APPLICATION OF THREE-LEVEL NAVIGATION TEMPLATE IN SURGERY FOR HEMIVERTEBRAE IN ADOLESCENTS

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Objective. To assess efficacy and safety of using a three-level navigation template in the surgical treatment of congenital spinal deformities.
Material and Methods. Three-level navigation templates were used in surgical treatment of four consecutively operated 10–17-year-old patients with congenital scoliosis associated with thoracic hemivertebrae. The correctness of screw position was evaluated according to CT data using a 2-mm increment method: class 0 – intraosseous screw position; class 1 – the screw extends beyond the pedicle cortex by less than 2 mm; class 2 – by 2–4 mm; and class 3 – by more than 4 mm. Preoperative DICOM data were processed with free software. The model of target zone and navigation template were 3D printed and used in surgery.
Results. Four of 16 (25 %) pedicles were narrower than 4.35 mm and were estimated as difficult for implantation with a planned violation of the integrity of the endplate. Perforation of the outer cortical layer took place in all these cases, and screw position corresponded to class 2 only in pedicle width of 1.9 mm. In pedicles wider than 4.35 mm, 11 of 12 (91.7 %) screws were implanted intraosseously. One screw extended beyond the pedicle cortex by 0.8 mm (class 1).
Conclusion. Three-level navigation template can be considered as an effective means of positioning transpedicular screws in secondarily changed segments adjacent to anomalous one and confounding implantation. Free software is sufficient for preparing 3D-model of target zone and navigation template, and such a model is a highly informative reference object that is convenient to use during the operation. A navigation template made using 3D printing does not require the use of expensive equipment, which can make surgery for congenital scoliosis more accessible.
Key Words: 3D printing, navigation template, congenital scoliosis.
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As the equipment and expendable supplies for 3D printing become less expensive and more available, this technology has been used in medicine to manufacture physical objects based on digital data more and more frequently. In surgery of the spine, cerebral and facial skull, middle ear, larynx, and heart [1–7], the object of intervention is a complex three-dimensional structure characterized by individual variability. Reproducing this three-dimensional structure is a novel imaging modality that supplements the conventional 3D imaging, simplifies preoperative planning, improves safety of the surgery, and reduces its traumaticity [8]. If high-precision implantation is needed, 3D printing will make it possible to manufacture a personified navigational tool that allows one to reproduce the directions and distances determined during surgery simulation [9].

The difficulties related to corrective surgeries performed for patients with congenital vertebral anomalies are usually caused by the anatomical features of the anomalous segment and the adjacent ones. Whereas the general principles of hemivertebra excision and instrumented correction of the deformity are well-known [10, 11], the procedure used for transpedicular screw implantation near the deformity apex can be challenging because of the anatomical features of pedicles (their small size). The involvement of these structures increases the risk of improper screw placement, including the risk of damaging the neural structures.

The objective of this study was to assess the effectiveness and safety of application of the three-level navigational template in surgical treatment of congenital spine deformities.

Material and Methods

Three-level navigational templates were used in surgical treatment of four consecutively operated 10–17-year-old patients with congenital spine deformities caused by thoracic hemivertebrae.

The demographic, clinical, and radiographic data of patients enrolled in the study are shown in Table 1.

If any of the frontal pedicle dimension (height or width) during preoperative planning was found to be less than 4.35 mm (the minimal diameter of a transpedicular screw in the standard implantation kit), screw implantation was regarded as potentially difficult (improper). The DICOM data obtained for preoperative CT scans were processed using open-source software. A virtual 3D model of the zone of interest covering the anomalous vertebra and the adjacent ones was built using the Threshold Effect of density in the Slicer program. Primary processing of the model involving the elimination of excessive elements and spatial orientation was then conducted using the Autodesk Meshmixer program. Blender 3D editor was used to visualize the planar cross sections of the vertebrae to be implanted and perform positioning of cylinder-shaped figures (a virtual drill) along the optimal transpedicular trajectories. The same cylinder simulated the pedicle of a hemivertebra (Fig. 1a). In case of prognostically difficult implantation, it was planned that the drill will move juxtapedicularly and perforate the outer cortical layer. Cylindrical defects corresponding to positions of the optimal transpedicular trajectories were simulated by subtracting the figures of the virtual drill from the model. Hence, five trajectories running through the pedicle of the hemivertebra and two adjacent vertebrae were formed in each model. The supporting plate of the navigational template corresponding to three adjacent vertebrae was formed using 3D graphics primitives. The supporting plate was shaped as an imprint from the posterior vertebral structures using the projection algorithm (Shrinkwrap modifier). Hollow cylindrical figures of guiding tubes simulated the position of a virtual drill. The navigational template was created by combining them with the supporting plate (Fig. 1b). The model of the zone of interest and the navigational template were exported to the STL format and 3D printed using PLA material (Fig. 1c, d).

The ready-to-use templates were subjected to low-temperature sterilization and utilized during surgical interventions. The posterior vertebral structures were identified according to osseous landmarks using the 3D model as a reference object and thoroughly skeletonized. The supporting plate of the navigational template was then placed onto the posterior structures, and its stability was controlled. The transpedicular trajectories through the guiding tubes were formed using the drill (Fig. 1e). The integrity of bone walls was controlled with a probe. Transpedicular screws (minimal diameter, 4.35 mm) were implanted into the vertebrae adjacent to the anomalous one. The body of the hemivertebra was resected by transpedicular eggshell osteotomy, and instrumented correction of the deformity was subsequently performed [11].

All the patients underwent postoperative CT scanning. The screw placement accuracy was assessed using the two-millimeter increment system [12]: class 0 – intraosseous screw positioning; class 1 – the screw extends beyond the pedicle cortex by less than 2 mm; class 2 – the screw extends beyond the pedicle cortex by less than 2–4 mm; and class 3 – the screw extends beyond the pedicle cortex by more than 4 mm.

Results

Table 2 shows the dimensions of the apical arch vertebrae (to be operated on) determined during preoperative planning, as well as postoperative assessment of positioning of transpedicular screws.

Hence, four (25 %) of 16 pedicles with pedicle width less than 4.35 mm were regarded as prognostically difficult for implantation (as the endplate integrity would probably be violated). Perforation of the outer cortical layer took place in all these cases (Fig. 2); class 2 screw position was observed only for pedicle width of 1.9 mm.

When the pedicle width was more than 4.35 mm, intraosseous screw positioning (class 0) was achieved in 11 (91.7 %) of 12 cases; in one case, the screw extended beyond the cortical layer by 0.8 mm (class 1).

Discussion

Among the vast number of publications addressed to application of navigational templates in spine surgery, most studies focus on screw placement into the cervical vertebrae in adult patients [13–19]. Closely related to our study, the publication by D.N. Kokushin et al. [20] is limited to *in vitro* application of navigational templates to manage hemivertebrae, while we found no data on clinical application of this method in a homogeneous patient population with spinal malformations.

Most authors prefer to print both the navigational template and the model of the zone of interest [13–15, 17–19, 21–25], although it is not always regarded as an obligatory stage [16, 26–28]. In our opinion, the model of the zone of interest improves the quality of preoperative planning, makes it easier to explain the essence of the pathology and the upcoming surgery to patients and their representatives. Furthermore, it makes orientation in the surgical wound easier and can be used for educational purposes. These properties of the model largely depend on subjective impressions. A survey study needs to be conducted to make them unbiased.

A reported drawback of the navigational template is that the posterior vertebral structures need to be meticulously skeletonized, which causes significant blood loss and tissue injury [29]. Meanwhile, planning joint fusion surgery per se requires skeletonization of the pos-

Table 1

The general age and sex characteristics of patients enrolled in the study and anatomical characteristics of the pathology

Patient	Sex	Age, years	Hemivertebra location	Cobb angle (degree of the apical scoliotic curve), degrees
1	M	12	T11 s	27
2	F	17	T3 s	26
3	F	12	T9 s	32
4	M	10	T9 s	40

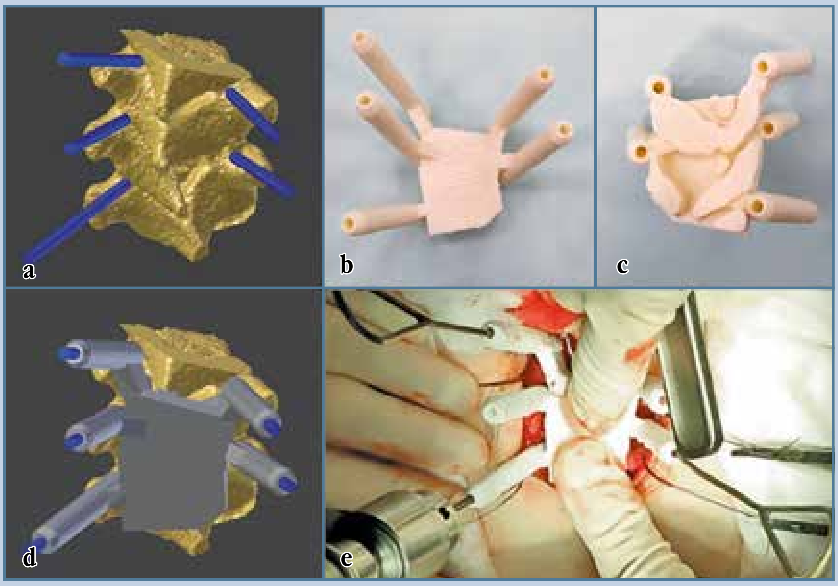

Fig. 1
Stages of preoperative modeling and perioperative application of a three-level template: **a** – virtual modeling of the surgery; **b** – a virtual model of navigational template with five guiding tubes; **c, d** – the ready-to-use three-level template, dorsal **(c)** and ventral **(d)** views; **e** – perioperative application of the template

terior structures as one of the prerequisites for the formation of complete local bone block.

Single-level navigational templates were used in most studies: they prevent the inaccuracy related to displacement of the adjacent vertebrae as the patient changes his or her body position [13, 14, 16–19, 23, 25]. Meanwhile, R.A. Kovalenko et al. [30] demonstrated that higher total instrumentation area increases template stability and, therefore, ensures better implantation accuracy. In particular, craniocaudal stability is improved by increasing the distance between two marginal supporting points in the sagittal plane. Hence, when performing transpedicular fixation of a limited-mobility zone, it is preferred to use one navigational template, which allows more reliable positioning of the supporting plate and minimizing the time needed to consecutively insert several templates. In turn, the application of a multi-level template consisting of several supporting plates linked by flexible inserts is superfluous [29].

To prevent displacement of the adjacent vertebrae, which is an error source during navigation, it was suggested that patients undergo preoperative CT scanning in prone position; however, it is impossible to ensure that the body position inside an MRI machine precisely coincides with that on the operating table [27, 28]. Meanwhile, in patients with congenital thoracic scoliosis caused by hemivertebrae, the apical curve formed by the hemivertebra and the adjacent vertebrae usually has limited mobility, which ensures stability of the three-level template.

The open-source software is sufficient for preparing the 3D model of the zone of interest and creating the navigational template. This model is a highly informative reference object that is convenient to use during surgery. The 3D printed navigational template does not require expensive equipment. It can be regarded as an alternative to the currently used CT navigation and allows one to conduct the type of surgeries discussed in this study at medical settings where the CT navigation equipment is not available.

Conclusions

The three-level navigational template is an effective and safe means of positioning transpedicular screws in children with thoracic hemivertebrae, including the pronounced changes in the segments adjacent to the abnormal one.

The limitations of this study include small sample size and no reference group.

All the authors have equally contributed to preparing this manuscript. The study had no sponsors. The authors declare that there is no conflict of interest.

Table 2

The minimal width of pedicles of the vertebrae adjacent to the anomalous one and postoperative evaluation of screw position accuracy

Patient	Level and side	Pedicle width, mm	Class of screw placement accuracy
1	T10, left	2.7	1
	T10, right	5.2	0
	T12, left	6.8	0
	T12, right	2.4	1
2	T2, left	5.3	0
	T2, right	4.9	1
	T4, left	8.3	0
	T4, right	1.9	2
3	T8, left	4.9	0
	T8, right	5.7	0
	T10, left	4.9	0
	T10, right	4.9	0
4	T8, left	2.9	1
	T8, right	4.6	0
	T10, left	6.7	0
	T10, right	4.9	0

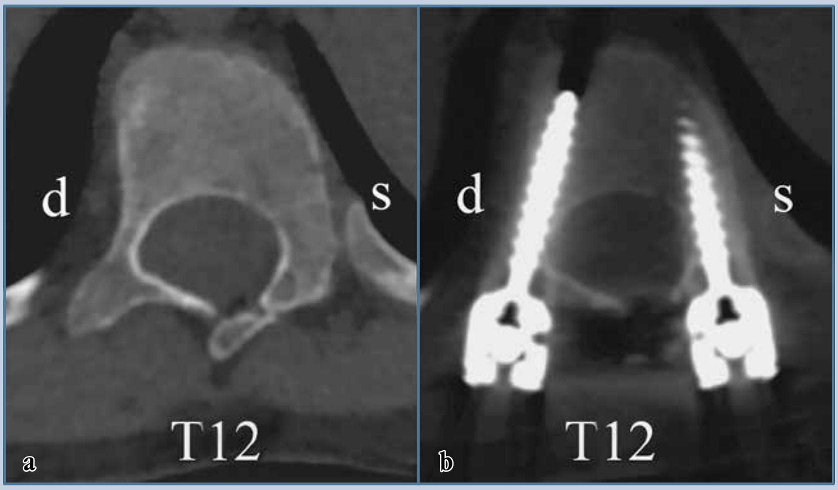

Fig. 2
The vertebra adjacent to the abnormal one: preoperative **(a)** and postoperative **(b)** MR scans: **a** – prognostically difficult implantation on the right side (pedicle width, 2.4 mm); **b** – the screw perforates the outer cortical plate on the right side (class 1)

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