COMPUTER 3D-MODELING OF PATIENT-SPECIFIC NAVIGATIONAL TEMPLATE FOR CERVICAL SCREW INSERTION

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Objective. To prove the effectiveness of 3D computer modeling and printing of patient-specific templates for cervical spine screw fixation.
Materials and Methods. Based on the MSCT data of three patients, 3D models of cervical vertebrae and guiding templates were produced. The screws were inserted transpedicularly into 3D-printed models of C2–C7 vertebrae and C1 lateral masses using standard cervical instrumentation. This technology was then clinically tested in a patient with C2 tumor, in whom posterior stabilization of C1–C3 vertebrae was performed using guiding templates. In the postoperative period, MSCT was performed to monitor the position of screws.
Results. When implanting screws into 3D-models, technical difficulties were not revealed. After insertion of screws, a visual assessment of the 3D vertebra model was made. Malpositions in models were not detected. Based on the proven technique, a clinical approbation was performed in a patient with normal cervical spine pattern. MSCT study revealed the deviation of screws relative to the planned trajectory by no more than 2 mm, with no malpositions.
Conclusion. The first domestic description of the technique of navigation using guiding templates is presented. Of all the existing methods, this is the most reliable way of screw positioning in the cervical spine. The possible insertion error does not affect the quality of positioning.
Key Words: transpedicular insertion, cervical spine, navigation, 3D modeling.

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Modern technologies of posterior stabilization of the cervical spine include the use of metal screws. Goel–Harms C1–C2 fixation is the most reliable type of fixation for craniocervical region, while transpedicular fixation is the best option for subaxial region. The existing methods of screw insertion can be conventionally divided into free-hand and navigation techniques. In the context of preventing malpositions, various methods of navigation are the safest techniques. To date, MSCT methods, which utilize complex and expensive equipment, have become widely used. However, mobility of the cervical spine does not allow absolutely accurate intraoperative positioning of the screws, which does not completely eliminate the risk of malpositions. Recently, more attention in the foreign literature has been paid to 3D-modeling and production of navigational templates for planning the trajectory of screw insertion [1–16]. Meanwhile, such works are absent in Russian literature.

Material and Methods

The study was performed at the Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics (Kurgan). Three-dimensional models of cervical vertebrae were obtained based on the MSCT data on three patients with various anomalies of cervical spine development. MSCT was performed on an "Aquilion 64" scanner (Toshiba), GE Light Speed, with a slice thickness of 0.5 mm and a resolution of 512 x 512 dpi. All images were saved in DICOM file format and transferred to a workstation with "InVesalius v. 3.0" software, which generated a 3D model of cervical vertebrae. After the 3D model was obtained, it was further exported to a .stl file format. Template modelling was performed based on the .stl model of the vertebrae using "AutoDesk Meshmixer" software. The working surface of the template was inverse to the vertebra surface, which provided an ideal fitting while taking into account the location of the adjacent vertebrae. After the template was obtained, the optimal trajectory depending on the diameter of the drill was determined (Fig. 1). For the convenience of the surgeon, each navigational template was numbered C1 to C7 on its reverse side. Once virtual 3D models of the vertebrae and templates were obtained, they were produced on an "Ultimaker 2GO" 3D printer from biodegradable PLA (Fig. 2).

After the templates were produced, the screws were inserted transpedicularly into 3D-printed models of C2–C7 vertebrae and C1 lateral masses of three patients using standard cervical instrumentation. The technology of 3D-modeling and determination of the optimal template production and navigation trajectory was further optimized based on the previously obtained data. This technology was clinically tested in a patient with C2 tumor, in whom posterior stabilization of C1–C3 vertebrae was performed using guiding templates. In the postoperative period, MSCT was performed to monitor the position of screws.

Results and Discussion

The use of the combination of MSCT with the software and a 3D printer allowed obtaining the templates for transpedicular screw fixation of the cervical spine. The 2.2-mm drill holes were made in the guiding templates. The template was tightly attached to the arch and the spinous process of the vertebra. Next, the hole for screw insertion was made first using high-speed bur and then with a drill followed by screw implantation in the produced hole (Fig. 3). No technical difficulties were noted during screw insertion in the 3D models. The 3D models were visually assessed after screw insertion. No malpositions were detected when using 3D models (Fig. 4).

Based on the optimized technique, clinical testing was conducted in a patient with a normal cervical vertebral column. Once 3D models and guiding templates were produced, screws were inserted transpedicularly into C1 lateral masses. The screws were also implanted into C3 lateral masses using freehand technique for higher structural rigidity. Intraoperative use of the templates required careful skeletonization of the posterior structures of C3 vertebra, whereas C1 required only isolation of the posterior arch, which prevented possible hemorrhage from the C1–C2 venous plexus. In addition, the bulk of soft tissues significantly limited the choice of the correct trajectory for transpedicular insertion of the screws into C3, which required counterincision for navigation. After implantation of the screw on one side, it was nesessary to detach the guiding tube on the same side, since the screw head interfered with tight fitting and, hence, precise positioning of the trajectory (Fig. 5). According to the MSCT data, no more than 2-mm deviation of the screws relative to the planned trajectory was noted; no malpositions were detected as well (Fig. 6).

The navigation technique using guiding templates is feasible; it allows one to obtain patient-specific navigational guides (templates) for accurate screw placement [11]. However, the requirement for a 3D printer can limit its widespread use. At the same time, this technique remains to be the most accurate approach for the correct screw insertion to date [4, 6, 7, 10]. Sparse studies on this issue describe various options of template production. Most of these works are devoted to navigation in the cervical spine, which indicates the greatest difficulty of screw insertion in this region [4–9, 13–15]. Various types of the technique utilizing one [4, 7] to three (for an awl, drill, and screw) templates [14, 15] are described. However, this does not affect the positioning accuracy significantly [4–6, 8, 14, 15]. The most frequent mistakes of navigation using guiding templates are deviations from a planned trajectory. Their value does not exceed 2 mm in 97.9 % of cases, with no malpositions noted [6]. A total of 95 % of cases reveal no deviations from the trajectory [13]. The error in screw insertion can be mostly due to the human factor. In this regard, one should use a template, which completely eliminates malposition.

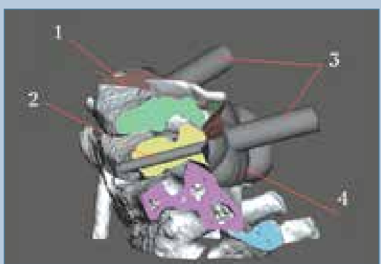

Fig. 1
Virtual modeling: screw insertion navigation, template surface modeling based on the location of the adjacent vertebrae: *1* – adjacent vertebra; *2* – guiding tube simulating the trajectory for screw insertion into the vertebral body; *3* – guiding tube on the template that defines the trajectory for the drill; *4* – template

Fig. 2
The obtained 3D models of the cervical vertebrae and templates for screw insertion navigation

To date, there are no studies describing substantial experience on navigational template application. All of the available works devoted to the cervical spine are limited to either cadaver studies or clinical series of 10 to 25 patients with a total number of implanted screws not exceeding 86. These circumstances confirm relevance of the current paper.

Conclusion

The first domestic description of the navigation technique using guiding templates demonstrates that this method can be used at a Federal Center specialized in surgical treatment of spine pathology. This is the most reliable technique of screw positioning in the cervical spine among all of the existing methods. The possible screw insertion deviation does not affect the quality of positioning.

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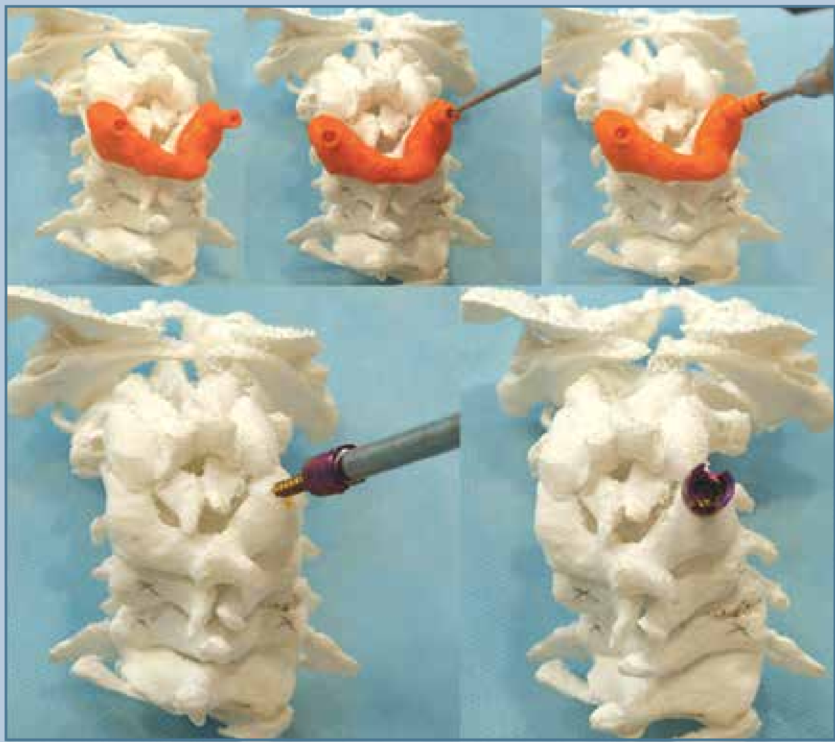

Fig. 3
Stages of screw insertion using template depicted on a 3D model

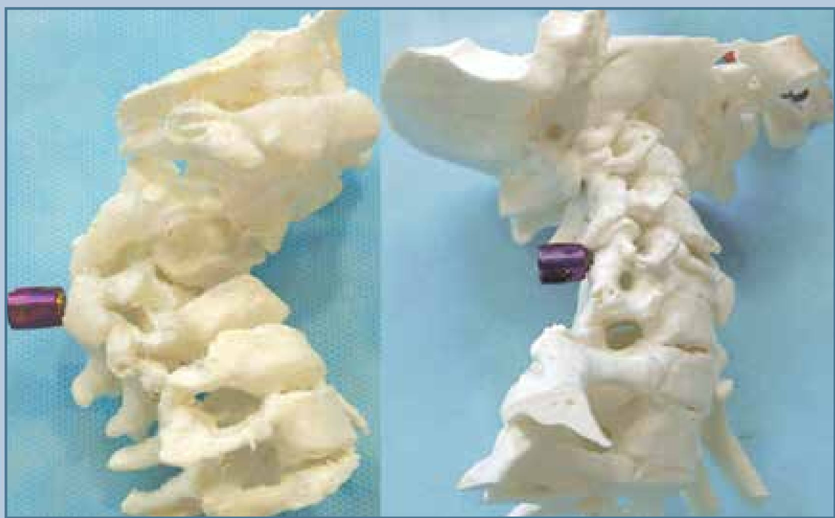

Fig. 4
Screw positioning on a 3D model (visual assessment after insertion using guiding templates)

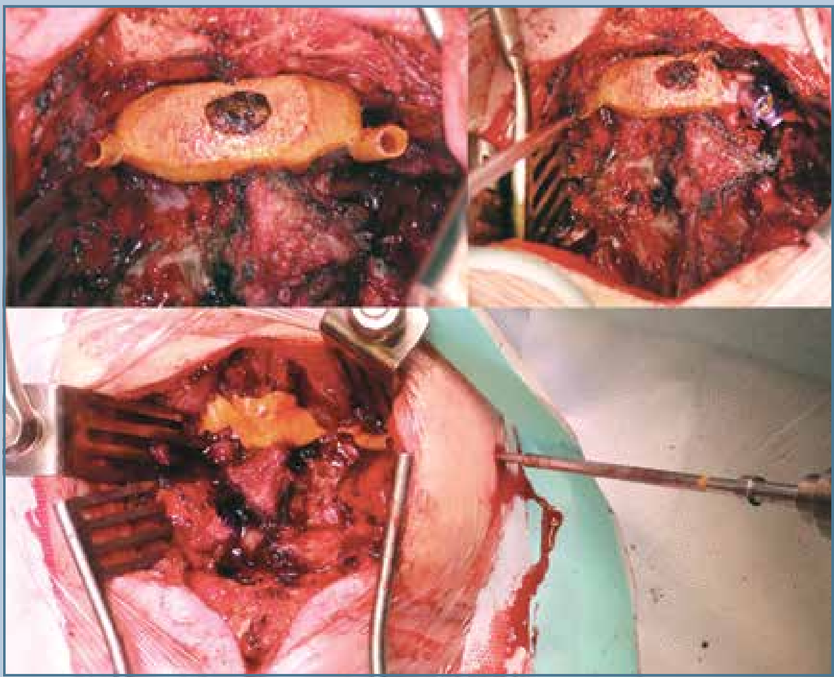

Fig. 5
Intraoperative photographs with the stages of screw insertion using the method of navigational guiding templates

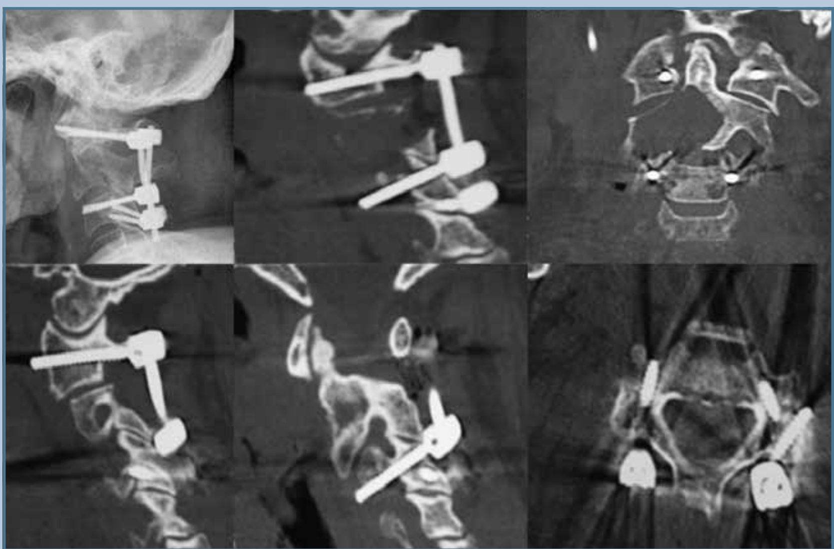

Fig. 6
Radiography and MSCT monitoring of screw position after surgery

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