Change in rates of primary atlantoaxial spinal fusion surgeries in the United States (1993–2015)

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OBJECTIVE The objective of this study was to investigate revision burden and associated demographic and economic data for atlantoaxial (AA) fusion procedures in the US.

METHODS Patient data from the National Inpatient Sample (NIS) database for primary AA fusion were obtained from 1993 to 2015, and for revision AA fusion from 2006 to 2014 using ICD-9 procedure codes. Data from 2006 to 2014 were used in comparisons between primary and revision surgeries. National procedure rates, hospital costs/charges, length of stay (LOS), routine discharge, and mortality rates were investigated.

RESULTS Between 1993 and 2014, 52,011 patients underwent primary AA fusion. Over this period, there was a 111% increase in annual number of primary surgeries performed. An estimated 1372 patients underwent revision AA fusion between 2006 and 2014, and over this time period there was a 6% decrease in the number of revisions performed annually. The 65–84 year-old age group increased as a proportion of primary AA fusions in the US from 35.9% of all AA fusions in 1997 to 44.2% in 2015, an increase of 23%. The mean hospital cost for primary AA surgery increased 32% between 2006 and 2015, while the mean cost for revision AA surgery increased by 35% between 2006 and 2014. Between 2006 and 2014, the mean hospital charge for primary AA surgery increased by 67%; the mean charge for revision surgery over that same period increased by 57%. Between 2006 and 2014, the mean age for primary AA fusions was 60 years, while the mean age for revision AA fusions was 52 years. The mean LOS for both procedures decreased over the study period, with primary AA fusion decreasing by 31% and revision AA fusion decreasing by 24%. Revision burden decreased by 21% between 2006 and 2014 (mean 4.9%, range 3.2%–6.4%). The inpatient mortality rate for primary AA surgery decreased from 5.3% in 1993 to 2.2% in 2014.

CONCLUSIONS The number of primary AA fusions between 2006 and 2014 increased 22%, while the number of revision procedures has decreased 6% over the same period. The revision burden decreased by 21%. The inpatient mortality rate decreased 62% (1993–2014) to 2.2%. The increased primary fusion rate, decreased revision burden, and decreased inpatient mortality determined in this study may suggest an improvement in the safety and success of primary AA fusion.

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KEYWORDS atlantoaxial spinal fusion; spine fusion; National Inpatient Sample; NIS; primary surgery; revision surgery

ABBREVIATIONS AA = atlantoaxial; ACDF = anterior cervical decompression and fusion; LOS = length of stay; NIS = National Inpatient Sample; PLIF = posterior lumbar interbody fusion; TLIF = transforaminal lumbar interbody fusion.

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ATLANTOAXIAL (AA) fusion is a surgical procedure performed to manage AA instability or arthrosis, the etiologies of which may be inflammatory, neoplastic, congenital, infectious, traumatic, or degenerative in nature.⁹ Patients with AA instability may present with neck pain, muscle spasm, difficulty flexing the cervical spine, facial paresthesias, headache, and pupil changes, among other symptoms.¹¹ Patients with severe AA degenerative joint disease may report disabling axial neck pain with neck rotation that is often strongly lateralizing in cases of unilateral degeneration. Due to the complex neurovascular anatomy of the craniocervical junction, this surgery should be performed by highly skilled surgeons to minimize risk.¹⁵ Further investigation of national trends is warranted in an effort to improve outcomes of this procedure.

Derman et al. found that from 1993 to 2012 in New York State, the proportion of AA fusion performed for rheumatic disease decreased, likely due to more widespread use of disease-modifying agents. As of 2012, fracture management became the most common indication for AA fusion at 44.1%.⁴ Derman et al. found that the incidence of AA fusion remained stable between 1997 and 2012 in New York State; Stein et al. found an increase in the incidence of primary fusion between 1993 and 2008.¹⁷ Together, these findings suggest that fusion revision rates may have decreased. However, there is a dearth of information regarding trends in AA fusion, whether primary or revision, regardless of indication. In the setting of national focus on value-based care, a better understanding of the demographic data of this patient population may result in improved health care utilization.

The purpose of this study was to determine epidemiological trends in both primary and revision AA fusion in order to evaluate the revision burden of AA fusion. Performing a longitudinal analysis allows for assessment of the yearly trends and economic impact of AA fusion. Identifying both hospital charge and cost data for AA fusion allows surgeons, policy makers, and hospital administrators to make informed decisions and improve cost-effective care. In this study, we utilized data from the National Inpatient Sample (NIS) database to compare two large national cohorts of patients: those who underwent primary AA fusion between 1993 and 2015, and those who underwent revision AA fusion between 2006 and 2014.

Methods

Data Source

Data were collected between 1993 and 2015 from the NIS database, which represents 44 states (US Department of Health and Human Services, Agency for Healthcare Research and Quality; <https://hcupnet.ahrq.gov>). The NIS database was developed for the Healthcare Cost and Utilization Project and constitutes the largest all-payer inpatient database in the US. The NIS database represents a 20% sample of discharges from US hospitals and was weighted to provide national estimates.

Patient Selection and Characteristics

Patient data from the NIS database for primary and

revision AA fusion surgeries from 1993 to 2015 were obtained based on the ICD-9 CM codes 81.01 and 81.31, respectively. ICD-9 CM code 81.01 is defined by the Centers for Disease Control and Prevention as atlas-axis spinal fusion, further defined as craniocervical, C1–2, or occiput–C2 fusion by anterior, transoral, or posterior technique. ICD-9 CM code 81.31 is defined as atlas-axis spinal fusion, inclusive of correction of pseudarthrosis of the spine. These codes do not differentiate between approach, as above, nor use of bone graft, internal fixation, or interbody device. Data for revision AA surgery was only available from 2006 to 2014; therefore, when comparing the two procedures, analysis was restricted to this time period. Data including national rates, hospital costs, hospital charges, length of stay (LOS), routine discharge, and mortality were investigated. Mortality data for primary AA fusion were available for 1993, 2003, 2004, 2008, 2009, 2010, and 2014, whereas for revision AA fusion these data are available only for 2008. Costs reflect the expenses incurred in the production of hospital services, while charges represent hospital billing. Cost data were only available from 2006 to 2015. Charge data for primary fusion were available from 1993 to 2014, but only between 2006 and 2014 for revision surgery. Revision burden is defined as the ratio of revision procedures to the sum of primary and revision procedures. All data reported had a relative standard error below 0.3.

The incidence of posterior lumbar interbody fusion (PLIF) and transforaminal lumbar interbody fusion (TLIF; ICD-9 CM code 81.08) and anterior cervical decompression and fusion (ACDF; ICD-9 CM code 81.02) were acquired from the NIS database. These data were available from 1997 to 2014. This was performed to compare the changes in incidence of these procedures to AA fusion.

The study was submitted to the IRB at the University of Pennsylvania, and determined to be exempt based on institutional guidelines.

Statistical Analysis

Cost and charge prices accounting for inflation were calculated using the Bureau of Labor Statistics Consumer Price Index calculator (<https://data.bls.gov/cgi-bin/cpicalc.pl>) adjusted to 2019. These values were compared to the nonadjusted cost and charge for both primary and revision AA fusion using the Student t-test.

Results

An estimated 52,011 patients received primary AA fusions between 1993 and 2014. The mean number of primary AA fusions was 2364 (range 1531–3837). Over this time period, there was a 111% increase in the total number of primary AA fusions performed. The number of AA fusions peaked in 2010 with 3837 having been performed that year. The incidence of primary AA fusion increased by 62.5% between 1993 and 2015, from 0.8 to 1.3 per 100,000 people. Linear projection suggests this value will increase to 1.7 by 2025 (Fig. 1). An estimated 1372 patients received revision AA fusions between 2006 and 2014. The mean annual number of revision surgeries was

FIG. 1. Incidence of primary AA fusion per 100,000 people, with linear projection to 2025 ($r^2 = 0.81$).

153 with a range of 83–191. Over this time period, there was a 6% total decrease in the number of revision AA fusions performed (Fig. 2).

In comparison to more common spinal fusion procedures such as PLIF, TLIF, and ACDF, AA fusion incidence has increased at a greater rate. From 1997 to 2014 the incidence of AA fusion has increased by 73%, in contrast to a 58% increase in PLIF/TLIF and a 40% increase in ACDF (Fig. 3).

The mean annual hospital cost for primary AA surgery increased 32% between 2006 and 2015 with an annual mean of \$35,086 and a range from \$29,583 to \$38,954. The mean cost for revision AA surgery increased by 35%. The annual mean cost for revision AA fusion was \$30,741 and the range was from \$20,850 to \$40,449. In both 2009 and 2013, the mean cost for revision and primary AA were nearly identical. Between 2006 and 2014, the mean hospital charge for primary AA surgery increased 67% (annual mean \$118,021, range \$83,431–\$139,674; Fig. 4). The mean charge for revision surgery increased by 57%

(mean \$101,760, range \$61,950–\$115,735). The trends in costs and charges for both primary and revision surgery were found to be independent of inflation over the same time period ($p < 0.05$).

From 2006 to 2014 the mean age for primary and revision AA fusion increased, for primary fusion by 14% (mean 60 years old, range of mean age per year 58–62 years old), and for revision fusion by 39% (mean 52 years old, range of mean age per year 44–60 years old). If stratified by age group, the 65–84-year-old age group has increased as a proportion of the total AA fusions in the US from 35.9% of all AA fusions in 1997 to 44.2% in 2015, a change of 23% (Fig. 5). This reflects a 64.1% increase in incidence in that age group from 2.72 (per 100,000) to 4.47 (Fig. 6).

Over the same period, the mean LOS for both procedures decreased, with primary AA fusion decreasing by 31% and revision AA fusion LOS decreasing by 24%. Patients undergoing revision AA fusion were more likely to be routinely discharged than those undergoing primary

FIG. 2. Total number of revision AA fusion surgeries (y-axis) between 2006 and 2014.

FIG. 3. Incidence of AA, PLIF/TLIF, and ACDF per 100,000 people between 1997 and 2014.

fusion, at rates of 65% and 50%, respectively. The mean inpatient mortality rate for primary cases for years available was 2.2% (range 1.9%–2.5%), while that of revision cases was 0.33%. A 21% downward trend of the revision burden was observed, with a mean of 4.9% over the study period (range 3.2%–6.4%; Fig. 7).

Discussion

Previous data have suggested that overall AA fusion rates have been stable, despite an increase in primary fusions, while details regarding other outcomes associated with AA fusion have been less clear.⁴ This study queried the NIS database for primary and revision AA fusion, and data regarding incidence, hospital costs, LOS, and mortality were analyzed. In the decade between 2006 and 2014, primary AA fusion in the US has increased by 22%, while revision rates have decreased by 6%. Over the

same period, the mean revision burden decreased by 21%. The decreasing revision burden suggests that while more primary AA fusions are being performed, fewer of them require revision.

The 65–84-year-old age group has grown as a proportion of AA fusions, which may indicate that the increase in overall incidence is at least in part due to an aging American population. The baby boomer generation started turning 65 in 2011, and by 2030 adults over 65 years old are anticipated to comprise 20% of the US population.⁶ It is possible that the increase in AA fusion, and the growth of the 65–84-year-old age group as a proportion of AA fusions, may in part be due to an aging American population with the usual age-related pathology. Trauma is the most common indication for AA fusion, and odontoid fractures occur in association with severe osteoporosis.^{4,13} Geriatric hip fractures, another type of fragility fracture, serve as a useful comparison. If increased rates of AA fusion are due

FIG. 4. Mean annual hospital charges are shown for primary AA fusion from 1994 to 2014, and for revision AA fusion from 2006 to 2014.

FIG. 5. Percentage of total AA fusions performed, stratified by age grouping, between 1997 and 2015.

to an increase in the geriatric patient population, analogous increases in hip fracture rates would be expected. However, the incidence of hip fractures has steadily declined since 2005.¹ Maturation of the baby boomer generation is unlikely to be the sole factor underlying these observed epidemiological changes in AA fusion.

In 2008, Smith et al. demonstrated that nonoperative treatment of odontoid fractures has a lower mortality rate and shorter LOS than operative treatment.¹⁶ NIS data suggest that primary AA fusion procedures are becoming safer, with a marked 62% decrease in mortality rate, from 5.3% in 1993 to 2.2% in 2014. This was associated with a decreased LOS for both revision and primary surgery. These improvements in mortality rate, decrease in revision burden, and an older patient demographic may

be explained by incremental improvements in AA fusion surgical technique, safety, postoperative care, and decision-making in the US.^{3,5,9,14} For example, the development of the utilization of C2 translaminar screws has outperformed other techniques and lowered the risk of neural and vascular injury.¹⁴ Although this technique is often used as a salvage method due to anatomical variation prohibiting pedicle or transarticular screw placement, some surgeons utilize this technique as a primary method of instrumented AA fusion given its lowered risk of neural and vascular injury.^{2,12} Further investigation is required to determine if improvements in surgical technique underlie the trend in decreased revision burden and mortality. Prospective randomized trials comparing complication rates between surgical techniques, including C1–2 transarticular

FIG. 6. Incidence of AA fusion per 100,000 people, organized by age group.

FIG. 7. Revision burden, defined as the ratio of revision procedures to the sum of primary and revision procedures, between 2006 and 2014.

ular screws, translaminar screws, C2 pedicle screws, or C2 pars screws would yield more detailed causative data. An example of a posterior technique using transarticular screws is demonstrated in Fig. 8.

Revision burden is one indicator of success of a surgical procedure, as it decreases with the rates of revision and may be a useful surrogate for future risk of revision. Prior to this study, the revision burden for AA fusion had not yet been published. During this study period, the overall revision burden of AA fusion decreased while the absolute number of primary AA fusions increased. There are several factors that may have influenced this trend. The decline in revision procedures has contributed to the decrease in revision burden, but an increased rate of primary procedures also decreases the revision burden. The improved safety profile of the procedure in the context of aforementioned developments in technique may underlie both an increase in the number of primary fusions and a decrease in that of revisions.^{3,9,14} In addition, a decrease in rates of AA fusion for rheumatic disease as reported by Derman et al. is likely a factor in decreased revision rates due to inherent challenges of treating this patient population.⁴ The increase in primary fusion warrants observation of the trend in revision rates over the coming years, as the decrease in burden is likely, at least in part, due to increased primary fusion, and advances made in the last decade may be better represented by future revision burden.

While AA fusion is becoming safer and more common, hospital costs have increased for primary (32%) and revision (35%) surgery. Mean hospital charges for these procedures have also increased, for primary AA surgery by 67% and for revision surgery by 57% (Fig. 4). Derman et al. found that the percentage of AA fusion indicated for traumatic fracture has been steadily increasing, from roughly 40% in 1997% to 44% in 2012.⁴ Guan et al. similarly found that between 2010 and 2015, 41% of AA fusions at a single institution were performed secondary to fracture.⁷ Patients admitted due to trauma have been found to incur higher hospital charges during their stay, likely due to inherently higher costs associated with emergency care.^{8,10}

This may account for the rise in hospital costs and charges seen in tandem with an increase in AA fusion rates and an increase in those procedures indicated for trauma. While these are possible suggestions to explain the rise in costs and charges, further economic investigation is needed to identify the strongest drivers of the increase in cost. Specifically investigating the contribution margins of the supplies, implants, facility fees, and personnel involved in the surgery may provide clarity on the main factors associated with the increase in costs.

The current study, a longitudinal analysis of an administrative inpatient database, was not designed to determine the cause of the observed trends. Prospective randomized trials are necessary to investigate the long-term outcomes of AA fusion and understand what drives these observed trends. However, given the expense and time associated with such a study, our retrospective analysis is a useful indicator of the increase in incidence and cost of this procedure. These trends can guide future focused research to allow more precise investigation to improve the efficacy, efficiency, and accessibility of AA fusion throughout the US.

Many of the limitations of this study are intrinsic to a large patient database such as the NIS, which is an administrative database. This database does not include physician-based fees or any factors following discharge. The surgeries were performed by a large variety of surgeons, allowing for differences in surgical technique and the possibility of indication bias. Furthermore, inaccuracies of ICD-9 CM billing codes, errors transferring data from hospital records to administrative records, underreporting of procedures, or exclusion of missing cases in the NIS database are all potential sources of error.

Conclusions

The incidence of AA fusion in the 65–84-year-old age group increased 64.1%, from 2.72 to 4.47 (per 100,000 people). The total number of primary AA fusions has increased 22%, while the number of revision procedures has

FIG. 8. Lateral cervical spine radiograph of patient status after posterior occipital–C2 transarticular fixation of a comminuted C1 fracture.

decreased 6% over the same 9-year period throughout the US. Between 2006 and 2015 the cost for primary AA fusion increased by 32% while the charge increased by 67%. This is in contrast to the mean LOS, which decreased for both primary AA fusion (31%) and revision AA fusion (24%). The revision burden decreased by 21% between 2006 and 2014. The inpatient mortality rate decreased 62% (1993–2014) to 2.2%. The increased primary fusion rate, decreased LOS, decreased revision burden, and decreased inpatient mortality rate determined in this study may suggest an improvement in the safety and success of primary AA fusion throughout the US.

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Disclosures

Dr. Pugely reports being a consultant for Globus Medical and Medtronic. Dr. Ludwig reports support of non-study-related clinical or research effort from AOSpine, PACIRA Pharmaceuticals, an AOA Omega grant, and Thieme; ownership in the Maryland Development Corporation; being a consultant for DePuy Synthes, K2M, and Globus Medical; direct stock ownership in Innovative Surgical Design and Advance Spinal Intellectual Property; being a board member for Globus Medical, the American Board of Orthopaedic Surgery, the American Orthopaedic Association, the Cervical Spine Research Society, and the Society for Minimally Invasive Spine Surgery; and serving on the governing board of the *Journal of Spinal Disorders and Techniques*, *The Spine Journal*, and *Contemporary Spine Surgery*. Dr. Saifi reports direct stock ownership in Vertera/NuVasive.

Author Contributions

Conception and design: Saifi, Lombardi, Milby, Pugely, Ozturk, Ludwig. Acquisition of data: Beschloss, Cazzulino. Analysis and interpretation of data: Hendow, Beschloss, Cazzulino, Louie. Drafting the article: Saifi, Hendow, Beschloss, Cazzulino. Critically revising the article: Saifi, Hendow, Beschloss, Cazzulino, Lombardi, Louie, Milby, Ozturk, Ludwig. Reviewed submitted version of manuscript: Saifi, Hendow, Beschloss, Cazzulino, Lombardi, Louie, Milby, Pugely. Approved the final version of the manuscript on behalf of all authors: Saifi. Administrative/technical/material support: Beschloss. Study supervision: Saifi, Hendow, Lombardi, Louie, Milby, Pugely, Ludwig.

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