Evolution of Adult Cervical Deformity Surgery Clinical and Radiographic Outcomes Based on a Multicenter Prospective Study: Are Behaviors and Outcomes Changing With Experience?

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Study Design. Retrospective cohort study. Objective. Assess changes in outcomes and surgical approaches for adult cervical deformity surgery over time.

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Summary of Background Data. As the population ages and the prevalence of cervical deformity increases, corrective surgery has been increasingly seen as a viable treatment. Dramatic surgical advancements and expansion of knowledge on this procedure have transpired over the years, but the impact on cervical deformity surgery is unknown.

Materials and Methods. Adult cervical deformity patients (18 yrs and above) with complete baseline and up to the two-year health-related quality of life and radiographic data were included. Descriptive analysis included demographics, radiographic, and surgical details. Patients were grouped into early (2013–2014) and late (2015–2017) by date of surgery. Univariate and multivariable regression analyses were used to assess differences in surgical, radiographic, and clinical outcomes over time.

Results. A total of 119 cervical deformity patients met the inclusion criteria. Early group consisted of 72 patients, and late group consisted of 47. The late group had a higher Charlson Comorbidity Index (1.3 vs. 0.72), more cerebrovascular disease (6% vs. 0%, both P<0.05), and no difference in age, frailty, deformity, or cervical rigidity. Controlling for baseline deformity and age, late group underwent fewer three-column osteotomies (odds ratio (OR)=0.18, 95% confidence interval (CI): 0.06–0.76, P=0.041). At the last follow-up, late group had less patients with: a moderate/high Ames horizontal modifier (71.7% vs. 88.2%), and overcorrection in pelvic tilt (4.3% vs. 18.1%, both P<0.05). Controlling for baseline deformity, age, levels fused, and three-column osteotomies, late group experienced fewer adverse events (OR=0.15, 95% CI: 0.28–0.8, P=0.03), and neurological complications (OR=0.1, 95% CI: 0.012–0.87, P=0.03).

Conclusion. Despite a population with greater comorbidity and associated risk, outcomes remained consistent between early and later time periods, indicating general improvements in care. The later cohort demonstrated fewer three-column osteotomies, less...
suboptimal realignments, and concomitant reductions in adverse events and neurological complications. This may suggest a greater facility with less invasive techniques.

**Key words:** cervical deformity, cervical surgery, complications, adverse events, alignment, outcomes, three-column osteotomies, realignment, invasiveness, comorbidity

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Cervical deformity (CD) is a progressive disease with an associated broad spectrum of symptoms including myelopathy, impaired swallowing, and an altered horizontal gaze. The prevalence of this condition is known to be increasing with the aging demographic and advances in surgical techniques and medical management have allowed for greater acceptance of surgical correction as a viable treatment option. Indeed, over the last decade, procedural approaches and patient selection have expanded to include cases of individuals who previously would not have been considered candidates.

Dramatic improvements in the field have been made as surgeons become better at identifying optimal approaches capable of maximizing outcomes while minimizing risk of complications. This includes identifying target thresholds of correction for various clinical and radiographic factors, as well as the relationship between spinopelvic parameters and associated disability. In addition, a variety of prognostic tools have been published which are capable of informing surgical planning and technical approaches. The impact of these relatively rapid improvements over more recent years on outcomes of patients treated for the adult cervical deformity (ACD), remains unknown.

In this context, we sought to evaluate changes in technical approaches, patient selection, and outcomes between patients treated by surgeons contributing cases to the International Spine Study Group Registry. We compared cases collected in the first two years of the registry (early group: between years 2013 and 2014) to those collected in later years (late group: between 2015 and 2017). This registry has been previously used to study and evaluate clinical performance and study factors influencing outcomes in patients treated for ACD. We hypothesized that patient’s in the later cohort would have higher comorbidities, fewer invasive surgical techniques, lower complication rates, and improved clinical outcomes as compared to the early cohort.

**MATERIALS AND METHODS**

**Study Design and Data Source**

This was a retrospective cohort study of a prospectively collected, multicenter database of operative CD patients enrolled from 2013 to 2017. Institutional Review Board approval was received at all thirteen participating centers prior to patient enrollment, with all participants consented. Patients were over 18 years and have radiographic evidence of CD, defined as: cervical kyphosis (C2–C7 Cobb angle >10°), cervical scoliosis (C2–C7 coronal Cobb angle <10°), C2–C7 sagittal vertical axis (cSVA) >40 mm, or chin-brow vertical angle >25°. Patients included in the study had preoperative and postoperative radiographic and health-related quality of life (HRQL) data with an average follow-up of 21.8 months. Routine audits, data checks, and yearly updates by dedicated research staff at each institution and a central research team ensure high fidelity and validity of the data elements entered.

**Data Collection**

Standardized forms were utilized for data collection to obtain demographic and surgical parameters. Surgical and complication data was collected following surgical intervention. Complications data (medical complications, radiographic complications, revisions) was collected as complications occurred or at follow-up time points and submitted to central International Spine Study Group (ISSG) research staff for evaluation and categorization into major versus minor based on predetermined criteria. Complications were defined as major if it there was a substantially prolonged hospitalization, involved an invasive intervention, led to prolonged morbidity, or resulted in death.

**HRQL Assessment**

HRQL questionnaires were collected preoperatively, and incrementally at follow-up time points up to two years. Those included the Neck Disability Index (NDI), Numerical Rating Scale (NRS) Neck, Euro-Qol 5 Dimension (EQ-5D), and the modified Japanese Orthopedic Association (mJOA) metrics.

**Radiographic Data Collection**

Full-length free-standing lateral spine radiographs were used to assess CD patients at baseline and follow-up intervals and analyzed with SpineView® (ENSAM; Laboratory of Biomechanics, Paris, France).

**Definition of Cervical Rigidity and Cervical Flexibility**

Cervical flexibility was defined by a change of $>10^\circ$ between flexion and extension imaging at C2–C7 cervical lordosis.

**Statistical Analysis**

Patients were stratified into two groups based on the date of surgery for their enrollment in the database: early group (2013–2014) and late group (2015–2017) for overall analysis between cohorts. Means comparison tests were used to establish baseline differences in age, body mass index (BMI), Charlson Comorbidity Index (CCI), frailty, baseline cervical, and thoracolumbar radiographic profile, and surgical details. Multivariate binary logistic regressions were used to assess differences in surgical approaches, alignment criteria, and complications between these two
Overall, 10% of patients reported bladder incontinence, and 10% reported bowel incontinence. Patients presented radiographically at baseline with a pelvic tilt (PT) of 18.8°; pelvic incidence of 53.0°; C7–S1 sagittal vertical axis of 45.2° ± 25.6°. Patient radiographic profile by Ames, Scoliosis Research Society (SRS)-Schwab, and SRS-Coronal Curve Type classifications in Table 1.

Overall Cohort Neurological Status
Overall, 10% of patients reported bladder incontinence, 5% bowel incontinence, 41% gait impairment, 40% hand clumsiness, 54% hand numbness, 25% bilateral paresthesia, 46% weakness, 19% broad or unstable gait, 8% corticospinal motor deficits, 12% intrinsic muscle atrophy, 21% hyperreflexia, 26% positive Hoffman’s sign, 7% lower limb spasticity, 4% had an upgoing plantar response.

RESULTS

Cohort Overview
A total of 119 ACD patients with complete baseline and up to two-year HRQL and radiographic data met inclusion criteria. Mean patient age was 61.3 ± 10.1 years, BMI of 28.8 ± 7.6 kg/m², CCI of 1 ± 1.3, a Frailty Index of 4.2 ± 0.1, with 66% of patients being female. Overall, 28 (24%) of patients had a previous fusion.

Cohort Baseline Radiographic Profile
Patients presented radiographically at baseline with a pelvic tilt (PT) of 18.8° ± 17.7°; C7–S1 sagittal vertical axis of −4.34 ± 66.8°, T1 slope minus cervical lordosis of 38.1° ± 21.4°, and cSVA of 45.2° ± 25.6°. Patient radiographic profile by Ames, Scoliosis Research Society (SRS)-Schwab, and SRS-Coronal Curve Type classifications in Table 1.

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Overall, 10% of patients reported bladder incontinence, 5% bowel incontinence, 41% gait impairment, 40% hand clumsiness, 54% hand numbness, 25% bilateral paresthesia, 46% weakness, 19% broad or unstable gait, 8% corticospinal motor deficits, 12% intrinsic muscle atrophy, 21% hyperreflexia, 26% positive Hoffman’s sign, 7% lower limb spasticity, 4% had an upgoing plantar response.

HRQL Comparison Between Early and Late Groups
From baseline to the last follow-up, NDI, EQ-5D score, and EQ-5D Visual Analog Scale, NRS Back, and NSR Neck were significantly improved. Table 2. Comparison between early and late groups HRQLs at last follow-up in Table 3. Patients in the late group had a higher postoperative EQ-5D (0.81 vs. 0.77, P = 0.008).

Surgical Overview
Operatively, patients had a mean of 7.6 ± 3.8 levels fused and estimated blood loss of 824.6 ± 844.6 mL. By surgical approach, 47.1% were posterior-only, 18.5% were anterior-only, and 34.5% underwent an anterior-posterior approach with 51.3% of patients having an osteotomy. The mean invasiveness index was 10 ± 3.2. Patients undergoing a three-column osteotomies (3COs) had a deformity primarily in the cervical-thoracic region (48%), followed by...
cervical (23%) and thoracic (19%) with a similar distribution between groups (P > 0.05). When controlling for cervical flexibility, there was no significant difference in the distribution of regions (P > 0.05).

### Baseline Differences Between Early and Late Cohorts

Early group consisted of 72 patients, and late group consisted of 47 patients. Late group had a higher CCI (1.3 vs. 0.72) and more cerebrovascular disease (6% vs. 0%, both P < 0.05). There were no differences in age, BMI, sex, or frailty (Table 4). There were no differences in baseline cSVA, T1 slope minus cervical lordosis, thoracic kyphosis (T4–T12), PI–LL, or PT. Sagittal vertical axis was lower for the late group (1.1 cm). There were no differences in the degree of deformity based on the Ames or SRS-Schwab parameters, cervical flexibility, or revision status. Late group had more patients with baseline hand clumsiness (53% vs. 32%, P = 0.021), and hyperreflexia (32% vs. 14%, P = 0.018).

### Differences in Surgical Factors Between Early and Late Cohorts

Late group had a lower surgical invasiveness (9 vs. 11, P = 0.005), specifically 3COs (7% vs. 25%, P = 0.025), with a higher rate of lower-grade techniques, such as facetectomies (17% vs. 8%, P = 0.033). Late group trended towards a lower estimated blood loss (677 vs. 921 mL, P = 0.124) and a shorter length of stay (LOS) (5.1 vs. 7.9 d, P = 0.065), with comparable levels fused, approach, or number of decompressions (P > 0.05). Table 5. Controlling for age, CCI, baseline deformity, and baseline flexibility, patients in late group underwent fewer 3COs [odds ratio (OR) = 0.11, 95% confidence interval (CI): 0.02–0.67, P = 0.016].

### Tables

**Table 3. Comparison Between Early and Late Groups Postoperative HRQLs**

<table>
<thead>
<tr>
<th>HRQL Metric</th>
<th>Mean ± SD</th>
<th>Early Group</th>
<th>Late Group</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDI</td>
<td>37.5 ± 21.6</td>
<td>31.6 ± 20.2</td>
<td>0.144</td>
<td></td>
</tr>
<tr>
<td>mJOA</td>
<td>14.1 ± 2.8</td>
<td>14.4 ± 3.6</td>
<td>0.538</td>
<td></td>
</tr>
<tr>
<td>EQ-5D score</td>
<td>0.77 ± 0.08</td>
<td>0.81 ± 0.09</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>NRS Back</td>
<td>4.9 ± 3.2</td>
<td>4.4 ± 3.0</td>
<td>0.340</td>
<td></td>
</tr>
<tr>
<td>NRS Neck</td>
<td>4.3 ± 3.0</td>
<td>3.6 ± 3.1</td>
<td>0.220</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4. Baseline Differences Between Early and Late Groups**

<table>
<thead>
<tr>
<th>Baseline Factor</th>
<th>Early Group</th>
<th>Late Group</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ± SD)</td>
<td>61.4 ± 10.7</td>
<td>61.3 ± 9.14</td>
<td>0.92</td>
</tr>
<tr>
<td>Sex (female) (%)</td>
<td>61</td>
<td>74</td>
<td>0.13</td>
</tr>
<tr>
<td>BMI (mean ± SD)</td>
<td>29.5 ± 8.8</td>
<td>28 ± 5.5</td>
<td>0.31</td>
</tr>
<tr>
<td>Charlson Comorbidity Index (mean ± SD)</td>
<td>0.72 ± 1.1</td>
<td>1.3 ± 1.4</td>
<td>0.024</td>
</tr>
<tr>
<td>Cerebrovascular disease (%)</td>
<td>0</td>
<td>6</td>
<td>0.03</td>
</tr>
<tr>
<td>ACD Frailty Index (mean ± SD)</td>
<td>4.3 ± 0.9</td>
<td>4.1 ± 1</td>
<td>0.25</td>
</tr>
<tr>
<td>Modified Cervical Deformity Index (mean ± SD)</td>
<td>0.18 ± 0.1</td>
<td>0.20 ± 0.12</td>
<td>0.35</td>
</tr>
</tbody>
</table>

**Table 5. Comparison of Surgical Details, Complication Rates, and Rates of DJK**

<table>
<thead>
<tr>
<th>Surgical details</th>
<th>Early</th>
<th>Late</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical invasiveness (mean ± SD)</td>
<td>10.6 ± 3.3</td>
<td>9.0 ± 2.9</td>
<td>0.005</td>
</tr>
<tr>
<td>Three-column osteotomy usage (%)</td>
<td>25</td>
<td>7</td>
<td>0.025</td>
</tr>
<tr>
<td>EBL (mean ± SD) (mL)</td>
<td>921 ± 882</td>
<td>677 ± 770</td>
<td>0.124</td>
</tr>
<tr>
<td>LOS (mean ± SD) (d)</td>
<td>7.9 ± 9.5</td>
<td>5.1 ± 3.5</td>
<td>0.065</td>
</tr>
</tbody>
</table>

Complications rates (%).

<table>
<thead>
<tr>
<th>Overall complications</th>
<th>Early</th>
<th>Late</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adverse events</td>
<td>17</td>
<td>4</td>
<td>0.04</td>
</tr>
<tr>
<td>Reoperations</td>
<td>6</td>
<td>4</td>
<td>0.75</td>
</tr>
<tr>
<td>Major complications</td>
<td>14</td>
<td>11</td>
<td>0.6</td>
</tr>
<tr>
<td>Minor complications</td>
<td>22</td>
<td>8</td>
<td>0.05</td>
</tr>
<tr>
<td>Neurological complications</td>
<td>16</td>
<td>2</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Rates of DJK (%).

<table>
<thead>
<tr>
<th>Two-year DJK</th>
<th>Early</th>
<th>Late</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe DJK</td>
<td>2.8</td>
<td>2.1</td>
<td>0.82</td>
</tr>
<tr>
<td>Symptomatic DJK</td>
<td>5.6</td>
<td>6.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Notes:**

- **Bold** indicates significant values.
- ACD indicates adult cervical deformity; BMI, body mass index; DJK, distal junctional kyphosis.
- EQ-5D indicates Euro-Qol 5 Dimension; HRQOL, health-related quality of life; mJOA, modified Japanese Orthopaedic Association; NDI, Neck Disability Index; NRS, Numerical Rating Scale.
Analysis of Differences in Complications
Late group had fewer overall complications (23% vs. 38%, \(P = 0.109\)), less adverse events (4% vs. 17%, \(P = 0.04\)), comparable rates of reoperation (4% vs. 6%, \(P = 0.75\)), and major complications (11% vs. 14%, \(P = 0.6\)), and trended lower in minor complications (8% vs. 22%, \(P = 0.051\)), and had less neurological complications (2% vs. 16%, \(P = 0.02\)). Table 5. Controlling for baseline deformity, age, levels fused, 3COs, late group experienced fewer adverse events (OR = 0.15, 95% CI: 0.28–0.8, \(P = 0.03\)), and less neurological complications (OR = 0.1, 95% CI: 0.012–0.87, \(P = 0.03\)). Rates of two-year distal junctional kyphosis (DJK), severe DJK, and symptomatic DJK were comparable between groups Table 5.

Differences in Postoperative Radiographic Alignment Between Early and Late Cohorts
Between late and early groups, there were no significant differences in last follow-up PT, PI, PI-LL, T4–T12, cSVA, T1 slope minus cervical lordosis, or C2–C7 (\(P > 0.05\)). Late group had fewer patients with a moderate/high Ames horizontal modifier (71.7% vs. 88.2%, \(P < 0.05\)), and no significant differences in any of the other Ames modifiers. Late group had fewer patients who were overcorrected in PT by age-adjusted criteria, (4.3% vs. 18.1%, \(P = 0.03\)), and less patients with a + or ++ deformity in PT (9.1% vs. 39.5%, \(P = 0.02\)). Controlling for age, CCI, cervical flexibility, previous fusions, and baseline deformity, there were no differences between the Ames parameters, SRS-Schwab parameters, or age-adjusted parameters by last follow-up. Figures

Case Examples
Figures 1–4 demonstrate the preoperative and one-year postoperative films of a patient with a cervicothoracic deformity in the early and late group treated with a 3CO and a low-grade technique, respectively.

DISCUSSION
Advancements in CD research over the past several years has broadly improved our basic understanding of sagittal deformity and compensatory mechanisms within the cervical spine. We now recognize the contributions of the global chain of correlation and the efforts of the cervical spine to maintain horizontal gaze with its wide range of motion. As the literature on CD grows, it is important to investigate whether these improvements in understanding translated into better surgical outcomes for patients. We also aim to assess the impact on surgical planning and surgical candidacy considerations. Our study is the only recent analysis on broader trends in the field of CD over several years, specifically looking at baseline, surgical, and postoperative factors. We found that patients undergoing ACD surgery more recently experienced significantly lower odds of adverse events as well as mild and neurological complications. Postoperative deformity occurred less often when classifying by either SRS-Schwab or Ames Modified Criteria. The usage of 3COs was lower, and patients who have undergone more recent ACD surgery had higher comorbidity scores.

Our results demonstrated a temporal decrease in rates of complications and adverse events in our population following ACD surgery, despite a significantly higher CCI in the late group. We attribute these improvements to advances in risk stratification, and surgical candidate and strategy selection. Passias and colleagues elucidated the role structural drivers of CD play in postoperative outcomes. Results show a better improvement in 1-year HRQL scores when the primary driver of ACD is the cervical spine as opposed to patients with a primary driver of malalignment.
in the thoracic region and stressed the importance of including the driver in fusion constructs. De la Garza-Ramos and colleagues in 2016 found predictors of prolonged LOS following posterior cervical surgery, including alcohol abuse and use of bone morphogenetic protein-2 (BMP-2) intraoperatively for posterior surgery, further supported by a recent publication that found bone morphogenetic protein to predict 90-day complications. However, Jain et al found BMP-2 to ultimately mitigate the occurrence of pseudarthrosis in adult spinal deformity surgery, leading to an overall favorable cost-utility. Therefore, despite increased risk for certain 90-day complications, surgical planning techniques and the incorporation of materials like BMP-2 should be considered to increase the likelihood of better long-term outcomes in this more complex cohort of patients.

Complications with ACD surgery are a common occurrence, similar to thoracolumbar ASD. Smith et al reported a 56% rate of at least one complication in operative ACD patients with at least one-year follow-up, with the most frequent complication being dysphagia. The results of our study indicate that the incidences of some commonly experienced complications are diminishing in ACD surgery. The 23% rate of complications and 2% rate of neurological complications observed in the later cohort is much improved from the complication rate published by Smith et al and a 13.5% neurological complication rate reported by a systematic review in 2010. With regard to neurological complications, a previous study found higher rates...
following 3CO compared to PSO in ACD surgeries performed by a single surgeon. The recent cohort underwent fewer 3COs, and our results revealed lower odds of neurological complications even after adjusting for 3CO use. In addition, our data is consistent with previous epidemiological studies regarding comorbidities, which identified increasing trends in the proportion of elderly Americans with one or more chronic diseases and are projected to increase with current obesity rates and increasing longevity. Patient comorbidities increase risks associated with ASD surgery thus a decreased complication rate, adverse events, and similar patient-reported outcomes in the later cohort despite higher mean CCI is an encouraging finding.

Patients in the more recent cohort underwent less invasive surgeries, attributable to lower rates of 3CO use. A recent publication by Passias et al developed a novel invasiveness index specific to CD, and a greater invasiveness score was found to predict the longer operative time, LOS, and greater blood loss. The 3CO corrective technique balances an ability to restore a large degree of curvature to the spine with a significantly increased risk of complications. From 2001 to 2011, the utilization of 3COs in ASD surgery rose to provide the necessary sagittal correction for increasingly complex and invasive surgeries. Since then, however, high complication risk coupled with novel age-adjusted alignment goals in ASD has shifted the philosophy toward less aggressive surgeries. The observed temporal decreases in 3COs and invasiveness of ACD procedures reflect consistency with the overall trend in ASD. Surgeons are opting for more physiologically shaped reconstructions, reserving aggressive pedicle subtraction osteotomies and vertebral column resections for cases of rigid kyphotic CD with an apex of deformity in a hyperkyphotic upper thoracic spine, or more commonly at the cervicothoracic junction.

Complementary to the greater understanding of how baseline and surgical factors impact outcomes is the appreciation of a global alignment and chain of correlations. Cervical curvature is one piece of the global interdependent spinopelvic alignment, and its deformity influences thoracic and lumbar alignment, as does the reverse. Cervical lordosis negatively correlates with PT indicating a compensatory mechanism of PT to maintain a horizontal gaze in the setting of cervical kyphosis, especially with previous thoracolumbar fusions. Ramchandran et al noted that increasing cSVA deformity causes compensatory upper cervical spine hyperlordosis and pelvic retroversion. We postulate the reduction in PT deformity postoperatively is due superior reconstructions requiring less compensation to maintain horizontal gaze, as illustrated by a reduced horizontal modifier deformity in the later group.

We appreciate several limitations to our study. Despite the multicenter, multisurgeon derivation of data, the retrospective study design carries risk of selection bias, confounding by indication, and expertise bias. In addition, although the clinical performance of members of the study group likely reflects that of ACD surgeons, there is the prospect for clustering at the level of the surgical center and provider to further confound results. The number of years we were able to include are beholden to the years over which the registry was developed and we cannot speak to earlier aspects of CD surgery, such as those which antedate 2013. The small sample size also contributes to lower statistical power and the potential for type 2 errors, including inability to detect secondary effects and interactions. There was also a fairly restricted adverse event rate, which may speak to restricted variation and truncation that cannot be measured, nor its impact quantified. The statistical approaches we employ here have to be viewed as exploratory as a result. The determinations should be used to support further specific evaluation in the field, using larger
cohorts, rather than used to direct clinical decisions. Nonetheless, given the relatively large sample and multicenter design, we believe this effort provides a useful temporal analysis on the evolution of ACD surgery over the course of the last decade.

CONCLUSION

Despite a population with greater comorbidity and associated risk, outcomes remained consistent between the early and later time periods, indicating general improvements in care. The later cohort demonstrated fewer 3COs, less suboptimal realignments, and reductions in adverse events. This may suggest a greater facility with less invasive techniques and better understanding regarding when to deploy specific treatment strategies that may optimize outcomes.

Key Points

- Dramatic improvements in the field have been made as surgeons become better at identifying optimal approaches capable of maximizing outcomes while minimizing the risk of complications.
- In this context, we sought to evaluate changes in technical approaches, patient selection, and outcomes between patients treated by surgeons contributing cases to the registry.
- Despite a population with greater comorbidity and associated risk, outcomes remained consistent between the early and later time periods, indicating general improvements in care.
- The later cohort demonstrated fewer 3COs, less suboptimal realignments, and reductions in adverse events.
- This may suggest a greater facility with less invasive techniques and a better understanding regarding when to deploy specific treatment strategies that may optimize outcomes.

References


