Original Article

Cervical fusion for degenerative disease: A comprehensive cost analysis of hospital complications in the United States from 2002 to 2014

ABSTRACT

Purpose: Recent data suggest great variability in costs for surgical hospitalization for spinal surgery. However, the magnitude of expenditures attributable to complications is unknown. The purpose of this study is to describe cost of care associated with surgical and medical complications after cervical spine surgery.

Materials and Methods: A retrospective cohort study utilizing the National Inpatient Sample years 2002–2014 was conducted. A weighted sample of 901,508 adults undergoing elective cervical fusion for degenerative indications was extracted using diagnostic and procedure codes. Twelve categories of major complications were identified, and patient/hospital variables were evaluated as predictors of the overall reimbursed cost using multivariate regression. Mean differences (B) and 95% confidence intervals were reported.

Results: The mean age was 52.2 ± 11.4 years, with 5.2% of patients experiencing a complication. Mean overall increase in inflation-adjusted cost associated with complication was $16,435 ± 10,358, varying significantly by type of complication, surgical approach, and number of levels fused. The most common complications and their attributed costs were dysphagia (1.6%, B = $2624 [2476–2771], $P < 0.001$), pulmonary complications (1.0%, B = $9334 [9110–9558], $P < 0.001$), and device-related complications (0.9%, B = $3125 [2927–3324], $P < 0.001$). The costliest complications were infection (0.1%, B = $25359 [24723–25994], $P < 0.001$), thromboembolism (0.1%, B = $17480 [16808–18153], $P < 0.001$), and neurological complications (0.2%, B = $10098 [9629–10567], $P < 0.001$).

Conclusions: Although complications are rare after elective cervical fusion, they are associated with dramatically increase costs of care as high as $25,359 in the setting of postoperative infection. Improved understanding of the economic magnitude of complications may help guide efforts in reducing health care spending and improving perioperative care.

Keywords: Cervical fusion, degenerative spine disease, health economics, inpatient complications, reimbursement

INTRODUCTION

Spine surgery to treat degenerative diseases in older patients and its associated costs has increased over the past two decades in the United States (US). Within a progressively aging population, analyses of trends have revealed a rise in the number of cervical procedures, an increase in costs from $12,933 in 2002 to $19,130 in 2010, comparatively shorter hospital stays, and low mortality.[1-3] Reasons for increasing costs include additional medical charges to manage older, more comorbid patients, regional variability in service delivery, and the impact of specialized instrumentation and advanced techniques in spinal fusion.[1,4] Evidence-based

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spine surgery, especially in an expensive health-care climate, dictates the need to improve the characterization of major perioperative events that contribute to morbidity and growing health-care expenditures.

Anterior cervical fusion (ACF) remains the most frequently used approach taken for cervical interbody fusion; however, in patients with severe stenosis and multilevel involvement, outcomes compared to posterior cervical fusion (PCF) are equivalent.[5] The surgical strategy relies on individual pathology and surgeon preference, and risks of complications exist for each approach.[6,7] Procedural risks to ACF include retraction-related injury to the hypoglossal and recurrent laryngeal nerves, esophagus, trachea, and nearby vascular structures.[8,9] PCF is associated with increased spinal cord, nerve root, or vascular injury.[10,11]

While cost trends of cervical fusion by patient, hospital, and regional variability have been previously reported,[1,2,4] an in-depth economic analysis of the costs associated with complications lacks in the literature. In a shifting climate of health-care economics, accurately assessing savings achieved in reducing complications have become increasingly necessary. The goal of this study is to describe the incidence of inpatient complications and identify the costliest complications after cervical spinal fusion.

MATERIALS AND METHODS

Data source

We extracted data from the National Inpatient Sample (NIS) years 2002–2014, which is sponsored and maintained by the Agency for Healthcare Research and Quality (AHRQ). Data use agreements were completed, and all AHRQ guidelines were followed. The NIS is the largest all-payer inpatient database in the US containing approximately seven million hospital discharges each year, which provides a stratified sample of 20% of all hospitals to represent 95% of the national population. Each case includes the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis and procedure codes. All patients' data are de-identified, and the Institutional Review Board approval was not required. The statement of Human and Animal Rights is not applicable to our study.

Inclusion and exclusion criteria

We queried for all patients at least 18 years old undergoing elective cervical fusion for spine degeneration [Supplementary Table 1]. Procedures are subcategorized by the number of levels fused (1–2 levels, 3–7 levels, and ≥8 levels) and by surgical approach (anterior, posterior, and combined). We excluded patients with the following diagnoses: all neoplasms associated with the spinal cord, spinal meninges, or nerve sheaths; intraspinal abscess; osteomyelitis; and spinal fractures.

Patient, hospital characteristics, and cost

Patient demographics and clinical variables include age, sex (male and female), race (Caucasian, African–American, Hispanic, and other), insurance (Medicare, Medicaid, private, and other), severity of illness (minor, moderate, and major/extreme), and mortality risk (minor, moderate, and major/extreme) as determined by All Patient Refined Disease-Related Group. Hospital variables include US region (Northeast, Midwest, South, and West), location/teaching status (rural, urban nonteaching, and urban teaching), and bed size (small, medium, and large).

Complications and cost

Inpatient complications were extracted using ICD-9-CM diagnosis codes and comprised the following: neurological, pulmonary, cardiac, renal/urinary, gastrointestinal, dysphagia, thromboembolism, accidental puncture/laceration, hematoma/vascular/seroma, anemia from blood loss, infection, and device/graft/implant/other [Supplementary Table 1]. We dichotomized patients into with and without complications. Cost was calculated from the hospital charge and the year-specific, hospital-specific cost-to-charge ratio provided by AHRQ (charge × [cost/charge ratio]). Inflation was adjusted to 2014 US dollar values.

Statistical analysis

Descriptive variables are presented using proportions for categorical variables and means and standard errors for continuous variables. National estimates were calculated using the weighted discharges supplied by AHRQ. Analyses of variance and multivariable linear regression analyses of the weighted sample were performed evaluating for predictors of the total estimated cost. Multivariable regression adjusted for the demographic and clinical variables. Mean differences (B) and 95% confidence intervals were reported. A statistical significance was assessed at $P = 0.001$. No data were reported for any groups with <10 patients. All data extraction, aggregation, and statistical analyses were executed using the Statistical Package for the Social Sciences, version 25 (IBM Corporation, Chicago, IL, USA).

RESULTS

Patient characteristics

A weighted sample of 901,508 adults was identified between 2002 and 2014. Patients were 52.2 ± 11.4 years old, 54.3% of females, 84.3% Caucasian, and 57.8% privately insured. Mean hospitalization was 1.6 ± 1.7 days with an overall

Table 1: Patient and hospital characteristics

Variable	Number of weighted cases (%)
Age, years (mean±SD)	52.2±11.4
Gender	
Male	412,309 (45.7)
Female	489,199 (54.3)
Race	
Caucasian	759,534 (84.3)
African American	65,400 (7.3)
Hispanic	43,022 (4.8)
Other	33,552 (3.7)
Insurance	
Medicare	208,410 (23.1)
Medicaid	47,677 (5.3)
Private	520,781 (57.8)
Other	124,640 (13.8)
Severity of disease	
Minor loss of function	719,208 (79.8)
Moderate loss of function	165,508 (18.4)
Major and extreme loss of function	16,792 (1.8)
Risk of mortality	
Minor likelihood	852,886 (94.6)
Moderate likelihood	40,886 (4.5)
Major and extreme likelihood	7736 (0.9)
Hospitalization length, days (mean±SD)	1.6±1.7
Surgical technique	
Anterior	847,830 (94.0)
Posterior	44,201 (4.9)
Combined approach	9477 (1.1)
Number of fusion levels	
1-2 levels	676,322 (75.0)
3-7 levels	111,698 (12.4)
≥8 levels	730 (0.1)
Complications	
None	854,220 (94.8)
≥1	47,288 (5.2)
Death during hospitalization	453 (<0.1)
Bed size	
Small	141,808 (15.7)
Medium	213,752 (23.7)
Large	545,948 (60.6)
Type of medical center	
Rural	38,355 (4.3)
Urban nonteaching	426,911 (47.4)
Urban teaching	436,242 (48.4)
Geographic region	
Northeast	165,020 (18.3)
Midwest	134,367 (14.9)
South	435,473 (48.3)
West	166,647 (18.5)
Total cost, $ (mean±SD)	16,435±10,358

SD - Standard deviation; $ - U.S. dollar

cost of $16435 ± 10358 per hospital admission [Table 1]. Most patients had minor loss of function (79.8%) and minor mortality risk (94.6%). ACF was most frequently utilized (94.0%), and 1–2 levels' fusions comprised 75.0% of patients. Supplementary Table 2 shows univariate analysis of patient variables and overall cost.

Multivariate linear regression indicated that age per year increment (B = $39 [37, 41], $P < 0.001$) and female patients (B = −$246 [−283, −208], $P < 0.001$) associated with decreased cost. Relative to Medicare, hospitals received more reimbursements for Medicaid (B = $722 [626, 817], $P < 0.001$), private (B = $550 [496, 603], $P < 0.001$), and other insurance (B = $811 [741, 882], $P < 0.001$). PCF (B = $7043 [6953, 7133], $P < 0.001$) and combined (B = $21261 [21,077, 21,445], $P < 0.001$) approach had higher cost relative to ACF. Three-to-seven levels' fusions (B = $6052 [5994, 6110], $P < 0.001$) and 8 levels' fusions (B = $17645 [17,007, 18,284], $P < 0.001$) were more expensive.

Hospital characteristics

Supplementary Table 2 shows the univariate analysis of hospital characteristics. Most procedures were done in hospitals with large bed size (60.6%), urban nonteaching hospitals (47.4%), and the South (48.3%). Multivariate analysis showed decreased cost in urban teaching hospitals (B = -$3951 [−4045, −3857], $P < 0.001$) and urban nonteaching hospitals (B = −$4152 [−4246,−4058], $P < 0.001$) compared to rural hospitals. Medium (B = −$1378 [−1438, −1317], $P < 0.001$]) and large (B = −$1796 [−1848 to − 1743], $P < 0.001$) hospitals had lower inpatient costs. Surgeries in the Midwest (B = $1484 [1419, 1549], $P < 0.001$), South (B = $1208 [1155, 1261], and West (B = $6525 [6461, 6588], $P < 0.001$) had higher costs.

Complications

Table 2 shows the incidences and univariate analyses. Dysphagia (1.6%) was the most common complication, followed by pulmonary (1.0%), device related (0.9%), anemia from blood loss (0.8%), renal/urinary (0.4%), hematoma/vascular/seroma (0.4%), cardiac (0.3%), gastrointestinal (0.2%), neurological (0.2%), accidental puncture/laceration (0.2%), thromboembolism (0.1%), and infection (0.1%). A total of 42 (<0.1%) inpatient deaths occurred. In patients who died, complication incidences were pulmonary (65.2%), cardiac (25.7%), renal/urinary (15.7%), neurological (14.9%), infection (13.9%), hematoma/vascular/seroma (10.6%), thromboembolism (9.6%), anemia (4.8%), and dysphagia (2.7%) [Table 2].

Table 3 shows multivariate regression of cost of care for each complication. Infection associated with highest increase in cost (B = $25359 [24,723, 25,994], $P < 0.001$), followed by thromboembolism (B = $17480 [16,808, 18,153], $P < 0.001$),

Table 2: Univariate analysis of cost for complications

Complications	Number of weighted cases (%)	Mean cost, $ with complication (SE)	Mean cost, $ without complication (SE)	Significant (*P*)
Dysphagia	14,503 (1.6)	23,072 (149)	16,322 (11)	<0.001
Pulmonary	8306 (1.0)	40,535 (398)	16,194 (10)	<0.001
Device/graft/implant/other	7481 (0.9)	25,189 (234)	16,356 (11)	<0.001
Anemia due to blood loss	6666 (0.8)	31,111 (298)	16,317 (11)	<0.001
Renal/urinary	2378 (0.4)	27,329 (542)	16,387 (11)	<0.001
Device/graft/implant/other	3586 (0.4)	30,082 (366)	16,376 (11)	<0.001
Cardiac	2502 (0.3)	31,999 (605)	16,388 (11)	<0.001
Gastrointestinal	1427 (0.2)	22,325 (462)	16,424 (11)	<0.001
Neurological	1320 (0.2)	35,604 (860)	16,404 (11)	<0.001
Accidental puncture/laceration	1684 (0.2)	25,252 (501)	16,417 (11)	<0.001
Thromboembolism	651 (0.1)	50,775 (1784)	16,048 (11)	<0.001
Infection	743 (0.1)	64,672 (1865)	16,392 (11)	<0.001
Death	422 (< 0.1)	45,688 (2130)	16,420 (11)	<0.001
Pulmonary	295 (65.2)	49,345 (2929)	21,719 (1845)	<0.001
Cardiac	111 (25.7)	37,697 (2286)	48,572 (2763)	0.024
Renal/urinary	71 (15.7.)	90,513 (9538)	36,646 (1229)	<0.001
Neurological	67 (14.9)	41,816 (2097)	46,311 (2450)	0.467
Infection	63 (13.9)	104,302 (10,737)	36,519 (1260)	<0.001
Hematoma/vascular/seroma	48 (10.6)	35,967 (1981)	46,801 (2357)	0.123
Thromboembolism	43 (9.6)	59,212 (9863)	44,314 (2216)	0.043
Anemia due to blood loss	22 (4.8)	55,852 (13,489)	45,314 (2204)	0.361
Dysphagia	12 (2.7)	29,011*	45,906 (2157)	0.372
Gastrointestinal	0	-	-	-
Accidental puncture/laceration	0	-	-	-
Device/graft/implant/other	0	-	-	-

Patients who experienced different categories of complications and died inhospital are entered as rows for each complication under the heading "Death". *Nonweighted cell count of 1. SE - Standard error

neurological (B = $10,098 [9629, 10567], $P < 0.001$), pulmonary (B = $9334 [9110, 9558], $P < 0.001$), cardiac (B = $5159 [4813, 5505], $P < 0.001$], hematoma/vascular/seroma (B = $5744 [5455, 6032], $P < 0.001$), anemia (B = $3874, [3660, 4088], $P < 0.001$), puncture/laceration (B = $3918 [3504, 4332], $P < 0.001$), device related (B = $3125 [2927, 3324], $P < 0.001$), dysphagia (B = $2624 [2476, 2771], $P < 0.001$), gastrointestinal (B = $1940 [1490, 2389], $P < 0.001$), and renal/urinary (B = $1920 [1634, 2206], $P < 0.001$).

DISCUSSION

In a weighted national sample of elective cervical fusion patients, we show that inhospital costs associated not only with the presence of complications but also that complication-associated costs vary greatly by the specific types of complication. Previous investigations have discussed general cost and procedure volume trends in the past two decades;[1-4] however, the absence of cost analysis controlling for complications has precluded the potential to understand the drivers of variation in spending. Findings from the present study may serve as evidence to assist with clinical strategies to provide cost-effective surgical care and expedite recovery.

Trends in care, outcomes, and cost

The overall cost of treatment and hospitalization was $16435 ± 10358. Our inflation-adjusted cost analysis demonstrates that spending increased 37.5%, from $13,545 to $18,626 between 2002 and 2011. This is consistent with previous results as well as with the trends in other spine surgeries.[1,3,4] Notably, cost declined 13.7% to $16,080 between 2012 and 2014 [Figure 1], which may parallel the shifts in health-care delivery in this period. National reforms under the Affordable Care Act beginning in 2010 steered away from volume-based, fee-for-service reimbursement, toward bundled-payment and performance-linked initiatives.[12] We show that overall charges have increased at a greater rate than cost [Figure 1]. When estimating health-care costs, the distinction between charge versus cost should not be overlooked. We see that Medicare status associated with lower reimbursement, and thus, the impact of payer status on health-care economics should be closely monitored in a progressively older patient population.

Health-care costs increase with disease severity and mortality risk, likely from more intensive postoperative care acuity. For patients who need extensive stabilization, 3–7 levels' fusions increase costs by $6052 and ≥8 levels'

Table 3: Multivariate regression of overall hospital cost

	B	SE	95% CI	Significant (*P*)
Complication (vs. no complication)				
Infection	25,359	324	24,723-25,994	<0.001
Thromboembolism	17,480	343	16,808-18,153	<0.001
Neurological	10,098	239	9629-10,567	<0.001
Pulmonary	9334	114	9110-9558	<0.001
Cardiac	5159	177	4813-5505	<0.001
Hematoma/vascular injury/seroma	5744	147	5455-6032	<0.001
Anemia due to blood loss	3874	109	3660-4088	<0.001
Accidental puncture, laceration	3918	211	3504-4332	<0.001
Device/graft/implant/other	3125	101	2927-3324	<0.001
Dysphagia	2624	75	2476-2771	<0.001
Gastrointestinal	1940	230	1490-2389	<0.001
Renal/urinary	1920	146	1634-2206	<0.001
Patient and hospital characteristics				
Age (years)	39	1	37-41	<0.001
Gender (vs. male)				
Female	−246	19	−283-−208	<0.001
Insurance (vs. Medicare)				
Medicaid	722	49	626-817	<0.001
Private	550	27	496-603	<0.001
Other	811	36	741-882	<0.001
Severity of disease (vs. minor)				
Moderate loss of function	968	26	918-1019	<0.001
Major and extreme loss of function	6779	96	6592-6967	<0.001
Risk of mortality (vs. minor)				
Moderate likelihood	331	51	231-432	<0.001
Major and extreme likelihood	8061	135	7796-8325	<0.001
Technique (vs. anterior)				
Posterior	7043	46	6953-7133	<0.001
Combined approach	21,261	94	21,077-21,445	<0.001
Number of fusion levels (vs. 1-2 levels)				
3-7 levels	6052	30	5994-6110	<0.001
≥8 levels	17,645	326	17,007-18,284	<0.001
Bed size (vs. small)				
Medium	−1378	31	−1438-−1317	<0.001
Large	−1796	27	−1848-−1743	<0.001
Type of medical center (vs. rural)				
Urban nonteaching	−3951	48	−4045-−3857	<0.001
Urban teaching	−4152	48	−4246-−4058	<0.001
Geographic region (vs. Northeast)				
Midwest	1484	33	1419-1549	<0.001
South	1208	27	1155-1261	<0.001
West	6525	32	6461-6588	<0.001

B - Mean difference; SE - Standard error; 95% CI - 95% confidence interval

fusions increase costs by $17,645. ACF is more commonly performed (94.8%) and less expensive compared to PCF and combined approaches [Figure 2]. PCF often involves additional instrumentation, and combined approach is reserved for patients with complex cervical disease entities. Older age and male gender associated with marginal increases in expenditure. In line with prior findings,[4] we report lower costs at high-volume, urban institutions, demonstrating possible economic leverage specific to larger institutions. Surgery in the western US is the most expensive and the least expensive in the Northeast. Reasons for the geographic differences are not well understood, which may reflect differences in labor cost, administrative and medical infrastructure, and the potential influence of state-level health legislature.

Common inpatient complications and cost of care

From 2002 to 2014, the proportion of patients with ≥1 complication was 5.2%. Complication rates in cervical

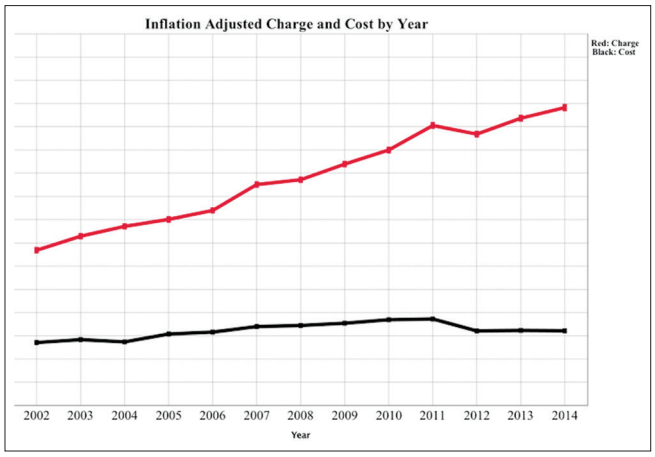

Figure 1: Cervical fusion, inflation adjusted charge and cost by year. Mean per patient charge versus cost for patients undergoing elective cervical fusion in the National Inpatient Sample years 2002–2014

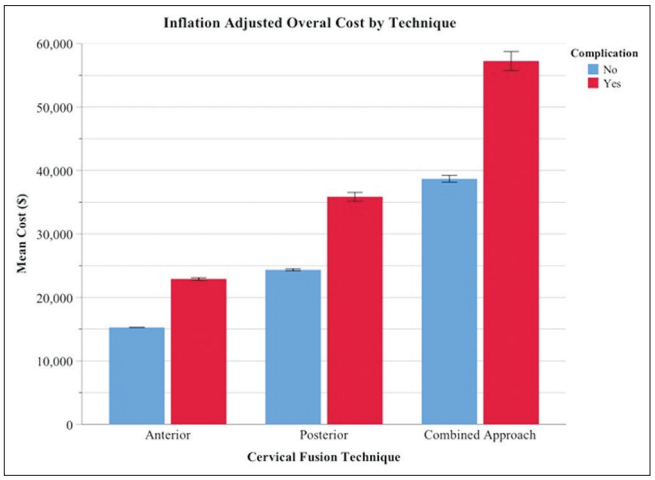

Figure 2: Mean cost for patients undergoing elective cervical fusion by the incidence of complications and type of surgical approach in the National Inpatient Sample Years 2002-2014

surgery historically range from 3.0% to 6.7%.[13-15] Differential rates often depend on patient sample, study design, and the targeted profile of complications, for which we employed a comprehensive search to capture the adverse events during the hospitalization. Our study shows that the most frequent complications and their adjusted costs were dysphagia (1.6%, $2624), pulmonary (1.0%, $9334), and device/graft/implant/other (0.9%, $3125). Overretraction during ACF on the trachea, esophagus, and surrounding soft tissues is well described in relation to swallowing difficulty postoperatively, with the incidence ranging from 1.7% to 50.3% based on the inclusion criteria and symptom severity.[16-18] Known risk factors of postoperative dysphagia include older age, multilevel fusion, and the use of bone morphogenetic protein.[19] Older surgical patients are prone to pulmonary events even after controlling for comorbidities,[20] and cervical surgery can further impede the return to respiratory baseline. Minimizing ventilation-related barotrauma or mechanical trauma, the use of long-acting muscle relaxants and adequate pain control is thought to improve recovery.

Whereas our study comprises only inhospital records, the course of recovery at follow-up, particularly for patients with dysphagia and respiratory dysfunction, would provide more information on long-term morbidity. Inpatient mortality following elective cervical fusion is rare at <0.1%, but it is of clinical importance to understand the major complications associated with deaths and to reduce these risks. Respiratory (65.2%), cardiac (25.7%), and renal (15.7%) events are frequently seen with inpatient mortality. Especially, in older patients undergoing cervical surgery, evaluation of cardiopulmonary and renal status should be prioritized throughout hospital stay. Blood pressure and volume management in the setting of significant volume loss and long procedures are important to reducing postoperative myocardial infarction.[21]

Complications with highest cost of care

Although overwhelmingly rare, infection after cervical fusion results in the highest cost increase at $25,359, which is consistent with previous findings from smaller cohorts.[22,23] Intraoperative bacterial seeding and poor wound care are risk factors of infections resulting in prolonged hospital stay and predisposition to reoperation and readmission, all of which undoubtedly increase morbidity and expenditures. Similarly, the incidence of venous thromboembolism extends hospitalization and adds to the overall expenditure burden by $17,480. Venous insufficiency, cardiac arrhythmia, obesity, and ischemic heart disease are risk factors of postoperative thromboembolism. Our findings corroborate incremental costs due to deep venous thrombosis in other inpatient settings[24] and further highlight the need to adhere to standardized prophylaxis guidelines to reduce the burden of postoperative recovery and cost.

Following the cost of care for infection and thromboembolism, neurological complications were the third costliest type of events at $10,098. Spinal cord and nerve root associated injuries are more prevalent in patients who present with complex spinal disease and/or require instrumentation, factors that make the operation more technically challenging and extend the operative duration. Maintaining adequate cord perfusion intraoperatively and avoidance of excessive flexion and/or extension are encouraged to reduce the risk of medullary lesion in spine surgery. Nerve root injury most often occurs at C5, and the time of symptom onset can range from immediately to several months postoperatively.[25]

Intraoperative neuromonitoring is commonplace in many large academic centers although its cost-effectiveness in reducing the rate of neurologic complications remains in need of further clarification.

Limitations

An important limitation is a reliance on reimbursement estimates using cost-to-charge ratios provided by the AHRQ for each hospital. There was no exact cost breakdown available in the NIS, e.g., cost of surgical procedure versus hospital stay, type of instrumentation and/or bone grafts used, and health system delivery may greatly affect overall costs related to surgery. Adjustments made in NIS sampling methodology, for example, sampling different hospitals year to year, or sampling different volume of cases per hospital year to year may explain some variability in trends. However, relative rates of complication within the study population remain highly relevant. NIS data include only inhospital events that were coded, which may often be subject to the assessment of nonclinical staff and may explain a component of variability in trends. Late complications, readmission events, and long-term outcome measures, all of which greatly contribute to additional expenditures, were not available for analysis and represented important future directions.

CONCLUSIONS

In a national sample of patients with degenerative spine disease undergoing cervical fusion, we characterize the incidences and quantify the inpatient costs associated with specific perioperative complications. The overall complication rate was 5.2%, of which the most common types were dysphagia, pulmonary, and device related. Hospital costs increased from 2002 to 2011, followed by a decreasing trend from 2012 to 2014. After adjusting for demographic/clinical variables and regional characteristics, we found that the cost increases are the greatest in the setting of infection, thromboembolism, and neurologic injury. Targeted evidence-based strategies may help optimize postoperative recovery and reduce complication-associated healthcare spending.

Acknowledgment

The study examined the national cost differences of inpatient complications for cervical fusion using discharge data from the NIS and the Nationwide Inpatient Sample, Healthcare Cost and Utilization Project and AHRQ. The authors have completed the mandatory training as per the AHRQ guidelines. This study contains no identifiable patient data.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Supplementary Table 1: Inclusion and exclusion criteria

Inclusion and exclusion criteria	ICD-9 code
Inclusion criteria	
Procedure codes	
Anterior cervical fusion	81.02
Posterior cervical fusion	81.03
1-2 level fusion	81.62
3-7 level fusion	81.63
≥8 level fusion	81.64
Diagnosis codes	
Spondylosis	721.0-721.1
Disc disease	722.0, 722.4, 722.91
Stenosis	723.0
Other cervical syndromes	723.1-723.9, 722.81
Complications	
Neurological	997.00-997.02, 997.09
Pulmonary	415.11, 512.1, 518.4, 518.5-518.53, 518.7, 518.81-518.84, 997.3-997.32, 997.39
Cardiac	410.0-410.9, 997.1, 998.02
Renal/urinary	584.5-9, 997.5
Gastrointestinal	997.4, 997.49
Dysphagia	787.2-787.29
Thromboembolism	415-415.12, 415.19, 451, 451.0-451.2, 451.19, 451.8-451.81, 451.9, 453.0-453.42, 453.8, 453.9
Accidental puncture/laceration	998.2
Hematoma/vascular/seroma	997.71, 997.72, 997.9, 997.2, 998.1, 998.11-998.13
Anemia due to blood loss	285.1
Infection	995.91-995.92, 996.60, 998.0, 998.3, 998.5-998.51, 998.59, 998.01
Device/graft/implant/other	996.0-996.5, 996.59, 996.2, 996.41-49, 996.70, 998.30-998.32, 998.6-998.81, 998.83, 998.89-998.9
Exclusion criteria	
Neoplasm	192.2, 225.2, 237.5, 225.4
Infection, preoperative	722.93
Fracture	805.2-805.9, 730.28, 733.13

ICD-9 - International Classification of Diseases, Ninth Revision

Supplementary Table 2: Univariate analysis of cost for patient and hospital characteristics

Variable	Mean cost, $ (SE)	Significant (*P*)
Age (years)		
18-44	14,623 (17)	<0.001
45-64	16,728 (15)	
65-84	18,242 (35)	
≥85	21,588 (389)	
Gender		
Male	16,685 (17)	<0.001
Female	16,225 (15)	
Insurance		
Medicare	17,639 (27)	<0.001
Medicaid	16,326 (46)	
Private	15,964 (14)	
Other	16,360 (29)	
Severity of disease		
Minor loss of function	15,564 (10)	<0.001
Moderate loss of function	18,250 (28)	
Major and extreme loss of function	35,639 (254)	
Risk of mortality		
Minor likelihood	15,967 (10)	<0.001
Moderate likelihood	21,140 (73)	
Major and extreme likelihood	42,642 (447)	
Surgical technique		
Anterior	789,367 (10)	<0.001
Posterior	25,995 (84)	
Combined approach	43,834 (297)	
Number of fusion levels		
1-2 levels	15,488 (11)	<0.001
3-7 levels	24,087 (49)	
≥8 levels	42,102 (1540)	
Bed size		
Small	16,937 (31)	<0.001
Medium	16,054 (22)	
Large	16,453 (15)	
Type of medical center		
Rural	19,354 (61)	<0.001
Urban nonteaching	16,559 (16)	
Urban teaching	16,048 (16)	
Geographic region		
Northeast	14,194 (24)	<0.001
Midwest	15,943 (24)	
South	15,573 (14)	
West	21,045 (34)	

SE - Standard error