THREE-DIMENSIONAL PLANNING AND USE OF INDIVIDUALIZED OSTEOTOMY GUIDING TEMPLATES FOR SURGICAL CORRECTION OF KYPHOSCOLIOSIS: A TECHNICAL CASE REPORT

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ABSTRACT

**Purpose:** To describe the use of 3D virtual planning and 3D printed patient specific osteotomy templates in the surgical correction of a complex spinal deformity.

**Introduction:** Vertebral column resections (VCR) for the correction of severe spinal deformities are technically demanding procedures with risk for major complications. Especially operations of the severely deformed spine call for new, more precise, methods of surgical planning. The new 3D technology can give rise to new possibilities for the surgical planning of spinal deformities.

**Methods:** We present a case of a young girl who suffers from skeletal dysplasia and severe congenital kyphoscoliosis. A closing wedge VCR was 3D virtual planned using medical computer design software. After the optimal 3D-wedge was planned, individualized osteotomy guiding templates were designed, for translation of the planned VCR towards the surgical procedure. During surgery the VCR was carried out by use of the osteotomy templates. A successful correction of the kyphoscoliosis was realized.

**Conclusion:** The kyphosis was successfully reduced using wedge shaped VCR, based on the pre-operative 3D virtual planning, assisted by 3D printed individualized osteotomy guiding templates. Besides direct translation of the planned VCR to surgery, the 3D templates and planning also facilitated great insight in the case-specific anatomy.
BACKGROUND

Vertebral column resections (VCR) and pedicle subtraction osteotomies (PSO) with posterior fixation is widely indicated for patients with rigid sharp angular thoracic kyphosis, such as greater than 70° in the sagittal plane, congenital kyphosis and hemi-vertebrae.1–3

To reduce the risk of injuries during the osteotomy and pedicle screw insertion, computer assisted surgery (CAS) systems are commonly used. In case of closing wedge vertebral osteotomy, the global osteotomy planes can be roughly planned using available pre-operative imaging data. However, the procedure remains technically demanding with risk for major complications.

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

CASE DESCRIPTION

A 12-year young girl presented with skeletal dysplasia and severe congenital kyphoscoliosis. Upon physical examination no sensory or motor loss was found. X-ray film measurements revealed a kyphosis angle of 74° in the sagittal plane, and a scoliosis with a Cobb angle of 62° (Figure 1 a,b). Pre-operative CT imaging showed trapezoidal anterior wedging of the T12 and L1 vertebrae. Moreover, a butterfly shaped T11 vertebra with minimal fusion of the two body centers was found. MR studies revealed an anterior positioning and stretching of the spinal cord over the kyphotic deformity, without signs of myelopathy (figure 1 c). Initially she was managed with a brace, however, due to the progressive and rigid deformity, it was decided to perform an extended PSO with posterior fixation in order to prevent any further progression and future neurological deficit.
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. We aimed for a correction around 40° in order to prevent excess dural buckling during wedge closing. Given the complexity of this case and the importance of flat osteotomy surfaces for bony fusion, a multidisciplinary team was established for exploring 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 in complex spinal deformities.

**MATERIALS AND METHODS**

Using Mimics v19 (Materialise, Leuven, Belgium), a 3D spine model was reconstructed using threshold-based bone segmentation of the acquired CT data (slice thickness of 0.6 mm). The models were exported to STL files and further 3D planning and modeling was performed in 3-matic v11 (Materialise, Leuven, Belgium). The aim was to correct the severe kyphoscoliosis via the closure of a 3D shaped wedge that hinges on the anterior
column. Virtual two-step plane and cut positioning was repeated until the optimal 3D wedge was reached. Care was taken to plan 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 just beneath the pedicles of T12, thereby creating large foramina to accommodate the both nerve roots.

The here presented 3D wedge planning strategy calls for a method that enables translation of the planned PSO towards the surgical procedure. We therefore chose to design individualized osteotomy guiding templates cranially and caudally from the planned wedge (Figure 2c). Supplementary video 1 shows an animation of the 3D planned correction and the use of the osteotomy guiding templates. The osteotomy planes were transformed into solid oval shaped planes that fit to the bone and can guide the surgical chisel. In addition, laminae and spinous process contact areas were created on adjacent vertebrae, given that, during the procedure, we might lose the initial contact areas at the level of the laminectomy (T11 and T12). Subsequently, the additional contact areas were connected to the oval templates by cylindrical shapes. Essential for the use of this multilevel guide concept was the presence of a severe rigid spine complex, which was confirmed by lateral bending radiographs, to ensure that the vertebral positions in the virtual planning environment are maintained during surgery. The final osteotomy templates and bone models were 3D printed in polyamide and sterilized using autoclave steam sterilization.

Figure 2. (A) Lateral view of the pre-planned 3D shaped wedge, superimposed on the 3D model of the spine. The cranial osteotomy plane (indicated in blue) is positioned through the butterfly-shaped T11 vertebra. The caudal osteotomy plane (indicated in red) is planned just below the pedicles of T12, allowing for the transposition of the 11th nerve root. (B) Posterior view of the planned angular reduction, kyphosis reduction of 41° and a scoliosis reduction of 12°. (C) Posterior view, templates positioned on vertebrae, in line with the planned osteotomy planes. The planned PSO is indicated in green.
During surgery, the 3D-printed bone model facilitated visual intraoperative guidance and identification of vertebrae levels. Pedicle screws were inserted using computer assisted surgery (CAS) at four levels on either side of the desired vertebral resection. Then, soft tissue was carefully removed from the spinous processes and laminae to ensure a tight bone contact and optimal fit of the osteotomy templates. A good fit of the templates on the vertebra was realized, confirming that individual vertebral positions were correct and no segmental shift occurred after the preoperative CT (Figure 3a). The first part of the osteotomy into the vertebral body was done with a surgical chisel (Figure 3b). After creating the initial cuts, the templates were removed and stabilization rods were inserted. The PSO was further completed by piecemeal method along the initial plane created with the guides. Subsequently, compressive forces were applied to close the wedge. This forced the two nerve roots into the single large newly created foramen.

![Figure 3. (A) Intraoperative placement of the osteotomy guiding templates on the vertebrae. (B) Wedge shaped extended PSO is carried out along the planes of the templates, note the central located dural sac (white arrows).](image)

The post-operative period was uneventful and she was discharged without any neurological deficit after 8 days. The early postoperative x-rays showed a satisfactory correction of the kyphoscoliosis, the kyphosis angle was reduced from 74° to 22° and her coronal plane was normalized (Figure 4).
DISCUSSION

The here presented case describes the value of 3D virtual planning and translation towards the surgical procedure by means of printed models (3D spine bone model and osteotomy templates) during kyphoscoliosis correcting surgery. The 3D planning and templates facilitated surgery in four key ways; (1) 3D insight of the case-specific anatomy, (2) identification of vertebrae levels during surgery, (3) malformed vertebrae visualization and its relation to the spinal cord, and most importantly, (4) direct translation of the planned PSO into the surgical site using 3D printed individualized osteotomy guiding templates.

The use of 3D virtual surgical planning and individualized osteotomy templates is a mature and widely accepted technique in oral and maxillofacial surgery.\textsuperscript{5–7} In spine
surgery, the usefulness of 3D printed anatomical models has been reported. Recent research in individualized templating for spine surgery, which translates the 3D virtual plan to surgery, is limited to drill guides for accurate pedicle screw placement. Patient-specific osteotomy templates have often been described for knee arthroplasty, however to our knowledge this is the first paper describing this technique for complex spinal osteotomies. We demonstrated in the current case that this 3D planning and printing technique is feasible for surgery of complex spinal deformities. From the surgeons perspective, the templates and bone models provided valuable guidance during the osteotomy in the severely deformed anatomy. Moreover the surgeons report that studying the 3D anatomy in a multidisciplinary team facilitated the surgical procedure due to enhanced spatial orientation.

The templates were designed in order to fit specific vertebrae, guiding the surgeon in performing the PSO according to plan. To maintain a good fit after laminectomy, the templates were designed as a multilevel osteotomy guide. The templates and bone models (T10-L2) were produced in polyamide by SLS printing, with a production cost of 175 US$ for this particular case. While the production costs are relative low, the majority of costs of these 3D planning procedures are attributable to the time investment of (design) specialists. The here presented case required a full day of work for segmentation and template design. The presented method can in future be cost-effective while it might hypothetically reduce surgery time and preclude the need for intraoperative radiography, especially when combined with patient specific drill guides.

While the templates provided great direction support for the surgeon, the use was nevertheless limited to the first stages of PSO. When approaching the apex of the wedge, temporary rods had to be placed for stabilization and safety. These rods could not be placed simultaneously with the templates. The future design of templates can therefore to be optimized and incorporate inlets for rod positioning. Also, the use of k-wires for temporary template fixation can be of added value to maintain position after partial bone resection, especially when performing a grade 3 PSO (Schwab system), using single-level template support. Current feasibility study was limited to describing the technical aspects and use of this new method in a qualitative manner. For future studies the technique should therefore be subjected to a comprehensive accuracy study and relate this to clinical outcome, thereby assessing its efficacy in a quantitative manner.

In conclusion, the novel use of 3D-virtual planning, 3D-printed spine models and osteotomy guiding templates, have facilitated the performance of the osteotomy and may in future contribute to safer spinal osteotomy procedures.
REFERENCES


