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DEFORMITY

Machine Learning Predicts the 3D Outcomes of Adolescent Idiopathic Scoliosis Surgery Using Patient–Surgeon Specific Parameters

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Study Design. Retrospective descriptive, multicenter study.

Objective. The aim of this study was to predict the three-dimensional (3D) radiographic outcomes of the spinal surgery in a cohort of adolescent idiopathic scoliosis (AIS) as a function preoperative spinal parameters and surgeon modifiable factors.

Summary of Background Data. Current guidelines for posterior spinal fusion surgery (PSF) in AIS patients are based on two-dimensional classification of the spinal curves. Despite the high success rate, the prediction of the 3D spinal alignment at the follow-ups remains inconclusive. A data-driven surgical decision-making method that determines the combination of the surgical procedures and preoperative patient specific parameters that leads to a specific 3D global spinal alignment outcomes at the follow-ups can lessen the burden of surgical planning and improve patient satisfaction by setting expectations prior to surgery.

Methods. A dataset of 371 AIS patients who underwent a PSF with two-year follow-up were included. Demographics, 2D radiographic spinal and pelvic measurements, clinical measurements of the trunk shape, and the surgical procedures were collected prospectively. A previously developed classification of the preoperative global 3D spinal alignment was used as an additional predictor. The 3D spinal alignment (vertebral positions and rotations) at two-year follow-up was used as the predicted outcome. An ensemble learner was used to predict the 3D spinal alignment at two-year follow-up as a function of the preoperative parameters with and without considering the surgeon modifiable factors.

Results. The preoperative and surgical factors predicted three clusters of 3D surgical outcomes with an accuracy of 75%. The prediction accuracy decreased to 64% when only preoperative factors, without the surgical factors, were used in the model. Predictor importance analysis determined that preoperative distal junctional kyphosis, pelvic sagittal parameters, end-instrumented vertebra (EIV) angulation and translation, and the preoperative 3D clusters are the most important patient-specific predictors of the outcomes. Three surgical factors, upper and lower instrumented vertebrae, and the operating surgeon, were important surgical predictors. The role of surgeon in achieving a certain outcome clusters for specific ranges of preoperative T10-L2 kyphosis, EIV angulation and translation, thoracic and lumbar flexibilities, and patient's height was significant.

Conclusion. Both preoperative patient-specific and surgeon modifiable parameters predicted the 3D global spinal alignment at two-year post PSF. Surgeon was determined as a predictor of the outcomes despite including 20 factors in the analysis that described the surgical moves. Methods to quantify the differences between the implemented surgeon modifiable factors are essential to improve outcome prediction in AIS spinal surgery.

Key words: adolescent idiopathic scoliosis, classification, data-driven, machine learning, surgical decision-making, surgical planning, three-dimensional.

Level of Evidence: 3

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Posterior spinal fusion surgery (PSF) in adolescent idiopathic scoliosis (AIS) aims to correct and stabilize the spinal deformity and prevent curve progression.[1] Various criteria have been proposed to guide the surgical decision-making in AIS population.[1–10] Postoperative curve progression and compensatory curve development have been reported while following these criteria.[4,10–12] These reports have called for a more comprehensive identification of the factors that affects the surgical outcomes in AIS.

Clinical classifications systems of the preoperative spinal alignments are based on 2D spinal radiographs.[1,13] The use of 2D radiographs, although facilitated the clinical application of these classification systems, disjoined the variations in 3D spinal deformity from the clinical management and surgical decision-making.[14–16] 3D classification of the spine in AIS showed that different scoliotic subtypes exist within the Lenke types, which respond differently to the surgeon modifiable factors.[14,15,17,18] Yet, it has not been tested whether it is possible to quantitatively predict the radiographic surgical outcomes in a heterogeneous cohort of AIS with varying 3D spinal alignment.

A relationship was found previously between the 3D preoperative spinal alignment and 3D radiographic spinal alignment after PSF as a function of the fusion levels in a small cohort of homogeneous (Lenke1 and 2) AIS patients.[19] In the present study, we aim to determine whether adding a large number of detailed surgical factors, as well as the preoperative demographics, clinical, and radiographic measurements from a multicenter, multisurgeon database can improve the prediction accuracy of the radiographic surgical outcomes. We hypothesized that patient-specific preoperative factors and surgeon modifiable factors both significantly predict the 2-year outcomes of the PSF in a heterogeneous cohort of AIS patients.

METHODS

Patient Population

A total of 371 AIS patients were selected consecutively and retrospectively from a prospectively collected database. Data from seven surgeons in three hospitals were included. Inclusion criteria were AIS patients who had received a PSF, with two view radiographs and 3D reconstructions of the spine at preoperative and 2-year follow-up, and preoperative clinical measurements of the trunk shape and flexibility. Patients with any neuromuscular or musculoskeletal diseases, other than scoliosis, were excluded.

Preoperative Factors

A total of 42 continuous variables, divided in three main categories of frontal and sagittal spinal and pelvic radiographic measurements; demographics and clinical measurement (age, weight, height, left, right and forward thoracic and lumbar flexion, and rib hump); and SRS-22 scores (Pain, General function, Self-Image, Mental Health, Satisfaction, and total score) were included (Table 1).

A total of 22 preoperative categorical variables were also included. These parameters are sex, Lenke classifications, Risser sign, Tri-radiate status, upper thoracic, thoracic, and thoracolumbar/lumbar (TLL) apex, end vertebral levels, and curve directions, T1 tilt direction, shoulder balance, stable vertebra, and classification of central sacral vertical line (CSVL). In addition, a previously described classification of the 3D spinal alignment was used to determine the preoperative 3D cluster groups (an additional categorical variable). In this classification method, the preoperative T1-L5 vertebral position and orientation in the three anatomical planes were determined from the 3D models of the spine. A probabilistic classification method determined a total of nine preoperative 3D clusters (Figure 1)[18]. This method used the 3D reconstruction of the biplanar radiographs to extracted 3D information regarding the vertebral position and orientation.[18,20] These clusters include four right thoracic types, three left thoracolumbar/lumbar types, one low apex right thoracic/thoracolumbar type, and one left thoracic type (Figure 1). The preoperative radiographic measurements and the distributions of the preoperative 3D clusters in each of the Lenke classes were described before.[18] A total of 64 patient-specific variables (42 continuous and 22 categorical) were used as preoperative patient-specific factors.

Surgical Factors

A total of 20 categorical surgical factors were collected to describe the surgical procedures. Surgeon, intraoperative traction, upper and lower instrumentation level (UIV, LIV), rods material, construct type, in-situ bending, Ponte osteotomy, posterior release, and correction maneuver (distraction–compression, and derotation methods) determined the surgical procedure.

Surgical Outcomes at 2-year Follow-up

Similar to the preoperative classification of the 3D spinal alignment, the 3D position and alignment of the T1-L5 vertebrae at 2-year follow-up were used to determine the postoperative clusters.[18] A total of three 3D postoperative spinal alignment groups were determined (Figure 2). These clusters were characterized subtypes with residual proximal curve (Type 1), hypokyphotic subtypes (Type 2), and subtype with residual lumbar curve and thoracic and lumbar rotation (Type 3). The cluster number was used as the categorical predicted outcome.

Model Development

After data normalization and imputation of missing data,[21,22] two predictive models were developed using the training set (80% of the data) to determine the role of the surgical and patient-specific factors in predicting the 3D outcome clusters. In the first model (Model 1), *only* the preoperative variables (64 predictors) were used to predict the 2-year outcome cluster groups. In the second model (Model 2), *both* preoperative and surgical factors were implemented in the model (84 predictors). An ensemble learning classification method with bootstrapping (Random Forest) was used to develop these models.[23,24] Random forest has been used as a powerful machine learning method that allows exploring the predictive models by aggregating multiple decision trees and extracting rules that facilitates comprehension of the predictive models' output.[23,24] This method is shown to be less prone to over-fitting compared to the other predictive modeling methods.[24] Using random forest as our classifier,[24] we calculated the accuracy of the

TABLE 1. Preoperative Quantitative Data.

	Measurement	Mean	SD	Min	Max	Skew	Kurtosis	SE
Radiographic measurements	Upper thoracic curve (°)	25.6	11.4	0.0	57.0	0.0	−0.3	0.6
	Thoracic curve (°)	52.6	15.0	5.0	118.0	−0.01	1.1	0.7
	Lumbar curve (°)	41.1	13.1	4.0	98.0	0.6	1.2	0.6
	Upper thoracic bend (°)	18.0	11.1	0.0	57.0	0.3	0.0	0.5
	Thoracic bend (°)	37.9	17.6	0.0	111.0	0.5	0.4	0.9
	Lumbar bend (°)	17.6	13.5	0.0	86.0	0.9	1.2	0.7
	Coronal C7 to CSVL, cm	−0.3	1.8	−5.5	4.3	0.1	−0.5	0.1
	Lateral C7 to sacrum, cm	0.1	2.3	−14.0	7.3	−0.8	4.4	0.1
	Thoracic apical to C7 plumb, cm	3.6	1.9	−4.2	9.9	−1.3	3.3	0.1
	Thoracic apical translation to CSVL, cm	3.3	2.9	−5.1	11.0	−0.3	−0.3	0.1
	TLL apical translation, cm	−1.8	2.2	−6.6	6.7	0.4	1.3	0.1
	T1 Tilt angle (°)	5.0	4.0	0.0	36.0	2.1	9.9	0.2
	EIV angulation (°)	7.6	21.3	−39.0	38.0	−0.5	−1.3	1.1
	EIV translation, cm	−0.4	1.8	−5.80	4.3	−0.2	−0.9	0.1
	Disc angulation below EIV (°)	3.6	5.3	−13.0	18.0	−0.3	0.3	0.2
	T2-T12 kyphosis (°)	31.8	14.5	−8.00	78.0	0.2	0.0	0.7
	T5-T12 kyphosis (°)	20.4	14.3	−16.0	62.0	0.1	−0.2	0.7
	T2-T5 kyphosis (°)	15.0	8.0	−8.00	38.0	−0.1	−0.1	0.4
	T10-L2 kyphosis (°)	0.3	12.8	−82.0	44.0	−0.4	4.2	0.6
	Lordosis T12/S1 (°)	−55.1	13.0	−98.0	−11.0	−0.2	0.4	0.6
	Pelvic incidence (°)	51.2	12.1	21.0	91.0	0.5	0.3	0.6
	Pelvic tilt (°)	8.2	7.5	−15.0	37.0	0.2	0.6	0.3
	Sacral slope (°)	43.1	8.8	19.0	72.0	0.3	0.3	0.4
	Junctional kyphosis-proximal (°)	6.9	4.9	−14.0	26.0	−0.1	1.2	0.2
	Junctional kyphosis-distal (°)	−12.2	11.5	−43.0	13.0	−0.2	−0.8	0.6
	Shoulder height, cm	7.5	7.9	1.0	34.0	1.1	0.5	0.4
	Trunk shift, cm	2.1	1.2	0.0	6.9	0.6	1.1	0.0
Clinical measurements	Age at diagnosis, y	12.3	1.4	11	13	0.1	0.2	0.0
	Age at surgery, y	15.2	1.4	14	16	0.0	0.1	0.0
	Rib hump thoracic (°)	13.9	5.53	0.0	30.0	−0.1	0.1	0.2
	Rib hump lumbar (°)	9.0	5.9	0.0	30.0	0.6	0.0	0.3
	Thoracic and lumbar flexion, cm	10.3	2.7	2.0	26.0	0.9	4.0	0.1
	Right thoracic/lumbar lateral flexion, cm	13.8	5.0	0.0	34.0	0.4	1.1	0.2
	Left thoracic/lumbar lateral flexion, cm	14.5	5.0	2.0	35.0	0.3	0.2	0.2
	Height, cm	162	10.5	58.2	193.0	−3.0	35.5	0.5
	Weight, kg	56.4	13.3	37.4	161.3	2.0	10.4	0.6
SRS scores	Pain	3.9	0.7	1.6	5.0	−0.5	0.0	0.0
	General function	4.3	0.6	1.6	5.0	−1.0	0.7	0.0
	Self−image	3.3	0.7	1.2	5.0	−0.2	0.2	0.0
	Mental health	3.9	0.6	1.8	5.0	−0.6	−0.1	0.0
	Satisfaction	3.6	0.9	1.0	5.0	−0.4	0.1	0.0
	Total	3.8	0.5	1.8	4.9	−0.6	0.2	0.0

The variables are presented in three categories of radiographic measurements, clinical measurements, and SRS scores. CSVL indicatesz central sacral vertical line; EIV, end instrumented vertebra; Max, maximum; Min, minimum; SD, standard deviation; SE, standard error; Skew, skewness; TLL, thoracolumbar/lumbar.

two predictive models (Model 1 and Model 2), and then using the model with the higher accuracy, determined the important predictors of the 3D spinal alignment outcomes. The variable importance was determined based on mean decrease in the model accuracy, which was calculated by excluding the predictor variables one by one.[23] Feature selection was used to extract the most frequent set of variable interactions (also known as if-then rules) with lowest classification error that predict a specific outcome group.[25] The *Frequency* was quantified as the proportion of patients that satisfied the given rule. The *Error* associated with each rule was defined as the number of incorrectly classified patients based on the rule's conditions divided by the number of patients that satisfied the rule's conditions.[25] Multiclass receiver-operating characteristic (ROC) and the area under the curve (AUC) were calculated for the validation dataset (the remaining 20% of the data that was not used in model development) to evaluate the model performance.

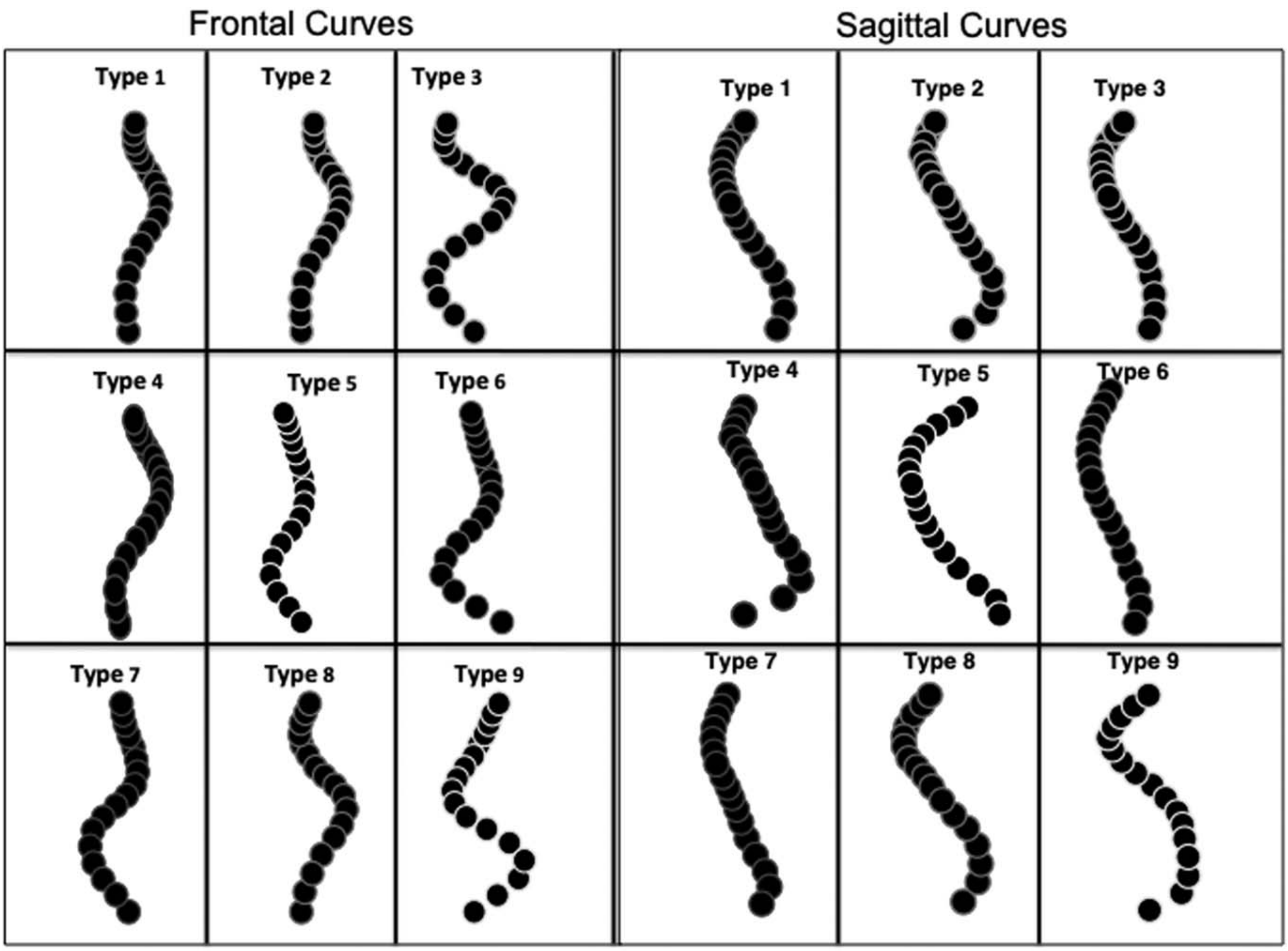

Figure 1. Schematics of the 3D preoperative clusters in the coronal and lateral views. **Type1–4 right thoracic curves**—Type1, two 3D curve (the direction of the vertebral rotation is different in thoracic and lumbar). Normal-hyper kyphosis. Lemniscate axial projection. Type 2, one 3D curve (the thoracic curve extends to the lumbar thus the direction of the vertebral rotation does not change between the thoracic and lumbar regions). Hypo-kyphosis. axial projection is loop-shaped. Type3—Thoracic and lumbar curves are close in magnitude with 2-3 3D curves. Normal-shaped kyphosis. Lemniscate axial projection. Type 4—one 3D curve. Hyperkyphosis. Axial projection is loop-shaped. **Types 5–6—Left lumbar curves**; Type 5, one 3D curve, hyper-kyphosis, loop-shaped axial projection. Type 6, two to three 3D curves, Normal or hypo kyphosis, lemniscate-shaped axial projection. **Type 7**—two to three 3D curves, hypokyphosis, lemniscate-shaped axial projection. **Type 8—Low apex thoracic/ Right thoracolumbar curve.** Sagittal profile hyper-normal kyphosis. Loop-shaped axial projection. **Type 9—Left thoracic-right lumbar,** normal kyphosis. Loop-shaped axial projection.

RESULTS

Predictor Variables

Table 1 presents the descriptive statistics of the continuous preoperative predictors. Except for lumbar bend, lateral C7 to sacrum (sagittal balance), thoracic apex to C7 plumbline, T1 tilt angle, shoulder height, height, weight, and SRS general function score, data are normally distributed (Table 1). Height, weight, and T1 tilt had heavy-tailed distribution, but the data were not treated for outliers (Table 1).[26]

The summary of the preoperative categorical data is presented in supplemental digital content, Table S1, http://links.lww.com/BRS/B665. In seven of 22 of these categorical data, >50% of the patients belonged to the same group: (sex [female], kyphosis modifier [neutral], proximal thoracic curve levels (upper) (C7), curve directions (right thoracic, left lumbar), and triradiate cartilage status [closed]) (Table S1, http://links.lww.com/BRS/B665).

For the surgical factors (supplemental digital content, Table S2, http://links.lww.com/BRS/B666), >50% of the patients received the same surgical treatment in the following 10 categories: intraoperative traction (yes), rod tensile strength (200 KSI both rods), construct type (all screws), in situ bending (yes), Ponte osteotomy (yes), wide posterior release (yes), derotation with two rods in (yes), derotation method with two rods in (segmental), both ends locked before direct vertebral rotation (yes), concave rod completely locked down before second rod is put in (yes) (Table S2, http://links.lww.com/BRS/B666).

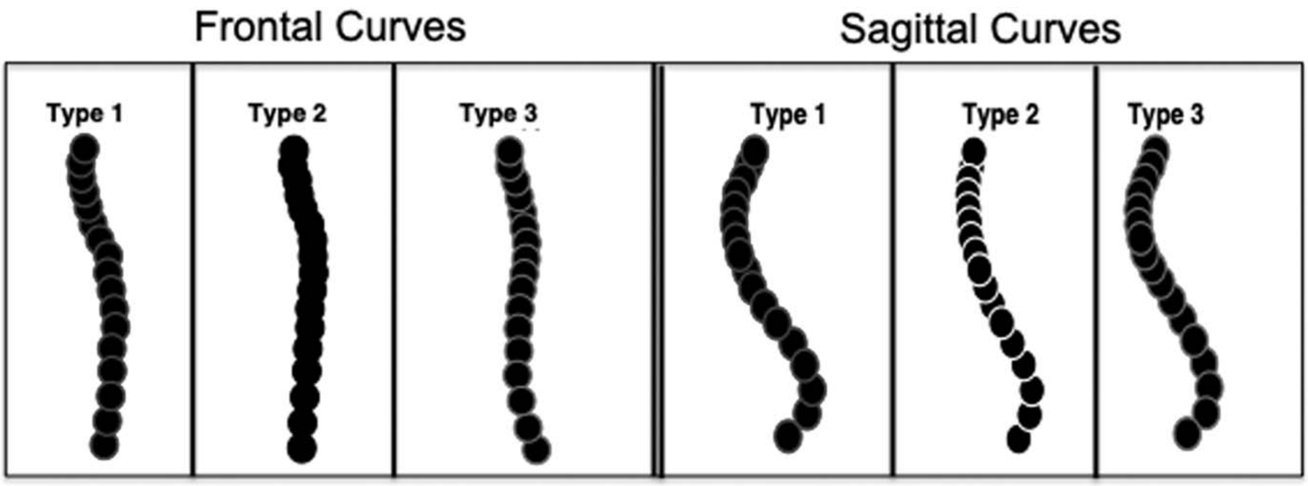

Figure 2. Schematics of the 3D postoperative (2-year follow-up) clusters. **Type 1**–residual thoracic rotation and proximal curve deformity. **Type 2**–the lowest T4-T12 kyphotic curve and smallest frontal residual curve. **Type 3**—the largest residual frontal curve and rotation among the three types.

Model Accuracy and Extracted Rules

Model accuracy was 64% when only preoperative factors were considered as predictors of the three outcome clusters (Figure 2). The model accuracy increased to 75% when both preoperative and surgical factors were used as predictors.

The mean decrease accuracy for the top 20 variables, as determined by Model 2, is plotted in Figure 3. The three surgical factors with highest impact on the model accuracy are UIV, LIV, and the surgeon. Four lumbar frontal parameters (TLL apical translation, lumbar modifier, lumbar apex, lumbar Cobb angle, and lumbar bend) appeared as important predictors, whereas only one thoracic variable (thoracic apex) significantly predicted the outcome groups (Figure 3).

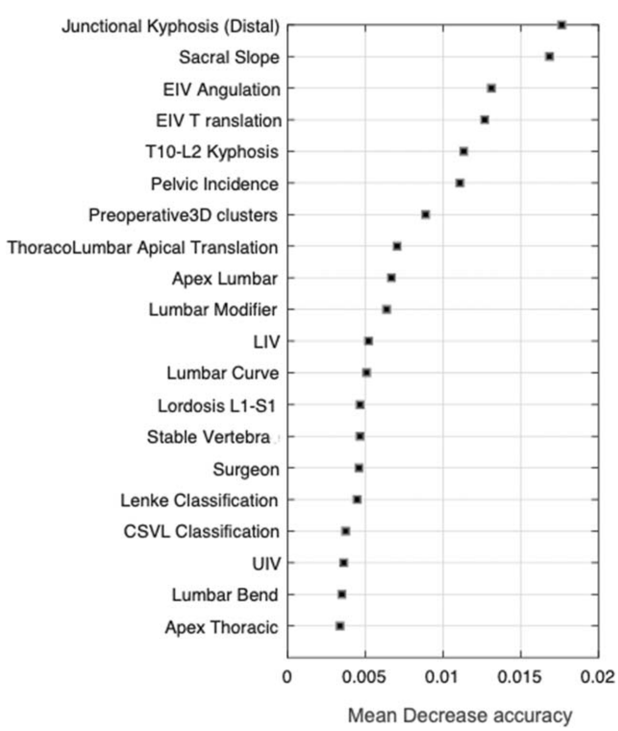

Figure 3. Receiver-operating characteristic curves and the area under the curve (AUC) for outcome clusters. The predicted variables are the three outcome (Type1, Type2, Type3) clusters shown in Figure 2.

Table 2 summarized the rules with the highest frequency and lowest error. Criteria based on the surgeon, T10-L2 kyphosis, 3D preoperative cluster, pelvic parameters, end instrumented vertebra (EIV), and curve flexibility appeared in more than one of the extracted rules (Table 2).

Model Validation

The receiver-operating characteristic (ROC) curves for validation dataset using Model 2 are shown in Figure 4. The area under the curve (AUC) for pairwise comparison of clusters 1 to 3 is 0.83, 95% confidence interval [CI] (0.79–87); 0.79, 95% CI (0.73–0.85); 0.86, 95% CI (0.81–0.91) (Figure 4).

DISCUSSION

We developed a predictive model of the PSF 3D radiographic outcomes and determined the most important predictors of such outcomes in a multicenter, multisurgeon cohort. Both patient-specific and surgeon modifiable factors predicted the overall 3D spinal alignment at 2-year postoperative. Our quantitative model predicted three clusters of surgical outcomes with an accuracy of 75% and determined the UIV and LIV and the operating surgeon as the main surgical predictors of the outcome (Figure 3).

Currently, the preoperative 2D scoliotic curve patterns are the main factors in guiding the surgical decision-making.[1] As such, research has focused on predicting the surgical outcomes based on the patient specific coronal and sagittal radiographic parameters.[10,12,27–29] Considering the surgeon modifiable factors in conjunction with preoperative spinal parameters improved the surgical outcome prediction.[4,9,15,19,30,31] Factors such as the position of LIV with respect to stable or neutral vertebrae, derotation and leveling of the LIV, and the imparted kyphosis were shown to be important predictors of the outcomes.[3,4,8,9,28,29,32–34]

TABLE 2. Extracted Rules and the Outcomes Associated With That Set of If-then Conditions. The Frequency and Error for Each of the Extracted Rules Are Shown

	Rules	Outcome Type	Frequency	Error
1	• Thoracic flexibility (thoracic bend< 53°) • EIV angulation <10° • T10-L2 kyphotic or <10° lordotic • Surgeons 1–5 (Hospitals 1 and 2)	1	0.22	0.09
2	• Height >155 cm • EIV translation <3 cm • T10-L2 kyphotic or <15° lordotic • Lenke Classification 1 • Surgeons 2–5 (Hospitals 1 and 2)	1	0.17	0.10
3	• 3D preoperative cluster 5–7 (TLL curves) • Pelvic tilt<10° • UIV at T8, T10-T11 • Lumbar modifier C	3	0.18	0.12
4	• Preoperative clusters 6, 7 • Lumbar flexibility (lumbar bend >20°) • EIV angulation> 15° • Primary release T4, T6-T8 • Surgeons 6 and 7 (Hospital 3)	3	0.20	0.21
5	• EIV translation>1 cm • Pelvic incidence>35° • 3D preoperative cluster 2, 4 (Single thoracic curve) • T1 Tilt Angle Direction (Left) • LIV at T11, T12 • Primary Release (Upper level) at T2, T3, T4	3	0.10	0.14
6	• Preoperative 3D cluster 2, 4, 8, 9 • DJK kyphotic or less than 5° lordotic • Sacral slope >45° • Rod maneuver: both compression and distraction	2	0.13	0.18

EIV indicates end instrumented vertebra; LIV indicates lower instrumentation level.

Considering these surgical factors proved useful in improving one surgical outcome, for example, uninstrumented curve correction, postural balance, and shoulder tilt or preventing junctional deformities.[3,4,8,9,32,33,35] Different from the present literature that predict one planar radiographic outcome, our analysis chose the global 3D spinal alignment as the predicted outcome (Figure 2). As such our model predicted the three outcome subtypes (Figure 2) as the main outcome groups of the PSF and determined the factors that can predict these outcome groups (Figure 3). Considering only three outcome types, while limits a detailed analysis of the surgical outcomes, provides an overview of the 3D spinal alignment at 2-year follow-up without scarifying the model accuracy.

Previously, it was shown that in a single-center, single-surgeon study, the preoperative 3D scoliotic subtypes relate to the postoperative 3D clusters as a function of UIV and LIV in 70% of the patients.[19] In the present study, we included several surgeons and 20 surgical factors yet, the model accuracy improved to 75%. This can be explained by the findings of our present study that the surgeon, UIV, and LIV are the most important surgical factors that predict the radiographic outcomes. In addition, although a large heterogeneous patient population was included here, 50% of the surgical variables were the same for all the patients (Table S2, http://links.lww.com/BRS/B666). A surgeon cohort who uses a more diverse correction techniques or methods to differentiate the implication of the current surgical factors, for example, sequences of the moves and the imparted force magnitudes are required to further tease out the differences between the surgeon modifiable techniques.

The rule extraction analysis is a powerful tool that allows exploring the random forest model and determining the interaction between the predictor and predicted variables when the full predictive model is not available (Table 2). Our analysis determined 40 rules that linked the radiographic outcomes to the preoperative and surgical factors; however, only six of them were not redundant and had acceptable frequency and error (Table 2). We specially presented the rules that included the preoperative classification of the spine (Lenke or 3D classification), information about the UIV and LIV, or the operating surgeons (Table 2). Figures 5A and B show the 2-year outcome of surgery for patients with 3D preoperative cluster 4 (Figure 1) with an outcome cluster 3 who satisfied all the conditions in Rule 5 (Table 2). The conditions of this rule were observed in 55 patients (15%) with eight misclassified patients (Table 2). Figure 5C shows a misclassified patient; although the conditions were satisfied, patient had an outcome cluster 2. The different outcomes for patients A-C could be related to the screw patterns and density,[36,37] differences in UIV level, slightly higher flexibility of the lumbar curve in patient C (17° lumbar bend) *versus*

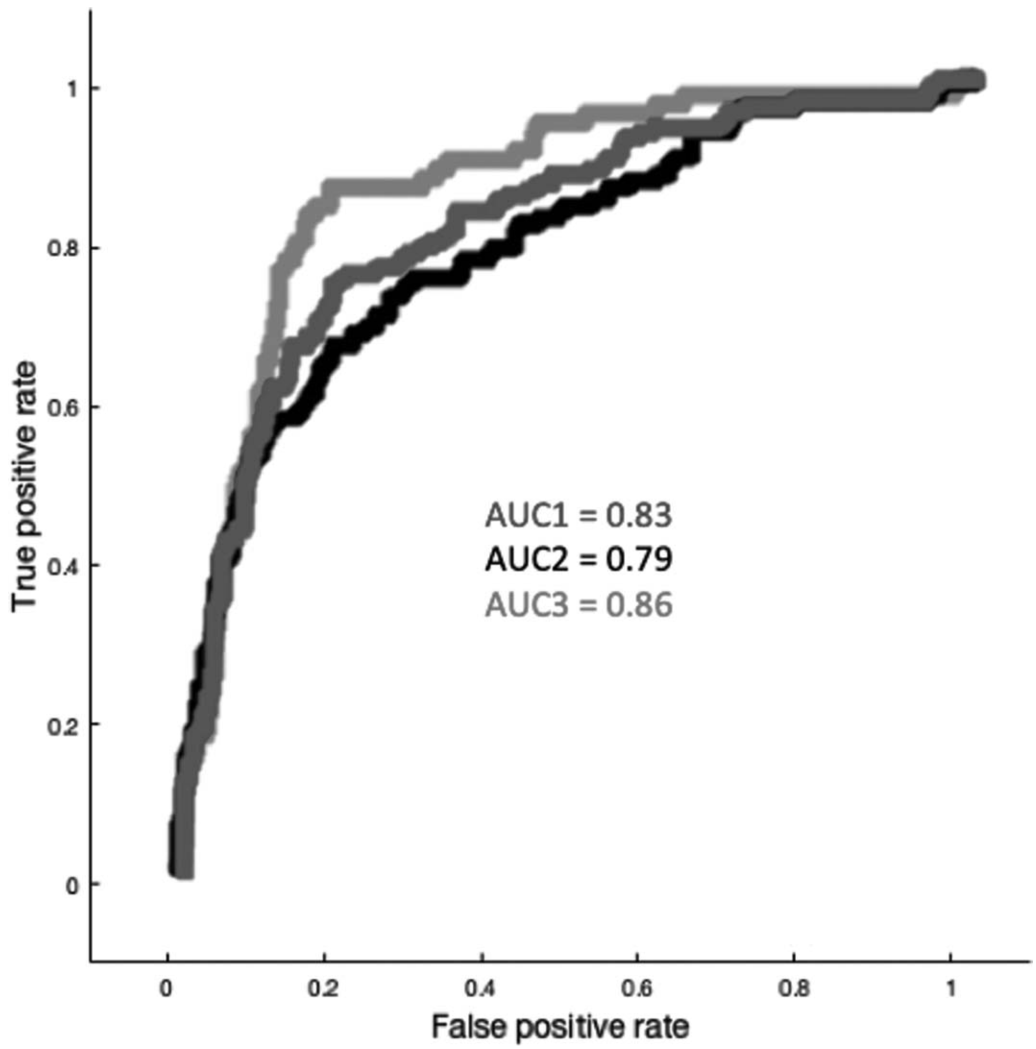

Figure 4. Predictors importance calculated based on the mean decrease in accuracy of the model as the variables were removed, one-by-one, from the model. The top 20 variables are shown in Figure 3.

patient A (21° lumbar bend).[29,38] Finally, patients with the same preoperative conditions as shown in rule 5 may have received different fusion levels, resulting in a different outcomes (outcome Type 2) (Figure 5D). The goals of the surgery and patient expectation should be considered when evaluating these outcomes.

The role of the operating surgeon in the surgical outcome of PSF had been shown before.[39] The surgeon was not only identified as an important predictor of the outcomes (Figure 3), but also interacted with patient-specific factors as determined in the extracted rules (Table 2). In three out of six of the extracted rules, it was shown that patients with the same preoperative characteristics have different outcomes depend on their operating surgeon (Table 2). Our rule extraction analysis also grouped the surgeon from the same hospitals together (Table 2). The role of implant types, training, surgeon assistants, and the surgical team, along with other hospital policies that may impact the outcomes merits further investigation. This finding suggests although the patient-specific factors can be collected in a standardized fashion thanks to the 3D models of the spine, the interaction between the surgeon-specific factors and the patient parameters may impact the surgical outcomes. As such, it is expected that developing surgeon-specific predictive models, although less generalizable to the surgeon community, can improve the model accuracy. For such model to yield reliable outcomes, adequate number of patients per hospital or surgeon will be required to re-train the model (supplemental digital content, Table S2, http://links.lww.com/BRS/B666).

Although we used a comprehensive database of AIS, many surgical factors that had been shown previously as predictors of the PSF outcomes, such as screw density and pattern,[36,37,40] and differential rod contour or patient-specific rod contouring,[7,41] standard *versus* wide posterior release,[42,43] were not included in our analysis. The surgeons who participated in this study were all trained in the United States and Canada, thus the role of variation in surgical techniques that might be practiced in other countries could not be evaluated.

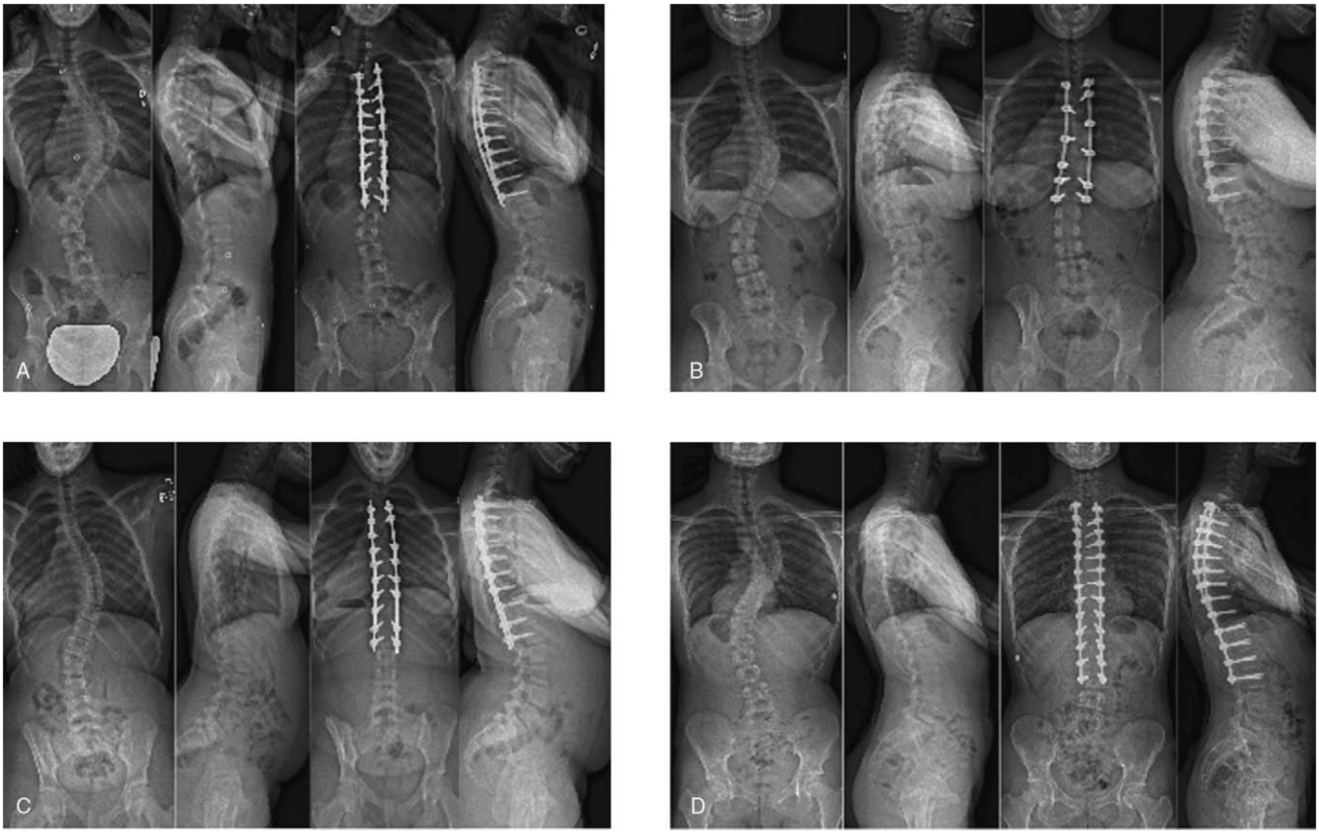

Figure 5. Outcome prediction using the random forest model and extracted rules (**A** and **B**) patients with preoperative characteristics cluster 4 were correctly classified according to rule 5 (Table 2) in cluster outcome Type 3. (**C**) Patient with preoperative cluster 4 and other surgical factors mentioned in rule 5 was not classified correctly (outcome cluster was Type 2). (**D**) Patient with the same characteristics as patients **A**–**C** received a different fusion levels resulted in Type 2 outcome group.

CONCLUSION

Preoperative patient-specific parameters in a cohort of AIS (64 variables) who received PSF predicted the 2-year spinal alignment clusters outcomes at 64% accuracy. Adding the surgical factors (increasing the number of predictors to 84) improved the outcome prediction to 75%. The most important surgical factors were the UIV, LIV, and the surgeon. A more detailed identification of the surgeon-specific factors can improve the surgical outcome prediction.

➢ Key Points

- Preoperative patient-specific parameters and surgeon-modifiable factors predict three surgical outcome groups with 75% accuracy.
- When only preoperative factors were considered as the predictors, the outcome prediction accuracy dropped to 64%.
- Surgical factors that significantly impacted the outcome predictions were the position of the UIV and LIV and the operating surgeons.
- The 3D preoperative clusters were an important predictor of the outcomes.
- A detailed description of the surgical moves can improve the outcome prediction of the PSF.

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