3D DESIGN AND PROTOTYPING IN SURGICAL TREATMENT OF CONGENITAL SPINE DEFORMITIES IN CHILDREN: THE FIRST EXPERIENCE

M.A. Gerasimenko, D.K. Tesakov, S.V. Makarevich, D.D. Tesakova, P.A. Bobrik, K.A. Krivorot, D.G. Satskevich, K.V. Pustavoitau

The Republican Scientific and Practical Centre for Traumatology and Orthopedics, Minsk, Belarus

The experience of using the method of 3D design and prototyping is examplified in a clinical case of surgical treatment of a six-year-old patient with kyphoscoliotic deformity of the spine due to congenital malformation of the L1 vertebra. At the stage of diagnostics and preoperative preparation, a created model of the deformed spine was used in the form of a breadboard variant made according to the data of spiral X-ray CT on a 3D printer from a plastic polymer material. The use of the created model of the deformed spine made it possible to additionally visualize and touch the pathological object in full size, to really assess the anatomical features and parameters of the interested vertebral segments and the altered spinal canal, which provided significant constructive assistance in planning surgical intervention and its immediate technical implementation.

Key Words: congenital malformations of the spine, 3D design and prototyping, surgery for spinal deformities.

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Spinal deformities due to congenital malformations are a very important and challenging field of modern orthopedics. Progressive deformities due to violation of segmentation and shape of the vertebrae in children during their physiological growth and development are of particular importance. This is because the spinal cord located in the spinal canal at the level of abnormal segments is also subjected to compressive displacement and deformation due to an increase in the spinal curvature. This process is accompanied by a high risk of development or aggravation of spinal neurological disorders with deterioration of clinical symptoms of a congenital disease, which is a rationale for surgical treatment [1–3].

Modern surgical interventions for this pathology involve removal of abnormal vertebrae and releasing vertebrotomy in combination with circular decompression of the spinal cord and reconstruction of the spinal canal. After that, the deformity is corrected and stabilized using implantable instrumentation system [4, 5]. It should be noted that a surgery for congenital spinal deformities is associated with an increased risk of various perioperative complications; therefore, the type of planned intervention for a congenital vertebral anomaly should be determined individually in each specific case. This requires appropriate diagnostic approaches when preparing a patient for surgical treatment, determining the technique, extent of surgery, number of stages, and instrumentation used.

In recent years, the method of three-dimensional (3D) design and prototyping has been used in reconstructive surgery of the spine. The method involves obtaining full-scale three-dimensional models of the spine or its altered departments made by a 3D printer at the stage of diagnosis and surgery planning. Data analysis showed that the use of this method as a medical technology allows for in-detail visualization and evaluation of changes in the spinal column and its structures, as well as for a differentiated approach to surgical correction and stabilization in spinal deformities of various etiologies, localization, and severity; it also makes it possible to develop and apply individual technical solutions for implantable instrumentation system for internal fixation and guide templates for installation of support elements for vertebral fixation [6–13]. There is evidence that the use of 3D models improves the accuracy of pedicle screw placement, which favorably affects the postoperative biomechanical stability of instrumentation and reduces the risk of damage to the neural structures [7].

The aim of the study is to analyze the use of 3D design and prototyping in surgical correction of congenital spinal deformity.

This article presents our first experience of using 3D design and prototyping in surgical treatment of kyphoscoliosis due to congenital malformation of the L1 vertebra in a six-year-old female patient.

Patient D., born in 2013, was treated and followed-up at Belarus Republican Scientific and Practical Centre for Traumatology and Orthopedics. As evidenced by medical history, the child was diagnosed with lumbar spine malformation immediately after birth. However, the orthopedic status remained relative-

ly stable until the age of five based on clinical symptoms; all growth parameters were within a normal range. The girl entered a regular kindergarten at the age of three. Parents first noticed changes in the child's motor performance and spontaneous episodes of stumbling when walking due to leg weakness when the girl reached the age of five. From this period, the girl's posture also began to deteriorate.

Examination revealed a slight horizontal asymmetry of the shoulder girdle, waist triangles, and scapulae angles. A small costal muscular ridge was visualized on the back surface on the left at the level of the thoracolumbar junction; a change in the sagittal profile in the form of local kyphosis increasing upon body flexion was observed (Fig. 1).

No anatomical and functional disorders of the upper and lower limbs were found. Evaluation of the neurological status revealed a slight decrease in muscle tendon and periosteal reflexes in the legs. Numbness and weakness in the legs occurring upon body flexion and disappearing upon straightening were noted.

Spine radiographs in the upright position (frontal and lateral projections) revealed lumbar spine malformation. The lateral radiograph showed L1 hypoplasia, with the wedge-shaped L1 vertebral body and a kyphotic deformity with the Cobb angle [13] at T12–L2 curvature of 49°. The frontal radiograph revealed thoracolumbar scoliosis with a 18° curvature at T11–L3 on the left. Spine MRI confirmed the presence of a congenital anomaly in the patient classified as L1 vertebra malformation due to segmental hypoplasia and kyphosis causing displacement and compression of the dural sac and the spinal cord in the spinal canal on the concave side of the curve [1, 3]. The MRI-derived kyphotic curve at T12–L2 was 40°. There were no structural changes in the spinal cord tissue along the entire spinal canal (Fig. 2).

An electrophysiological examination of the functional state of the spinal cord (spinal cord conduction assessed by general and stimulation electromyography) revealed asymmetrical biological activity in the muscles of the lower limbs upon voluntary motor actions. Up to 30 % decrease in the amplitude in *m. vastus lat., m. tibialis ant.,* and *m. soleus* and up to 20 % decrease in the amplitude in *m. vastus med.* and *m. extensor hall. long.* combined with activity changes were noted on the left side. Electrical pulse stimulation of *n. tibialis* demonstrated altered dynamics in H reflexes and M responses of *m. soleus*, indicating an up to 30 % decrease in reflex excitability compared to the physiological range. The obtained data objectively indicate changes in the functional state of lower limb muscles with innervation below L1 and their origin from the compressive load on the spinal canal at this level.

Based on the X-ray and MRI data, X-ray CT at T11–L3 as a region of planned surgical intervention was performed to clarify the anatomical features and parameters of the vertebrae of the deformed spinal segment (Fig. 3).

The diagnosed deformity of the spine and the spinal canal causing dural sac compression and spinal neurological complications was an indication for surgical treatment. The surgery included removal of the L1 vertebra, circumferential release and decompression of the spinal cord, reconstruction of the spinal canal followed by fusion of the T12–L2 vertebrae, and correction of kyphoscoliosis using implantable instrumentation system in combination with posterior spinal fusion with autologous bone at T12–L2.

Due to the small size of the patient's vertebrae and high technical risks of the surgical intervention, a full-scale 3D model of the deformed spinal region at T11–L3 was designed based on the X-ray CT data using the Rhino 6 software and made of plastic material using a 3D printer in collaboration with Medbiotech NP Ltd. (Minsk, Republic of Belarus).

The use of the 3D model allowed for in-detail visualization and evaluation of changes in the spinal column and its structures, as well as for a differentiated approach to surgical correction and stabilization in spinal deformities of various etiologies.

The use of the obtained 3D model made it possible to objectively visualize and touch the spinal deformity, assess the anatomical parameters of the vertebrae, reserve volume of the spinal and nerve root canals, as well as accurately estimate their position relative to the intraspinal structures (the spinal cord and nerve roots at T12–L2) before surgery. The positions of transpedicular fixation screws and a safe trajectory for their implantation were also determined (Fig. 4).

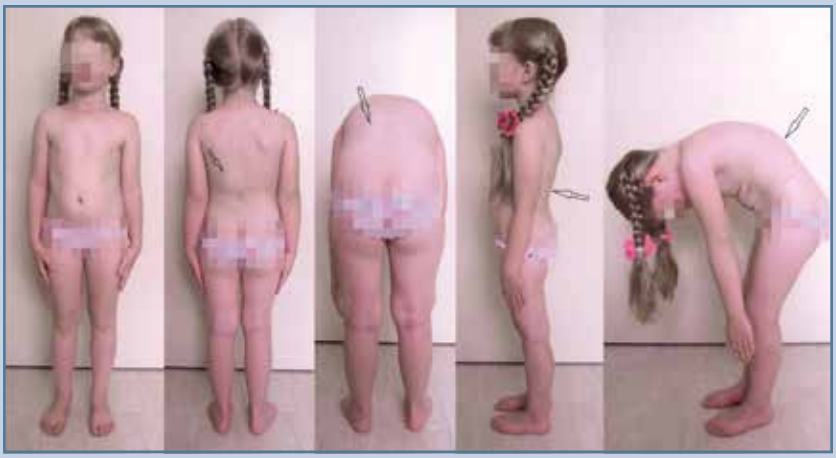

Fig. 1
Appearance of the patient D., aged six, during an orthopedic examination (year 2019)

The patient was operated on using the posterior approach; the surgery was performed in stages (Fig. 5).

A complete matching of intraoperatively visualized anatomical features and parameters of the vertebral segments with those of the obtained 3D model was noted during surgical intervention, starting from the moment of posterior approach. This allowed for optimizing all surgical stages in terms of increased operation safety and control of the risk of possible technical complications, especially during installation of transpedicular fixation screws, L1 vertebra removal, and corrective procedures using implantable instrumentation. As a result, a radical correction of kyphoscoliosis with complete decompression of the spinal cord and stabilization of the spine at T11–L3 using instrumentation was achieved. This was also confirmed by radiological examination (X-ray, MRI, and X-ray CT) data in the early postoperative period (Fig. 6).

There were no complications in the early postoperative period. The girl restored vertical functionality on day seven and discharged from the hospital on day 10 after the wound healed with primary intention. Afterwards, the patient wore a rigid custom-made polyethylene brace produced by a prosthesis manufacturer.

During the follow-up, the patient fully adapted to the altered spinal state, gained control over her posture and movements (Fig. 7), had no complaints, and entered the first grade of a general education school.

Control spinal radiographs obtained a year later showed preservation of the achieved correction of kyphoscoliosis (Fig. 8). The patient is still under medical supervision.

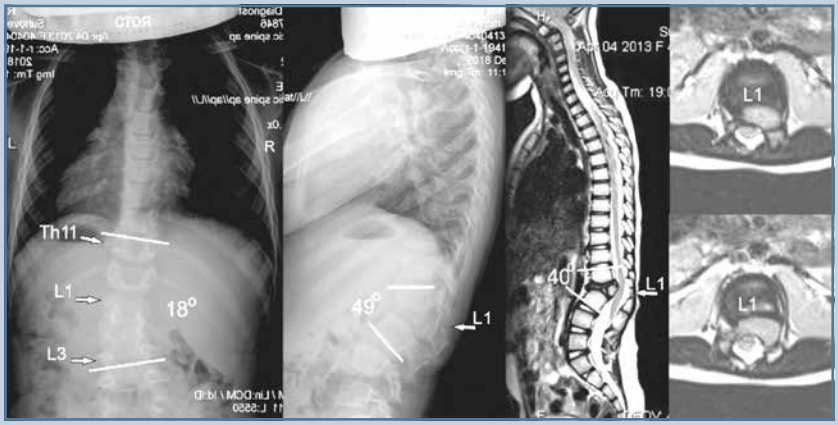

Fig. 2
Radiographs and MRI of the patient D., aged six

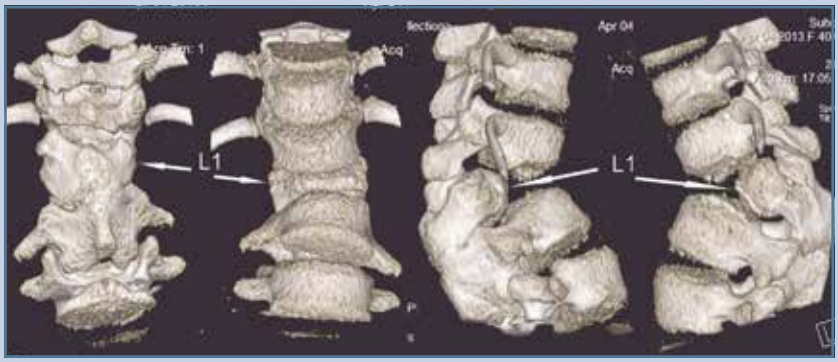

Fig. 3
Three-dimensional X-ray CT reconstruction of the T11–L3 vertebrae of the patient D., aged six

Conclusion

The presented experience of using 3D design and prototyping at the stage of preoperative diagnosis in a patient with spinal deformity due to congenital malformations indicates that this technology provides surgeons with a significant practical assistance. It creates an opportunity to additionally visualize a deformity, assess the anatomical features and parameters of the vertebrae with reserved volume in the spinal and nerve root canals, determine the required parameters for installation of support elements and a safe trajectory or region of their implantation, thereby reducing operative risks and optimizing the surgical treatment of pediatric patients with congenital anomalies of the spine.

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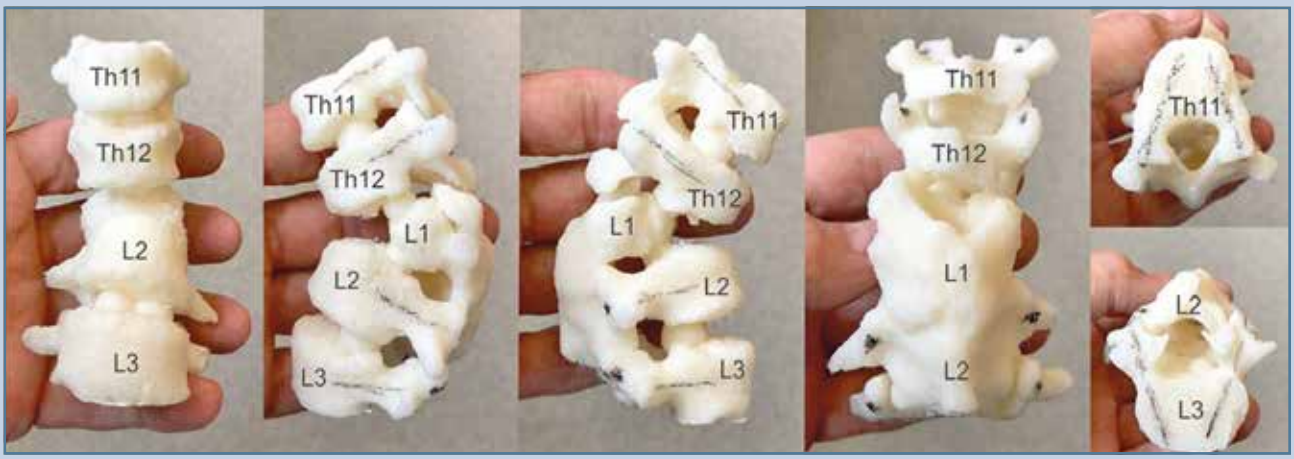

Fig. 4
A full-scale 3D model of the patient's T11–L3 region

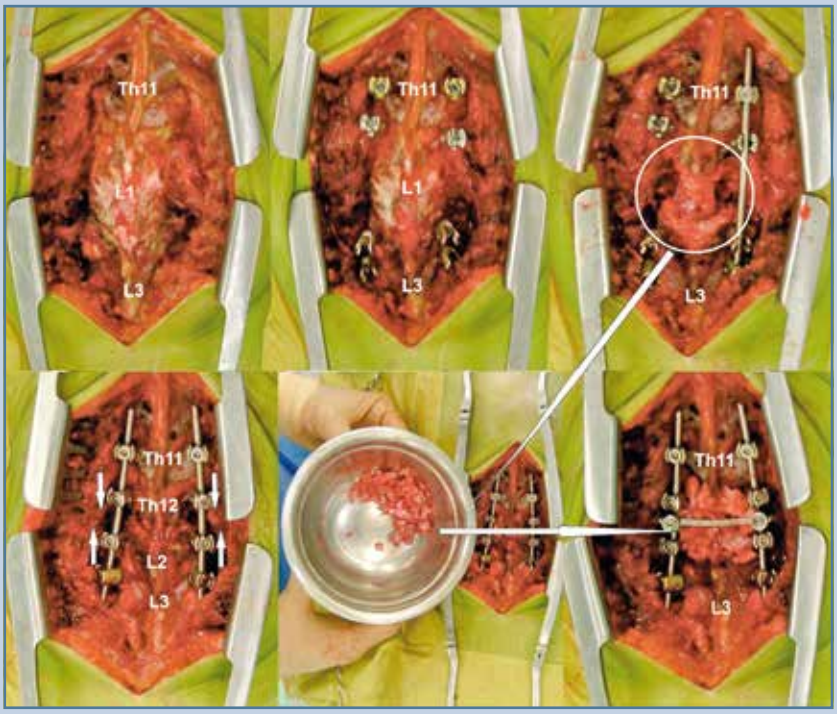

Fig. 5
Stages of the surgery

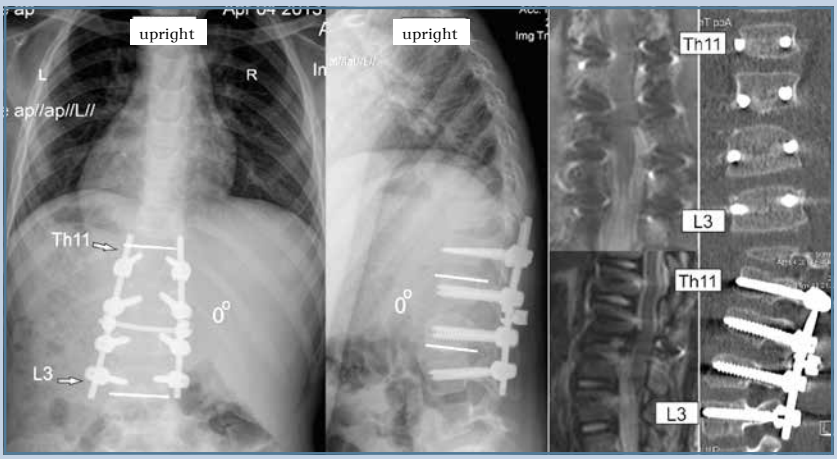

Fig. 6
Radiographs, MRI, and X-ray CT of the patient D., aged six, in the early postoperative period

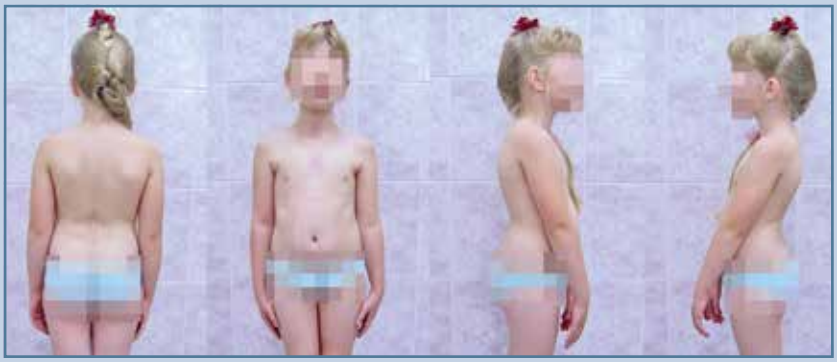

Fig. 7
Appearance of the patient D. one year after surgery

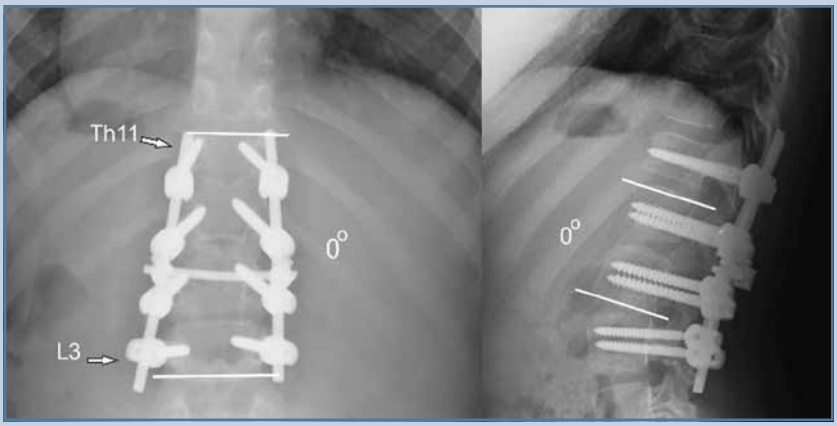

Fig. 8
Spine radiographs of the patient D. one year after surgery

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Address correspondence to:
Makarevich Sergey Valentinovich
Republican Scientific and Practical Centre
for Traumatology and Orthopedics,
60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus,
sv.mak@mail.ru

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Mikhail Aleksandrovich Gerasimenko, DMSc, Prof., Director of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0001-9151-0214, kanc@ortoped.by;
Dmitry Kimovich Tesakov, MD, PbD, Leading Researcher, Laboratory of Diseases and Consequences of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0002-0890-8174, dk-tesakov@yandex.ru;
Sergey Valentinovich Makarevich, DMSc, Associate Professor, Chief Researcher of the Laboratory of Traumatic Injuries of the Spine and Spinal Cord of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0001-8225-4423, sv.mak@mail.ru;
Daria Dmitryevna Tesakova, MD, PbD, Researcher of the Laboratory of Traumatic Injuries of the Spine and Spinal Cord of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0002-3603-8946, dr-tesakova@yandex.ru;
Pavel Aleksandrovich Bobrik, MD, PbD, Head of the Neurosurgical Department No. 2 of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0002-4607-0430, kanc@ortoped.by;
Kirill Anatolyevich Krivorot, MD, PbD, Senior Researcher of the Laboratory of Traumatic Injuries of the Spine and Spinal Cord of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0003-0456-2839, kirill.doc@mail.ru;
Dmitry Georgyevich Satskevich, MD, PbD, Deputy Director for Clinical Care of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0001-928-9665, kanc@ortoped.by;
Kiryl Vasilyevich Pustavoitau, Head of the Neurosurgical Department No. 1 of The Republican Scientific and Practical Centre for Traumatology and Orthopedics, 60/4 Leitenanta Kizhevatova str., Minsk, 220024, Belarus, ORCID: 0000-0001-6533-6021, kiryl.pustavoitau@gmail.com.