Clinical Case Report

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Combined 3D rapid prototyping and computer navigation facilitate surgical treatment of congenital scoliosis

A case report and description of technique

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Abstract

Rationale: This study describes the technique of combined Orbic 3D navigation (O3DN) and 3D rapid prototyping (3DRP) to assist surgical correction of congenital scoliosis.

Patient concerns: A 12-year-old boy with congenital scoliosis. His father brought him to our hospital upon noticing the boy's asymmetry of the trunk.

Diagnoses: Congenital scoliosis.

Interventions: O3DN and 3DRP were used to assist correction surgery in this patient.

Outcomes: The Cobb angle of segmental scoliosis (T8-L2) was 46.9° preoperatively and 2.3° at the last postoperative follow-up; correction was 95.1%. The average segmental kyphosis (T5-T12) was 45.2° preoperatively and 18.6° at the postoperative follow-up; correction was 58.9%. The preoperative sagittal imbalance of 56.2 mm was improved to 9.7 mm. The mean distance between the center sacral vertical line and the C7 plumb line was reduced from 5.7 to 4.1 mm. Operative time and bleeding volume was impressively little, with no misplacement of pedicle screws or other surgical complications.

Lessons: Combined 3DRP and O3DN helped achieve satisfactory correction for this case of congenital scoliosis. The application of 3DRP aided by O3DN in surgical treatment of congenital scoliosis can reduce operative time, lessen blood loss, reduce screw misplacement, and avoid neurovascular damage. However, patients' hospital costs were greater. Our lessons learnt are that the relative position between the tracker and the pedicle must be static to ensure the accuracy of the whole system during the entire operation.

Abbreviations: 3D = 3-dimensional, 3DRP = 3-dimensional rapid prototyping, CS = congenital scoliosis, CT = computed tomography, O3DN = Orbic 3D navigation.

Keywords: congenital scoliosis, navigation, rapid prototyping

1. Introduction

Congenital scoliosis (CS) is a 3-dimensional (3D) malformation of the spine. In the axial, sagittal, and coronal planes, respectively, CS mainly features vertebral rotation, variations in alignment, and deviations.[1–3] The goal of surgical treatment in CS is to obtain satisfactory correction of the deformities, while minimizing complications.

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Q-JL and TY contributed equally to this work.

The authors declare no conflicts of interest.

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Practically, the more accurate the implantations of the pedicle screws during surgery for CS, the less probability there will be of injury to neurovascular structures. In the past, screw insertion by freehand achieved outcomes that were considered acceptable.[4] However, as the angle of vertebral rotation increases, so does the difficulty of screw implantation,[5] and the malposition rate of freehand pedicle screw placement is 1.7% to 15.7%.[6,7] Measures to facilitate pedicle screw implantation in CS correction include guiding devices,[8] computer-assisted surgery,[9] robot-assisted surgery,[10] and 3D rapid prototyping.[11,12] Yet, the rates of screw malposition using these techniques remain too high, at 5.6% to 11.4%.[8–12]

Three-D rapid prototyping (3DRP) provides preoperative simulation and modeling of the spinal malformation, and intraoperative computer navigation allows the operator to visualize in real time the position and trajectory of the screw. In the present study, we combined 3DRP and intraoperative computer navigation (Orbic 3D navigation; O3DN) to optimally facilitate pedicle screw insertion and CS correction and minimize surgical risk. To our best knowledge, this is the first description in the literature of the use of this combined technology for the surgical treatment of CS.

2. Ethics

The Ethics Committee of Second Hospital of Jilin University, Changchun, China approved this report. The patient provided written informed consent for this report, and his information has been anonymized.

Table 1

Patient characteristics.

Sex	Age, ys	UEV	AV	LEV	SV	CFV	OT, mins	BL, mL	FU, mos
M	12	T8	T11	L2	T7	T1-2, T4-6, T8-9, L1-2	193	801	28

AV = apex vertebra, BL = blood loss, CFV = congenital fusion vertebrae, FU = follow-up, LEV = lower end vertebra, OT = operation time, SV = stable vertebra, UEV = upper end vertebra.

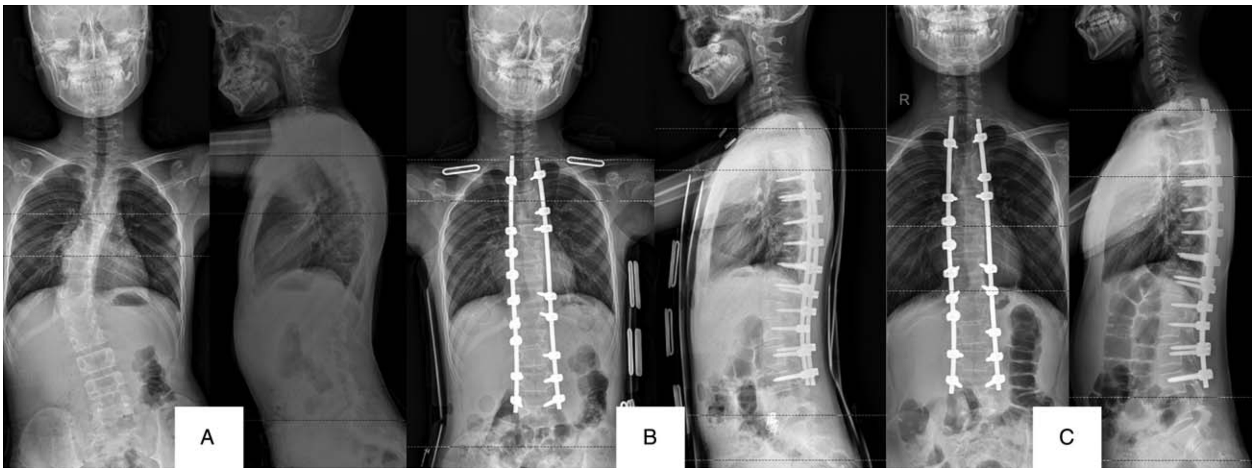

Figure 1. Anterior-posterior and lateral standing full-length spinal x-rays were obtained (A) preoperatively, (B) postoperatively, and (C) at the final follow-up visit.

3. Case report

3.1. Patient characteristics

The patient was a 12-year-old boy, whose father brought him to the hospital upon noticing non-symmetry of the trunk (Table 1). The boy was otherwise healthy and reported no discomfort. Examination revealed a razor back deformity on the right side. The patient had no sensory disturbance, and his muscle force and tension and knee and Achilles tendon reflexes were normal. He tested negative for the Hoffman sign, Babinski reflex, Chaddock reflex, patellar clonus, Lasègue test, and Bragard sign.

3.2. Imaging examination

X-ray imaging showed segmental scoliosis (T8-L2) of 46.9°, and segmental kyphosis (T5-T12) of 45.2° (Fig. 1A). The sagittal imbalance distance was 56.2 mm. The distance between the center sacral vertical line and the C7 plumb line was 5.7 mm. The upper end, apex, lower end, and stable vertebrae were, respectively, T8, T11, L2, and T7 (Table 1). Congenital fusion existed in T1-2, T4-6, T8-9, and L1-2. The patient had a Risser grade of V.

Nervous-system magnetic resonance imaging displayed a tethered cord, syringomyelia in the thoracic spinal cord, and diastematomyelia. Ultrasonic cardiography and pulmonary function tests were performed to evaluate whether heart or lung disease was present. Results of the electromyography of both lower extremities showed that the sensory and motor nerve conduction velocity of the lower extremities was normal, and the H reflex of the double tibial nerve was normal. The primary diagnosis was CS, spinal deformity (instrumented vertebra/segmentation defects), and diastematomyelia.

3.3. Preoperative preparation

The preoperative computed tomography (CT) image of the whole spine was scanned and the graphic data was recorded in the disc. The disc could be recognized by a computer navigation system. The diameter and length of the pedicle was precisely measured at the navigation workstation. In addition, the disc was entered into a 3D printer (AFS-450, Beijing Long Yuan Automated Fabrication System, Beijing, China), and an equal proportion model was produced by fused deposition modeling software (Fig. 2).

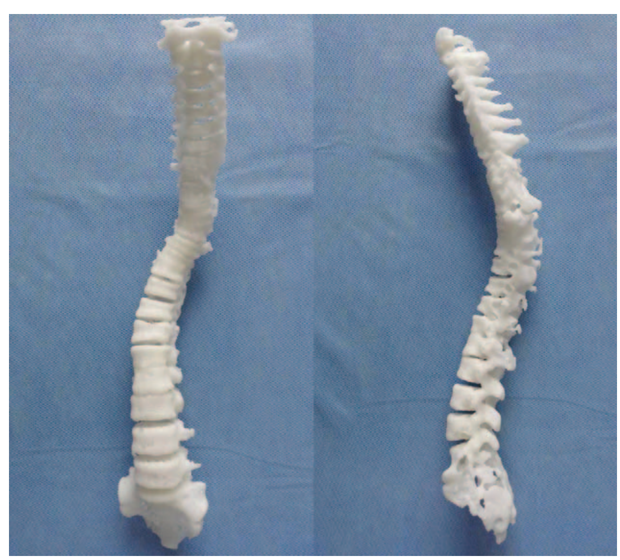

Figure 2. The 3DRP model of the whole spine, which allowed the surgeon understanding of the details of the deformed structures at multiple angles.

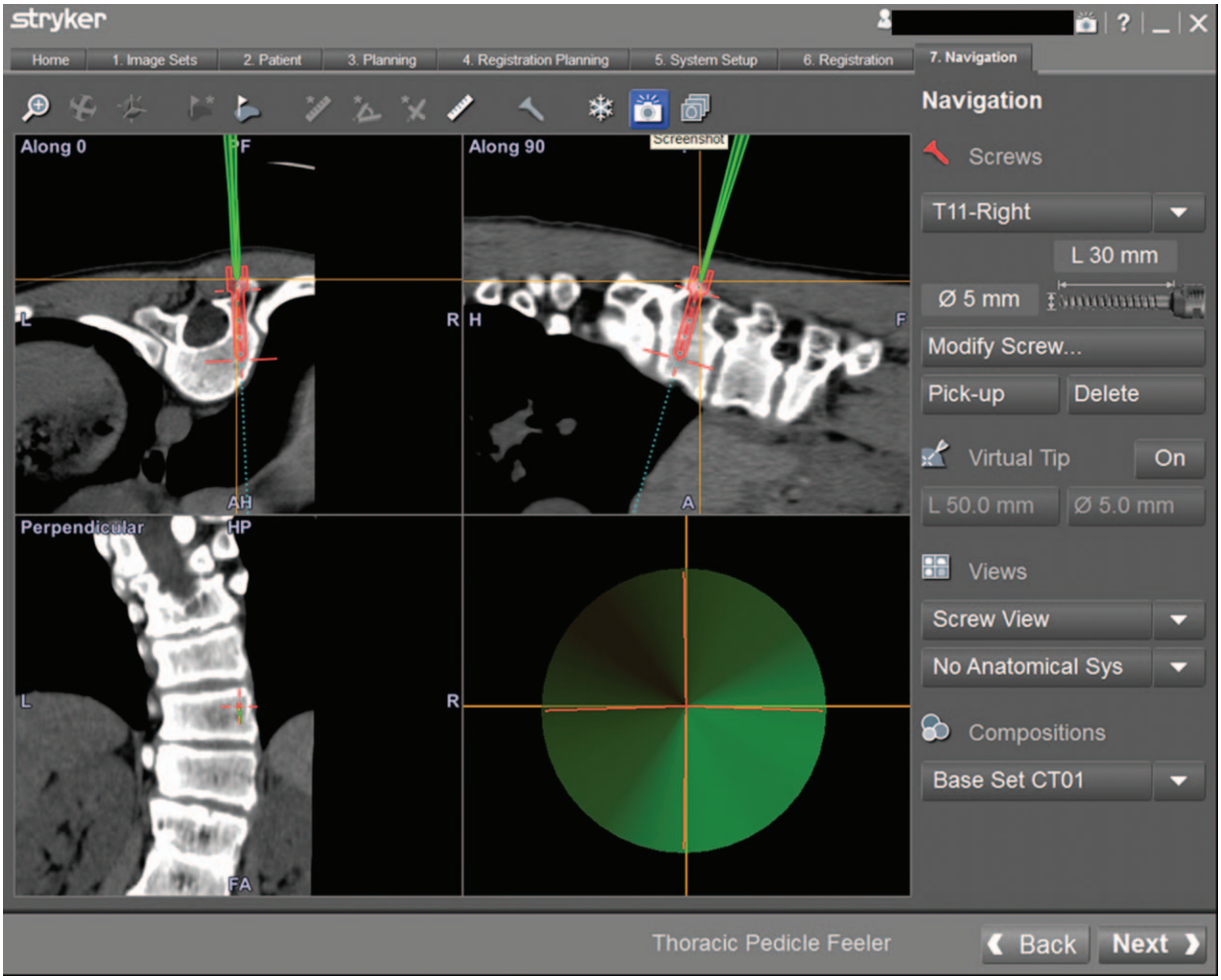

Figure 3. The navigation monitor provided a dynamic display of the trajectories of surgical instruments during screw implantation.

4. Surgical technique

The procedure was performed with the patient prone and under general anesthesia. The posterior structures of the lesion segments were exposed. The Navigation System workstation was started, and SpineMap 3D 2.0 software was chosen (Stryker Navigation, Kalamazoo, MI). A patient tracker (Stryker Leibinger GmbH, Freiburg, Germany) was fixed onto the vertebra spinous process. The instrument tracker, the patient tracker, and the system's C-arm tracker were activated. At the center of the segmental lesion intended to receive the pedicle screw implant, 190° scanning was performed, and 3D images of the lesion were obtained. The point of the needle and its trajectory were guided by navigation (Fig. 3). The anatomic structure of the lesion was easily identified by observing the 3DRP model (Fig. 2). Titanium rods were installed and the nut of the pedicle screw-rod system was tightened. Intraoperative frontal and lateral radiographs were taken to check the position of the implanted screws. Intraoperative spinal cord monitoring was performed, including somatosensory evoked potentials and motor evoked potentials.

Postoperatively, the patient used a brace to maintain stability for 3 months. The precision of the pedicle screws was determined by CT scans, and the screw position was evaluated as described by Ughwanogho et al.[13] Total spine x-rays were taken after the surgery and at the last follow-up at 28 months (Fig. 1B and C). The clinical picture was also collected before and after surgery (Fig. 4A and B). The following data were gathered retrospectively from the medical records: operative time, bleeding volume, and surgical complications.

The neurological function was intact postoperatively. No screw loosening, pseudarthrosis formation, or curve progression was found during the follow-up period. At the last follow-up at 28 months, the Cobb angle of segmental scoliosis was 2.3°, and correction was 95.1%; the segmental kyphosis (T5-T12) was 18.6° with 58.9% correction. The mean distance between the center sacral vertical line and the C7 plumb line was reduced from 56.2 to 9.7 mm, and the sagittal imbalance of 56.2 mm was improved to 9.7 mm (Table 2). The operative time was 193 minutes, and the bleeding volume was 801 mL (Table 1).

5. Discussion

Currently, the primary treatment method for CS is posterior spinal fixation with pedicle screw.[1,2] Due to screw misplacement is a major complication during surgery. To facilitate the success of the operation and minimize surgical risks, we combined the advantages of 3DRP technology and computer navigation. A 12-year-old boy with congenital scoliosis underwent corrective surgery with the assistance of O3DN and 3DRP. Segmental scoliosis (T8-L2), kyphosis (T5-T12) and sagittal imbalance were

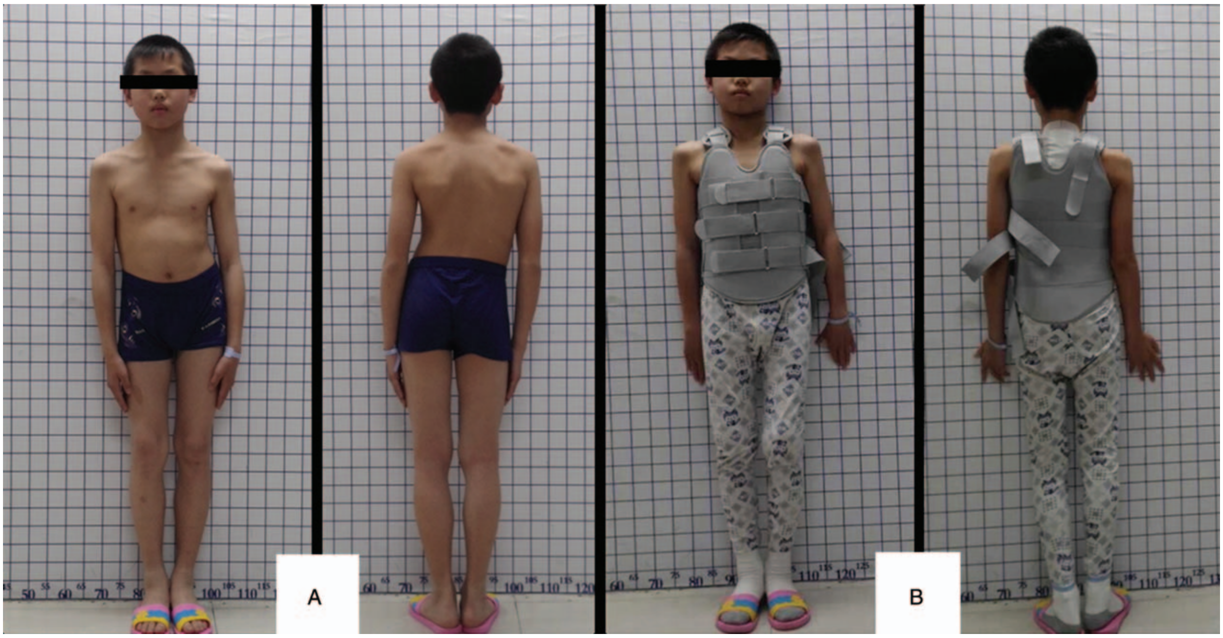

Figure 4. Clinical pictures of the patient (A) preoperatively, and (B) postoperatively.

improved effectively; In addition, with no misplacement of pedicle screws or other surgical complications.

In our study, none of the pedicle screws were misplaced, and there was no neurologic complication. The main curve correction was 95.1%, which is better than that reported by Quan and Gibson[14] (69.9%) or Fatyga et al.[15] (70%). In the present case, we attribute the accuracy of pedicle screw placement and good correction rate to the combined application of 3DRP and O3DN. In our opinion, this technology will help the surgeon avoid nerve compromise and pedicle damage and enhance stability of the spine.

In the present case, not including the time to make the 3D print model prior to surgery, the operative time was 193 minutes using 3DRP and O3DN, which is similar to that reported by Yang et al,[12] although I consider that our operation is more complex. Our positive outcome was probably due to the full understanding of the deformity of the spinal structures afforded by the 3D models that were created preoperatively. We were thus able to identify intraoperatively the entry point quickly, and the computer navigation guided the trajectory.

In addition, there is usually a lot of blood loss during deformity corrective surgery.[16] It is important for doctors to take effective measures to reduce bleeding during surgery, as allogeneic blood transfusion risks infection and hemodynamic complications. In this study, the blood loss was 801 mL, and we attribute this good result to the combined 3DRP and O3DN method and much shorter operative time.

Loosening of the pedicle screws is a common complication of posterior spinal fusion and fixation in spinal surgery. Ohtori et al[17] and Morr et al[18] reported rates of screw loosening of 7% and 19.5%, respectively. Screw loosening is associated with several complications, including screw breakage, pseudarthrosis, and even loose correction.[19,20] In the present case, no pedicle screw loosening was observed during the follow-up. In my view, this positive outcome was due to the simulated surgery using 3D printing technology, screw implantation aided by computer navigation, and the use of a brace to ensure fusion and maintain stability for 3 months postoperatively.

When the right pedicle channel was prepared for T10, the surgeon suspected the inaccuracy of the navigation image, and confirmed the drift of the navigation image after comparing it with the anatomical structure of the 3D print model. During the operation, the patient tracker was re-fixed, the surgical instruments were re-calibrated and the lesion images were scanned again. Finally, the screws were implanted under precise navigation. We consider that the movement of the patient tracker leads to inaccurate navigation intraoperative. In our opinion, if we find that the navigation is not accurate intraoperative, we should find out the reason and avoid blind pedicle screw planting so as to prevent the occurrence of complications such as nerve injury.

Although perfect results were achieved in this case, there are also some limitations. First, the application of 3DRP and O3DN was costly, and increased the patients' hospitalization charges. In addition, the follow-up duration was relatively short and longer observation periods are needed. To assess the effectiveness of combined 3DRP and O3DN technology for patients with CS,

Table 2

Correction in the coronal and sagittal planes.

SC (°)				SK (°)				SI(mm)			TS (mm)		
Pre	Post	FU	Corr (%)	Pre	Post	FU	Corr (%)	Pre	Post	FU	Pre	Post	FU
46.9	2.3	2.3	95.1	45.2	18.4	18.6	58.9	56.0	9.6	9.7	5.7	4.2	4.1

Corr = correction, FU = final follow-up, Post = postoperative, Pre = preoperative, SC = segmental curve, SI = sagittal imbalance, SK = segmental kyphosis, TS = trunk shift.

costs of the procedure to the patient should be reduced, and follow-ups should be longer.

6. Conclusion

Herein we demonstrated that preoperative 3DRP combined with intraoperative O3DN could facilitate a good therapeutic effect for surgical treatment of CS. Our experience is that during the entire operation, the relative position between the tracker and the pedicle must be static to ensure the accuracy of the whole system. The application of this combined method in CS should decrease the operative time, rate of screw loosening, risk of screw misplacement, and achieve a satisfactory correction. Therefore, preoperative 3DRP combined with intraoperative O3DN to treat CS is safe and efficacious, although it may increase the hospital cost of the patient.

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Author contributions

Data curation: Tong Yu.
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Writing – review & editing: Jian-Wu Zhao.

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