Three-Dimensional Planning and Use of Individualized Osteotomy-Guiding Templates for Surgical Correction of Kyphoscoliosis: A Technical Case Report

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■ OBJECTIVE: **We have described the use of 3-dimensional (3D) virtual planning and 3D printed patient-specific osteotomy templates in the surgical correction of a complex spinal deformity. Pedicle subtraction osteotomies (PSOs) for the correction of severe spinal deformities are technically demanding procedures with a risk of major complications. In particular, operations of the severely deformed spine call for new, more precise, methods of surgical planning. The new 3D technology could result in new possibilities for the surgical planning of spinal deformities.**

■ METHODS: **We present the case of severe congenital kyphoscoliosis in a young girl with skeletal dysplasia. A closing wedge-extended PSO was 3D virtual planned using medical computer design software. After the optimal 3D-wedge procedure was planned, individualized osteotomy-guiding templates were designed for translation of the planned PSO to the surgical procedure. During surgery, the PSO was performed using the osteotomy templates. Successful correction of the kyphoscoliosis was realized.**

■ RESULTS: **The kyphosis was successfully reduced using a wedge-shaped extended PSO using preoperative 3D virtual planning, assisted by 3D-printed individualized osteotomy-guiding templates.**

■ CONCLUSIONS: **In addition to direct translation of the planned PSO for surgery, the 3D planning also facilitated a detailed preoperative evaluation, greater insight into the case-specific anatomy, and accurate planning of the required correction.**

INTRODUCTION

Vertebral column resection and pedicle subtraction osteotomy (PSO) with posterior fixation are widely indicated for patients with rigid, sharp, angular thoracic kyphosis, such as kyphosis >70° in the sagittal plane, congenital kyphosis, and hemivertebrae.[1-3] To reduce the risk of injuries during the osteotomy and pedicle screw insertion, computer-assisted surgery systems have been commonly used. In the case of closing-wedge vertebral osteotomy, the global osteotomy planes can be roughly planned using the available preoperative imaging data. However, the procedure remains technically demanding with a risk of major complications.

The development of 3-dimensional (3D) surgical planning and printing has evolved rapidly within various surgical specialties. This technology could result in new possibilities for the surgical planning of spinal deformities. In this report, we present a new approach for complex closing wedge procedures by describing the case of a young girl with severe angular thoracolumbar kyphoscoliosis. We developed a workflow for precise 3D surgical planning for spinal deformities. The method includes the production and application of osteotomy templates for translation of the planned wedge to the surgical procedure. To the best of our knowledge, the presented strategy for 3D spinal osteotomy planning has not been previously reported.

Key words
- 3D planning
- 3D printing
- 3D surgery
- Kyphosis
- Scoliosis
- Spinal deformity
- Templates

Abbreviations and Acronyms
3D: 3-Dimensional
CT: Computed tomography
PSO: Pedicle subtraction osteotomy

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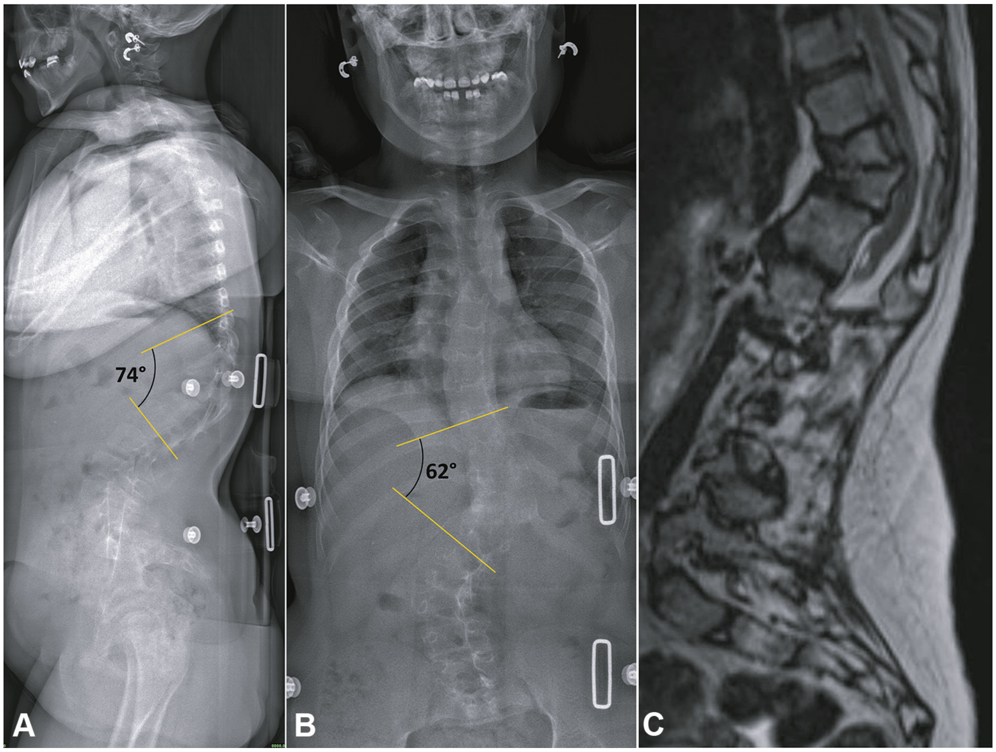

Figure 1. Preoperative imaging data showing (**A**) standing lateral radiograph film with the patient wearing her brace. (**B**) Standing posteroanterior radiograph film with the patient wearing her brace. (**C**) Magnetic resonance imaging scan showing the kyphotic deformity with elongation of the spinal cord.

CASE DESCRIPTION

A 12-year-old girl presented with skeletal dysplasia and severe congenital kyphoscoliosis. On physical examination, no sensory or motor loss was found. Radiographic film measurements revealed a kyphosis angle of 74° in the sagittal plane and scoliosis with a Cobb angle of 62° (**Figure 1A, B**). Preoperative computed tomography (CT) imaging showed trapezoidal anterior wedging of the T12 and L1 vertebrae. Moreover, a butterfly-shaped T11 vertebra with minimal fusion of the 2 body centers was found. Magnetic resonance imaging studies revealed anterior positioning and stretching of the spinal cord over the kyphotic deformity, without signs of myelopathy (**Figure 1C**). Initially, she was treated with a brace; however, because of the progressive and rigid deformity, it was decided to perform an extended PSO with posterior fixation to prevent any further progression and future neurological deficits.

The aim was to perform a closing wedge bone—disc—bone resection between T11 and T12, with the hinge located at the anterior longitudinal ligament. This osteotomy can be classified as grade 4P according to the Schwab classification system.[4] We aimed for a correction of approximately 40° to prevent excess dural buckling during wedge closure. Given the complexity of the present case and the importance of flat osteotomy surfaces for bony fusion, a multidisciplinary team was established to explore the assistance of 3D surgical planning. The team of surgeons and technical physicians, with 3D planning experience in our hospital, developed a 3D-guided method for closing wedge osteotomies for complex spinal deformities.

METHODS

Using Mimics, version 19 (Materialise, Leuven, Belgium), a 3D spine model was reconstructed using threshold-based bone segmentation of the acquired CT data (slice thickness, 0.6 mm). The models were exported to stereolithographic files, and further 3D planning and modeling was performed using 3-matic, version 11 (Materialise). The aim was to correct the severe kyphoscoliosis by the closure of a 3D-shaped wedge that hinged on the anterior column. Virtual 2-step plane and cut positioning was repeated until the optimal 3D wedge was reached. Care was taken to plan for sufficient bony contact surfaces for optimal wedge closing. The final wedge included a bone—disc—bone osteotomy with the apex located between T11 and T12 (**Figure 2A, B**). The superior margins of the wedge included the intervertebral disc, its cartilage endplates, and the subchondral bone caudally of the pedicles. The wedge inferior margins were planned to be just beneath the pedicles of T12, thereby creating large foramina to accommodate both nerve roots.

The 3D wedge planning strategy we have presented requires a method that enables translation of the planned PSO to the