Spine

SPINE Volume 39, Number 11, pp 881-885

Revision Surgery After 3-Column Osteotomy in 335 Patients With Adult Spinal Deformity

Intercenter Variability and Risk Factors

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Study Design. Multicenter, retrospective review.

Objective. To assess rates, site variability, and risk factors for revision surgery (RS) after 3-column osteotomy (3CO).

Summary of Background Data. Complex spinal osteotomies, including 3CO, are being increasingly performed in the setting of patients with adult spinal deformity with sagittal plane deformity. Three-column osteotomy procedures are associated with high complication and RS rates, but risk factors for complications and variability across centers for revision have not been well defined.

Methods. The incidence and indications for RS in 335 patients with adult spinal deformity were analyzed. RS indications were classified as "mechanical" (MR: implant failure, pseudarthrosis, junctional failure, and loss/lack of correction) or "nonmechanical" (NMR: neurological deficit, infection, wound dehiscence, and stenosis). Risks factors for RS were analyzed using generalized linear models.

Results. Three-month and 1-year RS incidences were 12.3% and 17.6%, respectively. Single-level 3CO (n = 311) had lower RS rates than multilevel 3CO (n = 24, 15.8% *vs.* 41.7%, *P* = 0.001). The 16.7% rate for single-level lumbar 3CO included 11.4% for MR and 5.7% for NMR. For all RS, 50% of MR and 78.6% of NMR occurred within 3 months of the index surgery. There was significant variation in rates across sites (range = 6.3%–31.9%, *P* = 0.001), however low- and high-volume sites had similar rates (18.2% *vs.* 16.2%, *P* = 0.503). Patients with MR were more likely to be sagittally undercorrected at 3 months (sagittal vertical axis = 7 cm *vs.* 3.2 cm, *P* = 0.003). Patients with NMR had more caudal 3CO levels (L4 *vs.* L3, *P* = 0.014) and larger 3CO bone resections than patients who did not (34° *vs.* 24.5°, *P* = 0.003).

Conclusion. Three-column osteotomy procedures for adult spinal deformity surgery can provide significant deformity correction and lead to marked improvement in function despite established complication and revision rates. This study shows that RS is associated with lower level osteotomy and higher residual sagittal vertical axis. There is significant variability in revision rates across sites independent of site volume, suggesting potential systems and practice variations that warrant further study.

Key words: adult spinal deformity, 3-column osteotomy, pedicle subtraction osteotomy, vertebral column resection, revision surgery, complications, variability.

Level of Evidence: 4

Spine 2014;39:881–885

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Acknowledgment date: October 4, 2013. Revision date: January 13, 2014. Acceptance date: January 30, 2014.

The manuscript submitted does not contain information about medical device(s)/drug(s).

The International Study Group Foundation from Depuy Spine grant funds were received in support of this work.

Relevant financial activities outside the submitted work: board membership, consultancy, expert testimony, employment, payment for lectures, patents, royalties, payment for development of educational presentations, stocks, travel/accommodations/meeting expenses.

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DOI: 10.1097/BRS.0000000000000304

Substantial focus has been directed recently on the importance of sagittal alignment in the surgical treatment of adult spinal deformity (ASD). Although compensatory measures may help to reduce positive sagittal malalignment, these measures, including pathological elevation of pelvic tilt, have been shown to correlate with greater disability, pain, and energy expenditure.[1,2] Thus, surgical correction of spinal deformity should include recognition of the importance of re-establishing or maintaining harmonious sagittal spinopelvic alignment.[2–7]

Vertebral osteotomies may be necessary to achieve adequate correction of the deformity in cases with severe, rigid curves and may be employed to help restore both coronal and sagittal spinopelvic alignment.[8] Failure to restore or maintain sagittal alignment may place patients at greater risk of developing pseudarthrosis and loss of correction, the most commonly cited conditions requiring revision surgery (RS).[4,9]

The spinal osteotomies that have the potential to produce the greatest correction of spinal deformity are those that extend through all three columns of the spine.[3] These 3-column osteotomies (3CO) include grade 3 resections[10] such as pedicle subtraction osteotomy (PSO) and grade 4 resections[10] such as vertebral column resection. Complication rates in the literature vary widely with 20% to 61% reported for PSO and 25% to 35% for vertebral column resection.[11–13]

Although 3CO procedures are associated with greater correction of ASD, there have been a wide range of reported revision rates in these procedures. At a minimum of 2 years of follow-up, revision surgical procedures after PSO procedures have been reported to occur in up to 20% of multicenter patients,[14] and up to 23% of single-center patient series.[15–18] Kim *et al*[19] reported revision operations in 8 of 35 (23%) study patients after PSO between 2- and 5-year follow-up, a longer average follow-up. Revision rates after vertebral column resection at a minimum of 2-year follow-up have been reported in up to 14% of adult patients,[20] and in up to 6% of mixed adult and pediatric patient populations.[15,21] Overall revision rates after 3CO procedures at 2-year minimum follow-up range between 12% and 16%.[12,15]

Risk factors and variability between centers for surgical revision after 3CO procedures have not been reported. The objectives of this study were two-fold. First, we sought to assess revision rates and risk factors for revision for a large, multicenter series of adults with spinal deformity treated with one or more 3COs. Second, we assessed the variability in rates of revision for 3CO across multiple centers.

MATERIALS AND METHODS

Study Design

This study is a multicenter retrospective case review of consecutive adult patients with spinal deformity treated with either single- or multilevel 3CO in the thoracolumbar spine. After institutional review board approval, data were extracted from a spine osteotomy database with contributions from 8 sites. The inclusion criteria for the osteotomy database included the following: age, 18 years or more and spinal deformity that was treated with at least one 3CO. Exclusion criteria included any patient with underlying neurological or neuromuscular conditions, known hip/knee/ankle/foot pathology that may affect joint position, sagittal radiographs without femoral heads or C7, or without a 3CO site clearly visible to calculate the degree of correction. In addition to the database inclusion/exclusion criteria, only patients with a full set of sagittal radiographs (baseline, 6 wk, 3 mo, and 1 yr postoperatively) and documented revision status up to 1 year after osteotomy surgery were included in the analysis. Sites that contributed fewer than 10 cases to the osteotomy database were excluded from analysis.

Data Collection

Data, including complications and revision rates, were collected by research assistants who were not directly involved with the care and treatment of the patients in the study. Collected data included patient demographics, medical history, surgical summary, hospital data, and full-length standing spine radiographs. All radiographical measurements were done using dedicated and validated Spineview software (ENSAM ParisTech, Paris, France). For each patient at each visit (baseline and at 3 mo and 1 yr postoperatively), measurements of pelvic parameters (pelvic incidence and pelvic tilt) and spine sagittal parameters (lumbar lordosis, thoracic kyphosis [TK], sagittal vertical axis, and T1 sagittal tilt) were performed. Patient data were reviewed by multiple investigators at one site to ensure that all sites contributed inclusive, accurate, and compatible data. After initial data collection, each physician was personally queried and each longitudinal radiograph was reviewed by a centralized research team.

Revision Data

The patient population was analyzed for incidence and indications for RS within 1 year of the index 3CO procedure. Patients were stratified by postoperative timing of the RS (*i.e.* within 3 mo or within 1 yr after the index surgery), and indication for RS. Indications for RS were classified as "mechanical" (MR: implant failure, pseudarthrosis, junctional failure, loss/lack of correction) or "nonmechanical" (NMR: neurological deficit, infection, wound dehiscence, stenosis).

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 20.0.0 (SPSS Inc., 2009, Chicago, IL) and results were expressed using means and standard deviations. Differences in numerical parameters between the RS group and control group were assessed using unpaired t tests, and differences in categorical variables between groups were analyzed using χ^2 tests. Site volume was classified as either high, if the number of patients treated was greater than 33 (10% of study population), or low, if there were fewer than 33 patients treated at 1 site. The level of significance for each statistical analysis was set at 5%, that is, $P < 0.05$.

RESULTS

Patient Population

A total of 335 patients from the 582 in the database met inclusion criteria for the current investigation. The study included 94 males (28.1%) and 238 females (71%); sex was not recorded for 3 patients. Patients were in the age range from 18 to 81 years (mean = 56.5 yr) and had an average body mass index of 27.3 kg/m^2. The index surgery was a revision (n = 263) in 78.5% of cases and was a primary procedure (n = 72) in 21.5% of cases. The majority of patients (n = 311, 93%) were treated with a single-level 3CO, and the remaining patients (n = 24; 7%) underwent a multi-level 3CO. The overall number of levels fused was in the range from 3 to 24 with an average of 11.3 levels per operation.

Revision Surgery

Forty-one (12.2%) patients were revised within the first 3 months after the index 3CO procedure, and a total of 59 (17.6%) patients underwent RS within 1 year of the index 3CO. As illustrated in Table 1, there were no significant differences in patient demographics between those who underwent RS and those who did not.

Three-month and 1-year RS incidences were 12.2% and 17.6%, respectively. The average number of revisions per patient was 0.12 within 3 months and 0.19 within 1 year of the osteotomy procedure. Analysis by indication for revision (MR/NMR; Table 2) revealed that at 3 months, the most common MRs were instrumentation failure (3%) and proximal junctional kyphosis (2.4%); the most common NMRs were infection/wound dehiscence (2.1%) and new neurological deficit (1.8%). A similar relative distribution was observed at 1 year, with the following incidences: instrumentation failure (4.5%), proximal junctional kyphosis (3.9%), infection/wound dehiscence (2.1%), and neurological deficit (2.1%). For all RS, 50% of the MRs and 78.6% of the NMRs occurred within 3 months of the index surgery.

Analysis by number of 3CO revealed that patients treated with single-level 3CO had lower RS rates than did patients treated with multi-level 3CO (15.8% *vs.* 41.7%, respectively; $P = 0.001$, odds ratio = 0.26). Thoracic (n = 63) and lumbar 3CO (n = 246) procedures had similar RS rates, 12.7% and 16.7%, respectively ($P = 0.442$, odds ratio = 1.32). For single-level lumbar 3CO, the rate of RS was 16.7% (MR = 11.4%, NMR = 5.7%).

Radiographical Analysis

Comparison of preoperative (prior to index 3CO procedure) radiographical measurements between patients who underwent a MR and those who did not demonstrated no significant differences. At 6 weeks, revision patients had a larger spinopelvic inclination (−0.7° *vs.* −3.5°, $P = 0.008$). This difference was maintained at 3 months (−0.2° *vs.* −4.2°, $P < 0.001$) with an additional significant radiographical difference in terms of TK (41° *vs.* 35°, $P = 0.038$).

Patients who sustained a NMR had a greater osteotomy resection than those who did not (34° *vs.* 24°, $P = 0.037$) and had a more caudal osteotomy level (L4 *vs.* L3, $P = 0.014$). No other significant differences were identified in terms of pre- or postoperative radiographical parameters.

Analysis by Site

Stratification of the incidence of RS by site revealed significant variability (Figure 1) in terms of overall incidence (range, from 6.3% to 31.9%; $P = 0.001$), as well as incidence of MR (range, 3.8%–27.8%; $P = 0.003$), or incidence of NMR (range, 0%–12.8%; $P = 0.036$). However, low- and high-volume 3CO centers had similar RS rates, 18.2% *vs.* 16.2%, respectively ($P = 0.503$, odds ratio = 1.38).

DISCUSSION

Revision rates after surgery for ASD are notably high, especially for those cases that require the most aggressive osteotomies.[9,11] This study provides an assessment of a large multicenter database of patients with ASD treated with 3CO. The overall rates of revision at 3 months and 1 year after the index procedure were 12.3% and 17.6%, respectively. The most common reasons for revision included proximal junctional kyphosis, instrumentation failure, new neurological deficit, and infection/wound dehiscence. In addition, this study demonstrated significant variation in the rates of revision across the centers that contributed cases, ranging from 6.3% to 31.9%. Notably, the rates of revision did not differ significantly across centers based on the number of 3COs contributed. Collectively, these data demonstrate that the rate of revision after 3CO is high (>1 in 6) and varies considerably across centers. This variation, along with the reasons for revision identified in this study, suggest that future study is warranted to improve the safety and durability of 3CO procedures.

The 17.6% RS rate within 1 year of the 3CO procedure in this study is similar to those previously reported, which range from 11.8% to 22.8%[12,14–20]; however, the length of postoperative follow-up differs from the literature values. In this study, the follow-up was 1 year after the index surgery; previous studies typically reported RS rates up to at least 2 years after the 3CO procedure. However, most revision procedures occurred within the first 3 months after the initial operation, suggesting that a 1-year follow-up should capture at least the majority of revisions.

A significant difference in RS rates across the 8 contributing centers was identified in this study. It is important to note that a significant difference in RS rates between high- and low-volume sites was not found, suggesting that case volume may not be the dominant factor in preventing the need for

TABLE 1. Patient Demographics

	Total (N = 335)	RS (N = 59)	No RS (N = 276)	*P*
Male/female	94/238	18/41	76/197	0.395
Age (yr)	56.47 ± 13.54	57.5 ± 13.3	56.3 ± 13.6	0.376
BMI (kg/m^2)	27.3 ± 6.9	28.1 ± 7.9	27.1 ± 6.7	0.262
Height (cm)	163.87 ± 10.65	165.7 ± 9.6	163.5 ± 10.8	0.757
Weight (kg)	73.64 ± 21.32	77.2 ± 22.3	72.9 ± 21.1	0.161

Data indicate mean ± standard deviation.
RS indicates revision surgery; BMI, body mass index.

TABLE 2. Rates of Surgical Revision for Adults With Spinal Deformity Treated With 3-Column Osteotomy Stratified by Reason for Revision

	Revision Within 3 mo of Index Procedure			Revision Within 1 yr of Index Procedure		
	N	Incidence (%)	% of All Revisions	N	Incidence (%)	% of All Revisions
Mechanical						
Instrumentation failure	10	3	20.8	15	4.5	20.8
Pseudarthrosis	5	1.5	10.4	10	3	13.9
PJK	8	2.4	16.7	13	3.9	18.1
Sagittal imbalance	2	0.6	4.2	7	2.1	9.7
Nonmechanical						
Neurological deficit	6	1.8	12.5	7	2.1	9.7
Infection/wound dehiscence	7	2.1	14.6	7	2.1	9.7
Painful instrumentation	1	0.3	2.1	3	0.9	4.2
Stenosis	3	0.9	6.3	3	0.9	4.2
Other						
Other	4	1.2	8.3	5	1.5	6.9
Unknown	2	0.6	4.2	3	0.9	4.2

PJK indicates proximal junctional kyphosis.

revision. Alternatively, it is possible that more experienced surgeons and higher volume centers may attract more complex deformities that may have inherently greater risk of requiring revision. It is also possible that specific differences in surgeon technique and patient selection that were not assessed in this study may also account for differences in revision rates across centers. These differences in revision rates suggest that there may be opportunity for more detailed investigation of systems and practice variations in an effort to improve the safety and durability of the 3CO procedure.

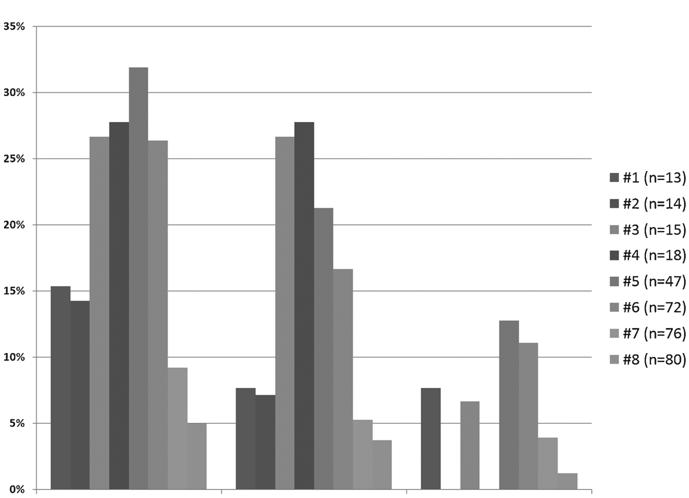

Figure 1. Rate of revision surgery by site. RS indicates revision surgery; NMR, nonmechanical; MR, mechanical. Sites are identified by shade and arranged by sample size from smallest to largest (left to right), as noted in the figure index.

This study also provides assessment of risk factors for RS after 3CO procedures. Multi-level 3CO procedures had significantly higher revision rates than did single-level 3CO procedures, which may primarily relate to the severity of the deformity and the magnitude of surgery and correction required. It is notable that sex, age, and body mass index were not significantly associated with need for RS. Patients who required a revision for mechanical failure did not differ significantly with regard to preoperative radiographical measures compared with those who did not require revision for mechanical failure; however, by 3 months after surgery, those requiring revision for mechanical failure did have poorer sagittal spinopelvic alignment and greater TK, which may have been the risk factors for subsequent revision.

Patients who required a revision for nonmechanical indications had a greater angle of bony resection at the osteotomy site. Although achieving greater osteotomy angular wedge resections can produce better focal deformity correction, this may place patients at greater risk of neurological compromise and new neurological deficits, which was one of the most common nonmechanical indications for RS. Thus, there seems to be a fine balance between overcorrection, undercorrection, and adequate correction. A larger osteotomy resection may increase the risk of requiring revision for a nonmechanical reason, but a smaller resection may lead to undercorrection of the deformity ultimately failing to rectify the initial condition and requiring revision.

The vertebral level of the osteotomy also correlated with the need for RS. Patients who underwent more caudal 3CO procedures were more likely to require MR surgery within

1 year of the index operation. Osteotomies of the L4 vertebral body had a significantly greater tendency to lead to revision than L3 osteotomies. Although it is possible that some unrecognized inherent issue with L4 3COs makes these osteotomies more vulnerable to mechanical failure than L3 3COs, it is very possible that this observation could relate to preferences among some centers to perform osteotomies at lower sites.

The primary limitation of this study is the retrospective design. In addition, there was no standardization among centers for patient selection, osteotomy techniques, instrumentation, or determination of thresholds and indications for RS. Strengths of this study include the multicenter design, collection of consecutive cases, large patient population, and standardization of radiographical assessment that was performed at a single institution.

CONCLUSION

3CO procedures for ASD surgery can provide substantial deformity correction and improved outcomes despite established complication and revision rates. There is great interest in lowering revision rates, particularly in high-risk osteotomy cases, due to their impact on the patient and health care system. This multicenter study identifies common reasons for RS including, undercorrection of sagittal alignment, pseudarthrosis, wound infection, and new neurological deficit. The need for RS in this study was associated with more caudal osteotomies and poorer postoperative sagittal alignment. There is significant variability in revision rates across sites independent of site volume, suggesting potential systems and practice variations that warrant further study.

➢ Key Points

- ❑ Revision surgery rates after 3CO are significantly different across institutions, with a 17.6% average rate of revision within 1 year of the index surgery (range, from 6.3% to 31.9%).
- ❑ Low- and high-volume centers did not show significant differences in revision rates after 3CO.
- ❑ More caudal (L4 *vs.* L3) and multiple (2 or more *vs.* 1) 3COs, as well as poorer postoperative radiographical sagittal outcomes (sagittal vertical axis, TK, and T1 spinopelvic inclination), are associated with higher revision rates.
- ❑ Patients who underwent nonmechanical RS had significantly greater bony resections during the index 3CO procedure than patients who did not.

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