eC **A commentary by Federico Mancini, MD, and Ernesto Ippolito, MD,** is linked to the online version of this article at jbjs.org.

# Predictors of Revision Surgical Procedure Excluding Wound Complications in Adult Spinal Deformity and Impact on Patient-Reported Outcomes and Satisfaction

## A Two-Year Follow-up

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**Background:** The surgical procedure to treat adult spinal deformity is challenging, with high rates of complications, including revision procedures performed to repair instrumentation failure or unplanned surgical complications. This study quantifies the incidence of, identifies predictors for, and determines health-related quality-of-life changes associated with revision procedures to treat adult spinal deformity.

**Methods:** We analyzed a multicenter database of patients who underwent a surgical procedure for adult spinal deformity, which was defined as having an age of eighteen years or older and scoliosis of ≥20°, sagittal vertical axis of ≥5 cm, pelvic tilt of ≥25°, and/or thoracic kyphosis of >60°. We focused on demographic, radiographic, health-related quality-of-life, and operative data at the two-year follow-up. Patients with primary infections were excluded. Predictive and confounding variables for revisions were identified using univariate analysis and multivariate logistic regression modeling.

**Results:** Two hundred and forty-three patients were included in this study; of these patients, forty (16.5%) underwent a revision surgical procedure (15% of these at six weeks, 38% between six weeks and one year, and 48% between one and two years). Screw or cage-related implant complications were the most common indications for revision, followed by proximal junctional kyphosis and rod failure. Positive predictors for a revision surgical procedure included total body mass, with an odds ratio of 1.33 (95% confidence interval, 1.04 to 1.70) per 10-kg increase, and preoperative sagittal vertical axis, with an odds ratio of 1.15 (95% confidence interval, 1.04 to 1.28) per 2-cm increase. Factors associated with lower risk of revision included use of bone morphogenetic protein-2 (BMP-2) (odds ratio, 0.16 [95% confidence interval, 0.05 to 0.47]) and greater diameter rods (odds ratio, 0.51 [95% confidence interval, 0.29 to 0.89]). Body mass index, although initially considered a potential predictor for a

*continued*

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revision surgical procedure, was not significantly different between primary and revision cohorts on univariate analysis and was therefore not input into the multivariate model. All patients improved in two-year health-related quality-of-life scores; revision subjects had lower overall improvement (Scoliosis Research Society [SRS] score; p = 0.016) from baseline. Revision status did not predict two-year patient satisfaction (p = 0.726), as measured by the SRS Satisfaction domain (SRS-22r).

**Conclusions:** Patients with greater preoperative sagittal vertical axis and high total body mass are at a higher risk for a revision surgical procedure following procedures to treat adult spinal deformity. Larger diameter rods and BMP-2 were associated with decreased revision odds. Revisions did not impact patient satisfaction at two years.

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

Adult spinal deformity negatively impacts quality of life and is increasing in prevalence with aging populations, affecting 9% of adults[1-4]. Surgical treatment is indicated for substantial deformity-related pain or disability resistant to non-operative measures or for deformity progression. Operative treatment advances and increased biomechanical understanding of adult spinal deformity are reflected in higher patient satisfaction and functional improvement[5]. Deyo et al. reported that complex spinal arthrodesis rates, primarily corrective surgical procedures to treat adult spinal deformity, increased fifteenfold from 2002 to 2007[6].

Surgical procedures to treat adult spinal deformity are technically challenging, with high rates of postoperative complications[7-9]. Yadla et al. reviewed 3299 patients undergoing a spine surgical procedure, with 41.2% experiencing perioperative adverse events[9]. Cho et al. reported a major complication rate of 34.3% in patients undergoing a long revision spinal surgical procedure by surgeons experienced in treating deformity[10]. Complication risk has increased among revision spinal arthrodeses, with less favorable outcomes and higher complication rates relative to primary surgical procedures[11]. Pichelmann et al. reported a 9% revision rate in 643 consecutive patients undergoing a surgical procedure to treat adult spinal deformity with follow-up of up to twenty-two years[12]. Rajaee et al. reported increased hospital charges associated with revision spinal arthrodeses[13]. The current study determined demographic, surgical, and radiographic risk factors for non-infection-related unplanned revisions following the initial surgical procedure to treat adult spinal deformity at a minimum two-year follow-up and evaluated the revision impact on health-related quality of life compared with patients with adult spinal deformity not requiring secondary procedures.

## Materials and Methods

This is a multicenter, retrospective review of prospectively acquired data for consecutive patients undergoing a surgical procedure to treat adult spinal deformity from 2009 to 2012 at eleven U.S. centers.

### *Study Design and Inclusion Criteria*

Prior to initiation, each site obtained institutional review board approval. The three inclusion criteria were: (1) patient age of eighteen years or older, (2) scoliosis of ≥20°, sagittal vertical axis (distance between C7 plumbline and posterior superior margin of the sacrum) of ≥5 cm, pelvic tilt of ≥25°, and/or thoracic kyphosis of >60°, and (3) a surgical procedure for sagittal plane deformity. Included subjects had complete demographic, radiographic, health-related quality-of-life, and operative data at the two-year follow-up. Patients with spinal deformity of neuromuscular etiology, active infections or malignancies, or inadequate operative data were excluded. Patients were assigned to one of two groups: (1) primary surgical procedure only with no revision surgical procedure within two years postoperatively, or (2) primary surgical procedure with at least one revision within the two years of follow-up.

### *Data Collection and Analysis*

Patient demographic characteristics, surgical date, complications, reoperation dates, and health-related quality-of-life outcomes were collected. Health-related quality-of-life outcomes and follow-up dates were collected and were calculated from the primary surgical procedure. Reoperation was defined as an unplanned return to the operating room resulting from the primary surgical procedure. Reoperations performed because of wound-related problems, including wound infection and/or dehiscence, were excluded. This decision was made prior to study initiation by a group of enrolling surgeons, such that only revisions due to instrumentation repair, repeat arthrodesis, or extension of instrumentation were analyzed. Revisions were

**TABLE I Time to Revision Surgical Procedure and Causes of Revision***

| Reason for Revision | Perioperative to Six Weeks (N = 6) | Six Weeks to One Year (N = 15) | One Year to Two Years (N = 19) | Total |
|---|---|---|---|---|
| Implant | 2 | 3 | 4 | 9 |
| Neurologic | 2 | 0 | 1 | 3 |
| Proximal junctional kyphosis | 0 | 7 | 1 | 8 |
| Rod breakage or pseudarthrosis | 0 | 2 | 9 | 11 |
| Instability | 0 | 3 | 0 | 3 |
| Other | 2 | 0 | 4 | 6 |

*The values are given as the number of patients.

**TABLE II Univariate Analysis of Potential Predictors Included in the Multivariate Regression**

| Predictor | Nonrevision Group* | Revision Group* | P Value† |
|---|---|---|---|
| Baseline patient demographic characteristic | | | |
| ASA grade | 2.23 | 2.38 | 0.21 |
| Baseline SRS activity score | 3.03 points | 2.81 points | 0.2 |
| Medical history of leg weakness | 45% | 57% | 0.23 |
| Age older than 65 years | 27% | 37.5% | 0.18 |
| Total body mass | 71.9 kg | 75.4 kg | 0.23 |
| Baseline radiographic parameter | | | |
| C7 sagittal vertical axis | 49.32 mm | 84.18 mm | 0.0075 |
| Coronal balance | 30 mm | 45 mm | 0.0075 |
| Coronal inclination | 3.21° | 4.69° | 0.0106 |
| Pelvic incidence minus lumbar lordosis | 12.6° | 17.5° | 0.18 |
| Surgical factor | | | |
| Demineralized bone matrix posterior | 31% | 42.5% | 0.16 |
| BMP-2 posterior | 63% | 47% | 0.043 |
| BMP-2 interbody | 32% | 17% | 0.05 |
| Rod diameter | | | 0.18 |
| 4.5 mm | 59% | 67% | |
| 5.5 mm | 11% | 17% | |
| 6.0 mm | 30% | 15% | |
| Pedicle subtraction osteotomy | 13.8% | 22.5% | 0.16 |
| Three-column osteotomy | 17.8% | 30% | 0.078 |
| Smith-Petersen osteotomies | 3% | 1.9% | 0.044 |

*The values are given as the mean. †Variables with a p value of <0.25 on univariate analysis were considered to be potential predictors of a revision surgical procedure and were considered when building the multivariate logistic regression model.

related to surgical technique and factors that could impact outcomes. The major complications that were analyzed were classified as implant-related, neurological, radiographic, and other. Intraoperative complications were recorded in the operating room, and postoperative complications were monitored until two years postoperatively. Determination of the complication and the indication of the cause of reoperation were made by the surgeon managing each patient.

Demographic information was collected at baseline, and health-related quality-of-life outcomes, including the Oswestry Disability Index (ODI)[14], Short Form-36 Health Survey Mental Component Summary (SF-36 MCS) and SF-36 Physical Component Summary (SF-36 PCS)[15], back and leg pain numerical rating scale, and Scoliosis Research Society Patient Questionnaire (SRS-22r)[16], were collected at all time points (baseline, six weeks, one year, and two years). Patient satisfaction was analyzed using the SRS-22r patient satisfaction domain. Radiographic parameters included sagittal vertical axis, pelvic tilt, pelvic incidence, lumbar lordosis, and pelvic incidence minus lumbar lordosis mismatch.

Total body mass, number of anterior or posterior levels instrumented, number of interbody arthrodeses, operative time (minutes), length of hospital stay (days), upper instrumented vertebra, presence of three-column osteotomies (including pedicle subtraction osteotomy and vertebral column resection), interbody fusion use, approach (posterior, anterior, extreme lateral interbody arthrodesis, anterior lumbar interbody arthrodesis), and rod diameter or type were assessed. Smoking history, Charlson Comorbidity Index scores, and American Society of Anesthesiologists (ASA) performance status grades were collected and were assessed for correlation with the risk of an early unplanned revision.

### *Statistical Analysis*

Patients who were undergoing revision and those who were not were compared with use of t tests and chi-square tests. Multivariate logistic regression modeling determined revision predictors. Variables with p values of <0.25 on univariate analysis were considered potential revision predictors and were evaluated during multivariate logistic regression model building. The model was built using backward elimination, bootstrap selection, and expert opinion. Significance was determined at $p < 0.05$. The final model had ten events per variable. Model fit was assessed with use of the Hosmer-Lemeshow test and C statistic or receiver operating characteristic (ROC) curve, with a Hosmer-Lemeshow p value of >0.05 and ROC curve of >0.70 considered adequate.

Multivariate logistic regression modeling, adjusting for potential confounders, determined the impact of revision surgical procedure on satisfaction. Multivariate repeated-measures mixed models measured the impact of revision on health-related quality of life: the two patient cohorts (revision compared with nonrevision), time (weeks since the primary surgical procedure up to two years postoperatively, with measurement follow-up time points at baseline, six weeks, one year, and two years), and the interaction between group and time were considered. The models were adjusted for known confounders of health-related quality of life: age, comorbidities (Charlson Comorbidity Index score), total body mass, major complications other than revision, and magnitude of the surgical procedure.

## Results

Two hundred and forty-three patients undergoing operative treatment for adult spinal deformity were included. Forty patients (16.5%) required revisions within two years of the primary procedure. Age, comorbidities, magnitude of the surgical procedure, such as construct length, and major complications were accounted and controlled for in the multiple regression analysis. Of the 696 patients excluded, 205 were operatively treated

**TABLE III Baseline and One-Year Postoperative Values for Pelvic Tilt, Lumbar Lordosis, and Thoracic Kyphosis for the Nonrevision Group and the Revision Group**

| | Nonrevision Group* | Revision Group* |
|---|---|---|
| Pelvic tilt | | |
| At baseline | 22.77° | 24.76° |
| At 1 year postoperatively | 20.90° | 23.30° |
| Lumbar lordosis | | |
| At baseline | 42.13° | 39.81° |
| At 1 year postoperatively | 52.11° | 50.24° |
| Thoracic kyphosis | | |
| At baseline | −31.24° | −32.46° |
| At 1 year postoperatively | −43.69° | −50.69° |

*The values are given as the mean.

and were excluded because of incomplete follow-up data. Of these 205 cases, eighteen required revisions: four were isolated wound and infection complications and fourteen (6.8%) constituted excluded revisions in this analysis due to incomplete data. The most prevalent cause for revision among these patients was implant complications (n = 6). Among the 205 excluded patients, 135 did not reach the two-year follow-up. Revisions occurred in five of these cases (3.7%). If these 135 cases had been included in the present analysis, the total revision rate would have been 11.9% (forty-five revisions of 378 patients). These additional five excluded revision cases constitute 1.3% of revisions in the total cohort; the reported revision rate in this study of 16.5% does not underestimate the rate in the entire utilized database given the number of excluded patients.

The mean estimated blood loss was 1734.46 mL for the patients undergoing the primary surgical procedure and 2021.98 mL for the patients undergoing the revision surgical procedure. The mean duration of the surgical procedure was 391.44 minutes for the primary surgical procedure and 412.95 minutes for the revision surgical procedure. The mean time to revision was 193.74 days. Table I shows time to revision and causes of revisions: 15% of revisions occurred within six weeks, 38% occurred within six weeks to one year, and 48% occurred within one to two years of the primary procedure. Revisions performed in the early postoperative period (zero to six weeks) were mainly related to implant complications or neurologic symptoms. Proximal junctional kyphosis, kyphosis above the uppermost instrumentation, was the predominant cause of revision six weeks to one year after the primary procedure, and rod breakage or pseudarthrosis was the principal reason for revision one to two years postoperatively. Proximal junctional kyphosis caused 46.7% of revisions from six weeks to one year compared with 5.3% from one year to two years (p = 0.0037). For proximal junctional kyphosis revisions, the upper instrumented vertebra was T3 to T12 (mean, T8). The proportion of revisions that were due to rod breakage or pseudarthrosis (failed fusion in which bone segments remain separated) was 13.3% from six weeks to one year compared with 47.4% from one year to two years (p = 0.048). Table II displays potential revision predictors from univariate analysis that were included in the multivariate regression. Baseline patient characteristics considered as potential revision predictors include ASA grade, baseline SRS-22r activity score, medical history of leg weakness, age older than sixty-five years, and total body mass (the ranges were 43.2 to 125.6 kg for the nonrevision group and 45.8 kg to 120 kg for the revision group).

Total body mass was found to be an independent predictor, but BMI was not, a finding that is consistent with previous and ongoing analyses, as total body mass reflects the absolute strain that is seen on the spinal implants that can potentially lead to failure and the need for revision. However, BMI is a reflection of physiologic status, which was not one of the leading causes of revision surgical procedures. Using BMI is not statistically accurate in this series. Anecdotally, a patient may have a high BMI but a lower body mass because of his or her height. This patient would have the same spinal implants placed, which would see different forces that can lead to failure of implants in high-demand adult deformity cases with corrections performed. As BMI was not considered a potential predictor of revision (p = 0.63 on univariate analysis), baseline radiographic parameters considered as potential predictors included the C7 sagittal vertical axis, pelvic incidence minus lumbar lordosis, coronal balance, and coronal inclination. Coronal balance and inclination are measures of global alignment determined using thoracolumbar or lumbar Cobb angles and the C7 plumbline. Table III displays radiographic parameter values in patients undergoing a primary surgical procedure and those undergoing a revision surgical procedure. Surgical factors considered include use of demineralized bone matrix (posterior), bone morphogenetic protein 2 (BMP-2) (posterior and interbody), rod diameter, and pedicle subtraction osteotomies, three-column osteotomies, or Smith-Peterson osteotomies. Improvements in sagittal balance were seen in patients undergoing osteotomy; the mean sagittal vertical axis improvement among revisions was 4.62 mm for patients undergoing osteotomy, 28.68 mm for patients undergoing revision, and

**TABLE IV Results of Multivariate Logistic Regression of Independent Predictors of a Revision Surgical Procedure**

| Predictor | Odds Ratio* | P Value |
|---|---|---|
| Total body mass (per 10-kg increase) | 1.33 (1.04 to 1.70) | 0.021 |
| Use of BMP-2 | 0.16 (0.05 to 0.47) | 0.001 |
| Rod diameter (per 2-cm increase) | 0.51 (0.29 to 0.89) | 0.018 |
| Sagittal vertical axis (per 1-mm increase) | 1.15 (1.04 to 1.28) | 0.006 |

*The values are given as the odds ratio, with the 95% CI in parentheses.

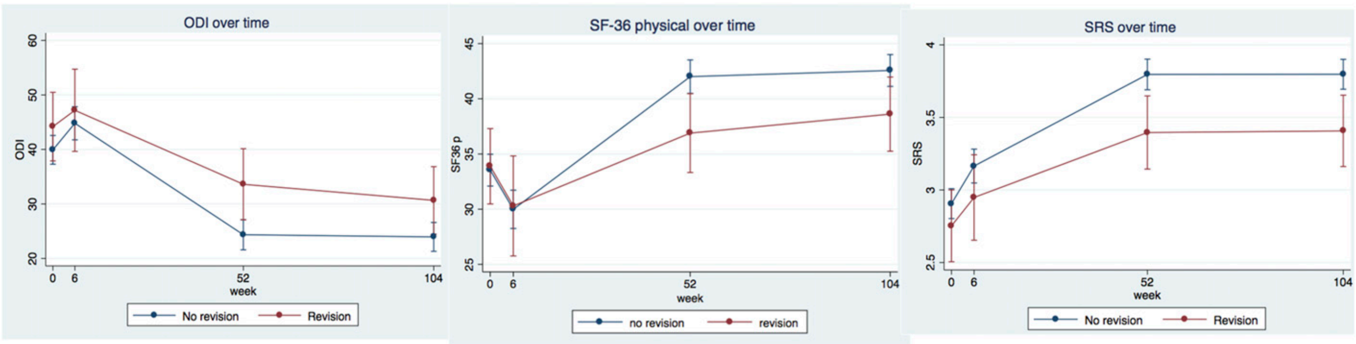


Fig. 1
Patient-reported outcomes (ODI, SF-36 PCS, and SRS) over time in the group that underwent revision and the group that did not undergo revision, accounting for confounders (age, comorbidities, magnitude of surgical procedure, and major complications). The error bars indicate 95% CI.

25.92 mm for patients not undergoing revision. The Appendix displays surgical approach distributions and six-week postoperative correction parameters for primary and revision cohorts.

Table IV shows the results of multivariate logistic regression. Positive predictors associated with revision include increased total body mass (odds ratio [OR], 1.33 [95% confidence interval (95% CI), 1.04 to 1.70] per 10-kg increase in total body mass) and increased preoperative sagittal malalignment measured by sagittal vertical axis (OR, 1.15 [95% CI, 1.04 to 1.28] per 2-cm increase in sagittal vertical axis). Negative predictors include BMP-2 use in the interbody graft (OR, 0.16 [95% CI, 0.05 to 0.47]) and increased rod diameter (OR, 0.51 [95% CI, 0.29 to 0.89]) per millimeter. This model allows correct prediction of 85% of cases (ROC = 0.73, Hosmer-Lemeshow statistic = 0.21). These analyses were reproduced to include the one patient who underwent revision because of an isolated wound complication, and the results remained consistent.

Figure 1 shows patient-reported outcomes in the revision and nonrevision groups over time. Both groups experienced significant improvements in health-related quality of life, as measured by the SF-36 ($p = 0.0001$), ODI ($p = 0.0001$), and SRS ($p = 0.0001$). The longitudinal improvement rate over time (SF-36, $p = 0.02$) and overall improvement compared with baseline (SRS, $p = 0.016$) were lower for patients who underwent revision. Adjusting for confounders, a revision surgical procedure did not predict patient satisfaction at two years postoperatively ($p = 0.726$).

## Discussion

Following the primary surgical procedure, 16.5% of patients with adult spinal deformity underwent revision procedures, excluding those related to infections. If revision procedures related to infections had been included, the rate would have been 17.5%. Of these revisions, 15% occurred at six weeks, 38% occurred at six weeks to one year, and 48% occurred at one to two years. The revision surgical procedure rate was comparable with previous rates of 10% to 25%[17,18]. Both groups (primary surgical procedure only and revisions) were similar with regard to baseline demographic characteristics, and there was no significant difference in existing comorbidities at the time of presentation, allowing for more valid comparisons between groups. Although health-related quality-of-life measurements improved significantly in all patients following treatment regardless of revision status, patients undergoing revision saw slower and less total improvement. To our knowledge, this finding was the first to document distinctions in the rate of health-related quality-of-life outcomes among non-infection-related revisions while confirming that improvements still occur. Although this may be a reflection of the longer follow-up interval in this series, the nature of the database requires consideration of the time points at which the health-related quality-of-life surveys were collected. The same one-year health-related quality-of-life data for both groups are from the primary surgical procedure, not adjusted for time when the revision surgical procedure was performed. Despite this, the results demonstrate that reoperation within one year affects health-related quality of life at one year for the minimum one-year follow-up cohort. Revision status did not predict two-year patient satisfaction. Perhaps most importantly, this series identified characteristics independently associated with revisions: positive predictors were total body mass and the presenting sagittal vertical axis, and BMP-2 use and thicker rods were associated with decreased revision odds.

### *Total Body Mass*

Debate exists surrounding obesity's association with complications, failed reconstructions, or reoperations after spinal surgical procedures; the meta-analysis by Jiang et al. showed increases in surgical site infection rate (OR, 2.33 [95% CI, 1.94 to 2.79]), venous thromboembolism (OR, 3.15 [95% CI, 1.92 to 5.17]), mortality (OR, 2.6 [95% CI, 1.50 to 4.49]), revision rate (OR, 1.43 [95% CI, 1.05 to 1.93]), operative time (OR, 14.55 [95% CI, 10.03 to 19.07]), and blood loss (mean difference, 28.89 mL [95% CI, 14.20 to 43.58 mL])[19]. Most studies in that meta-analysis were retrospective. Our study presents total body mass as a positive revision predictor, using prospectively collected clinical information. Our analysis showed that BMI did not predict revision, an interesting finding, as total body mass was an independent revision predictor. BMI may be a predictor of sustaining a medical complication that does not necessarily require a reoperation, whereas extra total body mass overall may place additional stress on the construct. This is consistent with previous and ongoing analyses as total body mass reflects the absolute strain that is seen on the spinal implants that can potentially lead to failure and the need for revision. However, BMI is a reflection of physiologic status and comorbid conditions, which were not one of the leading causes of revision surgery. Supporting this, a prior report indicated that BMI of ≥30 kg/m$^2$, although significantly increasing the incidence of major complications and wound infections, did not increase the risk for either radiographic complications or a revision surgical procedure[20]. Similarly, in evaluating risk factors for rod fracture, Akazawa et al. reported that obesity (BMI of ≥25 kg/m$^2$) did not increase the risk of breakage[21]. Consequently, total body mass, not BMI, may lead to nonunion or instrumentation issues, but further study is warranted.

### *Rod Diameter*

Rod diameter negatively predicted revision. Prince et al. prospectively assessed the effects of rod diameter on correction in adolescent idiopathic scoliosis after posterior spinal instrumentation and arthrodesis, using a multicenter database: patients receiving 5.5-mm rods had no difference in coronal plane correction compared with those receiving 6.35-mm rods. Missing from this analysis are postoperative clinical outcomes, as many studies have shown that radiographic improvement does not necessarily correlate with health-related quality-of-life improvement[11]. Although our database did not include rod composition information, Smith et al. demonstrated lower rod-failure rates with cobalt-chromium than with titanium alloy or stainless steel rods following pedicle subtraction osteotomies[22]. Rod diameter influences spinal device mechanical features. The percentage of load transferred to the disc varies according to load and instrumentation stiffness[23]. An in vitro biomechanical study showed that different diameter and material can modulate rod stiffness to withstand weight-bearing forces, but optimal stiffness requirements to obtain stable fusion or dynamic stabilization are unknown[23].

### *Sagittal Vertical Axis*

Cho et al. reported that patients requiring revisions, compared with patients not requiring revisions, presented with smaller preoperative lumbar lordosis (−32.3° compared with –46.1°; $p < 0.0001$) and a greater sagittal vertical axis (78.3 mm compared with 5.9 mm; $p < 0.0001$) at baseline prior to the corrective surgical procedure, despite similar initial patient health-related quality-of-life outcomes[24]. Although the specific reason for this is difficult to determine given our sample size limitations, it is conceivable that these more severe baseline radiographic measurements require greater pelvic parameter improvements at the time of the corrective surgical procedure. The lack of achieving both appropriate levels of lumbar lordosis relative to inherent pelvic parameters and an optimal sagittal vertical axis following an adult spinal deformity surgical procedure is associated with inferior outcomes. Equally important was the failure of the two-year sagittal vertical axis to predict revision. Cho et al. reported significant differences in the sagittal vertical axis at the final follow-up between adult patients with scoliosis undergoing a revision procedure and those undergoing a primary procedure, and differences in the interval change in the sagittal vertical axis were a risk factor for late complications among patients in the revision group[10]. Our series' findings likely reflect our study design, as our focus was determining baseline patient, surgical, and radiographic predictors of revision. Immediate postoperative radiographic achievements are critical for optimizing clinical outcomes, and future studies are ongoing to evaluate this.

### *BMP-2*

Use of rhBMP-2 for spine arthrodeses as an alternative or supplement to bone graft is controversial[25]. Although obviating the use of harvesting bone graft might reduce blood loss and operative times and might eliminate adverse events (hematoma, infection, chronic pain)[26,27], there are reports of complications associated with BMP use: obstructive airway edema in anterior cervical surgical procedures[28], ectopic bone formation[29], and increased cancer risk[30]. However, an extensive literature review found no association between BMP use and promotion of tumorigenesis or metastasis at a routine follow-up[31]. Our study demonstrated an association between BMP-2 use and decreased revision odds, a similar finding to that reported by Dagostino et al. in their large population-based database study[32]. BMP use correlated with a significant increase in hospital charges[32]. It is important for surgeons to consider the risk-benefit ratio of using BMP-2 compared with autologous bone graft and to assess current literature on BMP-2 use in spine surgical procedures.

Careful planning and alignment, termination of fixation, and precautions avoiding malposition or instrumentation failure might minimize reoperation requirements. However, the intergroup difference in reoperations disappeared with age. Patients undergoing primary and revision procedures who were older (younger than sixty years of age) reported lower preoperative function scores than younger patients. Older age was more important than revision status in determining preoperative health conditions.

### *Limitations*

The database's structure engenders multiple limitations. Radiographic parameters were reported preoperatively and at six weeks, one year, and two years postoperatively, so reporting these values immediately following the surgical procedure or revision is not possible. Additionally, the lack of complete follow-up data among certain patients who underwent operative procedures, some of which were revisions, did not permit their inclusion despite the potential relevance of these cases to our analysis. Despite quality control and collection data assurance, the results presented reflect surgeons' varying practices, contributing to the information gathered; our results therefore encompass different instrumentation techniques, degrees of correction, and surgical approaches, such that revision indications were not standardized. Regarding rod size, we acknowledge the potential for superior instrumentation biomechanics to negate the merits of size. This database only includes patients treated after 2008, thereby including modern instrumentation techniques.

### *Clinical Implications*

In conclusion, although a corrective surgical procedure to treat adult spinal deformity carries risk, potentially modifiable patient and surgical factors can mitigate this. Our analysis showed a 16.5% revision rate after the primary surgical procedure. Positive revision surgical procedure predictors were greater total body mass and worse sagittal vertical axis; negative predictors were use of thicker rods and BMP-2 use. Implant-related complications were the most common reoperation indicators. Health-related quality of life for patients undergoing revision improved, albeit more slowly than that for those not undergoing revision. Reoperation need may be minimized by carefully considering spinal alignment, fixation termination, and surgical procedure type (presence of osteotomy).

## Appendix

eA A table showing surgical approaches and six-week postoperative correction parameters for the nonrevision and revision groups is available with the online version of this article as a data supplement at jbjs.org. ■

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