Supine Imaging Is a Superior Predictor of Long-Term Alignment Following Adult Spinal Deformity Surgery

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Abstract

Study Design: Retrospective cohort study.

Objective: To investigate correlations between preoperative supine imaging and postoperative alignment.

Methods: A retrospective review was conducted of a single-institution database of patients with adult spinal deformity (ASD). Patients were stratified by fusion location in the lumbar or thoracic spine. Outcomes of interest were postoperative lumbar lordosis (LL) and thoracic kyphosis (TK). Sagittal alignment parameters were compared and correlation analyses were performed. Multilinear stepwise regression was conducted to identify independent predictors of postoperative LL or TK. Regression analyses were repeated within the lumbar and thoracic fusion cohorts.

Results: A total of 99 patients were included (mean age 63.2 years, 83.1% female, mean body mass index 27.3 kg/m²). Scoliosis Research Society classification demonstrated moderate to severe sagittal and/or coronal deformity (pelvic tile modifier, 18.2% ++; sagittal vertical axis, 27.3% ++, pelvic incidence minus lumbar lordosis mismatch, 29.3% ++, SRS type, 29.3% N type curve and 68.7% L or D type curve). A total of 73 patients (73.7%) underwent lumbar fusion and 50 (50.5%) underwent thoracic fusion. Correlation analyses demonstrated a significant association between pre- and postoperative LL and TK. Multilinear regression demonstrated that LL supine and pelvic incidence were significant predictors of postoperative LL ($r^2 = 0.568$, $P < .001$). LL supine, TK supine, and age were significant predictors of postoperative TK ($r^2 = 0.490$, $P < .001$).

Conclusion: Preoperative supine films are superior to standing in predicting postoperative alignment at 1-year follow-up. Anticipation of undesired alignment changes through supine imaging may be useful in mitigating the risk of iatrogenic malalignment.

Keywords

thoracic fusion, lumbar fusion, supine imaging, postoperative alignment

Introduction

Adult spinal deformity (ASD) is a disabling condition with reported prevalence ranging from 13% to 32% in the general population and reaching up to 60% in the elderly population. With an increase in life expectancy, the prevalence of ASD is only expected to grow. A recent National Institutes of Health–funded randomized controlled trial demonstrated that surgery can improve outcomes in patients with ASD compared with nonoperative treatment. However, surgical intervention for ASD is fraught with complications, reoperations, and high costs, emphasizing the importance of optimizing outcomes after the index operation.

Over the past decade, ASD-related research has established postoperative surgical alignment goals that maximize the
chance of obtaining optimal outcomes while mitigating the risk of mechanical complications.\(^9-^{14}\) However, consistently achieving the desired postoperative alignment, especially in long-term follow-up, has proven difficult.\(^{15-18}\) One possible explanation lies in the discrepancy between the patient position as seen on the radiographs used for preoperative planning (ie, the standing position) and in the operative room (ie, prone position). Despite investigations demonstrating the utility of positional radiographs in degenerative pathologies or adolescent deformity, there is limited research on their use in adult spinal deformity.\(^{19-25}\) The possibility that positional radiographs (eg, sitting or recumbent) can predict postoperative outcomes has only recently become a burgeoning area of ASD research.\(^{19,26,27}\)

Therefore, the objective of our study was to investigate potential correlations between preoperative supine imaging and postoperative alignment, focusing specifically on factors within the surgeon’s control intraoperatively (ie, lumbar and thoracic curvatures). We hypothesized that supine imaging would be superior to standing imaging as a predictor for postoperative alignment.

**Materials and Methods**

**Patient Sample**

A retrospective analysis was performed of surgically treated ASD patients from a single-center, single surgeon database (2014-2018) with a minimum of 1-year follow-up. Charts reviews were conducted after approval by the institutional review board. Inclusion criteria were adult patients (age \(>18\) years) with spinal deformity, defined as coronal Cobb angle greater than \(20^\circ\), \(C7\) sagittal vertical axis (SVA) \(>50\) mm, pelvic tilt (PT) \(>25^\circ\), or pelvic incidence minus lumbar lordosis mismatch (PI-LL) \(>10^\circ\). Given that the purpose of the study was to investigate the relationship of supine alignment with postoperative alignment, only patients with full-length lateral radiographs in the standing and supine positions were included. Exclusion criteria were deformities secondary to trauma, cancer, or a neuromuscular condition. All patients involved provided written informed consent to be part of this study.

**Data Collection**

Demographic parameters such as age, sex, gender, and body mass index (BMI) were collected from the electronic medical record. Full length lateral radiographs were collected preoperatively in standing and supine position, and postoperatively in standing position only (Figure 1). For supine radiographs, the patient was asked to lay on the table with their shoulders with their fingertips touching their clavicles (identical to the standing position films). Radiographs were analyzed by a researcher outside of the primary clinical team using a validated and dedicated software (Spineview, ENSAM ParisTech, Paris) for the following parameters: PI, PT, PI-LL (LL, L1-S1), thoracic kyphosis (TK, T4-T12), T1-pelvic angle (TPA), SVA (standing radiographs only), coronal C7 plumb line (C7PL, standing radiographs only), and maximum coronal Cobb angle (Max-Cobb).\(^{10}\) The measurements were verified by a second, more experienced researcher.

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**Figure 1.** Example of supine radiographs. Preoperative standing (A), preoperative supine (B), postoperative standing (C).
### Table 1. Radiographic Parameters of the Patient Sample Before and After Surgery Using Standing and Supine Imaging.

| Parameter | Pre-standing | Pre-supine | Post-standing | Overall | Pre-supine | Pre-post | Supine-post |
|-----------|--------------|------------|--------------|---------|------------|---------|------------|
| PI, deg   | 52.6 ± 13.6  | 52.4 ± 13.7| 52.3 ± 13    | 0.458   | 1.000      | 0.673   | 1.000      |
| PT, deg   | 21 ± 11.5    | 26 ± 10.7  | 15.9 ± 10.1  | 0.001   | 0.001      | 0.003   | 0.001      |
| PI-LL, deg| 11.6 ± 20.1  | 5.5 ± 16.4 | 2.7 ± 14     | 0.001   | 0.001      | 0.001   | 0.001      |
| LL, deg   | 49.9 ± 22.8  | 46.9 ± 18.7| 55 ± 14.4    | 0.001   | 0.001      | 0.001   | 0.001      |
| TK, deg   | −35.5 ± 19.7 | −26.7 ± 16.8| −41.6 ± 13.4| 0.001   | 0.001      | 0.001   | 0.001      |
| TPA, deg  | 19.7 ± 13.8  | 12 ± 12    | 11.6 ± 10.2  | 0.001   | 0.001      | 0.001   | 1.000      |
| SVA, mm   | 58 ± 80      | 14 ± 50    | 24 ± 20      | 0.001   | 0.001      | 0.003   | 0.001      |
| C7-PL, mm | 35 ± 33      | 38.1 ± 21.2| 23 ± 15.4    | 0.001   | 0.001      | 0.001   | 0.001      |

Abbreviations: PI, pelvic incidence; PT, pelvic tilt; PI-LL, pelvic incidence–lumbar lordosis mismatch; LL, lumbar lordosis; TK, thoracic kyphosis; TPA, T1 pelvic angle; SVA, sagittal vertical axis; C7-PL, C7 plumb line; MaxCobb, maximum Cobb angle.

*Boldfaced values indicate statistical significance (P < .05).

Comparison conducted with paired t-test due to lack of supine measurements.

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### Statistical Analyses

Patients were characterized by the type of fusion they underwent. Lumbar (or lumbopheracic) fusion was characterized as a fused spine spanning at least all the lumbar vertebra (L1-S1) with no limit to upper instrumented vertebra. Thoracic fusion was characterized by a fusion of the entire thoracic spine (T4-T12) with the majority of the lumbar spine left untouched. The incidence of 3-column osteotomies (3COs) was also recorded. Schwab–Scoliosis Research Society (Schwab-SRS) modifiers were applied to each patient.

Pre- to postoperative radiographic parameters were compared using paired t-tests. Postoperative PI-LL mismatch was compared between patients who underwent a 3CO and those who did not. Postoperative LL and TK were chosen as outcomes of interest, given that intraoperative modifications to these sagittal alignment measures mechanistically drive overall correction of global alignment. Univariate associations between demographics and preoperative radiographic parameters and postoperative parameters were explored using Pearson correlations. A multilinear stepwise regression was performed to control for confounding and identify independent correlations with postoperative alignment at 1 year. Finally, the cohort was stratified by type of fusion and the regression was repeated. Type I error rate was set as P < .05. Statistical analysis was conducted using SPSS Version 22.0 (IBM).

### Results

#### Patient Sample

A total of 101 patients met inclusion criteria. Supine radiographs were available for 99 of these patients. The cohort was majority female (83.1%) and middle aged (mean 57 ± 11.6 years), with mean BMI of 27.3 kg/m². Mean follow-up period was 21.0 ± 9.8 months. When sagittal deformity was classified using preoperative Schwab-SRS modifiers, 18.2% of the cohort had a ++ PT modifier, 27.3% had a + SVA modifier, and 29.3% had a ++ PI-LL modifier. In terms of coronal SRS type, 29.3% of the cohort had an N type curve, while 68.7% had an L or D type curve. Approximately one-fifth (20.6%) of patients underwent a 3CO.

In our cohort 73.7% of patients underwent a lumbar (or lumbopheracic) fusion and 50% underwent a thoracic fusion. The pre-to-post comparison of standing alignment demonstrated a significant change in alignment (Table 1) with an average decrease of PI-LL, PT, SVA, TK, and an average increase in T4-T12 (all Ps < .001). There were no significant differences in postoperative PI-LL between patients who received or did not receive a 3CO (P = .175).

#### Univariate Correlations With Postoperative Alignment

On univariate analysis, several factors were associated with postoperative LL and TK (Table 2). Specifically, postoperative LL significantly correlated with preoperative LL in supine (r = 0.668, P < .001) and standing positions (r = 0.608, P < .001), as well as with PI (r = 0.577, P < .001). Similarly, postoperative TK significantly correlated with preoperative TK in standing (r = 0.549, P < .001) and supine positions (r = 0.488, P < .001) along with age (r = 0.280, P < .005).

#### Independent Predictors of Postoperative Alignment

When the preoperative parameters were entered into multilinear regression analysis, only preoperative supine LL and PI emerged as independent correlates with postoperative LL (r² = 0.533). Similarly, preoperative supine LL, age, and preoperative standing TK were retained as independent correlates of postoperative TK (r² = 0.429).

The analysis was repeated after stratification of the sample by type of fusion (Table 3). In the lumbar fusion patients, preoperative supine LL and PI remained the only independent correlates of postoperative LL (r² = 0.514). Results were similar for the thoracic fusion patients, showing that preoperative supine LL, preoperative supine TK, and age were independently associated with postoperative TK.
Discussion

Our investigation found that ASD patients’ alignment changed from the standing to supine position, with an overall increase in LL and decrease in TK leading to improved PI-LL mismatch (<10°) and normalized TPA (<14°).10 We focused our outcomes of interest on postoperative LL and TK as these 2 parameters are directly controlled by the surgeon during the fusion. Similarly, we concentrated on these 2 outcomes of interest for the lumbar and thoracic fusion cohorts to ensure that we were analyzing patients who had undergone intraoperative correction of their LL (ie, lumbar fusion patients) or TK (ie, thoracic fusion patients). In these respective subgroups, univariate analyses demonstrated that both preoperative standing and supine LL and TK correlated with postoperative LL and TK. However, when these parameters were entered into multilinear regression models, only supine LL and TK were retained as independent correlates of postoperative LL and TK, respectively.

While we could not assess preoperative planning or intraoperative decision making, we hypothesize that there is a clinically useful relationship between supine imaging and the techniques needed for correction. In every case, supine imaging was obtained for preoperative planning purposes, specifically to estimate whether an osteotomy may be needed to achieve alignment goals. Our findings lead us to hypothesize that the supine film likely correlated with the intraoperative alignment of the spine after relaxation and positioning.25 For flexible, mild-moderate deformity this intraoperative alignment was likely very close to the desired outcome. On the other hand, when supine films did not show an acceptable regional alignment, then extra effort was exerted through osteotomies. This second point is supported by the fact that similar corrections were obtained with or without a 3CO (ie, patients who corrected through intraoperative positioning did not require a 3CO while those who did not correct underwent a 3CO). In other words, supine imaging correlated with the intraoperative decision making, which correlated with final alignment goals. This leads us to conclude that supine imaging is a useful preoperative planning tool that can predict the correction obtained by intraoperative positioning (ie, the flexibility of the spine) and subsequently, the need for further corrective techniques.

We are not the first investigators to note the utility of supine imaging in preoperative planning for lumbar deformity correction. In severe sagittal deformity (SVA > 10 cm), a 33% change in LL between supine to standing has been suggested as a “stiffness threshold” for requiring a 3CO in the lumbar spine.19 In an analysis of standing, supine, and intraoperative
radiographs (taken before the surgery began), the same investigators demonstrated that prone positioning on a Jackson table significantly increased LL in patients with decreased preoperative lordosis (eg, degenerative flatback deformity). Furthermore, they showed that the intraoperative positional lordosis was near equivalent to that of a supine radiograph. We were able to show that supine LL correlated with postoperative LL in patients who underwent lumbar fusions, seeming to indicate the correlation obtained by positioning may be the most important factor associated with postoperative TK included age and supine LL. The reasons behind these associations are identical to those explaining the relationship between supine LL and PI; namely, the past decade of ASD research has emphasized the importance of respecting age-related normative values of thoracic kyphosis in spinal deformity surgery. Multiple series of asymptomatic adult patients have demonstrated increased TK with age. This has led researchers to propose that elderly patients should be fused with more thoracic kyphosis compared with their younger counterparts, a strategy recommended as a method to reduce mechanical complications. The relationship between postoperative TK and supine LL is similar—research has shown that reciprocity between curves is necessary to restore the spine’s anatomic alignment. Clinically, severe mismatch between TK and LL has been associated with poor outcomes. Therefore, we believe that the associations between postoperative TK, age, and preoperative supine LL are products of advancements in ASD research.

This study is not without limitations. Most notably, the retrospective design precluded the capture of any information regarding the preoperative planning or intraoperative decision-making. We cannot assess whether the alignment achieved intraoperatively was in line with the goals of the surgery. Regardless, we still believe that the relationship of supine alignment with long-term (1 year) postoperative alignment is significant, as it allows the surgeon to preoperatively assess the corrections they will need to make once the patient is on the table. Furthermore, if supine imaging shows an undesired change (eg, a decrease in TK when a large LL correction is planned), this allows the surgeon to anticipate this positional change and plan accordingly. Second, while we assume that the intraoperative position was similar to supine films (as has been previously reported by Harimaya et al), we did not take pre-correction intraoperative films. Third, these findings represent a single-center experience, with surgeons who exclusively employ all-posterior, single stage surgeries. For these reasons, the results may not be externally valid to centers that use different techniques. Multicenter studies will be necessary, provided care is taken that the supine imaging is performed similarly among centers (ie, passive supine imaging, no forced hyperextension or patient-directed activity). Fourth, we did not stratify data by the presence of a 3CO. We attempted to mitigate this limitation by demonstrating that patients who underwent a 3CO had the same degree of postoperative correction as those who did not. Regardless, the relationship between supine and postop LL may have been different if only patients who had underwent a 3CO were analyzed. Although our analysis suggests that the degree of LL achieved through positioning is likely the most important determinant of long-term alignment, a larger series of patients with 3CO will be needed to differentiate the amount of correction achieved by a 3CO compared with the amount achieved from positioning alone. Fifth, we only included 1-year outcomes—a 2-year analysis may have shown further loss of alignment. However, we hypothesize that any loss of alignment past one year would likely be secondary to changes in the unfused segments. This hypothesis is supported by the fact that our correlations were similar in patients with fused thoracic or lumbar spines (Table 2).
In conclusion, our study provides evidence that supine LL and TK are superior predictors of long-term postoperative LL and TK compared to measurements made on standard preoperative imaging. Supine imaging is a useful preoperative planning tool as it allows surgeons to anticipate alignment changes that will occur once the patient is positioned for surgery. For mild-moderate deformity, relaxation of the spine with intraoperative positioning may get alignment close to the desired postoperative goals. On the other hand, if regional alignment remains unacceptable on supine films, then the need for an osteotomy should be anticipated. Furthermore, supine imaging allows surgeons to identify which segments of the spine are most flexible, as distribution of lordosis is increasingly recognized as an important influencer of mechanical outcomes. The anticipation of undesired alignment changes (eg, reduced thoracic kyphosis) through the utilization of supine imaging is especially useful in ensuring surgeons mitigate the risk of iatrogenic malalignment. A multicenter study will be needed to provide external validation for our results, as surgical techniques vary. Future investigations should also consider the incorporation of various radiographic positions (sitting, standing, supine) in order to formulate the most complete predictive model of postoperative radiographic outcomes.

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