Table 1. Continued

| Surgical subcategory                                           | ICD-9 code | Surgical procedure(s)                                                                                         |
|---------------------------------------------------------------|------------|----------------------------------------------------------------------------------------------------------------|
| Removal of both testes at same operative episode              | 6241       | Bilateral orchidectomy NOS                                                                                     |
| Low cervical cesarean section                                 | 741        | Lower uterine segment cesarean section                                                                        |
| Other and unspecified total abdominal hysterectomy             | 6849       | -                                                                                                               |
| Other removal of both ovaries and tubes at same operative     | 6561       | Excludes: that by laparoscope                                                                                   |
| episode                                                        |            |                                                                                                               |
| Laparoscopic total abdominal hysterectomy                      | 6841       | Total laparoscopic hysterectomy                                                                                 |
| Classical cesarean section                                    | 740        | Transperitoneal classical cesarean section                                                                     |
| Fat graft of skin and subcutaneous tissue                     | 8687       | Replacement of subcutaneous tissue and fascia for (scalp, face, neck, chest, back, buttock, abdomen, perineum, pelvic region, arms, hands, legs, feet) with autologous tissue substitute percutaneous approach, extraction of subcutaneous tissue and fascia for (scalp, face, neck, chest, back, buttock, abdomen, perineum, pelvic region, arms, hands, legs, feet) percutaneous approach |
| Bilateral simple mastectomy                                    | 8542       | Bilateral complete mastectomy                                                                                  |
| Removal of implant of breast                                   | 8594       | -                                                                                                               |
| Other free skin graft to other sites                           | 8669       | Excludes: heterograft, homograft                                                                               |
| Homograft to skin                                              | 8666       | Graft to skin of amnionic membrane from donor skin from donor                                                  |
| Sphenoidectomy                                                | 2264       | -                                                                                                               |
| Incision of multiple nasal sinuses                            | 2253       | -                                                                                                               |
| Sphenoidotomy                                                 | 2252       | -                                                                                                               |
| Control of epistaxis by ligation of ethmoidal arteries         | 2104       | -                                                                                                               |
| Ethmoidectomy                                                 | 2263       | -                                                                                                               |

ICD-9, International Classification of Diseases, 9th revision; NOS, not otherwise specified.
Supplementary Table 2. 100 surgeries that were most frequently performed

| Procedure name                                                      | ICD-9 code | Procedure frequency | No. of stroke | Incidence of stroke (%) |
|---------------------------------------------------------------------|------------|---------------------|---------------|-------------------------|
| Low cervical cesarean section                                       | 741        | 516,134             | 41            | 0.01                    |
| Total knee replacement                                              | 8154       | 191,443             | 173           | 0.09                    |
| Percutaneous transluminal coronary angioplasty                      | 0066       | 165,698             | 761           | 0.46                    |
| Laparoscopic cholecystectomy                                        | 5123       | 141,814             | 117           | 0.08                    |
| Hemodialysis                                                        | 3995       | 115,663             | 454           | 0.39                    |
| Total hip replacement                                               | 8151       | 98,769              | 111           | 0.11                    |
| Laparoscopic appendectomy                                           | 4701       | 92,255              | 22            | 0.02                    |
| Other and unspecified total abdominal hysterectomy                   | 6849       | 691,39              | 27            | 0.04                    |
| Open reduction of fracture with internal fixation; femur            | 7935       | 51,207              | 275           | 0.54                    |
| Percutaneous abdominal drainage                                     | 5491       | 46,708              | 93            | 0.2                     |
| Episiotomy                                                          | 736        | 45,878              | *             | 0.01                    |
| Thoracentesis                                                       | 3491       | 45,733              | 175           | 0.38                    |
| Other cervical fusion of the anterior column, anterior technique    | 8102       | 41,651              | 45            | 0.11                    |
| Open reduction of fracture with internal fixation; tibia and fibula | 7936       | 41,571              | 42            | 0.1                     |
| Other exploration and decompression of spinal canal                 | 0309       | 37,827              | 77            | 0.2                     |
| Excision of intervertebral disc                                     | 8051       | 37,514              | 18            | 0.05                    |
| Partial hip replacement                                             | 8152       | 36,879              | 250           | 0.68                    |
| Other and unspecified vaginal hysterectomy                           | 6859       | 33,798              | *             | 0.02                    |
| Angioplasty of other non-coronary vessel(s)                         | 3950       | 32,919              | 157           | 0.48                    |
| Other appendectomy                                                  | 4709       | 32,117              | 13            | 0.04                    |
| Lumbar and lumbosacral fusion of the anterior column, posterior technique | 8108   | 31,922              | 53            | 0.17                    |
| Radical prostatectomy                                               | 605        | 27,682              | 12            | 0.04                    |
| Endarterectomy; other vessels of head and neck                      | 3812       | 27,172              | 433           | 1.59                    |
| Other transurethral prostatectomy                                   | 6029       | 25,617              | 33            | 0.13                    |
| Interruption of the vena cava                                       | 387        | 22,439              | 288           | 1.28                    |
| Closed reduction of fracture with internal fixation; femur          | 7915       | 22,214              | 114           | 0.51                    |
| Laparoscopically assisted vaginal hysterectomy                       | 6851       | 20,672              | *             | 0.01                    |
| Excision or destruction of other lesion or tissue of heart, endovascular approach | 3734   | 20,145              | 62            | 0.31                    |
| Open and other right hemicolecotomy                                 | 4573       | 20,075              | 117           | 0.58                    |
| Other partial resection of small intestine                          | 4562       | 19,867              | 121           | 0.61                    |
| Lumbar and lumbosacral fusion of the anterior column, anterior technique | 8106   | 18,861              | 23            | 0.12                    |
| Other lysis of peritoneal adhesions                                 | 5459       | 18,711              | 48            | 0.26                    |
| Open and other sigmoidectomy                                        | 4576       | 18,441              | 90            | 0.49                    |
| Cholecystectomy                                                     | 5122       | 17,557              | 57            | 0.32                    |
| Nephroureterectomy                                                  | 5551       | 16,516              | 45            | 0.27                    |
| Insertion of intercostal catheter for drainage                      | 3404       | 16,069              | 52            | 0.32                    |
| Open and other replacement of aortic valve with tissue graft        | 3521       | 15,928              | 416           | 2.61                    |
| Complete thyroidectomy                                              | 064        | 15,238              | *             | 0.04                    |
| Circumcision                                                        | 640        | 15,138              | *             | 0.01                    |
| Amputation of toe                                                   | 8411       | 15,130              | 29            | 0.19                    |
| (Aorto)coronary bypass of two coronary arteries                     | 3612       | 14,793              | 216           | 1.46                    |
| Other and unspecified subtotal abdominal hysterectomy                | 6839       | 14,602              | *             | 0.01                    |
| Other excision or destruction of lesion or tissue of brain          | 0159       | 14,476              | 468           | 3.23                    |
| Lumbar and lumbosacral fusion of the posterior column, posterior technique | 8107   | 14,067              | 29            | 0.21                    |
# Supplementary Table 2. Continued

| Procedure name                                                                 | ICD-9 code | Procedure frequency | No. of stroke | Incidence of stroke (%) |
|-------------------------------------------------------------------------------|------------|---------------------|---------------|-------------------------|
| Open reduction of fracture with internal fixation; radius and ulna            | 7932       | 13,718              | 10            | 0.07                    |
| (Aorto)coronary bypass of three coronary arteries                            | 3613       | 13,380              | 238           | 1.78                    |
| Other open incisional hernia repair with graft or prosthesis                 | 5361       | 13,063              | *             | 0.04                    |
| Laparoscopic total abdominal hysterectomy                                      | 6841       | 12,607              | *             | 0.03                    |
| Open reduction of fracture with internal fixation; humerus                    | 7931       | 12,565              | 10            | 0.08                    |
| Other (peripheral) vascular shunt or bypass                                   | 3929       | 12,302              | 57            | 0.46                    |
| Unilateral extended simple mastectomy                                          | 8543       | 12,087              | *             | 0.02                    |
| Arteriovenostomy for renal dialysis                                           | 3927       | 11,559              | 70            | 0.61                    |
| Transurethral removal of obstruction from ureter and renal pelvis             | 560        | 11,027              | 10            | 0.09                    |
| Incision of cerebral meninges                                                | 0131       | 10,929              | 357           | 3.27                    |
| Biopsy of lymphatic structure                                                | 4011       | 10,455              | 36            | 0.34                    |
| Internal fixation of bone without fracture reduction; femur                   | 7855       | 10,171              | 40            | 0.39                    |
| Other transurethral excision or destruction of lesion or tissue of bladder   | 5749       | 10,151              | 28            | 0.28                    |
| Laparoscopic right hemicolecotomy                                             | 1733       | 10,099              | 24            | 0.24                    |
| Percutaneous nephrostomy without fragmentation                                | 5503       | 9,998               | 41            | 0.41                    |
| Laparoscopic lysis of peritoneal adhesions                                    | 5451       | 9,655               | 11            | 0.11                    |
| Arthroplasty; other total shoulder replacement                                | 8180       | 9,130               | 11            | 0.12                    |
| Other amputation below knee                                                  | 8415       | 8,776               | 66            | 0.75                    |
| Unilateral thyroid lobectomy                                                  | 062        | 8,775               | *             | 0.0                     |
| Open and other replacement of aortic valve                                    | 3522       | 8,633               | 205           | 2.37                    |
| Open and other partial gastrectomy                                            | 4389       | 8,582               | *             | 0.08                    |
| Excision of axillary lymph node                                               | 4023       | 8,537               | *             | 0.02                    |
| Laparoscopic sigmoidectomy                                                    | 1736       | 8,432               | 12            | 0.14                    |
| Endovascular implantation of other graft in abdominal aorta                  | 3971       | 8,414               | 37            | 0.44                    |
| Thoracoscopic excision of lesion or tissue of lung                           | 3220       | 8,401               | 31            | 0.37                    |
| Revision of hip replacement, both acetabular and femoral components          | 0070       | 7,814               | 21            | 0.27                    |
| Excision of lesion of other soft tissue                                       | 8339       | 7,457               | 13            | 0.17                    |
| Other free skin graft to other sites                                          | 8669       | 7,308               | 15            | 0.21                    |
| Dorsal and dorsolumbar fusion of the posterior column, posterior technique   | 8105       | 7,204               | 18            | 0.25                    |
| Other unilateral salpingo-oophrectomy                                         | 6549       | 7,105               | *             | 0.01                    |
| Other kidney transplantation                                                  | 5569       | 7,093               | *             | 0.13                    |
| Revision of knee replacement, total (all components)                         | 0080       | 6,983               | *             | 0.11                    |
| (Aorto)coronary bypass of four or more coronary arteries                      | 3614       | 6,942               | 134           | 1.93                    |
| Implant of pulsation balloon                                                 | 3761       | 6,913               | 151           | 2.18                    |
| Open and other left hemicolecotomy                                            | 4575       | 6,733               | 56            | 0.83                    |
| Other removal of both ovaries and tubes at same operative episode             | 6561       | 6,644               | *             | 0.11                    |
| Other endovascular procedures on other vessels                                | 3979       | 6,577               | 76            | 1.16                    |
| Other lobectomy of lung                                                      | 3249       | 6,539               | 37            | 0.57                    |
| Other revision of vascular procedure                                         | 3949       | 6,309               | 35            | 0.55                    |
| Other repair of urinary stress incontinence                                   | 5979       | 6,230               | *             | 0.03                    |
| Arthroplasty; partial shoulder replacement                                    | 8181       | 6,110               | *             | 0.08                    |
| (Aorto)coronary bypass of one coronary artery                                 | 3611       | 6,108               | 79            | 1.29                    |
| Other cervical fusion of the posterior column, posterior technique            | 8103       | 5,539               | 20            | 0.36                    |
| Incision of perirectal tissue                                                | 4881       | 5,520               | *             | 0.04                    |
**Supplementary Table 2. Continued**

| Procedure name                                      | ICD-9 code | Procedure frequency | No. of stroke | Incidence of stroke (%) |
|-----------------------------------------------------|------------|---------------------|---------------|-------------------------|
| Other anterior resection of rectum                  | 4863       | 5,506               | 15            | 0.27                    |
| Other myectomy                                      | 8345       | 5,416               | 21            | 0.39                    |
| Unilateral simple mastectomy                        | 8541       | 5,286               | *             | 0.02                    |
| Single internal mammary-coronary artery bypass      | 3615       | 5,282               | 69            | 1.31                    |
| Attachment of pedicle or flap graft to other sites  | 8674       | 5,254               | *             | 0.11                    |
| Partial nephrectomy                                 | 554        | 5,180               | *             | 0.15                    |
| Other and unspecified hysterectomy                   | 689        | 5,129               | *             | 0.06                    |
| Amputation above knee                               | 8417       | 5,021               | 53            | 1.06                    |
| Percutaneous vertebral augmentation                  | 8166       | 4,749               | *             | 0.19                    |
| Laparoscopy                                         | 5421       | 4,724               | *             | 0.11                    |
| Amputation through foot                             | 8412       | 4,686               | 20            | 0.43                    |
| Open heart valvuloplasty of mitral valve without replacement | 3512       | 4,597               | 79            | 1.72                    |

ICD-9, International Classification of Diseases, 9th revision.

*Any results showing numbers less than 10 patients to maintain patient privacy.*
**Supplementary Table 3.** One hundred surgeries that had the highest number of strokes

| Procedure name                                                                 | ICD-9 code | No. of stroke | Procedure frequency | Incidence of stroke (%) |
|--------------------------------------------------------------------------------|------------|---------------|---------------------|-------------------------|
| Percutaneous transluminal coronary angioplasty                               | 0066       | 761           | 165,698             | 0.46                    |
| Other excision or destruction of lesion or tissue of brain                    | 0159       | 468           | 14,476              | 3.23                    |
| Hemodialysis                                                                  | 3995       | 454           | 115,663             | 0.39                    |
| Endarterectomy; other vessels of head and neck                                | 3812       | 433           | 27,172              | 1.59                    |
| Open and other replacement of aortic valve with tissue graft                  | 3521       | 416           | 15,928              | 2.61                    |
| Incision of cerebral meninges                                                 | 0131       | 357           | 10,929              | 3.27                    |
| Clipping of aneurysm                                                          | 3951       | 294           | 2,856               | 10.29                   |
| Interruption of the vena cava                                                 | 387        | 288           | 22,439              | 1.28                    |
| Open reduction of fracture with internal fixation; femur                      | 7935       | 275           | 51,207              | 0.54                    |
| Endovascular (total) embolization or occlusion of head and neck vessels      | 3972       | 252           | 4,174               | 6.4                     |
| Partial hip replacement                                                       | 8152       | 250           | 36,879              | 0.68                    |
| (Aorto)coronary bypass of three coronary arteries                            | 3613       | 238           | 13,380              | 1.78                    |
| (Aorto)coronary bypass of two coronary arteries                               | 3612       | 216           | 14,793              | 1.46                    |
| Open and other replacement of aortic valve                                   | 3522       | 205           | 8,633               | 2.37                    |
| Excision of lesion or tissue of cerebral meninges                            | 0151       | 193           | 4,549               | 4.24                    |
| Thoracentesis                                                                 | 3491       | 175           | 45,733              | 0.38                    |
| Thoracostomy                                                                 | 3481       | 173           | 191,443             | 0.09                    |
| Endovascular removal of obstruction from head and neck vessel(s)             | 3974       | 171           | 926                 | 18.47                   |
| Angioplasty of other non–coronary vessel(s)                                  | 3950       | 157           | 32,919              | 0.48                    |
| Implant of pulsation balloon                                                  | 3761       | 151           | 6,913               | 2.18                    |
| Other incision of brain                                                       | 0139       | 138           | 2,628               | 5.25                    |
| (Aorto)coronary bypass of four or more coronary arteries                     | 3614       | 134           | 6,942               | 1.93                    |
| Other partial resection of small intestine                                    | 4562       | 121           | 19,867              | 0.61                    |
| Laparoscopic cholecystectomy                                                  | 5123       | 117           | 141,814             | 0.08                    |
| Open and other right hemicolecotomy                                            | 4573       | 117           | 20,075              | 0.58                    |
| Closed reduction of fracture with internal fixation; femur                    | 7915       | 114           | 22,214              | 0.51                    |
| Total hip replacement                                                         | 8151       | 111           | 98,769              | 0.11                    |
| Percutaneous angioplasty of extracranial vessel(s)                           | 0061       | 110           | 4,312               | 2.55                    |
| Other craniotomy                                                              | 124        | 104           | 3,030               | 3.43                    |
| Resection of vessel with replacement; thoracic vessels                        | 3845       | 98            | 1,499               | 6.54                    |
| Open and other replacement of mitral valve with tissue graft                  | 3523       | 95            | 2,783               | 3.41                    |
| Percutaneous abdominal drainage                                               | 5491       | 93            | 46,708              | 0.2                     |
| Endovascular embolization or occlusion of vessel(s) of head or neck using     | 3975       | 91            | 1,166               | 7.8                     |
| bare coils                                                                    |            |               |                     |                         |
| Open and other sigmoidectomy                                                  | 4576       | 90            | 18,441              | 0.49                    |
| (Aorto)coronary bypass of one coronary artery                                | 3611       | 79            | 6,108               | 1.29                    |
| Open heart valvuloplasty of mitral valve without replacement                  | 3512       | 79            | 4,597               | 1.72                    |
| Other exploration and decompression of spinal canal                           | 0309       | 77            | 37,627              | 0.2                     |
| Other endovascular procedures on other vessels                               | 3979       | 76            | 6,577               | 1.16                    |
| Arteriovenostomy for renal dialysis                                           | 3927       | 70            | 11,559              | 0.61                    |
| Single internal mammary–coronary artery bypass                               | 3615       | 69            | 5,282               | 1.31                    |
| Other amputation below knee                                                   | 8415       | 66            | 8,776               | 0.75                    |
| Open and other replacement of mitral valve                                   | 3524       | 64            | 2,639               | 2.43                    |
### Supplementary Table 3. Continued

| Procedure name                                                                 | ICD-9 code | No. of stroke | Procedure frequency | Incidence of stroke (%) |
|--------------------------------------------------------------------------------|------------|---------------|---------------------|-------------------------|
| Excision or destruction of other lesion or tissue of heart, endovascular approach | 3734       | 62            | 20,145              | 0.31                    |
| Extracranial-intracranial vascular bypass                                        | 3928       | 60            | 434                 | 13.82                   |
| Ventricular shunt to abdominal cavity and organs                                  | 234        | 59            | 4,201               | 1.4                     |
| Cholecystectomy                                                                    | 5122       | 57            | 17,557              | 0.32                    |
| Other (peripheral) vascular shunt or bypass                                        | 3929       | 57            | 12,302              | 0.46                    |
| Open and other left hemicolectomy                                                  | 4575       | 56            | 6,733               | 0.83                    |
| Lumbar and lumbosacral fusion of the anterior column, posterior technique         | 8108       | 53            | 31,922              | 0.17                    |
| Amputation above knee                                                             | 8417       | 53            | 5,021               | 1.06                    |
| Insertion of intercostal catheter for drainage                                    | 3404       | 52            | 16,069              | 0.32                    |
| Other lysis of peritoneal adhesions                                               | 5459       | 48            | 18,711              | 0.26                    |
| Other craniectomy                                                                  | 0125       | 46            | 1,008               | 4.56                    |
| Other cervical fusion of the anterior column, anterior technique                  | 8102       | 45            | 41,651              | 0.11                    |
| Nephroureterectomy                                                                | 5551       | 45            | 16,516              | 0.27                    |
| Endovascular implantation of graft in thoracic aorta                              | 3973       | 45            | 1,216               | 3.7                     |
| Open reduction of fracture with internal fixation; tibia and fibula                | 7936       | 42            | 41,571              | 0.1                     |
| Resection of vessel with replacement; aorta, abdominal                              | 3844       | 42            | 2,570               | 1.63                    |
| Low cervical cesarean section                                                      | 741        | 41            | 516,134             | 0.01                    |
| Percutaneous nephrostomy without fragmentation                                     | 5503       | 41            | 9,998               | 0.41                    |
| Internal fixation of bone without fracture reduction; femur                       | 7855       | 40            | 10,171              | 0.39                    |
| Incision of vessel; lower limb arteries                                           | 3808       | 39            | 1,783               | 2.19                    |
| Endovascular implantation of other graft in abdominal aorta                       | 3971       | 37            | 8,414               | 0.44                    |
| Other lobectomy of lung                                                           | 3249       | 37            | 6,539               | 0.57                    |
| Biopsy of lymphatic structure                                                     | 4011       | 36            | 10,455              | 0.34                    |
| Other revision of vascular procedure                                              | 3949       | 35            | 6,309               | 0.55                    |
| Replacement of ventricular shunt                                                  | 0242       | 35            | 3,278               | 1.07                    |
| Extracorporeal membrane oxygenation                                               | 3965       | 34            | 389                 | 8.74                    |
| Other transurethral prostatectomy                                                 | 6029       | 33            | 25,617              | 0.13                    |
| Annuloplasty                                                                       | 3533       | 32            | 1,465               | 2.18                    |
| Thoracoscopic excision of lesion or tissue of lung                                 | 3220       | 31            | 8,401               | 0.37                    |
| Pericardiomy                                                                       | 3712       | 31            | 3,094               | 1                      |
| Other transplant of liver                                                          | 5059       | 31            | 2,095               | 1.48                    |
| Incision of vessel; upper limb vessels                                            | 3803       | 31            | 942                 | 3.29                    |
| Heart transplantation                                                              | 3751       | 31            | 882                 | 3.51                    |
| Open heart valvuloplasty of aortic valve without replacement                      | 3511       | 31            | 735                 | 4.22                    |
| Percutaneous angioplasty of intracranial vessel(s)                                 | 0062       | 31            | 359                 | 8.64                    |
| Partial excision of pituitary gland, transsphenoidal approach                     | 0762       | 30            | 3,337               | 0.9                     |
| Amputation of toe                                                                  | 8411       | 29            | 15,130              | 0.19                    |
| Lumbar and lumbosacral fusion of the posterior column, posterior technique         | 8107       | 29            | 14,067              | 0.21                    |
| Other transurethral excision or destruction of lesion or tissue of bladder        | 5749       | 28            | 10,151              | 0.28                    |
| Exploratory laparotomy                                                             | 5411       | 28            | 4,374               | 0.64                    |
| Aorta-iliac-femoral bypass                                                        | 3925       | 28            | 2,399               | 1.17                    |
| Excision or destruction of other lesion or tissue of heart, open approach          | 3733       | 28            | 1,529               | 1.83                    |

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### Supplementary Table 3. Continued

| Procedure name                                                                 | ICD-9 code | No. of stroke | Procedure frequency | Incidence of stroke (%) |
|-------------------------------------------------------------------------------|------------|---------------|---------------------|-------------------------|
| Insertion of implantable heart assist system                                 | 3766       | 27            | 474                 | 5.7                     |
| Partial excision of pituitary gland, transfrontal approach                   | 0761       | 25            | 246                 | 10.16                   |
| Laparoscopic right hemicolectomy                                             | 1733       | 24            | 10,009              | 0.24                    |
| Other repair of aneurysm                                                     | 3952       | 24            | 1,581               | 1.52                    |
| Lumbar and lumbosacral fusion of the anterior column, anterior technique     | 8106       | 23            | 18,861              | 0.12                    |
| Total splenectomy                                                            | 415        | 23            | 4,123               | 0.56                    |
| Percutaneous balloon valvuloplasty                                           | 3596       | 23            | 1,095               | 2.1                     |
| Lobectomy of brain                                                           | 0153       | 23            | 585                 | 3.93                    |
| Ventricular shunt to extracranial site NEC                                   | 239        | 23            | 407                 | 5.65                    |
| Laparoscopic appendectomy                                                     | 4701       | 22            | 92,255              | 0.02                    |
| Revision of hip replacement, both acetabular and femoral components          | 0070       | 21            | 7,814               | 0.27                    |
| Other myectomy                                                               | 8345       | 21            | 5,416               | 0.39                    |
| Revision of arteriovenous shunt for renal dialysis                           | 3942       | 21            | 4,469               | 0.47                    |
| Other cervical fusion of the posterior column, posterior technique           | 8103       | 20            | 5,539               | 0.36                    |
| Amputation through foot                                                      | 8412       | 20            | 4,686               | 0.43                    |

ICD-9, International Classification of Diseases, 9th revision; NEC, not otherwise specified.
## Supplementary Table 4. One hundred surgeries that had the highest incidence of perioperative stroke, with procedure frequency ≥10

| Procedure name                                                                 | ICD-9 code | Incidence of stroke (%) | Procedure frequency |
|--------------------------------------------------------------------------------|------------|-------------------------|---------------------|
| Implantation or insertion of biventricular external heart assist system         | 3760       | 20                      | 15                  |
| Endovascular removal of obstruction from head and neck vessel(s)                | 3974       | 18.47                   | 926                 |
| Incision of vessel; intracranial vessels                                       | 3801       | 18.18                   | 11                  |
| Other excision of vessel; intracranial vessels                                 | 3861       | 17.5                    | 40                  |
| Percutaneous insertion of intracranial vascular stent(s)                       | 0065       | 16.67                   | 12                  |
| Extracranial-intracranial vascular bypass                                       | 3928       | 13.82                   | 434                 |
| Lobotomy and tractotomy                                                        | 132        | 11.43                   | 35                  |
| Clipping of aneurysm                                                           | 3951       | 10.29                   | 2,856               |
| Partial excision of pituitary gland, transfrontal approach                     | 0761       | 10.16                   | 246                 |
| Other removal or destruction of corneal lesion                                 | 1149       | 9.9                     | 11                  |
| Extracorporeal membrane oxygenation                                            | 3965       | 8.74                    | 389                 |
| Percutaneous angioplasty of intracranial vessel(s)                             | 0062       | 8.64                    | 359                 |
| Incision of vessel; abdominal veins                                            | 3807       | 8                       | 25                  |
| Endovascular embolization or occlusion of vessel(s) of head or neck using bare coils | 3975   | 7.8                     | 1,166               |
| Partial excision of pituitary gland, unspecified approach                      | 0763       | 7.55                    | 53                  |
| Resection of vessel with anastomosis; intracranial vessels                     | 3831       | 7.14                    | 28                  |
| Other operations on pancreas                                                   | 5299       | 6.67                    | 15                  |
| Excision of uvula                                                              | 2772       | 6.67                    | 15                  |
| Insertion of temporary non-implantable extracorporeal circulatory assist device | 3762       | 6.6                     | 33                  |
| Resection of vessel with replacement; thoracic vessels                         | 3845       | 6.54                    | 1,499               |
| Endovascular (total) embolization or occlusion of head and neck vessels        | 3972       | 6.4                     | 4,174               |
| Adjunct vascular system; procedure on single vessel                            | 0040       | 6.25                    | 32                  |
| Insertion of percutaneous external heart assist device                         | 3764       | 6.25                    | 16                  |
| Incision of vessel; aorta                                                      | 3804       | 6.15                    | 65                  |
| Endovascular embolization or occlusion of vessel(s) of head or neck using bioactive coils | 3976 | 5.9                     | 305                 |
| Insertion of implantable heart assist system                                   | 3766       | 5.7                     | 474                 |
| Ventricular shunt to extracranial site NEC                                     | 0239       | 5.65                    | 407                 |
| Transapical replacement of aortic valve                                        | 3506       | 5.56                    | 18                  |
| Craniotomy and craniectomy; reopening of craniotomy site                      | 0123       | 5.49                    | 328                 |
| Excision, destruction, or exclusion of left atrial appendage                   | 3736       | 5.41                    | 37                  |
| Other incision of brain                                                        | 0139       | 5.25                    | 2,628               |
| Incision of vessel; other thoracic vessels                                     | 3805       | 4.9                     | 102                 |
| Total excision of pituitary gland, transfrontal approach                       | 0764       | 4.76                    | 21                  |
| Other craniectomy                                                             | 0125       | 4.56                    | 1,008               |
| Sphenoidectomy                                                                | 2264       | 4.37                    | 183                 |
| Other excision of vessel; other thoracic vessels                               | 3865       | 4.35                    | 23                  |
| Incision of multiple nasal sinuses                                             | 2253       | 4.35                    | 23                  |
| Excision of lesion or tissue of cerebral meninges                             | 0151       | 4.24                    | 4,549               |
| Open heart valvuloplasty of aortic valve without replacement                  | 3511       | 4.22                    | 735                 |
| Other extracapsular extraction of lens                                         | 1359       | 4.17                    | 24                  |
| Aorta-subclavian-carotid bypass                                                | 3922       | 4.12                    | 437                 |
| Lobectomy of brain                                                            | 0153       | 3.93                    | 585                 |
| Division of thyroid isthmus                                                    | 0691       | 3.77                    | 53                  |
| Cardiotomy                                                                    | 3711       | 3.74                    | 107                 |
Supplementary Table 4. Continued

| Procedure name                                                      | ICD-9 code | Incidence of stroke (%) | Procedure frequency |
|--------------------------------------------------------------------|------------|-------------------------|---------------------|
| Endovascular implantation of graft in thoracic aorta               | 3973       | 3.7                     | 1,216               |
| Placement of intracerebral catheter(s) via burr hole(s)            | 0128       | 3.63                    | 248                 |
| Heart transplantation                                              | 3751       | 3.51                    | 882                 |
| Other intra-abdominal vascular shunt or bypass                     | 3926       | 3.49                    | 172                 |
| Intraoperative cardiac pacemaker                                   | 3964       | 3.45                    | 29                  |
| Other craniotomy                                                   | 0124       | 3.43                    | 3,030               |
| Open and other replacement of mitral valve with tissue graft       | 3523       | 3.41                    | 2,783               |
| Sphenoidotomy                                                     | 2252       | 3.31                    | 121                 |
| Combined heart-lung transplantation                                | 336        | 3.3                     | 33                  |
| Incision of vessel; upper limb vessels                             | 3803       | 3.29                    | 942                 |
| Operations on carotid body, carotid sinus and other vascular bodies| 398        | 3.28                    | 122                 |
| Incision of cerebral meninges                                     | 0131       | 3.27                    | 10,929              |
| Other excision or destruction of lesion or tissue of brain         | 0159       | 3.23                    | 14,476              |
| Partial excision of pineal gland                                  | 0753       | 3.13                    | 64                  |
| Excision of accessory spleen                                      | 4193       | 3.13                    | 32                  |
| Endovascular replacement of aortic valve                          | 3505       | 2.94                    | 68                  |
| Total correction of transposition of great vessels, not elsewhere classified | 3584 | 2.94 | 34 |
| Incision of vessel; abdominal arteries                             | 3806       | 2.93                    | 273                 |
| Percutaneous insertion of carotid artery stent(s)                 | 0063       | 2.91                    | 103                 |
| Incision of vessel; other vessels of head and neck                 | 3802       | 2.91                    | 103                 |
| Other surgical occlusion of vessels; other vessels of head and neck | 3882       | 2.85                    | 281                 |
| Reopening of recent thoracotomy site                              | 3403       | 2.78                    | 144                 |
| Transluminal coronary atherectomy                                  | 1755       | 2.78                    | 36                  |
| Ligation of thoracic duct                                         | 4064       | 2.78                    | 36                  |
| Other repair of retinal detachment                                 | 1459       | 2.78                    | 36                  |
| Other surgical occlusion of vessels; intracranial vessels           | 3881       | 2.73                    | 110                 |
| Control of epistaxis by ligation of ethmoidal arteries             | 2104       | 2.7                     | 37                  |
| Repair of endocardial cushion defect with tissue graft             | 3563       | 2.63                    | 114                 |
| Total ostectomy of other facial bone with synchronous reconstruction| 7644       | 2.63                    | 38                  |
| Open ablation of renal lesion or tissue                            | 5532       | 2.63                    | 38                  |
| Open and other replacement of aortic valve with tissue graft       | 3521       | 2.61                    | 15,928              |
| Ventricular shunt to circulatory system                            | 232        | 2.6                     | 77                  |
| Percutaneous angioplasty of extracranial vessel(s)                | 0061       | 2.55                    | 4,312               |
| Trocar cholecystostomy                                            | 5102       | 2.53                    | 79                  |
| Soave submucosal resection of rectum                               | 4841       | 2.5                     | 40                  |
| Other operations on heart and pericardium                          | 3799       | 2.44                    | 41                  |
| Open and other replacement of mitral valve                         | 3524       | 2.43                    | 2,639               |
| Open and other replacement of pulmonary valve with tissue graft    | 3527       | 2.41                    | 166                 |
| Suture of peritoneum                                               | 5464       | 2.38                    | 84                  |
| Other dental restoration                                          | 2349       | 2.38                    | 42                  |
| Percutaneous mitral valve repair with implant                      | 3597       | 2.38                    | 42                  |
| Open and other replacement of aortic valve                         | 3522       | 2.37                    | 8,633               |
| Creation of conduit between right ventricle and pulmonary artery   | 3592       | 2.34                    | 128                 |
| Other and unspecified repair of atrial septal defect               | 3571       | 2.32                    | 518                 |
| Procedure name                                      | ICD-9 code | Incidence of stroke (%) | Procedure frequency |
|----------------------------------------------------|------------|-------------------------|---------------------|
| Aorta-renal bypass                                 | 3924       | 2.27                    | 44                  |
| Systemic to pulmonary artery shunt                 | 390        | 2.26                    | 177                 |
| Isolation of segment of small intestine             | 4551       | 2.25                    | 89                  |
| Closed (aspiration, percutaneous) biopsy of spleen | 4132       | 2.22                    | 45                  |
| Incision of vessel; lower limb arteries             | 3808       | 2.19                    | 1,783               |
| Implant of pulsation balloon                        | 3761       | 2.18                    | 6,913               |
| Annuloplasty                                        | 3533       | 2.18                    | 1,465               |
| Other excision of vessel; other vessels of head and neck | 3862  | 2.17                    | 46                  |
| Percutaneous balloon valvuloplasty                  | 3596       | 2.1                     | 1,095               |
| Incision of pituitary gland                         | 0772       | 2.08                    | 48                  |
| Fat graft of skin and subcutaneous tissue           | 8687       | 2.06                    | 97                  |
| Other division of bone; scapula, clavicle, and thorax (ribs and sternum) | 7731 | 2.04 | 49 |

ICD-9, International Classification of Diseases, 9th revision; NEC, not otherwise specified.
### Supplementary Table 5. ICD-9 codes used in identifying perioperative strokes

| Type of stroke          | Diagnostic ICD-9 code |
|-------------------------|-----------------------|
| Ischemic stroke         | 43301, 43311, 43321, 43331, 43381, 43391, 43401, 43411, 43491, 436 |
| Iatrogenic stroke       | 99702                 |
| Hemorrhagic stroke      | 430, 431, 4329        |

ICD-9, International Classification of Diseases, 9th revision.
### Supplementary Table 6. Full list of the systematic review

| Author                  | Year | Surgical procedure                     | Country      | Sample size | Stroke no. | Stroke incidence (%) |
|-------------------------|------|----------------------------------------|--------------|-------------|------------|-----------------------|
| Abbas et al.¹           | 2015 | CABG                                   | Pakistan     | 115         | 7          | 6.0                   |
| Aboyans et al.²         | 2008 | CABG                                   | France       | 1,022       | 37         | 3.60                  |
| Abraham et al.³         | 2002 | Abdominal aortic aneurysm repair       | United States| 116         | 1          | 0.90                  |
| AbuRahma⁴               | 1996 | CEA                                    | United States| 399         | 7          | 1.75                  |
| AbuRahma⁵               | 2004 | CEA                                    | United States| 357         | 10         | 2.80                  |
| AbuRahma et al.⁶        | 2008 | CAS                                    | United States| 100         | 2          | 2.0                   |
| AbuRahma et al.⁷        | 2010 | CEA                                    | United States| 200         | 2          | 1.0                   |
| AbuRahma et al.⁸        | 2010 | CEA and CAS                            | United States| 192         | 3          | 1.56                  |
| AbuRahma et al.⁹        | 2005 | CEA                                    | United States| 187         | 3          | 1.50                  |
| AbuRahma et al.¹⁰       | 2004 | CEA                                    | United States| 144         | 6          | 4.16                  |
| AbuRahma et al.¹¹       | 2007 | CEA                                    | United States| 200         | 6          | 3.0                   |
| AbuRahma et al.¹²       | 2002 | CEA                                    | United States| 200         | 7          | 3.50                  |
| Ackerstaff et al.¹³     | 1996 | CEA                                    | Netherlands  | 301         | 13         | 4.31                  |
| Ad et al.¹⁴             | 2011 | Cox-Maze procedure                     | United States| 124         | 1          | 0.8                   |
| Ad et al.¹⁵             | 2015 | Mitral valve surgery                   | United States| 387         | 3          | 0.76                  |
| Ad et al.¹⁶             | 2013 | Cox-Maze procedure                     | United States| 232         | 4          | 1.70                  |
| Ad et al.¹⁷             | 2017 | Cox-Maze procedure                     | United States| 709         | 4          | 0.56                  |
| Alcantara et al.¹⁸      | 2014 | CEA                                    | United States| 181         | 0          | 0                     |
| Alnasser et al.¹⁹       | 2017 | Transcatheter valve-in-valve implantation| Canada       | 162         | 2          | 1.23                  |
| Alonso-Coello et al.²⁰  | 2017 | Noncardiac surgeries                   | Multiple     | 8,346       | 60         | 0.72                  |
| Amato et al.²¹          | 2015 | CEA                                    | Italy        | 202         | 3          | 1.49                  |
| Ambrosi et al.²²        | 2016 | Musculoskeletal system or abdominal cavity surgeries | Moldova | 400         | 2          | 0.50                  |
| Ansel et al.²³          | 2010 | CAS                                    | United States| 257         | 5          | 1.90                  |
| Antunes et al.²⁴        | 1999 | CABG                                   | Portugal     | 107         | 3          | 2.8                   |
| Anzola et al.²⁵         | 2004 | Patent foramen ovale transcatheter closure| Italy       | 140         | 0          | 0                     |
| Amaoutougli et al.²⁶    | 2017 | Endovascular repair of abdominal aortic aneurysm | Multiple | 153         | 3          | 1.96                  |
| Aronsen²⁷               | 2009 | Cardiac surgery                        | United States| 1,405       | 20         | 1.42                  |
| Ascher et al.²⁸         | 2002 | CEA                                    | United States| 226         | 3          | 1.30                  |
| Ascione et al.²⁹        | 2004 | CABG                                   | United Kingdom| 686         | 5          | 0.73                  |
| Ascione et al.³⁰        | 2005 | CABG                                   | United Kingdom| 470         | 6          | 1.27                  |
| Ascione et al.³¹        | 2001 | CABG                                   | United Kingdom| 253         | 14         | 5.53                  |
| Ascione et al.³²        | 2002 | CABG                                   | United Kingdom| 4,077       | 45         | 1.10                  |
| Asimakopoulos et al.³³  | 2006 | Off pump CABG                          | United Kingdom| 251         | 2          | 0.80                  |
| Assadian et al.³⁴       | 2008 | CEA                                    | Austria      | 338         | 2          | 0.60                  |
| Assadian et al.³⁵       | 2007 | Carotid endarterectomy                 | Austria      | 363         | 5          | 1.38                  |
| Assadian et al.³⁶       | 2005 | CEA                                    | Austria      | 1,210       | 30         | 2.48                  |
| Asteriou et al.³⁷       | 2013 | CABG                                   | Greece       | 200         | 6          | 3.0                   |
| Avine et al.³⁸          | 2016 | TAVI                                   | France       | 368         | 14         | 3.80                  |
| Axira et al.³⁹          | 2002 | Peripheral angioplasty                 | United Kingdom| 1,377       | 6          | 0.44                  |
| Ayad⁴⁰                  | 2016 | Percutaneous coronary intervention     | Egypt        | 160         | 0          | 0                     |
| Baklanov et al.³¹       | 2006 | Coronary stenting                      | United States| 197         | 0          | 0                     |
| Ballotta et al.³²       | 2008 | CEA                                    | Italy        | 102         | 0          | 0                     |
| Ballotta et al.³³       | 2005 | Carotid coiling or kinking            | Italy        | 129         | 0          | 0                     |
| Ballotta et al.³⁴       | 2008 | CEA                                    | Italy        | 374         | 0          | 0                     |
| Author          | Year | Surgical procedure          | Country       | Sample size | Stroke no. | Stroke incidence (%) |
|-----------------|------|----------------------------|---------------|-------------|------------|----------------------|
| Ballotta et al. | 2004 | CEA                        | Italy         | 363         | 3          | 0.77                 |
| Ballotta et al. | 2003 | CEA                        | Italy         | 624         | 4          | 0.64                 |
| Ballotta et al. | 1999 | CEA                        | Italy         | 336         | 5          | 1.49                 |
| Ballotta et al. | 2001 | CEA                        | Italy         | 547         | 5          | 0.91                 |
| Ballotta et al. | 2014 | CEA                        | Italy         | 1,773       | 8          | 0.39                 |
| Banach et al.   | 2008 | Open heart surgery         | Poland        | 260         | 5          | 1.92                 |
| Baracchini et al.| 2012| eCEA                       | Italy         | 1,294       | 8          | 0.55                 |
| Ballotta et al. | 2014| CEA                        | Italy         | 1,773       | 8          | 0.39                 |
| Banach et al.   | 2015| CEA                        | Greece        | 337         | 0          | 0                    |
| Berens et al.   | 1992| Cardiac surgery            | United States | 1,087       | 22         | 2.02                 |
| Bernhardt et al.| 2015| Orthotopic liver transplant| Germany       | 134         | 1          | 0.70                 |
| Bertolini et al.| 1997| Myocardial revascularization| Italy        | 100         | 3          | 3.0                  |
| Berwanger et al.| 2016| Patients undergoing noncardiac surgeries in patients >45 with an overnight hospital stay | Multiple | 22,815 | 123 | 0.54 |
| Bilfinger et al.| 2000| Complex cardiac surgery    | Netherlands   | 1,075       | 31         | 2.88                 |
| Binder et al.   | 2015| TAVI                       | Switzerland   | 598         | 18         | 3.01                 |
| Birincioglu et al.| 1999| CABG                       | Turkey        | 722         | 13         | 1.80                 |
| Bishu et al.    | 2014| TAVR                       | United States | 277         | 2          | 0.72                 |
| Boehm et al.    | 2007| CABG                       | Germany       | 1,447       | 35         | 2.41                 |
| Börgermann et al.| 2013| Aortic valve replacement   | Germany       | 808         | 9          | 1.11                 |
| Borst et al.    | 2007| CEA                        | Netherlands   | 102         | 1          | 0.98                 |
| Borst et al.    | 2001| CEA                        | Netherlands   | 599         | 20         | 3.34                 |
| Bohrke et al.   | 2002| CEA                        | Austria       | 146         | 0          | 0                    |
| Braun et al.    | 2002| Transcatheter closure of patent foramen ovale | Germany | 276 | 0 | 0 |
| Breuer et al.   | 1983| CABG                       | United States | 421         | 22         | 5.22                 |
| Britenden et al.| 2000| CEA                        | Scotland      | 226         | 6          | 2.65                 |
| Brosig et al.   | 2013| lower limb revascularization| Romania     | 231         | 0          | 0                    |
| Brosig et al.   | 2013| Valve and/or coronary surgery| Czech Republic | 224         | 6          | 2.68                 |

Supplementary Table 6. Continued
### Supplementary Table 6. Continued

| Author                  | Year | Surgical procedure                                             | Country     | Sample size | Stroke no. | Stroke incidence (%) |
|-------------------------|------|---------------------------------------------------------------|-------------|-------------|-------------|----------------------|
| Bull et al.             | 1993 | CABG                                                          | Canada      | 245         | 5           | 2.04                 |
| Camous et al.           | 2014 | Pulmonary endartectomy                                        | France      | 207         | 3           | 1.45                 |
| Canaud et al.           | 2011 | Thoracic endovascular aortic repair                           | France      | 186         | 0           | 0                    |
| Cao et al.              | 1997 | CEA                                                           | Italy       | 469         | 15          | 2.91                 |
| Cao et al.              | 2000 | CEA                                                           | Italy       | 1,353       | 28          | 2.07                 |
| Carrier et al.          | 1997 | CABG                                                          | Canada      | 224         | 3           | 1.34                 |
| Castriota et al.        | 2008 | CAS with cardiopulmonary bypass                               | Italy       | 178         | 1           | 0.56                 |
| Chen et al.             | 2009 | Cardiac surgery with cardiopulmonary bypass                   | United States | 122      | 6           | 4.92                 |
| Cieri et al.            | 2008 | CAS                                                           | Italy       | 223         | 7           | 3.14                 |
| Cimochowski et al.      | 1997 | CABG                                                          | United States | 111      | 1           | 0.90                 |
| Cohen et al.            | 1998 | Valve and/or coronary surgery                                 | Canada      | 115         | 2           | 1.74                 |
| Cooper et al.           | 2013 | Anaortic off-pump CABG                                        | Australia   | 1,135       | 5           | 0.44                 |
| Coscas et al.           | 2010 | Open surgery for carotid stenosis                             | France      | 119         | 3           | 2.52                 |
| Crouch et al.           | 2015 | TAVI                                                          | Australia   | 114         | 3           | 2.63                 |
| Da Col et al.           | 2008 | Myocardial revascularization                                  | Italy       | 257         | 1           | 0.39                 |
| Da Silva et al.         | 1996 | CEA                                                           | United Kingdom | 108     | 4           | 3.70                 |
| Dake et al.             | 1998 | Endovascular repair of descending aortic aneurysm             | United States | 103      | 7           | 6.80                 |
| D'Angelo et al.         | 2001 | CEA                                                           | Italy       | 100         | 1           | 1                    |
| Darling et al.          | 1998 | CEA                                                           | United States | 470     | 5           | 1.06                 |
| Darwazah et al.         | 2010 | Myocardial revascularization                                  | Israel      | 350         | 0           | 0                    |
| M.Davies et al.         | 1993 | CEA                                                           | Australia   | 389         | 10          | 2.57                 |
| J.Davies et al.         | 2016 | SAVR or TAVR                                                  | United States | 573     | 11          | 1.92                 |
| De Santis et al.        | 2016 | Carotid surgery                                              | Italy       | 285         | 4           | 1.28                 |
| Debing et al.           | 2007 | CEA                                                           | Belgium     | 742         | 16          | 2.16                 |
| Debing et al.           | 2011 | CEA                                                           | Belgium     | 1,351       | 18          | 1.33                 |
| Dewick et al.           | 1997 | Open heart surgery                                           | Germany     | 101         | 14          | 13.86                |
| Deng et al.             | 2006 | Coronary revascularization                                   | China       | 179         | 1           | 0.60                 |
| Detter et al.           | 2002 | CABG                                                          | Germany     | 340         | 0           | 0                    |
| Devereaux et al.        | 2011 | Noncardiac surgeries in patients older than 45 yr             | Multiple    | 432         | 1           | 0.23                 |
| Di Biase et al.         | 2014 | Catheter ablation of atrial fibrillation with radiofrequency | Multiple    | 428         | 2           | 0.47                 |
| Didier et al.           | 2016 | CEA                                                           | United States | 25,626 | 86          | 0.34                 |
| Dinkel et al.           | 1992 | Carotid surgery                                              | Germany     | 125         | 0           | 0                    |
| Donaldson et al.        | 1993 | CEA                                                           | United States | 396     | 1           | 0.22                 |
| Dong et al.             | 2016 | CAS                                                           | China       | 154         | 9           | 5.84                 |
| Dong et al.             | 2017 | CAS                                                           | China       | 358         | 10          | 2.79                 |
| Dorigo et al.           | 2008 | CEA                                                           | Italy       | 3,324       | 19          | 0.47                 |
| Lam et al.              | 2007 | CAS                                                           | United States | 133     | 4           | 2.96                 |
| Larsen et al.           | 1988 | Noncardiac noncarotid surgeries                               | Denmark     | 2,463       | 6           | 0.20                 |
| Lee et al.              | 2013 | CABG                                                          | Multiple    | 541         | 18          | 3.33                 |
| Lennard et al.          | 1999 | CEA                                                           | United Kingdom | 252    | 4           | 1.59                 |
| Liapis et al.           | 2001 | CEA                                                           | Greece      | 308         | 7           | 2.07                 |
| Likosky et al.          | 2003 | CABG                                                          | United States | 11,825 | 177       | 0.99                 |
| Linden et al.           | 2007 | Coronary revascularization                                   | United States | 611     | 39          | 6.38                 |
| Loponen et al.          | 2003 | CABG                                                          | Finland     | 1,318       | 34          | 2.58                 |
Supplementary Table 6. Continued

| Author          | Year | Surgical procedure                                                                 | Country       | Sample size | Stroke no. | Stroke incidence (%) |
|-----------------|------|--------------------------------------------------------------------------------------|---------------|-------------|-------------|----------------------|
| Love et al.     | 2000 | CEA                                                                                  | Australia     | 443         | 8           | 1.80                 |
| Lübke et al.    | 2015 | CEA                                                                                  | Germany       | 1,880       | 28          | 1.49                 |
| MacDonald et al.| 1998 | CABG                                                                                 | Canada        | 100         | 6           | 6                    |
| Mandeville et al.| 2015 | Bifurcation resection and interposition of a polytetrafluoroethylene graft and CEA | Belgium       | 153         | 4           | 2.61                 |
| Mattos et al.   | 1992 | CEA                                                                                  | United States | 478         | 16          | 2.94                 |
| McCollum et al. | 1997 | Carotid surgery                                                                      | Multiple      | 709         | 15          | 2.11                 |
| McKhann et al.  | 2002 | CABG                                                                                 | United States | 2,711       | 72          | 2.66                 |
| Mitchell et al. | 1999 | Thoracic endovascular aortic repair                                                 | United States | 103         | 7           | 6.80                 |
| Mukerji et al.  | 2015 | CEA                                                                                  | United Kingdom| 728         | 17          | 2.33                 |
| Mullenix et al. | 2002 | CEA                                                                                  | United States | 267         | 6           | 2.24                 |
| Naylor et al.   | 2000 | CEA                                                                                  | United Kingdom| 500         | 4           | 0.80                 |
| Newman et al.   | 1996 | CABG                                                                                 | United States | 2,417       | 68          | 3.20                 |
| Nicholls et al. | 1985 | CEA                                                                                  | United States | 134         | 2           | 1.49                 |
| Nordanstig et al.| 2017 | CEA                                                                                  | Sweden        | 418         | 11          | 2.63                 |
| Ott et al.      | 1980 | CEA                                                                                  | United States | 240         | 4           | 1.29                 |
| Pell et al.     | 2004 | CEA                                                                                  | Scotland      | 877         | 22          | 2.51                 |
| Radu et al.     | 2013 | CAS                                                                                  | Germany       | 279         | 6           | 2.15                 |
| Rafiq et al.    | 2012 | CABG                                                                                 | Denmark       | 194         | 10          | 3.09                 |
| Roach et al.    | 1996 | CABG                                                                                 | United States | 2,108       | 63          | 2.99                 |
| Saini et al.    | 2017 | Minimally invasive surgical ablation for atrial fibrillation                        | United States | 109         | 1           | 0.92                 |
| Salazar et al.  | 2001 | Cardiac surgery                                                                      | United States | 5,971       | 214         | 3.58                 |
| Salem et al.    | 2011 | CEA                                                                                  | United Kingdom| 109         | 2           | 1.83                 |
| Samson et al.   | 1998 | CEA                                                                                  | United States | 654         | 11          | 1.68                 |
| Sandison et al. | 2000 | CEA                                                                                  | United Kingdom| 333         | 8           | 2.40                 |
| Santo et al.    | 2008 | Cardiac surgery                                                                      | Italy         | 925         | 9           | 0.97                 |
| Schmitz et al.  | 2003 | Cardiac surgery                                                                      | Germany       | 582         | 8           | 1.37                 |
| Schneider et al.| 1997 | CEA                                                                                  | United States | 186         | 7           | 3.48                 |
| Schoenefeld et al.| 2012 | CEA                                                                                  | Germany       | 540         | 19          | 3.52                 |
| Schoof et al.   | 2007 | CABG and/or valve surgery                                                            | Germany       | 2,797       | 67          | 2.40                 |
| Senay et al.    | 2011 | CABG                                                                                 | Turkey        | 3,248       | 32          | 0.99                 |
| Shapira et al.  | 2006 | CABG                                                                                 | United States | 2,450       | 28          | 1.14                 |
| Shaw et al.     | 1985 | CABG                                                                                 | United Kingdom| 312         | 15          | 4.81                 |
| Spes et al.     | 2007 | CAS                                                                                  | Germany       | 371         | 9           | 2.22                 |
| Stabile et al.  | 2010 | CAS                                                                                  | Italy         | 1,300       | 12          | 0.92                 |
| Subban et al.   | 2016 | TAVI                                                                                 | Australia     | 209         | 9           | 4.31                 |
| Suematsu et al. | 2000 | CABG                                                                                 | Japan         | 179         | 6           | 3.35                 |
| Takach et al.   | 1995 | CEA                                                                                  | United States | 248         | 2           | 0.75                 |
| Tatoulis et al. | 1999 | Coronary revascularization                                                           | Australia     | 3,220       | 26          | 0.81                 |
| Trehan et al.   | 1997 | CABG                                                                                 | India         | 792         | 6           | 0.76                 |
| Trehan et al.   | 2000 | CABG                                                                                 | India         | 3,660       | 35          | 0.96                 |
| Verhoeven et al.| 2005 | CEA                                                                                  | Netherlands   | 200         | 11          | 5.47                 |
| Veselka et al.  | 2009 | CAS                                                                                  | Czech Republic| 176         | 2           | 0.93                 |
| Walker et al.   | 1995 | CEA                                                                                  | Multiple      | 825         | 15          | 1.82                 |
| Walkes et al.   | 2002 | CABG                                                                                 | United States | 1,069       | 31          | 2.90                 |
| Author          | Year | Surgical procedure                  | Country     | Sample size | Stroke no. | Stroke incidence (%) |
|-----------------|------|-------------------------------------|-------------|-------------|------------|-----------------------|
| Weimar et al.   | 2012 | Cox-Maze procedure                  | United States | 212         | 2          | 0.94                  |
| Weinstein       | 2001 | CABG                                | United States | 2,217       | 51         | 2.30                  |
| Wenaweser et al.| 2011 | TAVI                                | Switzerland | 256         | 9          | 3.52                  |
| Burns et al.    | 1991 | CEA                                 | Australia   | 223         | 14         | 5.86                  |
| Wöhrl et al.    | 2016 | TAVI                                | Germany     | 235         | 5          | 2.13                  |
| Woeifie et al.  | 2002 | CEA                                 | Germany     | 111         | 3          | 2.70                  |
| Wolman et al.   | 1999 | Cardiac and coronary surgery        | United States | 273         | 21         | 7.69                  |
| Wong et al.     | 1999 | CEA                                 | Canada      | 184         | 8          | 4.35                  |
| Yadeau et al.   | 2011 | Ambulatory shoulder surgery         | United States | 1,169       | 0          | 0                    |
| Young et al.    | 1996 | CEA                                 | United States | 721         | 10         | 1.39                  |
| Zannetti et al. | 1999 | CEA                                 | Italy       | 1,305       | 13         | 1.00                  |
| Zarins et al.   | 2009 | CEA and CAS                         | United States | 397         | 12         | 3.02                  |
| Zhang et al.    | 2015 | Aortic valve replacement            | Germany     | 113         | 1          | 0.88                  |
| Ziemann et al.  | 2017 | Cardiac surgery                     | Germany     | 983         | 14         | 1.42                  |
| Zipfel et al.   | 2008 | Endovascular repair of abdominal aortic aneurysm | Germany | 126         | 4          | 3.17                  |

CABG, coronary artery bypass grafting; CEA, carotid endarterectomy; CAS, carotid artery stenting; eCEA, eversion carotid endarterectomy; TAVI, transcatheter aortic valve implantation; TAVR, transcatheter aortic valve replacement; SAVR, surgical aortic valve replacement.
Supplementary Figure 1. PRISMA 2009 flow diagram. Adapted from Moher et al. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.
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