Three-Column Osteotomy in Adult Spinal Deformity

An Analysis of Temporal Trends in Usage and Outcomes

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Background: Three-column osteotomies (3COs), usually in the form of pedicle subtraction or vertebral column resection, have become common in adult spinal deformity surgery. Although a powerful tool for deformity correction, 3COs can increase the risks of perioperative morbidity.

Methods: Operative patients with adult spinal deformity (Cobb angle of >20°, sagittal vertical axis [SVA] of >5 cm, pelvic tilt of >25°, and/or thoracic kyphosis of >60°) with available baseline and 2-year radiographic and health-related quality-of-life (HRQoL) data were included. Patients were stratified into 2 groups by surgical year: Group I (2008 to 2013) and Group II (2014 to 2018). Patients with 3COs were then isolated for outcomes analysis. Severe sagittal deformity was defined by an SVA of >9.5 cm. Best clinical outcome (BCO) was defined as an Oswestry Disability Index (ODI) of <15 and Scoliosis Research Society (SRS)-22 of >4.5. Multivariable regression analyses were used to assess differences in surgical, radiographic, and clinical parameters.

Results: Seven hundred and fifty-two patients with adult spinal deformity met the inclusion criteria, and 138 patients underwent a 3CO. Controlling for baseline SVA, PI-LL (pelvic incidence minus lumbar lordosis), revision status, age, and Charlson Comorbidity Index (CCI), Group II was less likely than Group I to have a 3CO (21% versus 31%; odds ratio [OR] = 0.6; 95% confidence interval [CI] = 0.4 to 0.97) and more likely to have an anterior lumbar interbody fusion (ALIF; OR = 1.6; 95% CI = 1.3 to 2.3) and a lateral lumbar interbody fusion (LLIF; OR = 3.8; 95% CI = 2.3 to 6.2). Adjusted analyses showed that Group II had a higher likelihood of supplemental rod usage (OR = 21.8; 95% CI = 7.8 to 61) and a lower likelihood of proximal junctional failure (PJF; OR = 0.23; 95% CI = 0.07 to 0.76) and overall hardware complications by 2 years (OR = 0.28; 95% CI = 0.1 to 0.8). In an adjusted analysis, Group II had a higher likelihood of titanium rod usage (OR = 2.7; 95% CI = 1.03 to 7.2). Group II had a lower 2-year ODI and higher scores on Short Form (SF)-36 components and SRS-22 total ($p < 0.05$ for all). Controlling for baseline ODI, Group II was more likely to reach the BCO for the ODI (OR = 2.8; 95% CI = 1.2 to 6.4) and the SRS-22 total score (OR = 4.6; 95% CI = 1.3 to 16).

Conclusions: Over a 10-year period, the rates of 3CO usage declined, including in cases of severe deformity, with an increase in the usage of PJF prophylaxis. A better understanding of the utility of 3CO, along with a greater implementation of preventive measures, has led to a decrease in complications and PJF and a significant improvement in patient-reported outcome measures.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Adult spinal deformity is a potentially debilitating condition that often requires surgical correction in order to reduce pain and improve quality of life[1]. For many patients, spinal deformity in the thoracolumbar region is semiflexible and may be successfully treated with posterior column osteotomies or multilevel interbody fusions[2,3]. There are a variety of osteotomy options available, including Smith-Petersen osteotomies (SPOs) or 3-column osteotomies (3COs, often in the form of pedicle subtraction osteotomies [PSOs] or vertebral column resection [VCR]). However, in cases of severe, rigid, kyphotic deformity, flat-back syndrome, and severe ankylosing spondylitis, among others, patients may

*A list of the International Spine Study Group members is included in a note at the end of the article.

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often require the more invasive 3CO in order to achieve adequate correction[3-5].

Despite being highly effective in restoring alignment, 3COs carry a substantial risk of complications, with postoperative morbidity occurring in as many as 40% to 60% of cases[6-9]. Since 2010, an increasingly patient-centered, more conservative approach toward optimum realignment goals in adult spinal deformity surgery has been appreciated, including the development of the age-adjusted criteria[10]. The utility of the 3CO in achieving desired alignment goals is well documented in the literature; however, because of the complexity, invasiveness, and inherent risks of a 3CO, this approach may be declining over time[11]. The impact of this temporal trend in the use of this operative approach for adult spinal deformity correction currently has an unknown impact on outcomes, including complications as well as patient-reported measures.

In this context, we sought to retrospectively evaluate changes in the use of the 3CO as well as associated alterations in postoperative morbidity and outcomes among patients whose data were reported to the multicenter registry of the International Spine Study Group (ISSG). The current work spans the treatment of patients between 2008 and 2018, with minimum 2-year radiographic and clinical follow-up. We hypothesized that patients treated within the most recent 5-year period would be less likely to have received a 3CO and would also have lower rates of postoperative complications with concomitantly superior patient-reported outcomes.

Materials and Methods

Study Design

We conducted a retrospective cohort review of a prospective, multicenter adult spinal deformity registry maintained by the ISSG. Prior to enrollment and initiation of the study, institutional review board approval was obtained. Patients were consecutively enrolled from 13 participating centers, with data-set inclusion criteria consisting of patients ≥18 years of age who underwent surgical intervention for adult spinal deformity with fusion to the pelvis. Radiographically, adult spinal deformity was defined as pelvic tilt (PT) of >25°, sagittal vertical axis (SVA) of >5 cm, Cobb angle of >20°, and/or thoracic kyphosis of >60°. The reasons for exclusion and loss to follow-up are shown in Appendix A. Routine audits, data checks, and yearly updates by dedicated research staff at each institution ensure high fidelity and validity of the data elements entered. Patients with available baseline and 2-year radiographic and health-related quality-of-life (HRQoL) data were included in the present investigation.

Data Collection and Radiographic Parameters

Standardized forms were utilized for collection of data on demographic and surgical parameters. Baseline demographic characteristics collected were age, body mass index (BMI), Charlson Comorbidity Index (CCI), biological sex, and Adult Spinal Deformity Frailty Index. Operative details compiled included levels fused, operative time, estimated blood loss, surgical approach, usage and types of osteotomies, decompressions, invasiveness index, usage of proximal junctional kyphosis (PJK) prophylaxis (e.g., hooks, tethers, cement at the proximal extent of the fusion construct), and usage of supplemental rods. "Overall hardware complications" included the following: rod dislocation, a painful implant, implant prominence, screw breakage, screw loosening, rod breakage, implant failure, and implant malposition, collectively occurring by 2 years postoperatively. Complication data were collected as complications occurred, or at the follow-up time points, and submitted to central ISSG research staff for evaluation and categorization. Complications were defined as "major" if there was a substantially prolonged hospitalization, an invasive intervention was required, or the complication led to prolonged or permanent morbidity or resulted in death during the first 2 years. Routine audits, data checks, and yearly updates by a dedicated research team at each institution, in conjunction with the central ISSG research staff, ensured that the database was consistently maintained at a high standard of quality. Clinical outcomes were assessed using patient-reported outcome measures administered at the time of follow-up intervals and included the Oswestry Disability Index (ODI), the Scoliosis Research Society (SRS)-22, and the Short Form (SF)-36. Free-standing full-length lateral spine radiographs (36-inch cassette) were collected and analyzed utilizing SpineView (ENSAM, Laboratory of Biomechanics) software according to previously published validated and standardized techniques.

Description of Radiographic and HRQoL Outcomes

Severe sagittal deformity was defined as an SVA of >9.5 cm, corresponding to a ++ classification per the SRS-Schwab classification of adult spinal deformity[12]. "Match" was defined as an ideal, age-adjusted, postoperative alignment according to the criteria of Lafage et al. (matched, undercorrected, or overcorrected)[10]. The best clinical outcome (BCO) for the ODI was defined as a 2-year ODI of <15, and the BCO for the SRS-22 was defined as an SRS-22 total of >4.5 on the basis of the work of Smith et al.[13]. Proximal junctional failure (PJF) was defined according to the criteria described by Lafage et al.: a proximal junctional angle of ≥28.0° and a change in the proximal junctional angle of ≥22° from baseline[14].

Statistical Analysis

Patients were stratified into 2 groups on the basis of their date of surgery: Group I, 2008 to 2013; and Group II, 2014 to 2018. This date range was selected because the earliest enrollment occurred in 2008, and the last enrollment with 2-year data occurred in 2018. The rate of 3CO usage in these 2 cohorts was assessed. Next, analyzing only those patients in Group I and Group II who had a 3CO, the number of complication events, surgical details, and patient-reported outcomes at the 2-year time point were compared between the 2 groups. Bivariate comparisons were made using t tests for continuous outcome variables and chi-square tests for categorical data. Multivariable regressions were used to conduct adjusted analyses, accounting for clinical confounders. Statistical analysis was performed using SPSS software (v21.0; IBM).

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Results

Overall Cohort

Baseline Radiographic Profile

In total, 752 patients with adult spinal deformity and complete baseline and 2-year follow-up met the inclusion criteria. Patients lost to follow-up before 2 years were more often male and underwent less invasive surgeries and had significantly different scores on HRQoL measures both at baseline and 1-year follow-up compared with those with full 2-year follow-up (see Appendices B and C). Patients had a mean age (and standard deviation) of 59.9 ± 14.0 years, BMI of 27.7 ± 6.0 kg/m^2, and CCI of 1.8 ± 1.7, and 79% of the patients analyzed were female. Patients presented radiographically at baseline with an average PT of 24.4° ± 10.8°, pelvic incidence minus lumbar lordosis (PI-LL) of 16.7° ± 21.0°, SVA of 8.1 ± 7.2 cm, and T4-T12 thoracic kyphosis of −34.3° ± 19.0°.

Surgical Overview

Operatively, patients had a mean 11.4 ± 3.9 levels fused, estimated blood loss of 1,505.6 ± 1,459.7 mL, and operative time of 378.1 ± 135.5 minutes. The most common upper instrumented vertebra (UIV) was T10 (25.4%), followed by T4 (16.2%) and T3 (12.2%). In terms of lower instrumented vertebra (LIV), 608 (81%) of the patients underwent a fusion to the pelvis, 5.7% had an LIV of L4, and 4.9% had an LIV of L5. In terms of surgical approach, 85% underwent a posterior-only and 15% underwent a combined anterior-posterior approach. The mean surgical invasiveness index was 89.8 ± 36. A total of 452 (60%) of the patients had a decompression, and 540 (72%) of the patients had an osteotomy: 59% had at least 1 SPO, 14% had a PSO, 1% had a corpectomy, and 4% had a VCR. In total, 138 (18%) of the patients underwent a 3CO. Thirty-six percent of the patients had a prior fusion. Group I included 376 patients, with 21% undergoing a 3CO. Group II included 376 patients, with 16% undergoing a 3CO.

Isolated Cohort of Patients with 3CO

Overview and Baseline Radiographic Profile

One hundred and thirty-eight patients with adult spinal deformity and complete baseline and 2-year follow-up met the inclusion criteria and were isolated for analysis. Group I consisted of 79 patients, and Group II consisted of 59 patients. The mean patient age was 62.7 ± 11.2 years, BMI was 28.9 ± 5.5 kg/m^2, CCI was 2 ± 1.8, and 72% of the patients were female. The results of an analysis of differences in baseline demographics and radiographic parameters between the 3CO cohorts is shown in Table I. Figure 1 presents a patient from Group I treated utilizing a PSO, and Figure 2 presents a Group II patient managed alternatively.

TABLE I Baseline Demographic and Radiographic Differences Between the 3CO Groups

Parameter	Group I	Group II	P Value
Age* *(yr)*	61.5 ± 11.9	64.3 ± 9.9	0.138
Female sex	73%	69%	0.615
BMI* *(kg/m^2)*	28.8 ± 5.5	29 ± 5.6	0.793
Charlson Comorbidity Index*	1.9 ± 1.9	2.1 ± 1.73	0.574
Frailty Index*	3.9 ± 1.54	3.7 ± 1.5	0.334
Pelvic tilt* *(°)*	31.6 ± 10.2	31.5 ± 10.6	0.935
Pelvic incidence* *(°)*	56.6 ± 13.8	59.5 ± 14.8	0.238
PI-LL* *(°)*	31.6 ± 20.3	32.4 ± 24.3	0.813
T4-T12 thoracic kyphosis* *(°)*	−33.5 ± 23.9	−35 ± 23.2	0.571
SVA C7-S1* *(cm)*	12.5 ± 7.5	11.7 ± 8.1	0.564

*The values are given as the mean and standard deviation.

Surgical Overview

Operatively, patients had a mean 12.4 ± 3.9 levels fused, estimated blood loss of 2,937.7 ± 1,939.7 mL, and operative time of 424.4 ± 130.5 minutes. In terms of surgical approach, 85% underwent posterior-only and 15% underwent a combined anterior-posterior approach. A comparison of surgical details between the 3CO cohorts is shown in Table II.

Analysis of Differences in Overall Cohort

Controlling for baseline SVA and PI-LL, history of revision, age, and CCI, patients in Group II were less likely to receive a 3CO (21% versus 31%; odds ratio [OR] = 0.6; 95% confidence interval [CI] = 0.4 to 0.97; p = 0.02). Among an isolated cohort of 317 patients who matched the age-adjusted SVA or PI-LL postoperatively, an adjusted analysis showed that Group II had a lower likelihood of 3CO usage (OR = 0.53; 95% CI = 0.27 to 0.98; p = 0.03). In a cohort of 226 patients with severe sagittal deformity, an adjusted analysis showed that Group II had a lower likelihood of receiving a 3CO (OR = 0.45; 95% CI = 0.2 to 0.8; p = 0.012). Regarding the type of prophylaxis, Group II had a higher usage of hooks (26% versus 14%; p = 0.001), tethers (33% versus 3.4%; p = 0.001), and minimally invasive posterior spinal fusion (MIS PSF, 26% versus 0%; p ≤ 0.001). Multivariable results are shown in Table III.

Analysis of Differences in Isolated 3CO Cohort

Multivariable analysis controlling for age, baseline deformity, CCI, and invasiveness showed that Group II had a higher likelihood of PJK prophylaxis using hooks, tethers, and/or cement (OR = 2; 95% CI = 0.86 to 4.7; p = 0.11), and a higher likelihood of supplemental rod usage (OR = 21.8; 95% CI = 7.8 to 61; p = 0.001). Group II had a higher usage of tethers (18% versus 3%; p = 0.008) and MIS PSF (5% versus 0%; p = 0.069). Multivariable results are shown in Table IV.

Fig. 1

Radiographic images of a 72-year-old female patient with the following baseline radiographic profile: PT of 30.1°, PI of 60.1°, PI-LL of 33.8°, C7-S1 SVA of 19.4 cm, and a coronal C7 plumbline of 4.2 cm. Postoperatively, the patient had a PT of 22.7°, PI-LL of 8.3°, SVA of 10.2 cm, and a coronal C7 plumbline of 6.0 cm. Correction was achieved with an L3 PSO.

Differences in Postoperative Realignment in 3CO Cohort

There were no significant differences between the groups with respect to the number of patients matching age-adjusted PT, SVA, or PI-LL. Additionally, there were no significant differences in the number of patients who had "0" deformity per the SRS-Schwab or in the measures of PT, SVA, or PI-LL at 2 years postoperatively.

Differences in Likelihood of Overall Complications, Mechanical Complications, and Revisions in 3CO Cohort

Controlling for age, CCI, baseline SVA, baseline PI-LL, and revision status, Group II experienced lower likelihood of overall complications (OR = 0.32; 95% CI = 0.117 to 0.853; p = 0.023) and reoperations (OR = 0.34; 95% CI = 0.146 to 0.793; p = 0.013), with no significant reduction in major complications. An adjusted analysis showed that Group II had a lower likelihood of developing PJF (OR = 0.23; 95% CI = 0.07 to 0.76; p = 0.017), rod breakage (OR = 0.30; 95% CI = 0.1 to 0.9; p = 0.026), overall hardware complications (OR = 0.28; 95% CI = 0.1 to 0.8; p = 0.019), and PJK revision surgeries (OR = 0.214; 95% CI = 0.08 to 0.574; p = 0.002) by 2 years (Table IV). The results of mechanical complications while controlling for usage of the anterior approach, multi-rod constructs, ALIF/LLIF (anterior lumbar interbody fusion/lateral lumbar interbody fusion), and/or prophylaxis usage are reflected in Appendix 1.

Differences in Clinical Outcomes in 3CO Cohort

Group II demonstrated a lower 2-year ODI, higher SRS-22 total and component scores, and higher SF-36 component scores. Full baseline and 2-year patient-reported outcomes are shown in Table V. Controlling for baseline disability, Group II was more likely to reach the BCO for the ODI (OR = 2.8; 95% CI = 1.2 to 6.4; p = 0.019) and SRS-22 total score (OR = 4.6; 95% CI = 1.3 to 16; p = 0.019). Multivariable results are shown in Table IV.

Differences in Material of Rods Used in 3CO Cohort

Controlling for age, CCI, baseline SVA, baseline PI-LL, and revision status, patients in Group II had a higher likelihood of titanium rod usage (OR = 2.7; 95% CI = 1.03 to 7.2; p = 0.044) (Table IV), with comparable usage of cobalt-chromium.

Analysis of Differences in Interbody Fusions in the Overall Cohort

In the full cohort of 752 patients, Group II had a higher likelihood of ALIF usage (OR = 1.6; 95% CI = 1.3 to 2.3; p = 0.025), and a higher likelihood of LLIF usage (OR = 3.8; 95% CI = 2.3 to 6.2; p < 0.001) compared with Group I. The number of levels of ALIF and LLIF can be found in Table VI. In a subanalysis to determine the use of ALIF and LLIF among non-

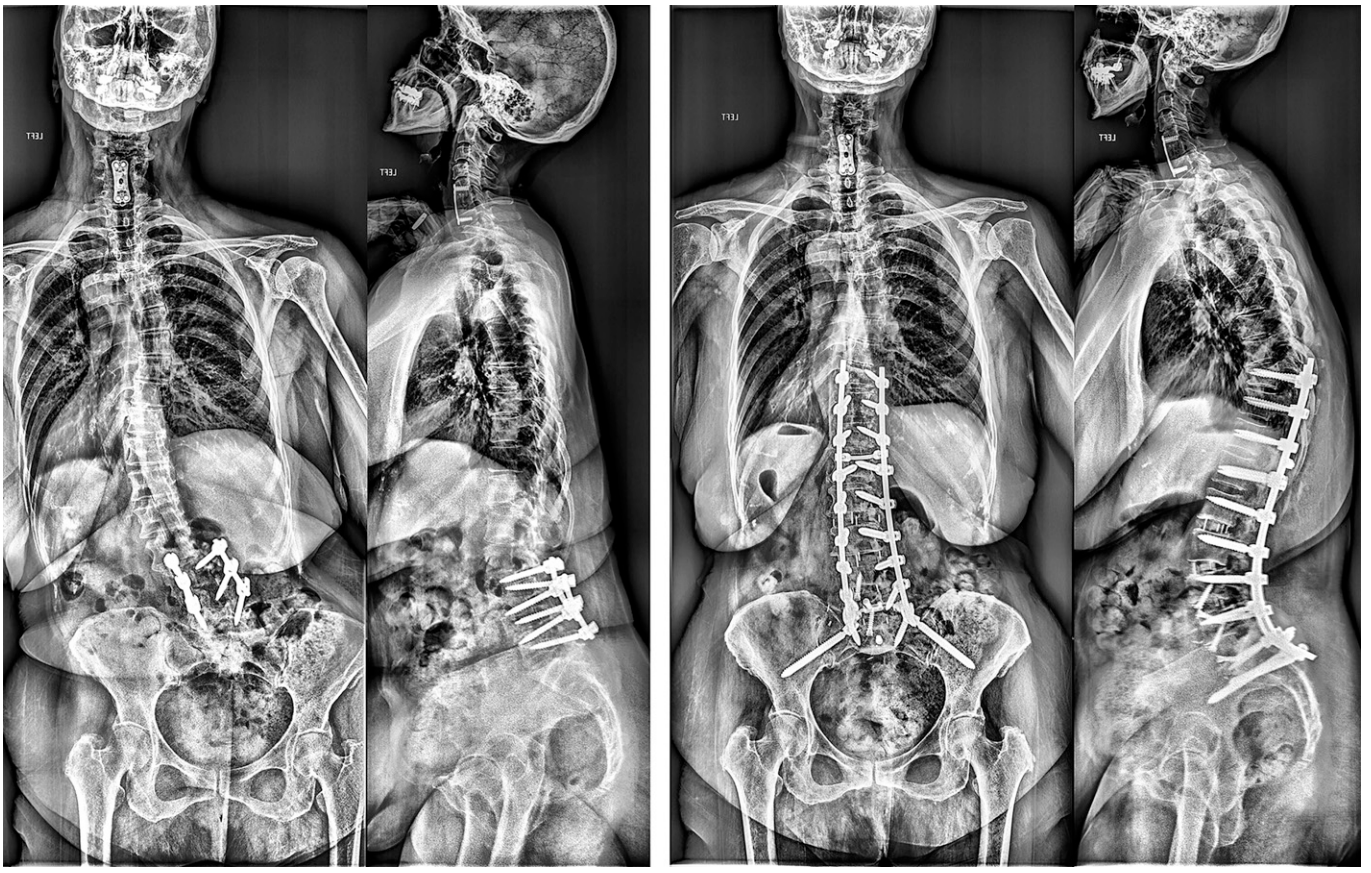

Fig. 2

Radiographic images of a 66-year-old female patient with a history of previous L3-L5 fusion with the following baseline radiographic profile: PT of 27.5°, PI of 66.3°, PI-LL of 22°, and C7-S1 SVA of 10.5 cm. Postoperatively, the patient had a PT of 20.1°, PI-LL of 2.1°, and SVA of 5.7 cm. The patient was matched in age-adjusted SVA, PT, and PI-LL by 2 years. Radiographic correction was achieved with the use of an anterior column release with lateral interbody fusion at L3-L4 and a lateral interbody fusion without anterior column release at L2-L3, as well as anterior lumbar interbody fusions (ALIFs) with robotically placed cages at the previously treated L4-S1 nonunion sites. The patient had 2 ALIFs, and pelvic screws have haloed. There is a compression fracture at the UIV.

TABLE II Comparison of Surgical Details Between 3CO Groups

Surgical Details	Group I	Group II	P Value*
Estimated blood loss† *(mL)*	3,178 ± 2,159	2,615 ± 1,560	0.091
Operative time† *(min)*	406 ± 124	450 ± 119	**0.038**
No. of levels fused	13 ± 3.9	11.7 ± 3.7	0.050
Average UIV	T7	T8	0.160
Average LIV	S1	S1	0.324
Decompression	62%	71%	0.265
Invasiveness index†	128 ± 29	112 ± 28.4	**0.003**
Anterior approach	0%	0%	
Posterior approach	79%	91%	0.057
Combined approach	21%	9%	0.057
Fused to pelvis	95%	93%	0.672
History of fusion	75%	75%	0.989

*Bold indicates a significant value ($p < 0.05$). †The values are given as the mean and standard deviation.

TABLE III Multivariable Results for the Likelihood of Receiving a 3CO Among Overall Cohort and Subgroups, and Likelihood of Minor Complications*

Variable Tested	Group II Vs. Group I	
	Odds Ratio (95% CI)	P Value
Likelihood of overall 3CO usage	0.62 (0.4-0.97)	**0.02**
Likelihood of 3CO usage among SVA or PI-LL matched patients	0.53 (0.27-0.98)	**0.03**
Likelihood of 3CO usage among patients with severe sagittal deformity	0.45 (0.2-0.8)	**0.012**
Likelihood of minor complications	0.71 (0.5-0.95)	**0.021**

*CI = confidence interval. Bold indicates a significant value ($p < 0.05$).

3CO patients, controlling for age, CCI, baseline SVA, baseline PI-LL, and revision status, patients in Group II had a higher likelihood of usage of ALIF (OR = 1.8; 95% CI = 1.2 to 2.6; p = 0.008) and a higher likelihood of usage of LLIF (OR = 3.6; 95% CI = 2.1 to 6.0; p < 0.001) compared with Group I. Multivariable results are shown in Table IV. Full multivariable results, including the controls used, are shown in Appendix 1.

Discussion

Several demographic and clinical factors have culminated in an increased prevalence of adult spinal deformity over the last 20 years. Corrective realignment has a positive impact on a patient's functionality and lifestyle, and this has contributed to an increase also seen in the prevalence of corrective surgeries for adult spinal deformity over the last 10 to 15 years[15,16]. Three-column osteotomies have the potential to restore alignment, but they also carry a substantially increased risk of complications[11]. Consequently, there may have be a declining trend in the use of such procedures since 2010 through 2013. In this analysis, we sought to evaluate changes in the use of 3COs in a multi-institutional registry between 2008 and 2018 and to assess differences in complications as well as patient-reported outcomes.

Our results indicate that, between 2014 and 2018, reliance on 3CO declined, even in cases of severe deformity. At the same time, we found an increase in the usage of PJK prophylaxis. These trends were associated with a concomitant reduction in complications as well as a significant improvement in patient-reported outcomes. One of the most interesting findings in our study is increased usage of ALIFs among Group II

TABLE IV Multivariable Results for Surgical Details, Complications, and HRQoL Outcomes*

Variable Tested	Group II Vs. Group I	
	Odds Ratio (95% CI)	P Value
Usage of prophylaxis among 3CO cohorts	2.0 (0.86-4.7)	0.11
Usage of supplemental rods among 3CO cohorts	21.8 (7.8-61)	**0.001**
Rates of overall complications among 3CO cohorts	0.32 (0.117-0.853)	**0.023**
Rates of reoperations among 3CO cohorts	0.34 (0.146-0.793)	**0.013**
Development of PJF among 3CO cohorts	0.23 (0.07-0.76)	**0.017**
Rod breakage by 2 years among 3CO cohorts	0.30 (0.10-0.9)	**0.026**
Hardware complications by 2 years among 3CO cohorts	0.28 (0.1-0.8)	**0.019**
PJK revision surgery by 2 years among 3CO cohorts	0.214 (0.08-0.574)	**0.002**
Reaching best clinical outcome for ODI among 3CO cohorts	2.8 (1.2-6.4)	**0.019**
Reaching best clinical outcome for SRS-22 total score among 3CO cohorts	4.6 (1.3-16)	**0.019**
Usage of titanium rods among 3CO cohorts	2.7 (1.03-7.2)	**0.044**
Usage of ALIF among overall cohort	1.6 (1.3-2.3)	**0.025**
Usage of LLIF among overall cohort	3.8 (2.3-6.2)	**0.001**
Usage of ALIF among non-3CO patients	1.8 (1.2-2.6)	**0.008**
Usage of LLIF among non-3CO patients	3.6 (2.1-6.0)	**<0.001**

*Bold indicates a significant value ($p < 0.05$). PJF = proximal junctional failure, LLIF = lateral lumbar interbody fusion, and ALIF = anterior lumbar interbody fusion.

TABLE V Comparison of Baseline and 2-Year Patient-Reported Outcomes Between 3CO Groups

	Group I	Group II	P Value*
Baseline HRQoL score†			
ODI	48.4 ± 18.2	44.6 ± 17.2	0.250
SF-Physical Component Score	29.7 ± 9.1	29.3 ± 9.9	0.801
SF-Mental Component Score	42 ± 15.5	45 ± 13.8	0.248
SRS-22 activity	2.6 ± 0.9	2.8 ± 0.83	0.468
SRS-22 pain	2.2 ± 0.8	2.3 ± 1.0	0.435
SRS-22 appearance	2.1 ± 0.7	2.2 ± 0.8	0.353
SRS-22 mental	3.2 ± 1.0	3.4 ± 0.9	0.099
SRS-22 satisfaction	2.7 ± 1.1	2.7 ± 1.1	0.766
SRS-22 total	2.6 ± 0.7	2.7 ± 0.7	0.290
SF-36 physical functioning	27.3 ± 10.5	28.2 ± 10.6	0.480
SF-36 role physical	29.2 ± 10.9	29.7 ± 11.8	0.808
SF-36 body pain	31.4 ± 8.5	31.8 ± 9.7	0.775
SF-36 general health	43.2 ± 11.2	43.4 ± 10.2	0.895
SF-36 vitality	37.5 ± 10.2	39.7 ± 12.3	0.245
SF-36 social functioning	33.7 ± 13.4	34.4 ± 13.7	0.785
SF-36 role emotional	36.3 ± 16.1	39.3 ± 16.1	0.292
SF-36 mental health	40.6 ± 14.8	44.3 ± 11.8	0.121
2-yr HRQoL score†			
ODI	35.9 ± 20.0	26 ± 21.7	**0.012**
SF-Physical Component Score	35.8 ± 10.9	38.2 ± 12.4	0.228
SF-Mental Component Score	47.2 ± 13.6	53.0 ± 10.0	**0.008**
SRS-22 activity	3.2 ± 1.0	3.6 ± 1.0	**0.010**
SRS-22 pain	3.0 ± 1.1	3.5 ± 1.1	**0.025**
SRS-22 appearance	3.3 ± 0.82	3.6 ± 0.9	**0.045**
SRS-22 mental	3.4 ± 0.9	4 ± 0.7	**0.008**
SRS-22 satisfaction	4.0 ± 0.9	4.1 ± 1.0	0.740
SRS-22 total	3.4 ± 0.7	3.7 ± 0.8	**0.006**
SF-36 physical functioning	33.7 ± 11.7	37.0 ± 12.7	0.118
SF-36 role physical	35.4 ± 12.8	40.0 ± 11.2	**0.040**
SF-36 body pain	40.7 ± 11.2	43.2 ± 11.8	0.226
SF-36 general health	44.2 ± 11.2	47.4 ± 10.5	0.221
SF-36 vitality	44.5 ± 11.9	48.6 ± 12.8	0.070
SF-36 social functioning	39.5 ± 13.7	45.2 ± 12.9	**0.015**
SF-36 role emotional	36.3 ± 16.2	39.3 ± 16.1	**0.001**
SF-36 mental health	47.8 ± 11.6	51.1 ± 9.5	**0.078**
% achieving MCID by 2-yr follow-up			
ODI	47%	43%	0.605
SF-Physical Component Score	45%	60%	0.111
SRS-22 total	72%	75%	0.753
SRS-22 activity	60%	64%	0.665
SRS-22 mental	50%	40%	0.314
SRS-22 appearance	70%	64%	0.434
SRS-22 pain	62%	63%	0.935

*Bold indicates significant p values ($p < 0.05$). †The values are given as the mean and standard deviation. MCID = minimal clinically important difference.

TABLE VI Number of Levels of ALIF and LLIF Used Between Group I and Group II

No. of Levels	ALIF*		LLIF*	
	Group I	Group II	Group I	Group II
1	13	50	1	19
2	14	30	5	25
3	31	15	10	23
4	16	3	8	14
5	3	4	3	
6	7		1	

*The values are given as the number of patients.

patients who did not receive a 3CO. Other research found that the rates of ALIF in the United States increased, in general, between 2007 and 2014, likely because of favorable clinical outcomes and low complication rates[17]. In a 2018 study, ALIFs were shown to be highly effective in restoring appropriate lumbar lordosis in mild deformity, and several studies have proposed the utility of ALIFs in the treatment of more complex deformity in which a 3CO would generally be warranted[18-20]. A 2021 systematic review by Formica et al. revealed data suggesting that an ALIF with a hyperlordotic cage was an adequate alternative for obtaining desired lumbar lordosis, with complications rates lower than those seen with a PSO[21]. The shift in the usage of ALIF in cases in which a 3CO traditionally has been used, even in cases of severe deformity, may play a sizable role in the reduction in 3CO utilization seen in Group II, as well as the lower overall complication rate found in Group II versus Group I.

We also identified meaningful reductions in rod breakage and overall hardware complications in the group of patients treated in later years. Previous work found that symptomatic rod fracture occurred commonly after PSO, most frequently at, or adjacent to, the site of the 3CO because of a high amount of mechanical stress in this region[22,23]. Similar findings were reported by Yang et al. regarding pseudarthrosis and rod fracture[24]. Scheer et al. maintained that the usage of supplemental rods could increase construct load-sharing and prevent the incidence of rod fracture[25]. In our study, among patients who had a 3CO, we found significantly higher usage of supplemental rods in Group II, and this may have contributed to the lower incidence of rod breakage. Other work indicated that the use of titanium rods was associated with a lower incidence of PJK compared with cobalt-chromium because of rod stiffness[26,27]. The usage of titanium rods was higher in Group II, while the use of cobalt-chromium remained constant, suggesting that the rod material may have also contributed to the diminished likelihood of PJF that we observed in this cohort.

Although alternative strategies have emerged, there are circumstances in which the 3CO maintains an essential role in adult spinal deformity surgery. In cases of severe and rigid coronal and/or sagittal deformity, iatrogenic flatback, ankylosing spondylitis, or previous multilevel fusion, a 3CO may be the best option to restore appropriate spinal alignment[28-32]. Quarto et al. stated specifically that cases of fusions with previous multiple anterior interbody cages and persistent coronal or sagittal imbalance are candidates for a 3CO[29].

Limitations

There were several limitations to this study, outside of those that are normally present in works with a retrospective study design. Although the data are derived from multiple surgeons and centers participating in this study group, there was still the prospect for selection, indication, and expertise bias to confound results. In addition, this bias may extend to the patients lost to follow-up, for whom patient satisfaction or other possible factors involving either the provider or treatment may be the reasoning for the discontinuation of care. Additionally, it should be mentioned that patients lost to follow-up may have experienced different outcomes from the results of this study. While we believe that the members of this international study group engage in practices that are reflective of general trends in the field of spinal deformity surgery as a whole, there is the prospect of clustering based on surgical center, surgical training, and practice patterns, which could further confound results. This may have a greater prospect for influence over the post-surgical outcome measures as opposed to the tendency to use 3COs, which may consequently be more generalizable to the field as a whole. We recognize that our determinations regarding improved outcomes following reduction in the use of 3COs merit further validation in independent cohorts of patients derived from different centers.

Conclusions

Over a 10-year period, we documented a reduction in the usage of 3CO for patients treated for adult spinal deformity, including in cases of severe deformity. Over the same period, there was an increase in the application of techniques for PJK prophylaxis. These temporal trends were associated with reductions in complications and PJF as well as a significant improvement in patient-reported outcome measures.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/H180). ■

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