# Predictive Modeling of Length of Hospital Stay Following Adult Spinal Deformity Correction: Analysis of 653 Patients with an Accuracy of 75% within 2 Days

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■ BACKGROUND: **Length of stay (LOS) after surgery for adult spinal deformity (ASD) is a critical period that allows for optimal recovery. Predictive models that estimate LOS allow for stratification of high-risk patients.**

■ METHODS: **A prospectively acquired multicenter database of patients with ASD was used. Patients with staged surgery or LOS >30 days were excluded. Univariable predictor importance ≥0.90, redundancy, and collinearity testing were used to identify variables for model building. A generalized linear model was constructed using a training dataset developed from a bootstrap sample; patients not randomly selected for the bootstrap sample were selected to the training dataset. LOS predictions were compared with actual LOS to calculate an accuracy percentage.**

■ RESULTS: **Inclusion criteria were met by 653 patients. The mean LOS was 7.9 ± 4.1 days (median 7 days; range, 1−28 days). Following bootstrapping, 893 patients were modeled (653 in the training model and 240 in the testing model). Linear correlations for the training and testing datasets were 0.632 and 0.507, respectively. The prediction accuracy within 2 days of actual LOS was 75.4%.**

■ CONCLUSIONS: **Our model successfully predicted LOS after ASD surgery with an accuracy of 75% within 2 days. Factors relating to actual LOS, such as rehabilitation bed availability and social support resources, are not captured in large prospective datasets. Predictive analytics will play an increasing role in the future of ASD surgery, and future models will seek to improve the accuracy of these tools.**

## INTRODUCTION

Surgery for the treatment of adult spinal deformity (ASD) represents a growing subset of all adult spine surgery. Approximately 32% of the adult population and >60% of the elderly population have scoliosis.[1,2] Furthermore, the spinal deformity medical subspecialty has expanded as the aging population increases.[3] These surgeries are also some of the costliest, with primary surgery costing >$100,000 and revision surgery costing >$50,000.[4-6] Length of stay (LOS) following ASD surgery is the time period allowing for recovery to levels safe enough for a return to home or rehabilitation.

It is critical to stratify medical and surgical risks preoperatively to anticipate and minimize LOS, thus conserving hospital resources and mitigating pressure from third-party payers. In addition to preoperative medical optimization, developing tools to predict LOS and perioperative risk will become increasingly important in ASD surgery. Insurance providers generally approve inpatient LOS based on billing or diagnostic codes, which fail to

**Key words**
- Adult spinal deformity
- Length of stay
- Predictive model

**Abbreviations and Acronyms**
**ASA**: American Society of Anesthesiologists
**ASD**: Adult spinal deformity
**LOS**: Length of stay

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**Table 1.** Patient Demographics ($N = 653$ Patients)

| Variable | Value |
|---|---|
| Age, years, mean ± SD (range) | 58 ± 15 (18—86) |
| Sex | |
| Female | 504 (78%) |
| Male | 143 (22%) |
| BMI, mean ± SD | 27 ± 6 |
| ASA class | |
| I | 47 (7%) |
| II | 315 (48%) |
| III | 254 (39%) |
| IV | 9 (1%) |
| ODI score, mean ± SD | 44 ± 18 |
| SF-36 score, mean ± SD | 31 ± 10 |
| Prior surgery | 305 (47%) |
| Prior fusion | 233 (36%) |
| Smoker | 45 (7%) |
| Normal neurologic examination | 458 (70%) |
| Spinopelvic parameters mean ± SD | |
| Pelvic tilt, ° | 23 ± 11 |
| PI-LL mismatch, ° | 16 ± 21 |
| SVA, cm | 6.9 ± 7.5 |

BMI, body mass index; ASA, American Society of Anesthesiologists; ODI, Oswestry Disability Index; SF-36, 36-Item Short Form Health Survey; PI-LL, pelvic incidence—lumbar lordosis mismatch; SVA, sagittal vertical axis.

**Table 2.** Surgical Characteristics ($N = 653$ Patients)

| Variable | Value |
|---|---|
| Site of fusion | |
| Anterior | 4 (0.6%) |
| Posterior | 642 (98.3%) |
| Upper instrumented vertebrae | |
| Cervical | 5 (0.8%) |
| Upper thoracic (T1-T5) | 287 (44%) |
| Middle thoracic (T6-T9) | 53 (8%) |
| Lower thoracic (T10-L2) | 276 (42%) |
| Lumbosacral | 23 (4%) |
| Lower instrumented vertebrae | |
| Thoracic | 12 (2%) |
| Lumbar | 139 (21%) |
| Sacroiliac | 493 (76%) |
| Iliac fixation | 435 (67%) |
| Levels decompressed | |
| None | 254 (39%) |
| 1 | 355 (54%) |
| 2 | 35 (5%) |
| 3 | 4 (1%) |
| Osteotomies | |
| Smith-Peterson | 343 (53%) |
| Three-column | 155 (24%) |
| LOS, days, mean ± SD | 8 ± 4 |

LOS, length of stay.

completely or accurately capture the morbidity associated with the specific procedure, particularly without data on patient frailty, surgical invasiveness, and estimates of complication rates. A tool that allows facilities, institutions, and providers to more accurately estimate LOS based on granular data has the potential to more appropriately estimate resource allocation, reimbursement, and bed census before a procedure.

A number of studies have attempted to retrospectively review factors relating to LOS. Most factors are related to patient age; overall health; and metrics related to case complexity, such as duration, number of levels fused, and blood loss. Developing more nuanced tools requires newer statistical techniques and large prospective datasets. Predictive modeling has been used in ASD surgery to generate accurate models for estimating major complications, cervical alignment, and proximal junctional kyphosis.[7,8] The statistical methods underlying predictive analytics are powerful and wide-spanning; they currently play critical roles in business, banking, advertising, and government, but their application in the medical field remains in its infancy. Given the financial implications underlying LOS, particularly with respect to high-risk ASD surgery, developing tools that can estimate this metric is increasingly important.

## MATERIALS AND METHODS

### Patient Population

A prospectively acquired database of consecutive patients with ASD collected through the International Spine Study Group was retrospectively reviewed. Patients were collected from across 11 sites in the United States. Each institution had institutional review board approval. Inclusion criteria included age >18 years and presence of spinal deformity defined as at least 1 of the following: Cobb angle >20°, sagittal vertical axis >5 cm, pelvic tilt >25°, and thoracic kyphosis >60°. Exclusion criteria included spinal deformity secondary to a neuromuscular etiology, presence of active infection or malignancy, staged surgery with a different hospitalization, or LOS >30 days.

### Data Collection, Radiographic Assessment, and Health-Related Quality of Life Measures

The demographic and clinical data collected included patient age, sex, race, body mass index, number and type of comorbidities and Charlson Comorbidity Index,[9] and prior spine surgery and/or

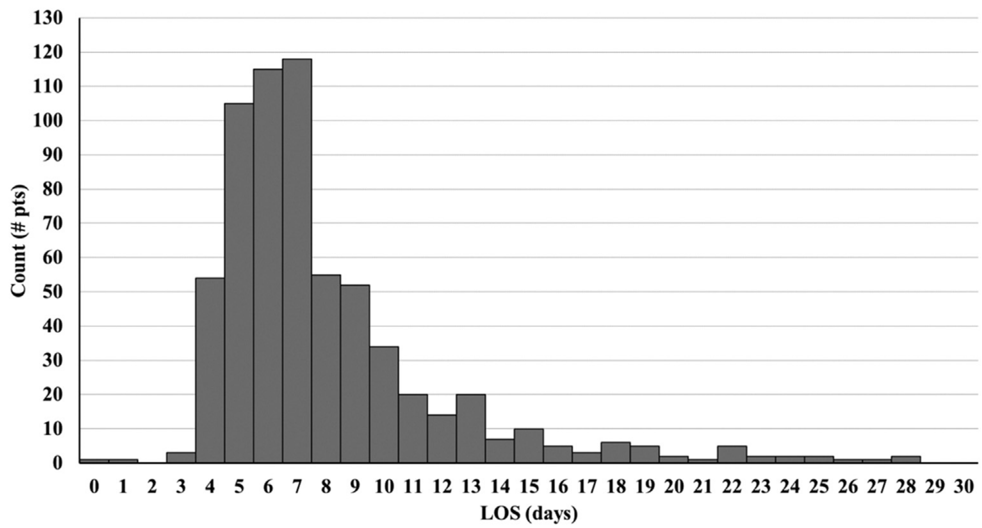


**Figure 1.** Distribution of hospital length of stay in days. Pts, patients; LOS, length of stay.

fusion. Surgical data collected included American Society of Anesthesiologists (ASA) physical status classification; whether the surgery was a primary or revision procedure; whether the surgery was staged; postoperative intensive care unit stay (yes/no); the presence of a 3-column osteotomy (pedicle subtraction osteotomy or vertebral column resection); the presence of iliac fixation; uppermost instrumented vertebra; lowermost instrumented vertebra; the use of allograft, autograft, or bone morphogenetic protein; the need for blood transfusion; and the number of posterior and anterior levels fused. The presence of (yes/no) and the number of levels were also collected for direct decompression Smith-Petersen osteotomy and interbody fusion.

Standardized health-related quality of life measures included the Oswestry Disability Index, 36-Item Short Form Health Survey, and Scoliosis Research Society-22r. Two standard summary scores were calculated based on the Physical Component Summary and the Mental Component Summary of the 36-Item Short Form Health Survey. The Scoliosis Research Society-22r questionnaire provided a total score and multiple subdomains, including activity, pain, appearance, mental, and satisfaction. A numeric rating scale score ranging from 0 (no pain) to 10 (most unbearable pain) was assessed for back and leg pain separately.

Full-length freestanding lateral spine radiographs (36-inch cassette) at baseline were analyzed using validated software (Spineview; Laboratory of Biomechanics of ENSAM, Paris, France).[10-12] All radiographic measures were performed at a central location based on standard techniques[11] and included coronal Cobb angles of thoracic and lumbar curves, coronal plumb line, thoracic kyphosis (T4-T12; Cobb angle between superior endplate of T2 and inferior endplate of T12), lumbar lordosis (Cobb angle between superior endplate of L1 and superior endplate of S1), sagittal vertical axis (C7 plumb line relative to S1), pelvic tilt, T1 spinal inclination, T1 pelvic angle, and mismatch between pelvic incidence and lumbar lordosis. The Scoliosis Research Society—Schwab coronal curve type was determined for all patients.[13]

## Statistical Analysis and Model Construction

Among 66 variables initially evaluated, 40 were included in the final model based on univariable predictor importance of $\geq$0.90, redundancy, and collinearity testing. A generalized linear model was created using modern predictive analytic methods.[14] Missing values within the database were imputed using standard techniques such as mean and median imputation.[14] All imputed data comprised <10% of the data for a given variable, and thus all the variables had at least 90% complete data.[14] Internal validation was performed by generating a training and testing dataset from a bootstrap sample with replacement using a random number generator. The testing dataset was acquired from patients randomly omitted from the bootstrap sample. The model was created based on the training dataset, and the final predictions were analyzed using the testing dataset. The outcome of LOS was determined to be skewed and thus was transformed using the natural log for model training and testing. The final predicted LOS was then converted back to standard LOS in days. Accuracy was calculated by comparison of predicted LOS with the actual LOS of the testing dataset. The model was built using commercially available software (IBM SPSS Modeler Version 16; IBM Corp., Armonk, New York, USA).

# RESULTS

## Patient Demographics

The final cohort included 653 patients. There were 504 women and 143 men with an average age of 58 ± 15 years (range, 18—86 years). Average body mass index was 27 with ASA classes as follows: I in 47 cases, II in 315 cases, III in 254 cases, and IV in 9 cases. Mean Oswestry Disability Index score was 44, and mean 36-Item Short Form Health Survey score was 31. Among all patients, 305 underwent previous surgery (47%), 233 of which were fusions (36%). Forty-five patients were smokers (7%). Patient demographics and spinopelvic parameters are summarized in Table 1.

**Table 3.** Variables Included in Predictive Model for Length of Stay

| | |
|---|---|
| 1 | Staged Surgery (Yes/No) |
| 2 | C7 sagittal vertical axis |
| 3 | Number of posterior levels fused |
| 4 | Charlson Comorbidity Index |
| 5 | Number of comorbidities |
| 6 | Preoperative Oswestry Disability Index |
| 7 | Iliac fixation (yes/no) |
| 8 | SRS activity |
| 9 | SRS appearance |
| 10 | Number of interbody fusion levels |
| 11 | SRS total |
| 12 | T1 pelvic angle |
| 13 | SF-36 Physical Component Score |
| 14 | Coronal C7 plumb line distance |
| 15 | Age |
| 16 | Frailty index |
| 17 | Work status |
| 18 | Frailty category |
| 19 | Lowermost instrumented vertebra category |
| 20 | Number of 3-column osteotomies (PSO/VCR) |
| 21 | Uppermost instrumented vertebra |
| 22 | Mismatch between pelvic incidence and lumbar lordosis |
| 23 | SRS pain |
| 24 | ASA class |
| 25 | Uppermost instrumented vertebra category |
| 26 | Blood transfusion (none, autogeneic, allogeneic, autogeneic and allogeneic) |
| 27 | Osteotomy (yes/no) |
| 28 | Back pain numeric rating scale |
| 29 | Preoperative leg numbness/tingling |
| 30 | SRS mental |
| 31 | Thoracic kyphosis (T4-T12) |
| 32 | SF-36 Mental Component Score |
| 33 | Allograft (yes/no) |
| 34 | Prior spinal fusion (yes/no) |
| 35 | Pelvic tilt |
| 36 | Normal preoperative neurologic examination (yes/no) |
| 37 | SRS-Schwab coronal curve type |
| 38 | Number of prior years with spine problems |
| 39 | Maximum Cobb angle |
| 40 | Use of BMP-2 (yes/no) |

SRS, Scoliosis Research Society; SF-36, 36-Item Short Form Health Survey; PSO, pedicle subtraction osteotomy; VCR, vertebral column resection; ASA, American Society of Anesthesiologists; BMP-2, bone morphogenetic protein 2.

Fusions were anterior in 4 cases and posterior in 642 cases. Upper instrumented vertebrae were as follows: 5 cervical, 287 upper thoracic, 53 middle thoracic, 276 lower thoracic, and 23 lumbosacral. Lower instrumented vertebrae were as follows: 12 thoracic, 139 lumbar, and 493 sacroiliac with 435 cases of iliac fixation. Surgical decompression was performed in 60% of cases. Three-column osteotomies were performed in 24% of cases. Mean LOS was 7.9 ± 4.1 days (median 7 days; range, 0–28 days). Surgical characteristics are summarized in **Table 2**. The distribution of LOS is presented in **Figure 1**.

### Predictive Model

Using the 40 variables listed in **Table 3** after variable selection described in Materials and Methods, a general linear model was constructed. The training dataset consisted of 653 patients (with replacement), and the testing dataset consisted of 240 patients (36.8%) not included in the training dataset based on the bootstrap algorithm. The linear correlations for the training and testing datasets were 0.632 and 0.507, respectively. Testing dataset accuracy within 2 days of actual LOS was 75.4% (181 of 240 patients). The 40 variables are ranked based on predictor importance in **Table 3**.

## DISCUSSION

Tools for predicting LOS in ASD will become increasingly relevant, particularly in the management of high-risk patients. Despite its clinical and financial relevance, there is a paucity of literature on this topic. McGirt et al.[15] recently introduced the Carolina-Semmes Grading Scale for predicting LOS in patients undergoing elective surgery for degenerative lumbar pathologies (1–3 levels only). The scale included age >70 years, ASA Physical Classification System class >III, Oswestry Disability Index score >70, diabetes, Medicare/Medicaid insurance, nonindependent ambulation, and fusion.

Other authors have sought to identify individual factors contributing to increased LOS in spine surgery. Bennett et al.[16] found that the Central Sensitization Inventory, a tool that quantifies symptoms related to central sensitization syndrome, an abnormal and intense enhancement of pain mechanisms, was associated with increased LOS even after controlling for other known variables. Sanoufa et al.[17] found that preoperative and postoperative anemia as well as the magnitude of change postoperatively were associated with hospital stay and overall cost. Zheng et al.[18] reviewed patients undergoing revision lumbar spine surgery and found that age, unemployment, ≥3 comorbid conditions, and complications were associated with LOS. In this case, unemployment may be a surrogate for disease severity or identify patients with more complex social support systems. Gruskay et al.[19] performed a retrospective analysis of a single center's experience with 1- to 3-level lumbar procedures and found that only age and ASA class were associated with LOS. The authors found that contrary to their expectations, no comorbidity was predictive of LOS, and in fact patients with heart disease had shorter LOS, likely owing to more extensive preoperative work-up and closer medical management. This finding suggests that preoperative risk stratification can aid in the appropriate allocation of resources and positively affect patient outcomes.

National datasets have been used to assess factors relating to LOS in large populations. Using data from the American College of Surgeons National Surgical Quality Improvement Program database from 2005 to 2010, Basques et al.[20] identified >1800 patients who underwent elective posterior lumbar fusion. In their study, the authors recognized age, morbid obesity (defined as body mass index ≥40), ASA class, operative time, multilevel procedures, and intraoperative blood transfusions as predictors of extended LOS. Other authors have also examined factors related to surgeries with typically short hospital stays, such as minimally invasive transforaminal lumbar interbody fusions. Siemionow et al.[21] found that patients who stayed >24 hours had higher estimated blood loss, received more crystalloids, had longer surgical time, had lower end of case temperature, had lower hemoglobin, and had lower preoperative narcotic use.[21] This is one of the few analyses that incorporates immediate postoperative factors into LOS, which suggests that dynamic or point-of-care tools may play a role during the patient's hospital stay; identifying these factors early may help minimize unnecessarily prolonged hospital courses.

In the future, institutional multidisciplinary committees may play a role in preoperative risk stratification and medical and surgical optimization of patients before surgery. Sienas et al.[22] reported on a multidisciplinary committee that was established to comment on factors related to LOS before lumbar fusion surgery. The group compared their data over 3 years with benchmarks published by the U.S. Agency for Healthcare Research and Quality. This committee established effective discharge plans, patient education, and partnerships with rehabilitation facilities and was able to demonstrate a statistical improvement in LOS compared with national averages.

The model presented in this article successfully predicted LOS after ASD surgery with an accuracy of 75% within 2 days. To our knowledge, this is the first and most comprehensive predictive model for ASD surgery to date, and it incorporates demographic, radiographic, medical, surgical, and health-related quality of life variables. Previous studies have identified more obvious and recognizable variables related to LOS; many are either directly or indirectly related to the patient's overall health and complexity of the surgery. This is the first model tailored specifically to patients with ASD and generated using modern advanced predictive analytic techniques. Factors that may have limited the accuracy of the model include variables not captured in this large database and variables that are difficult to quantify, such as bed availability at rehabilitation facilities, social support resources, and individual surgeon preferences. Regardless, this predictive model has the potential to identify high-risk patients and aid in point-of-care decision making in the preoperative or immediate postoperative setting to guide providers and third-party payers as well as counsel patients. For advanced predictive models, understanding the actual model methodology can be challenging, as they do not produce a visible formula or identify individual variable weights; the model performs this analysis based on the variables shown in **Table 3** and generates an estimated LOS, so the user does not necessarily see the specific impact of each variable. Although different from traditional statistical methods, this type of analysis is routinely used in business, banking, advertising, and government; its role in the medical field is still evolving, but it has transformative potential to improve assessments of risk, particularly in surgical patients.

## CONCLUSIONS

We present a model for predicting LOS in patients undergoing ASD surgery. Forty variables were tested and validated in a dataset containing 653 patients acquired through a retrospective analysis of a multicenter prospective dataset from the International Spine Study Group. The model was able to predict LOS with 75% accuracy within 2 days. To our knowledge, no such model developed specifically for patients with ASD currently exists. This tool will continue to evolve over time with more advanced datasets that include more nuanced variables. Ultimately, LOS can be influenced by factors that cannot be quantified, such as rehabilitation bed availability or personal and family support; however, developing tools that predict outcomes, complications, and LOS will be ubiquitous throughout health care.

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