The effect of C2–3 disc angle on postoperative adverse events in cervical spondylotic myelopathy

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OBJECTIVE Complete radiographic and clinical evaluations are essential in the surgical treatment of cervical spondylotic myelopathy (CSM). Prior studies have correlated cervical sagittal imbalance and kyphosis with disability and worse health-related quality of life. However, little is known about C2–3 disc angle and its correlation with postoperative outcomes. The present study is the first to consider C2–3 disc angle as an additional radiographic predictor of postoperative adverse events.

METHODS A retrospective chart review was performed to identify patients with CSM who underwent surgeries from 2010 to 2014. Data collected included demographics, baseline presenting factors, and postoperative outcomes. Cervical sagittal alignment variables were measured using the preoperative and postoperative radiographs. Univariable logistic regression analyses were used to explore the association between dependent and independent variables, and a multivariable logistic regression model was created using stepwise variable selection.

RESULTS The authors identified 171 patients who had complete preoperative and postoperative radiographic and outcomes data. The overall rate of postoperative adverse events was 33% (57/171), and postoperative C2–3 disc angle, C2–7 sagittal vertical axis, and C2–7 Cobb angle were found to be significantly associated with adverse events. Inclusion of postoperative C2–3 disc angle in the analysis led to the best prediction of adverse events. The mean postoperative C2–3 disc angle for patients with any postoperative adverse event was $32.3^\circ \pm 17.2^\circ$, and the mean for those without any adverse event was $22.4^\circ \pm 11.1^\circ$ ($p < 0.0001$).

CONCLUSIONS In the present retrospective analysis of postoperative adverse events in patients with CSM, the authors found a significant association between C2–3 disc angle and postoperative adverse events. They propose that C2–3 disc angle be used as an additional parameter of cervical spinal sagittal alignment and predictor for operative outcomes.

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KEYWORDS C2–3 disc angle; cervical sagittal alignment; cervical sagittal vertical axis; Cobb angle; postoperative adverse events; T1 slope

CERVICAL spondylotic myelopathy (CSM) is a common but frequently undiagnosed manifestation of the spinal degenerative process. The pathology involves chronic, repetitive trauma to the spinal cord. CSM is the most common etiology of acquired spinal cord dys-

function in the adult population.^{6,7,31,34,36,43} Conservative, nonoperative management is only appropriate for mild, nonprogressive CSM, and surgical treatment is warranted for progressive, moderate to severe CSM.^{9,28} Both ventral and dorsal surgical approaches, as well as a combination of

ABBREVIATIONS AUC = area under the curve; CSM = cervical spondylotic myelopathy; HRQOL = health-related quality of life; ROC = receiver operating characteristic; SVA = sagittal vertical axis.

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both approaches, are used as common operative management options. Although there is uncertainty regarding the optimal approach, the operative objective to achieve decompression, stabilization, and restoration of appropriate alignments remains clear. Posterior cervical instrumented fusion has been demonstrated to be effective in stabilizing the spine without causing significant morbidity, thereby reducing pain and producing high fusion rates.^{9,20} It also avoids the major complication of postlaminectomy kyphosis that can otherwise occur in 20%–30% of patients in whom a concomitant fusion was not performed.^{18,22,40} Adjacent segment disease, or symptomatic adjacent segment degeneration, however, has been reported to occur in up to 30% of patients within 10 years following instrumented spinal fusion.^{19,40} When posterior laminectomy is performed without fusion, disruption of stabilizing structures, including the facet joints and surrounding ligaments, predisposes the spine to excessive segmental motion.^{2,19,26,35,40} This leads to the progressive loss of normal cervical lordosis, musculoskeletal pain, deformity, and adjacent segment disease, which can lead to neurological compromise and the need for reoperation.^{11,15,19,22,26,35}

Several demographic and pathological factors play a role in the development and progression of adjacent segment disease and kyphosis. A thorough preoperative evaluation of the images is essential, as certain radiographic values have been demonstrated to be predictive of postoperative complications and overall outcomes.^{1,5,25,37,41,44} Previous studies have correlated cervical sagittal imbalance, elevated T1 slope, and kyphosis with adjacent segment disease, disability, and a worse health-related quality of life (HRQOL).^{1,5,10,11,15,21,24,25,29,38,39,41} However, there is a lack of data and studies that have evaluated whether there are unique radiographic parameters that are predictive of postoperative instrumentation failure that lead to poor clinical outcomes and the need for reoperation after posterior cervical fusion.

In the present study, we evaluated various preoperative and postoperative radiographic variables in order to explore which factors were associated with postoperative adverse events. We hypothesized that, in addition to the previously defined cervical alignment variables, an increased angle at the C2–3 disc space would predict postoperative adverse events. By identifying predictors of radiographic and clinical postoperative failure, spine surgeons can minimize the risk of complications and need for reoperation and can aim for optimal surgical outcomes.

Methods

Population/Data Collection

An institutional review board protocol was obtained prior to conducting the study. The electronic medical records were retrospectively reviewed to identify all patients with CSM who underwent posterior cervical decompression and fusion performed at a single tertiary-care institution from 2010 to 2014. Decompression via full laminectomy was performed and did not extend beyond the level of interest. Instrumented fusion was performed by placing lateral mass screws in the subaxial spine. For those patients in whom decompression was performed past the

level of C6, instrumented fusion was extended beyond the cervicothoracic junction and pedicle screws were placed in the upper thoracic levels. Study data were collected and managed using REDCap tools hosted at our institution.¹⁷

The primary aim of this study was to explore the factors that were associated with postoperative adverse events occurring between 2 months and 2 years postoperatively after each patient's first surgery. Adverse events were defined as the following events that occurred or observations made postoperatively: reoperation, progressive kyphosis in the adjacent level, pseudarthrosis, adjacent segment degeneration (due to adjacent segment pathology secondary to disc herniation or cord compression), or adjacent segment disease (symptomatic adjacent segment degeneration with radiculopathy or myelopathy).

Descriptive statistics were based on the preoperative and postoperative sagittal alignment as determined by the following independent variables: C2–7 Cobb angle, C2–7 sagittal vertical axis (SVA), C2–3 disc angle, and T1 slope. Radiographic angles were measured in a blinded fashion by chief and senior neurosurgery residents at the time of the data collection (B.S.L., K.M.W.). All radiographs were acquired in the standard fashion with the patient in the upright, standing position without a brace, and postoperative radiographs were all obtained at the first clinical follow-up 4–6 week after surgery. All but the C2–3 disc angle were measured using previously described techniques.^{1,5,21,25,41} To the authors' knowledge, this is the first study to evaluate the C2–3 disc angle, which is measured on a standing or upright radiograph by assessing the angle created by the line drawn parallel to the C2–3 disc space and the line parallel to the floor (Fig. 1).

Statistical Analysis

Using logistic regression models, we analyzed multiple continuous independent variables and their effects on adjacent segment degeneration, adjacent segment disease, and progressive kyphosis of the adjacent level, as these were the only variables with sufficient occurrences to allow for use of regression modeling. The remaining variables, including demographic and other radiographic characteristics, served as independent variables. Univariable logistic regression analyses were used to explore the association between dependent and independent variables first. The following variables were tested: sex, race, state residency, median income (calculated using zip code), marital status, current smoking status, antiinflammatory medication usage, age, body mass index, preoperative and postoperative measurements and changes of the C2–7 Cobb angle, C2–7 SVA, C2–3 disc angle, T1 slope, construct length, and the presence of a laminectomy at the cranial or caudal terminal construct level.

We then created a multivariable logistic regression model using stepwise variable selection as the reference by including all independent variables. The significance level for entry into and exit from the model was 0.15. Non-parametric methods were used to estimate the areas under the receiver operating characteristic (ROC) curves.⁸ A $p < 0.05$ was considered statistically significant. All analyses were conducted with SAS version 9.4 (SAS Institute).

FIG. 1. Illustrative representation of the measurement of C2–3 disc angle in a degenerative spine (**left**) and after surgical deformity correction with decompression and instrumented fusion (**right**). Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2017–2018. All rights reserved. Figure is available in color online only.

Results

We identified a total of 171 patients who met the aforementioned inclusion criteria, and their complete demographic data were obtained (Table 1). The mean preoperative and postoperative radiographic measurements of the

TABLE 1. Patient characteristics and demographics

Variable	Value
No. of patients	171
Age (yrs)	61 ± 14
Male	56%
Body mass index	29 ± 6
Smoking history	55%
Current smokers	21%
Medications	
Antidepressants	36%
Anxiolytics	26%
Narcotics	42%
Steroids	15%
Comorbidities	
Hypertension	64%
Dyslipidemia	44%
Diabetes	23%
Presenting symptoms	
Axial pain	56%
Radicular pain	49%
Paresthesias	40%
Myelopathy	63%

Continuous variables are presented as the mean ± SD, and categorical variables are presented as percentages. Percentages in each category combine to greater than 100% because an individual patient may have had more than one diagnosis/symptom.

C2–7 Cobb angle, C2–7 SVA, C2–3 disc angle, and T1 slope are listed in Table 2. The rate of the overall adverse events in our series was 33% (57 of 171 patients), and 19% of the patients (32 of 171) had more than one adverse event. We found that 15% of the patients (25 of 171) underwent reoperation, 24% (41 of 171) had progressive kyphosis at the adjacent level, 5% (8 of 171) had pseudarthrosis, 24% (41 of 171) had adjacent segment degeneration, and 18% (31 out of 171) had adjacent segment disease.

We compared the preoperative and postoperative alignment measurements between patients who developed postoperative adverse events and those who did not (Table 3). None of the preoperative radiographic parameters demonstrated a significant correlation with adverse events. Postoperative C2–3 disc angle was the only radiographic parameter that had significant associations with all of the listed adverse events, including pseudarthrosis and reoperation. Postoperative C2–7 Cobb angle was significantly different between patients who developed progressive kyphosis, adjacent segment degeneration, and adjacent segment disease and those who did not. Postoperative C2–7 SVA was significantly different only between patients who developed progressive kyphosis and those who did not. Postoperative T1 slope was not found to have a significant correlation with any particular adverse event (Table 3).

The mean postoperative C2–3 disc angle was found

TABLE 2. Mean preoperative and postoperative alignment measures

Measure	Preop	Postop	p Value
C2–7 Cobb angle	−5.7 ± 15	−4.8 ± 14	0.63
C2–7 SVA	39.7 ± 18	43.1 ± 19	0.12
C2–3 disc angle	25.1 ± 15	25.8 ± 14	0.70
T1 slope	27.2 ± 7.1	28.7 ± 7.9	0.11

Values are presented as the mean ± SD.

TABLE 3. Radiographic parameters in postoperative adverse events

Adverse Event	W/ Each Adverse Event	W/o Each Adverse Event	p Value
Reoperation			
Preop Cobb angle	-2.6 ± 13.5	-6.2 ± 15.3	0.4
SVA	44.3 ± 21.3	38.9 ± 17.3	0.3
C2–3 disc angle	24.2 ± 13.1	30.8 ± 23.1	0.1
T1 slope	38.6 ± 6.7	27.0 ± 7.1	0.3
Postop Cobb angle	-0.9 ± 15.0	-5.5 ± 13.3	0.1
SVA	50.1 ± 23.5	41.9 ± 17.6	0.05
C2–3 disc angle	34.3 ± 20.6	24.3 ± 12.4	0.002*
T1 slope	29.7 ± 8.5	28.5 ± 7.8	0.5
Kyphosis			
Preop Cobb angle	-6.4 ± 15.2	-5.5 ± 15.1	0.8
SVA	42.1 ± 14.9	38.9 ± 18.7	0.4
C2–3 disc angle	27.3 ± 17.8	24.4 ± 13.8	0.4
T1 slope	25.9 ± 7.2	27.6 ± 7.0	0.3
Postop Cobb angle	2.1 ± 14.1	-7.1 ± 12.6	0.0002*
SVA	48.8 ± 20.6	41.3 ± 17.8	0.03*
C2–3 disc angle	35.8 ± 17.6	22.5 ± 11.2	<0.0001*
T1 slope	27.3 ± 8.0	29.2 ± 7.8	0.2
Pseudarthrosis			
Preop Cobb angle	-2.8 ± 14.8	-5.8 ± 14.3	0.6
SVA	26.9 ± 16.2	39.9 ± 17.2	0.1
C2–3 disc angle	19.0 ± 8.9	25.0 ± 15.1	0.4
T1 slope	23.6 ± 3.8	27.5 ± 7.2	0.2
Postop Cobb angle	2.9 ± 20.3	-5.5 ± 13.6	0.1
SVA	49.1 ± 17.0	42.4 ± 18.3	0.3
C2–3 disc angle	39.1 ± 9.6	24.7 ± 14.1	0.009*
T1 slope	23.7 ± 4.9	28.8 ± 8.0	0.05
Adjacent segment degeneration			
Preop Cobb angle	-3.3 ± 13.7	-6.4 ± 15.4	0.4
SVA	40.9 ± 16.8	39.3 ± 18.3	0.7
C2–3 disc angle	27.2 ± 17.8	24.4 ± 13.8	0.4
T1 slope	26.4 ± 6.9	27.5 ± 7.1	0.5
Postop Cobb angle	2.4 ± 12.9	-7.2 ± 13.0	0.0001*
SVA	47.2 ± 19.9	41.8 ± 18.3	0.1
C2–3 disc angle	34.1 ± 17.3	23.1 ± 11.9	<0.0001*
T1 slope	27.7 ± 7.4	29.0 ± 8.0	0.4
Adjacent segment disease			
Preop Cobb angle	-3.1 ± 15.3	-6.2 ± 15.0	0.4
SVA	40.1 ± 18.4	39.4 ± 17.9	0.7
C2–3 disc angle	27.8 ± 20.2	24.5 ± 13.5	0.4
T1 slope	27.0 ± 4.9	27.3 ± 7.5	0.9
Postop Cobb angle	1.7 ± 12.0	-6.3 ± 13.5	0.004*
SVA	46.3 ± 18.6	42.4 ± 18.8	0.3
C2–3 disc angle	34.3 ± 17.8	23.8 ± 12.5	0.0004*
T1 slope	27.3 ± 5.9	29.0 ± 8.2	0.3

Values are presented as the mean ± SD.

* Statistically significant.

to be significantly higher in patients with postoperative adverse events than that in those without adverse events: 34.3° ± 20.6° in patients who required reoperation versus 24.3° ± 12.4° in those who did not; 48.8° ± 20.6° in those with progressive kyphosis versus 41.3° ± 17.8° in those without it; 39.1° ± 9.6° in those with pseudarthrosis versus 24.7° ± 14.1° in those without it; 34.1° ± 17.3° in those with adjacent segment degeneration versus 23.1° ± 11.9°

in those without it; and 34.3° ± 17.8° in those with adjacent segment disease versus 23.8° ± 12.5° in those without (Table 3). The mean postoperative C2–3 disc angle for patients with any postoperative adverse event was 32.3° ± 17.2°, and that for those without any adverse event was 22.4° ± 11.1° ($p < 0.0001$).

Because postoperative C2–3 disc angle, C2–7 SVA, and C2–7 Cobb angle were the parameters significantly

TABLE 4. Multivariable regression

	AUC	OR (95% CI)	p Value
Adjacent segment degeneration			
AUC	0.74		<0.0001
Postop Cobb angle		1.03 (0.98, 1.08)	0.2
Postop SVA		0.97 (0.93, 1.01)	0.14
Postop C2–3 disc angle		1.08 (1.03, 1.15)	0.004
Adjacent segment disease			
AUC	0.77		<0.0001
Postop Cobb angle		1.00 (0.96, 1.04)	0.89
Postop SVA		0.96 (0.93, 1.00)	0.04
Postop C2–3 disc angle		1.10 (1.03, 1.16)	0.002
Progressive kyphosis			
AUC	0.78		<0.0001
Postop Cobb angle		1.01 (0.97, 1.05)	0.58
Postop SVA		0.96 (0.93, 1.00)	0.07
Postop C2–3 disc angle		1.11 (1.04, 1.19)	0.0002

associated with certain postoperative adverse events, they were included in a multivariable regression model, again with the outcome variable being postoperative adverse events within 2 years (Table 4). Given the limited number of subjects, we were unable to perform multivariable analysis for certain postoperative adverse events that occurred less frequently, particularly reoperation and pseudarthrosis, as those models would have been underpowered to detect significance. Only the postoperative C2–3 disc angle had statistical significance in all listed postoperative adverse events.

Inclusion of the postoperative C2–3 disc angle in the model led to a statistically significant prediction of adjacent segment degeneration, adjacent segment disease, and progressive kyphosis with an area under the curve (AUC) of 0.74, 0.77, and 0.78, respectively, which were greater than when postoperative C2–3 disc angle measure was excluded. Odds ratios of postoperative C2–3 disc angle were 1.08, 1.10, and 1.11 for adjacent segment degeneration, adjacent segment disease, and progressive kyphosis, respectively (Table 4).

Among the nonradiographic variables included in our analysis, only the age, sex, and antiinflammatory drug use were shown to have a significant correlation with postoperative adverse events. The ROC curve for custom algorithm, including postoperative C2–3 disc angle, C2–7 SVA, C2–7 Cobb angle, age, sex, and antiinflammatory drug use, was made showing a statistically significant correlation between these variables and postoperative adverse events. The AUC was 0.8507 for the various multivariable analyses, which each included the listed variables (Fig. 2).

Discussion

Posterior cervical laminectomy and instrumented fusion remains an effective operative treatment for CSM.^{18,20,40} Positive cervical sagittal balance, construct length, the relationship to spinal transitional zone at the

FIG. 2. ROC curve for a custom algorithm, including postoperative C2–3 disc angle, C2–7 SVA, C2–7 Cobb angle, age, sex, and antiinflammatory drug use.

cervicothoracic junction, advanced age, and greater extent of decompression have been previously shown to increase the risk of postoperative complications and reoperation rates. Cervical sagittal balance is among the most frequently cited factors, correlating with clinical outcomes after posterior cervical fusion. The restoration of sagittal balance and lordosis improves the overall functional outcomes, pain scores, and the prevention of future deformity.^{1,11,14–16,22,27,35,37,41,44}

In the present study, certain radiographic variables, including the C2–7 SVA, C2–7 Cobb angle, and C2–3 disc angle were found to be predictive of certain postoperative adverse events. Both C2–7 SVA and Cobb angle have been previously shown to correlate with radiographic failure and worse HRQOL; however, the C2–3 disc angle is a radiographic measure that has been minimally investigated to this point.^{1,30,32,33,37,42,44} A study by Katsumi et al. investigated the incidence of postoperative deformity leading to instability after decompression via laminectomy was performed in the cervical spine.²³ The authors demonstrated the presence of cervical instability at the C2–3 disc space after C2 laminectomy and that the C2–3 disc angle increased from 5.5° to 14.5°. Moreover, a C2 laminectomy leading to such increased C2–3 disc angle was found to be a significant risk factor for postoperative instability.²³ This study did not directly investigate the effect of the C2–3 disc angle but provided further evidence of the vulnerability at the C2–3 disc space. This vulnerability may be due, in part, to the complex muscular and ligamentous attachments between the axis and the atlantooccipital region.⁴

This correlation between a greater C2–3 angle and radiographic failure is not unexpected. Similar phenomena have been reported with sacral slope, T1 angle, sagittal alignment, and global relationships between spinal and pelvic parameters.^{1,5,10,21,24,25,29,38,39,41} Cervical lordosis is derived from the sum of the segmental angles between

FIG. 3. Lateral cervical radiographs of a patient before surgery (A) and at 1 year follow-up (B), showing mild kyphosis and anterolisthesis at C2–3. Lateral radiograph demonstrating progressive anterolisthesis of C2 on C3 at the last follow-up (C), ultimately requiring reoperation and extension of the fusion construct. Figure is available in color online only.

cervical vertebrae and is important in overall function and quality of life. Of the 42° of cervical lordosis found in healthy patients, approximately 32° comes from C1–2 and 2° comes from the C2–3 level (nearly 81% of overall cervical lordosis).^{1,12,13,16} This dependence on the upper cervical spine to maintain the majority of cervical lordosis also makes it susceptible to failure, especially in the presence of cervical sagittal imbalance and an elevated T1 angle. In patients with greater C2–3 disc angles, additional stress is placed on the C1–2 level in order to maintain neutral head position (Fig. 3).^{3,4}

When evaluating a patient with a high C2–3 disc angle, especially if that patient has undergone a previous cervical fusion, it is reasonable to consider this region as a transitional zone, similar to the cervicothoracic junction or lumbosacral junction. Above the C2–3 disc space, the region from the craniocervical junction, extending down to the axis, is unique to the rest of the spine and allows for more mobility and more degrees of freedom than any other region. Below the C2–3 level, the cervical spine is more uniform, allowing for mobility but not to the same extent as the region above. During surgical planning, one can consider extending fusion constructs to C2, thereby crossing this “transitional zone,” particularly when the patient’s C2–3 disc angle is increased and with the presence of overall positive sagittal balance. This technique would be consistent with those used in other transitional regions of the spine, wherein constructs extended beyond the junctional zone have reduced failure rates.^{3,4,26} It should be noted, however, that this approach would lead to diminished motion in the upper cervical spine and additional risk of vertebral artery injury.

In our prediction model with odds ratios of postoperative C2–3 disc angle being 1.08, 1.10, and 1.11 for adjacent segment degeneration, adjacent segment disease, and progressive kyphosis, respectively, the odds of such

adverse events increase by 8%, 10%, and 11%, respectively, for every 1° increase in the postoperative C2–3 disc angle. In other words, an increase in postoperative C2–3 disc angle by 10° would translate into 116%, 159%, and 184% increased odds of developing the respective adverse event. Moreover, because the mean postoperative C2–3 disc angle for patients with any postoperative adverse event was significantly higher than that for those without any adverse event ($32.3^\circ \pm 17.2^\circ$ vs $22.4^\circ \pm 11.1^\circ$; $p < 0.0001$), we suggest accordingly that patients with postoperative C2–3 angle $> 32^\circ$ may be more prone to developing a postoperative adverse event, and we predict that the rate of postoperative adverse events and complications could be lowered if the C2–3 disc angle were below 32° and closer to being parallel to the floor.

The correlation among cervical sagittal balance, cervical lordosis, thoracic kyphosis, and T1 angle has been previously reported.^{1,24,41} In our study the average postoperative C2–3 disc angle for patients with any postoperative adverse event was significantly higher, and inclusion of postoperative C2–3 disc angle in the prediction model led to a statistically significant prediction of adverse events. Such results are in line with the aforementioned discussion and add an additional variable correlating to both the C2–7 SVA and Cobb angles, as well as to clinical outcomes. This reinforces the notion that multiple cervical alignment parameters may be used in conjunction during surgical planning.

There were several variables that were included in our analysis, such as tobacco use, construct length, and the presence of a distal-level laminectomy, which have previously been reported to be associated with failure of fusion, postoperative kyphosis, and worsened postoperative HRQOL outcomes.^{1,11,22,37,41,44} Decompression via cervical laminectomy alone has been known to induce kyphotic deformity, and therefore, many surgeons advocate exten-

sion of the fusion construct to at least one level beyond the terminal level of the decompression. This strategy is designed to add an additional level of stability between the fusion construct and the remainder of the spine; however, in our analysis, laminectomy at the terminal end of the fusion construct was not found to be statistically significantly associated with adverse events.

Our analysis was limited by the retrospective study design and a relatively small sample size restricted to the posterior-approach group only. As a result, only certain variables had sufficient occurrences to allow for the use of regression modeling. Additional prospective studies are warranted to further understand the effect of C2–3 disc angle, by reviewing a larger sample size, including patients who have undergone operation via anterior or combined approach, collecting more comprehensive radiographic and clinical parameters, and incorporating HROQL measures. It would also be useful to establish a normal range for the C2–3 disc angle in the populations of patients with nondegenerative and degenerative disorders and to quantify a more definitive numerical value for the angle. Last, longer-term follow-up of these patients will be essential to see if the trend toward adverse events in patients with high C2–3 disc angles continues.

Conclusions

In our retrospective multivariable analysis of postoperative adverse events in patients with CSM, a significant association was found between the postoperative C2–3 disc angle and the rate of postoperative radiographic adverse events. We found the C2–3 disc angle to be statistically significantly associated with postoperative outcomes and other standard, accepted parameters of spinal sagittal alignment. These relationships suggest that C2–3 disc angle may serve as an additional radiographic parameter by which to assess the degree of restoration of cervical sagittal alignment.

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Author Contributions

Conception and design: Lee, Walsh, Kalfas, Benzel. Acquisition of data: Lee, Walsh, Lubelski. Analysis and interpretation of data: Lee, Walsh, Lubelski. Drafting the article: Lee, Walsh, Lubelski. Critically revising the article: Lee, Walsh, Lubelski, Steinmetz, Mroz, Benzel. Reviewed submitted version of manuscript: Lee, Walsh, Lubelski, Steinmetz, Mroz, Kalfas, Benzel. Approved the final version of the manuscript on behalf of all authors: Lee. Statistical analysis: Lee, Walsh, Lubelski, Knusel. Administrative/technical/material support: Schlenk, Benzel. Study supervision: Steinmetz, Mroz, Schlenk, Benzel.

Supplemental Information

Previous Presentations

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