Prediction of Accuracy and Screw Size by Pedicle Anatomic Parameters and Screws in Idiopathic Scoliosis With Freehand Screw Placement Based on Machine Learning

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Research article

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Abstract

Study Design: A retrospective study.

Objective: To investigate a machine learning algorithm to explore the influence of pedicle morphological parameters and pedicle screw size on safe screw placement in the treatment of idiopathic scoliosis with freehand. And a model was built to guide the selection of screw

Methods: We analyzed 52 patients with idiopathic scoliosis who underwent correction surgery in our hospital from June 2012 to December 2019, including 17 males and 35 females aged 10-20 years. All pedicle screws were placed by freehand. Preoperative and postoperative X-ray and CT scans of whole spine were performed to measure Cobb Angle and pedicle morphological parameters, including transverse diameter of the pedicle, sagittal diameter of the pedicle, length of the pedicle channel, rotation angle of vertebrae, angle of the sagittal plane of pedicle and angle of the horizontal plane of pedicle. Screw penetration grading was also evaluated. Random forest were used to build a machine learning model to help the decision making of choosing an appropriate screw based on pedicle parameters and screw size.

Results: A total of 888 screws and pedicles were included. The satisfactory rate of screw placement was 88.5%. The pedicle screw size was analyzed and predicted based on screw penetration and pedicle morphological parameters. The AUROC of random forest classification model achieved 0.712. The goodness of fit(R^2) was 0.546.

Conclusion: Our model could provide guidance for the doctor to choose the length of the screw before surgery, and the classification model could also give a preliminary prediction of whether there would be anterior screw penetration based on the pedicle parameters.

Introduction

Idiopathic scoliosis refers to a type of spinal deformity without abnormal development or neuromuscular abnormalities, which manifests as scoliosis and rotational deformity. The prevalence among adolescents aged 10–16 is 2 ~ 4%[1]. Scoliosis without treatment could cause back pain, cardiopulmonary disfunction or neurologic disfunction [2]. For patients whose Cobb angle was more than 20° with a progression more than 5° when revision, braces are usually used. When Cobb angle was more than 40° and brace treatment cannot control the progression of deformity, surgery would be considered. The pedicle screw system has advantages of strong pull-out strength resistance, multi-plane stability, less fusion joints, less postoperative support [3]. When applied to correction surgery, it has strong correction strength, lower incidence of complication and lower reoperation rate[4,5]. Nowadays, freehand technique is the most common technique of pedicle screw placement. The trajectory of screw is determined through the judgment of the anatomical structure and tactile feedback. It is a reliable technique with the advantages of shorter operation time, less radiation dose, and low economic burden. The screw misplacement rate ranges from 1.9–27%[6,7], with lower incidence of vascular and nerve complications.[8] The proportion of abnormally narrow pedicle of idiopathic scoliosis patients is significantly higher than that of normal people. Previous reports showed that, for abnormal pedicles, the probability of misplacement of screws with freehand is 3 times that of normal pedicles[9].Therefore, it's meaningful to have a clear understanding for pedicle development. A study of Chinese people showed[2] that the proportion of abnormal pedicles in patients with idiopathic scoliosis is 65%. Female, thoracic pedicles and pedicles on concave side are independent risk factors for pedicle deformity [2,9]. Before surgery, the surgeon needs to measure the pedicle parameters by himself and choose the screw subjectively, which requires abundant experience and long learning curve.

Artificial intelligence technology aims to replicate human intelligence with computer and algorithm and has been applied in orthopedics for diagnosis, decision making and prediction[10–12]. The most advanced representative of this technology in orthopedics is surgical robot[11]. Artificial intelligence systems can diagnose vertebral compression fracture with a sensitivity of 95.7%[13]. These applications mainly based on a technique known as machine learning. Machine learning involves an algorithm to creates a model to describe the associations between data, which can be used to predict future events[14]. Random forest is a classification and regression tree decision analysis methodology, which consists of train and detect[15], previously described in detail[16,17].

This original study brought machine learning into screw selection during surgery preparation process. We took the form of supervised learning to build a random forest model based on satisfactory screws placed by well-experienced surgeon and pedicle morphological parameters. And we hope this model can help surgeons on appropriate screw selection.

Methods

This study was reviewed and approved by the Peking University Third Hospital Medical Science Research Ethics Committee (IRB00006761-M2020093).

Inclusion and exclusion criteria

Inclusion criteria: ①Age < 24 years; ②Diagnosed as idiopathic scoliosis; ③Posterior approach correction surgery was performed in our department; ④Pedicle screw was placed by freehand; ⑤Preoperative and postoperative CT scan was performed.

Exclusion criteria: ①Patients with other spine dysplasia, neuromuscular abnormalities or bone metabolism diseases; ②Patients with any other screw placement technique such as guide templates, navigation, robots, etc. ③Patients with incomplete preoperative and postoperative imaging data;

General information

We searched the diagnosis of idiopathic scoliosis in our system for patients undergoing correction surgery. According to the inclusion and exclusion criteria, a total of 52 cases (17 males and 35 females) of idiopathic scoliosis were included. Freehand technique was used in all screws. The average age was 15.1 ± 3.8 (10–32) years old, and preoperative Cobb angle was 52.0°±15.7° (21°-103°). A total of 888 pedicles and screws were analyzed.

Imaging measurement

Statistics were measured through the tools with PACS system. Cobb angle was measured in whole spine X-ray image and the following indicators were measured in spinal CT (Fig. 1)

1. Transverse diameter of pedicle(TD): The transverse diameter of pedicle is the maximum width of the pedicle perpendicular to the central axis of the pedicle on the horizontal plane. CD is the transverse diameter of the pedicle.
2. The length of the pedicle channel(CL): AB is the length of the pedicle bone channel at the widest level of the pedicle.
3. The angle of the sagittal plane of pedicle(SA): On the widest level of the pedicle, the angle β between AB and the anatomical neutral sagittal line is the angle of the sagittal plane of pedicle.
4. Rotation angle of vertebrae(RA): The angle α between the mid-sagittal line of the vertebral body and the anatomical neutral sagittal line is the rotation angle of vertebrae.
5. Sagittal diameter of the pedicle(SD): The sagittal diameter of the pedicle is the maximum height of the pedicle perpendicular to the central axis of the pedicle on the sagittal plane. EF is the sagittal diameter of the pedicle.
6. Angle of the horizontal plane of pedicle(HA): The angle γ between the central axis of the pedicle and the patient's anatomical neutral horizontal line is the Angle of the horizontal plane of pedicle.
7. Assessment of the accuracy of screw placement: The pedicle cortical breach was assessed on postoperative CT. For medial and lateral breach, the axial image was used while for upper and lower breach, coronal and sagittal images were used. The grading standards were proposed by Gertzbein [18]and Rao [19]. Grade 0, no cortical breach; Grade 1, cortical breach<2 mm;Grade 2, cortical breach 2–4 mm; Grade 3, cortical breach > 4 mm. Grade 2 was considered to have a risk of complications, while grade 3 had a high risk of complications. In some abnormal thoracic pedicles, it was unavoidable to breach the cortex; therefore, the in-out-in technique would be used, in which the screw trajectory went through the pedicle-rib junction, with the tip of the screw remaining in the vertebral body. This was defined as grade 0. [20]As for anterior breach, the grades are as followed: Grade 0, no cortical breach; Grade 1, cortical breach<4 mm;Grade 2, cortical breach 4–6 mm; Grade 3, cortical breach > 6 mm[21]. Grade 2 was considered to have a risk of complications, while grade 3 had a high risk of complications. Both grades 2 and 3 were defined as unsatisfied screw placement[21].

All the above imaging measurements were performed independently by three orthopedic surgeons, and the results were the average of the three groups. Before the formal measurement, we reached a consensus on the measurement method.

Machine Learning

The classification and regression models are based on random forest, and the programming language for model construction and calculation is python using the *sklearn* package, and the generation of related graphics calls *matplotlib* and *seaborn* packages. Data are randomly sampled and assigned to a class, e.g., parameters of a pedicle. Features from each class are then extracted from training data, e.g., the screw size of each screw and the screw's penetration grade. Split functions are identified that evaluate the features from training dataset to grow a tree. The data are passed on the tree and the tree grows from roots to leaves. Each tree outputs a result. Detection is the result of a probability distribution function to classify the test sample at the leaf. For this study, when the model was set up, we hope to input the data with parameters of a pedicle, and get an output of screw size.

The number of decision trees used in the two random forest models is 100 and other parameters are default. The random forest training dataset included pedicle morphological parameters mentioned above, accuracy of screw placement and screw size.

Results

A total of 888 screws and pedicles were included, with 542 screws in Grade 0, 244 screws in Grade 1, 65 screws in Grade 2 and 37 screws in Grade 3. The satisfactory rate of screw placement was 88.5%.

We used all the dataset to train and predict whether the screw will penetrate based on our random forest (RF) classification model. To evaluate the robustness of the classification model and other models,10-fold cross-validation was conducted. The ROC curve of the random forest classification model was shown in Fig. 2A and the area under the curve (AUROC) achieved 0.712, showing that our model could play a better distinguishing effect on this affect. After that, we proposed a regression model based on random forest, taking the dataset of accuracy of screw placement as the training set, to predict the screw length and width which should be selected before surgery. For our regression model, we chose the goodness of fit (R^2) to evaluate the accuracy of calculation model. Considering that the predicted value is a discrete variable, we took the average of the screw length predicted results (R^2 = 0.546) and display the regression line in Fig. 2B. However, the screw width seemed to have little correlation with the patient's detailed information (R^2 = -0.15). The decision of the surgical screw width depends more on the doctor's past surgical experience.

Discussion

Pedicle screw is currently the most widely used internal fixation technique, which can provide good fusion and multi-plane correction strength within a limited distance[22]Luo[5] et al. used Meta-analysis to study the application of pedicle screw system for correction surgery, the total complication rate was 6.46%, and the reoperation rate was 1.97%. The correction was good on coronal plane, and the improvement of Cobb angle was also significantly better than that of mixed internal fixed technique. Pedicle screw misplacement is one of the most common complications in correction surgery, and might cause vascular or neurological injure, pedicle fracture, internal fixation failure and postoperative pain and so on[3,21]. Freehand is a reliable technique with a low misplacement rate from 0.4–27%[3,6,7,23], and a low screw-related complication rate(0-1.7%)[24]. Freehand has advantages of shorter operation time, less blood loss, lower radiation dose and lower economic burden[22,25–27], and also has disadvantages such as long learning curve and higher requirements for experience. In this study, 52 patients were treated with freehand, and a total of 888 screws were placed. The average preoperative Cobb angle of the patients was 52.0°±15.7° (21°-103°), and the screw placement satisfaction rate reached 88.5%. No screw-related complications occurred. The overall screw placement in this trial was satisfied.

For patients with idiopathic scoliosis, pedicle dysplasia is the main factor that increases the difficulty of screw placement. Akazawa[28] et al. reported that when the pedicle cortex channel was smaller than 1mm, the misplacement rate is high as 31.5%. As for abnormal pedicle, the probability of misplacement of screws with bare hands is 3 times that of normal pedicles.[9]Huang[2] et al. analyzed 87 patients with idiopathic scoliosis, rate of abnormal pedicles was as high as 65% among 2958 screws. Most of severely abnormal pedicles were located from T2-T10. The independent risk factors for abnormal pedicles included female patients, upper thoracic pedicles, Cobb angle of main curve greater than 70° and concave side pedicles, etc. Lee[29]et al. studied 182 patients and got a conclusion that the diameter of pedicle gradually decreased from T1 to T4. Gao[30]et al. studied 60 females(2718 screws) with Lenke type 1 idiopathic scoliosis, and found that TD of concave pedicle was smaller than that of the convex side and the rate of deformity was higher. TD near apical area had the largest variation. Davis[1]et al found that diameter and height of pedicles near apical area and on concave side were smaller than that of convex side, which causes low accuracy of screw placement, after studied 22 patients. Liljenqvist[31] et al. also got an similar conclusion and found that the LC of T5 is the smallest.

At present, the morphological study of pedicle is mostly based on Sarwahi's standard[9]: Type A, cancellous bone channel diameter > 4mm; Type B, cancellous bone channel diameter is 2-4mm; Type C, cancellous bone channel diameter < 2mm but cortical channel diameter > 2mm; Type D, cortical channel diameter < 2mm. Type B, C, and D pedicles are abnormal. Although this standard can evaluate the degree of pedicle deformity, there is no proof for its guiding role in clinical practice. In our study, we brought parameters as RA, HA, SA and LC except TD, SD in order to describe the spatial attributes of pedicles more specifically. The parameters were measured via CT, because the actual pedicle parameters has a good correlation with parameters measured on CT[31,32]Sarwahi[9]et al. distinguished cortical channel and cancellous channel. However, we determined the midpoint of the cortical bone to measure TD and SD, which simplified the measurement steps and reduce error from multiple measurements and the limitation of pixels.

In this study, we used machine learning to build a model to explore the relationship between pedicle parameters and screw size and the satisfaction of screw placement and tried to make a prediction of best selection through pedicle parameters. A regression model based on random forest was proposed. We trained the model with all the data set. And we found that this model can only predict if there would be an anterior penetration and the screw length. The AUROC achieved 0.712. The R^2 was 0.546. TD and screw width which was concerned by surgeons in previous literatures didn't show a significant correlation to the accuracy. This might because the interior and lateral breach is more likely to lead to vascular and neurological complications, when selecting screws, safer and more conservative selection might be made.

This is an origin research that combine machine learning and spine surgery, we hope that this can bring new methods into clinical practice. There are still some limitations of this study. First, the sample size was limited, more data should be included to perfect the model with deep learning. Second, although the measurement was performed by several researchers, it still might be subjective error. In the future, we are looking forward to include more center and patients and combine image recognition technology and deep learning together to provide strong evidence for clinical practice.

Conclusions

Surgeons should pay more attention to the length of screws. And our model could provide a more accurate choice for the doctor to choose the length of the screw before surgery, and the classification model could also give a preliminary prediction of whether there would be anterior screw penetration based on the patients' data.

Abbreviations

Transverse diameter of pedicle	TD
The length of the pedicle channel	CL
The angle of the sagittal plane of pedicle	SA
Rotation angle of vertebrae	RA
Sagittal diameter of the pedicle	SD
Angle of the horizontal plane of pedicle	HA
Area under the curve	AUROC

Declarations

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Competing interests

The authors declare that they have no competing interests.

Ethics approval

We received approval to conduct this retrospective study described in this manuscript from the Peking University Third Hospital Medical Science Research Ethics Committee (IRB00006761-M2020093).

Consent to participate: This is a retrospective study, which got permission for exempting for informed consent from Ethics Committee.

Consent for publication

The clinical article was expected to publish in your journal. Note: 1. Data is true 2. The manuscript has not been previously published, in whole or in part, or submitted elsewhere for review. 3. No controversy in authors' order

Availability of data and material

Please contact author for data requests

Code availability: N/A

Authors' contributions

QD is the first author of the manuscript, and made contributions to all aspects of the experiment. ZH, YS was the co-first author, who is responsible for data analyzing. YZ is the corresponding author and instructor of the manuscript, and was the surgeon performing the surgery. ZC is the supervisor of the manuscript helping with edition of manuscript. WL, CS, WZ, YJ, ZS and XG was involved in the surgery and provided advice on manuscript. All authors read and approved the final manuscript.

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Tables

Table 1 Results of ROC curve and Binary logistic regression analysis

Parameters	AUC	p	β	p	OR	95%CI
TD	0.592	.006	0.136	0.092	1.146	0.978-1.342
SA	0.485	.651	-0.002	0.998	0.998	0.978-1.018
RA	0.467	.324	-0.043	0.015	0.958	0.925-0.991
SD	0.578	.017	-0.008	0.888	0.992	0.887-1.110
HA	0.401	.003	-0.019	0.039	0.981	0.963-0.999
CL(□38.6mm)	0.659	.000	1.101	0.000	3.008	1.734-5.218
Screw length□SL□			-0.032	0.229	0.969	0.920-1.020
Screw width□SW□			-0.017	0.731	0.983	0.891-1.084

Figures

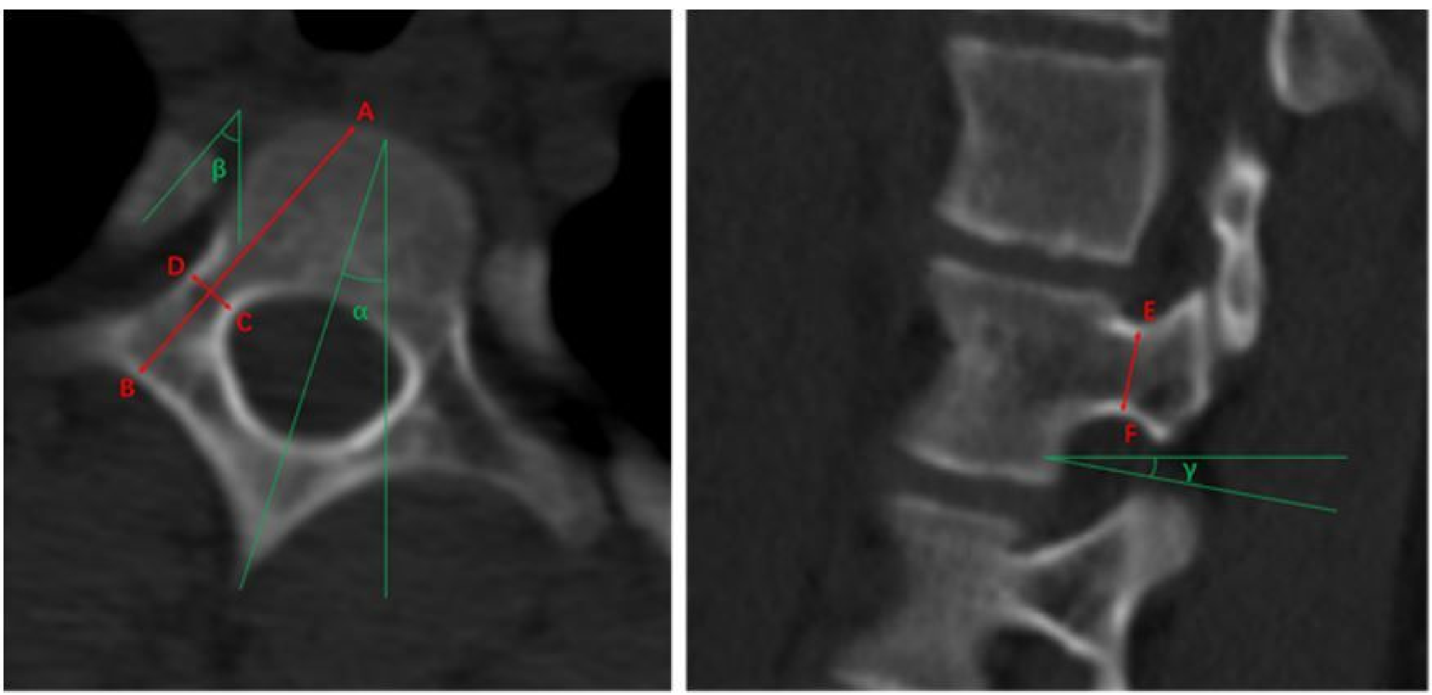
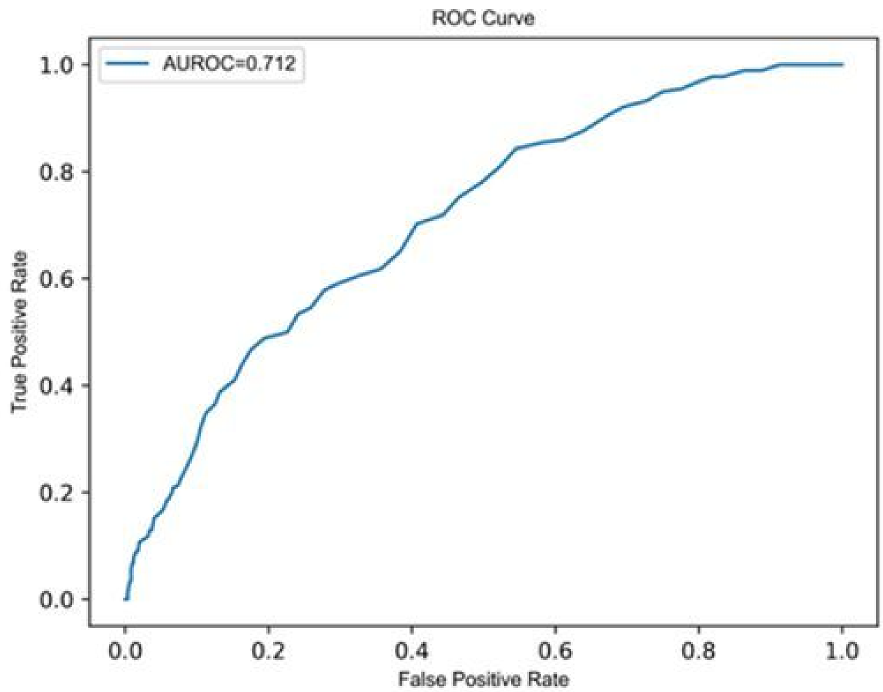


Figure 1

Measurement of morphological parameters of pedicle AB: length of the pedicle channel; CD: transverse diameter of the pedicle; EF: sagittal diameter of the pedicle; Lα rotation angle of vertebrae Lβ angle of the sagittal plane of pedicle; Lγ: angle of the horizontal plane of pedicle.



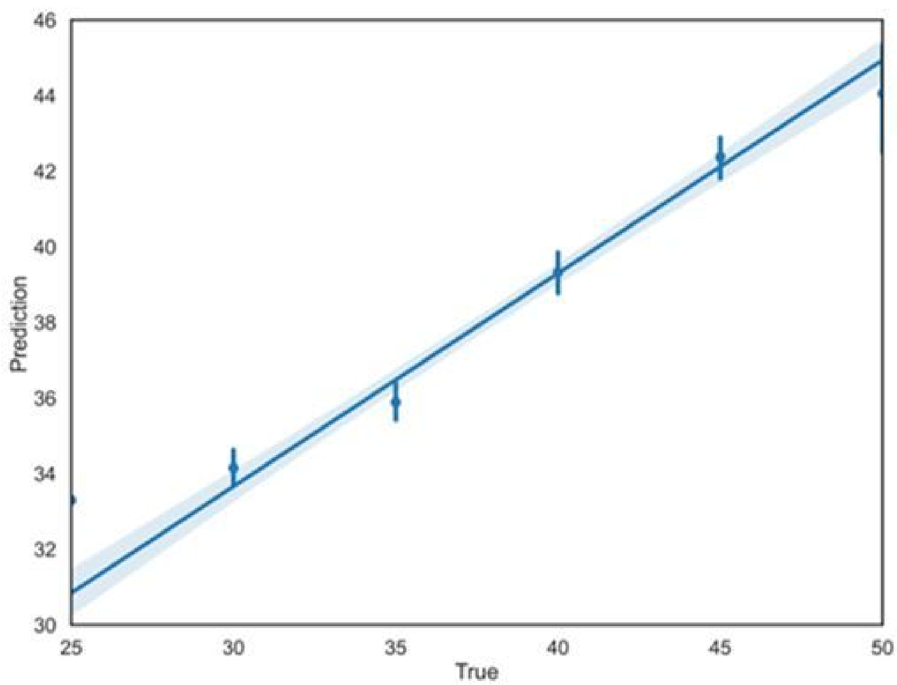


Figure 2

The ROC curve of the random forest classification model was shown in Fig.2A the predicted value is a discrete variable, we took the average of the screw length predicted results (R2 = 0.546) and display the regression line in Fig. 2B.