Trends in Posterior Cervical Fusion for Deformity in the United States from 2000 to 2017

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BACKGROUND: Posterior cervical decompression and fusion (PCF) is a common treatment for cervical spondylotic myelopathy. Treatment paradigms are shifting from simple decompression and fusion to correcting cervical deformities.

OBJECTIVE: To identify trends in PCF with an emphasis on cervical deformity and surgical complexity.

METHODS: Adults who underwent PCF from 2000 to 2017 were retrospectively identified in the Premier Healthcare Database (PHD) using International Classification of Disease Codes (ICD) 9 and 10. Patients were dichotomized into those with or without deformity diagnosis. PCF complexity was defined by adjunct surgical codes, including anterior cervical fusion, extension to thoracic levels, and osteotomy. Patient characteristics, including demographics, functional comorbidity index (FCI), and hospital characteristics, were extracted and annual procedures were projected to the US population.

RESULTS: A total of 68,415 discharges for PCF were identified. Compound annual growth rate (CAGR) of PCF from 2000 to 2017 for nondeformity cases was 9.7% and 16.5% for deformity. The demographics with the greatest growth were deformity patients aged 65 to 74 yr (15.1%). The CAGR of anterior cervical fusion and extension to thoracic levels was higher for deformity patients compared to nondeformity patients, 13.6% versus 3.9% and 20.4% versus 16.6%, respectively.

CONCLUSION: Rates of PCF for deformity are increasing at a greater rate than nondeformity PCF. The most growth was seen among deformity patients aged 65 to 74 yr. Surgical complexity is also changing with increasing use of anterior cervical fusion and extension of PCF to include thoracic levels.
cervical fusion data from the New York state from 1997 to 2012 and found significant increases in the rate of surgery, particularly anterior fusion in the elderly. Additionally, surgical indications, length of stay, and complication profiles differed based on the surgical approach.

The past decade has led to a more nuanced understanding of cervical alignment and sagittal deformity.\(^\text{8}\) Cervical kyphosis leads to draping of the cord against vertebral bodies and increases longitudinal tension due to the cord being tethered by the dentate ligaments and cervical nerve roots.\(^\text{9,10}\) Over time the cord becomes compressed and flattened, producing increased intramedullary pressure, neuronal loss, disruption of blood flow, and demyelination.\(^\text{11-14}\) Subsequently, the goals of surgery for CSM have evolved to extend beyond simple decompression and fusion to include deformity correction and restoration of normal cervical sagittal alignment.\(^\text{15}\)

### Objectives
Demographics and outcomes following fusion for CSM are well documented, but there is a paucity of data on trends in cervical deformity and surgical complexity with respect to PCF. We sought to characterize trends in PCF with respect to patient age, medical comorbidities, and surgical complexity, with a focus on cervical deformity.

### METHODS

#### Participants and Variables
Adult patients, 18 yr or older, who underwent PCF from 2000 to 2017 were identified in the Premier Healthcare Database (PHD) using International Classification of Disease Codes (ICD) 9 and 10. The time frame for this study was selected to maximize the years and to provide trending information on more than a decade of time. Patients were excluded only if they had a diagnosis of fractures of the spine, skull, neck, thorax, or upper extremities (eg, hands) with the same episode of care as the PCF. Both elective and nonelective episodes of care with PCF were included in this study. Patients were dichotomized into those with or without a deformity diagnosis based on the presence of the 737.x series codes for ICD 9 or M40.x and M41.x series codes for ICD 10. The codes used in this study have been validated by published studies evaluating trends and outcomes among patients undergoing PCF\(^\text{16}\) or diagnosed with spinal deformity.\(^\text{17-19}\) ICD 9 codes were mapped to the corresponding ICD10 codes using the EncoderPro software (Optum360\(^\text{®}\)).

PCF complexity was defined by the presence of adjacent ICD 9 or 10 procedure codes used within the same admission as index PCF, including the use of anterior cervical fusion (ACF), extension of the posterior fusion to include thoracic levels, and use of an osteotomy. Variables collected included patient age, gender, and comorbidity status using the functional comorbidity index (FCI), an 18-item list of diagnoses that measure diagnoses related to patients’ physical function, unlike the Charlson or Elixhauser comorbidity indices, which capture diagnoses related to patients’ mortality.\(^\text{20}\) Teaching status of the hospital where the patient underwent PCF and procedure duration time of the PCF were collected. Institutional Review Board approval was not required since this study involved deidentified data acquired from the PHD.

### Data Sources

The PHD contains complete clinical coding, hospital cost, and patient billing data from over 700 hospitals in the United States participating in its healthcare alliance.\(^\text{21}\) This group was formed for hospitals to share knowledge, improve patient safety, and reduce risks. Participation is voluntary, and although the database excludes federally funded hospitals (eg, Veterans Affairs), the hospitals that are included are nationally representative based on bed size, geographic region, location (urban/rural), and teaching hospital status, and it represents approximately 25% of annual US inpatient admissions. The database contains date-stamped logs of all billed items by the cost-accounting department, which includes medications, laboratory tests, diagnostic studies, therapeutic services, and primary and secondary diagnoses of each patient’s hospitalization. Demographic and payor information are linked to each patient. Service level information for each hospital day is recorded, which includes details on medication and devices received.

### Quantitative Variables and Statistical Methods

The yearly volume of PCF for the overall cohort and by patients’ deformity status and complexity type was projected to the US population using weights generated by PHD.\(^\text{22}\) The projection weights when applied to the data from PHD will produce nationally representative inpatient discharges. The weights were generated using the American Hospital Association (AHA) 1998 Annual Survey: The AHA survey was utilized to identify the universe of US hospitals and the weights were generated at the hospital level. The hospital-level weights were applied to individual discharges. To validate the estimates, the projected PHD data were compared to the 1998 National Hospital Discharge Survey (NHDS) and demonstrated to be similar by age group, gender, race/ethnicity, and average length of stay. Yearly rates of PCF procedures per 100 000 patients were estimated for the overall population undergoing PCF by dividing the number of patients undergoing PCF procedures in a specific year by the number of patients in the database for the corresponding year and the proportion was multiplied by 100 000. Rates were stratified by patient age and surgical complexity for the overall cohort that underwent PCF and by deformity status. To evaluate the growth of procedures, compound annual growth rates (CAGRs) of projected counts and rates were calculated. The CAGR was used in this study to estimate the average yearly change in the volume or rate. The CAGR was calculated using this formula: CAGR = ((\text{End year}/\text{Start year})^{1/\text{number of years}}) – 1. The frequency and percent of patients undergoing PCF at teaching and nonteaching hospitals and median operating room time of procedures were calculated. SAS Enterprise Guide for Windows version 7.15 was used to generate projected counts, raw counts, frequencies, and median values, and Microsoft Excel version 1902 was used to generate rates and CAGRs. This manuscript was prepared in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) checklist.\(^\text{23}\)

### RESULTS

#### Participants
A total of 68 415 discharges for PCF were identified over the study period. This included 51 423 PCF alone, 11 263 PCF with ACF, 4382 PCF with thoracic fusion, 1115 PCF with ACF and thoracic fusion, 92 PCF with osteotomy, 60 PCF with thoracic fusion and osteotomy, 48 PCF with ACF and osteotomy, and
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23 PCF with thoracic fusion and osteotomy and ACF. Within the entire cohort, 6518 discharges carried a diagnosis of cervical deformity compared to 61 897 without cervical deformity.

Descriptive and Outcome Data

The total number of projected patients per year that underwent PCF increased from 5553 in 2000 to 31 911 in 2017, and the rate of patients that underwent PCF in the database increased from 8.0 per 100 000 patients in 2000 to 24.1 per 100 000 patients. The CAGR for the projected number of patients and the rate of patients per year undergoing PCF was 10.2% and 6.3%, respectively. Among nondeformity cases, the projected number of patients per year increased from 5323 to 28 315 and the rate of patients per year undergoing surgery without deformity increased from 7.7 to 21.4 per 100 000 patients; the CAGRs were 9.7% and 5.9%, respectively. Among patients with cervical deformity, the projected number of patients per year that underwent surgery increased from 230 to 3596 and the rate of patients per year that underwent surgery increased from 0.3 to 2.7 patients per 100 000 patients; the CAGRs were 16.5% and 13.0%, respectively. These results are summarized in Figure 1. Deformity cases comprised 4.1% of the projected number of patients undergoing PCF in 2000 compared to 11.3% in 2017. The net percent change of the projected number of patients was 432% for nondeformity cases compared to 1463% for deformity cases. Therefore, although the projected number of patients with cervical deformity was less than that for nondeformity, deformity cases grew more over the 18-yr time period compared to nondeformity cases.

Trends in Patient Demographics

Patients undergoing PCF were stratified by age. Among all PCF cases, the CAGR of the rate of surgery was 5.3% for ages 18 to 64 and 8.0% for age ≥ 65. The age group-specific CAGRs of the rate of surgery were as follows: 0.6% for ages 18 to 44, 5.1% for ages 45 to 54, 6.2% for ages 55 to 64, 7.8% for ages 65 to 74, 7.8% for ages 75 to 84, and 7.9% for age ≥ 85. The age-specific CAGRs of the rate of surgery for nondeformity patients were as follows: 0.1% for ages 18 to 44, 4.6% for ages 45 to 54, 5.8% for ages 55 to 64, 7.2% for ages 65 to 74, 7.5% for ages 75 to 84, and 7.6% for age ≥ 85. For deformity patients, the age-specific CAGRs of the rate of surgery were as follows: 6.7% for ages 18 to 44, 15.1% for ages 45 to 54, 12.1% for ages 55 to 64, 15.1% for ages 65 to 74, 11.4% for ages 75 to 84, and 1.7% for age ≥ 85. The surgery rates over time and projected counts of deformity and nondeformity patients are presented in Figure 2.

To assess changes in the overall health of PCF patients, we assessed FCI scores over the study period. Overall, there was a trend towards increasing comorbidity scores in both deformity and nondeformity patients. Among all patients, the proportion of patients with an FCI score of 1 to 2 decreased from 64.7% in 2000 to 22.3% in 2017, while, over the study period, patients with an FCI score of 3 to 5 increased from 26.0% to 58.0% and FCI score of ≥ 6 increased from 0.5% to 18.2% (Figure 3). These trends were present in both deformity and nondeformity cohorts. Based on the most recent data from 2017, deformity versus nondeformity patients had a higher proportion of FCI score of ≥ 6 (23.4% vs 17.6%) and had the same proportion of FCI score of 3 to 5 (58.0%).

Trends in Case Complexity

To assess changes in surgical case complexity, surgeries were classified as PCF alone, PCF with ACF (PCF + ACF), PCF with posterior thoracic fusion (PCF + thoracic), or PCF with osteotomy (PCF + osteotomy). Among nondeformity patients, the CAGRs of the rate of surgical cases were as follows: 5.5% for PCF alone, 3.9% for PCF + ACF, 16.6% for PCF + thoracic, 15.2% for PCF + ACF + thoracic, −4.4% for PCF + osteotomy, −7.8% for PCF + thoracic + osteotomy, −5.9% PCF + ACF + Osteotomy, and −10.3% for PCF thoracic + ACF + osteotomy. Among deformity patients, the AGR of the rate of surgical cases were as follows: 9.3% for PCF alone, 13.6% for PCF + ACF, 20.4% for PCF + thoracic, 12.0% for PCF + ACF + thoracic, 7.2% for PCF + thoracic + osteotomy, −7.9% for PCF + osteotomy, −12.1% for PCF + ACF + osteotomy, and −13.7% for PCF thoracic + ACF + osteotomy. The surgery rates over time and the projected number of patients by surgery type for deformity and nondeformity cases are presented in Figure 4. Operative time across the study period was also assessed. Among nondeformity patients, the median operative time was relatively stable across the study period ranging from 240 to 244 min. Among deformity patients, we observed an increase in operative time from 253 min in 2000 to 330 min in 2017 (Figure 5). Among the deformity cases performed, the percentage of deformity cases performed at teaching hospitals over the study period was similar to the percentage of nondeformity cases performed at teaching hospitals among all nondeformity cases, and has reached a relatively stable level since 2008 ranging from 54% to 61% (Figure 6).

DISCUSSION

Key Results

The results from this study suggest the rates of PCF for deformity are increasing at a greater rate than nondeformity PCF. The most significant growth was seen among deformity patients aged 65 to 74 yr. Surgical complexity is also changing with increasing use of ACF and extension of PCF to include thoracic levels. These novel data suggest rapid growth in surgery for cervical deformity.

Limitations

There are several limitations to this study. Use of the PHD requires us to estimate the number of PCF cases in the United States based on weights generated using AHA survey data; thus, these figures do not represent the actual number of operations performed. However, this weighting methodology has been validated using the National Hospital Discharge Survey,22 and
the weighting provides an estimate of the number of cases while maintaining the same hospital characteristics across years, which therefore minimizes the effect of hospital characteristics on the observed counts. Furthermore, although the hospitals in PHD are not a random selection of hospitals in the United States, the database has been demonstrated to be nationally representative of US hospitals, and has been used by several published studies to evaluate national trends in surgery and other healthcare areas. Additionally, deformity patients were captured based on ICD 9/10 codes, not radiographic parameters. As such, we
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FIGURE 3. Trend in FCI scores over study period. Proportion of patients with FCI scores of 0, 1 to 2, 3 to 5, and ≥ 6 shown for nondeformity cases performed each year, including representative pie graphs at 5-yr intervals A. Similar data shown for patients with a deformity diagnosis B.

Interpretation

The US aging population is experiencing a significant shift as medical care advances and life expectancy increases. Based on US census data from 2000 to 2010, the first set of “baby boomers” increased by 21% from 41 million to just under 50 million, which represents the most rapidly growing demographic in the United States. By the year 2050, the number of individuals 65 yr and older is projected to reach 89 million, which is double the current size. Advances in the treatment of cardiovascular disease and cancer have prolonged both life expectancy and quality of life. Longer life expectancy places increased stress on the musculoskeletal system, including the cervical spine, since it is susceptible to degeneration over time. Furthermore, as individuals age, they are increasingly less satisfied with a diminishing quality of life, particularly given improvements in the safety and efficacy of surgery. This phenomenon is well-recognized in cohorts from Japan, a “superaging” society with a high demand for healthy life expectancy. In a study of over 45 000 spine surgeries performed from 2004 to 2015 in the Nagoya Spine Group, the largest demographic was in the age range 70 to 79 (25.7%). Improvements in anesthesia and postoperative care have also improved the safety of surgery on the elderly, contributing to the rise in spine surgery among this demographic.

In the United States, surgery for age-related spinal deformity has increased over the past several decades. Hospital discharges carrying a diagnosis of abnormal spinal curvature in adults and the number of fusions for deformity have both increased by over 150%. Complexity of deformity surgery has also increased with more long-segment constructs and 3-column osteotomies. Use of wedge osteotomies, interbody grafts, and bone morphogenetic protein have all seen dramatic increases, which reflect more severe deformities and more complex operations.

Other important factors associated with the growth of PCF include the increase in fellowship-trained spine surgeons. A greater number of surgeons increases our capacity to treat a higher volume of the spine patients in a given year. Additionally, advances in instrumentation have made spinal fusion safer and easier, particularly for ACF and PCF. Over the 18-yr study period, we found a larger median difference in median operative time among PCF for deformity conditions versus PCF for nondeformity conditions, 77 min versus 4 min. Interestingly, the largest increase was observed from 2000 to 2006 when median operative time increased from 253 to 360 min. From 2007 to 2017, operative
time was stable and underwent a slight decrease to 330 min by 2017. We suspect that these data represented a learning curve that has since stabilized. Part of this is attributable to improvements in surgeon skill, but it is also important to recognize that trainees are gaining exposure to these complex technique and instrumentation systems earlier in their careers, thus improving their familiarity and efficiency with these surgical procedures.

Over the course of this study, an increase in patient medical complexity was suggested by the increase of higher comorbidity scores over the time period evaluated. Patients with a score of ≥6 increased from 0.5% to 18.2% across the study period. By 2017, 23.4% of deformity patients and 17.6% of nondeformity patients had a score of ≥6. Similar trends with increasing comorbidity have been identified in other trend studies on PCF.5,6 Future studies on cervical deformity trends should include analyses on trends in length of stay, complications, rehabilitation, and mortality.

This study has a very important implication on the future of cervical spine surgery. Given the rapid growth in PCF, particularly among patients with underlying cervical deformity, the number of patients requiring revision surgery will also increase. Reported revision rates for multilevel PCF range from 7.4% to 18.1%; however, these rates may be higher in a pure deformity cohort. Revision PCF in deformity patients will require a complex understanding of the principles of revision surgery, cervical deformity correction, and advanced instrumentation systems that can accommodate the needs of this challenging cohort. Both surgeons and industry must be prepared to meet the impending needs of this population. Future studies are needed to determine which patients are most likely to benefit from complex cervical reconstruction, require preoperative medical optimization, or benefit from osteobiologics or other adjuncts to promote fusion. Future studies should also assess the cost and clinical outcomes associated with PCF for deformity.

**Generalizability**

This study reports trends from a nonrandom but nationally representative sample of hospitals in the United States. While these findings reflect national trends, they may not fully characterize regional or institutional practice patterns and variations.
This study does not reflect trends in surgery for PCF outside the United States.

**CONCLUSION**

The goal of this study was to assess trends in PCF for patients with a diagnosis of cervical deformity compared to those without. Using the PHD, we found that rates of PCF for deformity are increasing at a greater rate than for nondeformity, with CAGRs of 16.5% and 9.7%, respectively. Among patients included in our analysis, the highest rate of PCF growth was seen among deformity patients aged 65 to 74 yr. Surgical complexity also increased across the study period with greater use of ACF and extension of PCF to include thoracic levels. Furthermore, patients undergoing PCF demonstrated increasing functional comorbidity scores across the study period. These findings demonstrate the
important role of PCF in the treatment of cervical deformity and stress the need of improved understanding of the management of these complex cases, particularly in older patients with greater comorbidities.

Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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