# TRANSPEDICULAR FREE-HAND FIXATION IN THE SUBAXIAL CERVICAL SPINE

**_Sh.Sh. Magomedov, M.Yu. Dokish, A.P. Tatarintsev_**
_Vreden Russian Research Institute of Traumatology and Orthopaedics, St. Petersburg, Russia_

**Objective.** To analyze the results of surgical treatment of patients with injuries and diseases of the cervical spine operated on using transpedicular fixation with free-hand technique.
**Matherial and Methods.** A total of 97 patients with unstable injuries, congenital and acquired deformities, as well as with tumorous lesions of the cervical spine were examined. All patients were evaluated for the stability and reliability of transpedicular fixation in the long-term period, with the analysis of mistakes and complications that arose during treatment.
**Results.** Positive results were obtained in 94.8 % of cases, and signs of fixation instability were absent in all patients. Despite 125 cases of pedicle wall perforation, only four patients required revision surgeries. A low rate of complications was noted, including no damage to the vertebral artery. The pain syndrome in patients decreased.
**Conclusion.** The obtained results prove high efficiency and sufficient safety of the free-hand technique for the cervical spine fixation. At the same time, the technique requires careful preoperative preparation and examination of patients, thorough knowledge of anatomy of the operated area, and experience and qualification of the surgeon.
**Key Words:** transpedicular screw fixation. cervical spine, spinal stability, surgical complications.

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Pathological process in the cervical spine often leads to instability in connection with anatomical and biomechanical features of this area. Therefore, instrumented fixation is currently an important stage of many surgical procedures in the cervical spine.

In the case of intact posterior vertebral column, anterior fixation of the cervical spine alone can suffice, but in most cases of extensive injury, involving the posterior ligamentous and muscular system and intervertebral joints, posterior instrumented fixation of the spine is required.

Lateral mass insertion and transpedicular insertion are the most common methods of screws fixation of the cervical spine [1–6, 10–12, 16, 24, 29]. Facet screw fixation is believed to be safer, simpler, and comparable to transpedicular fixation in some aspects of reliability [16, 24], but it requires stabilization and immobilization of a large number of spinal motion segments. However, in many cases of total instability associated with traumatic injury or pathological process, especially in the case of reduced bone mineral density, only transpedicular fixation can restore the supporting ability of all three vertebral columns and provides reliable stabilization of the cervical spine [11, 12, 16, 24]. This is especially important in elderly patients with concomitant osteoporosis or disseminated spine tumor, when short fixation is insufficient and a significant number of intact vertebral segments should be blocked.

The study was aimed at analyzing the results of surgical treatment of patients with injuries and diseases of the cervical spine, who were operated on using transpedicular fixation.

## Material and Methods.

Study design. A single-center retrospective non-randomized cohort study.

All patients were operated on in 2010–2016. The follow-up period averaged 2 years (6–48 months).

The study was carried out at the Vreden Russian Research Institute of Traumatology and Orthopedics (St. Petersburg). The study included 97 patients (55 males and 42 females) with cervical spine pathology, who were treated using posterior instrumented stabilization. The average age of the patients was 48 (25–76) years. The pathological processes, which necessitated surgical treatment, are shown in Table 1; injuries to the cervical spine and their consequences, degenerative processes, and tumors were the most common ones.

Inclusion criterion was the performed insertion of pedicle screws into C3–C7 vertebral bodies using the free-hand technique, including that in patients who undergone occipitospondylodesis and fixation of the cervicothoracic spine up to and including T3 (Fig. 1).

Exclusion criteria were the loss of contact with the patient after surgery, no data of the postoperative CT of the spine, patient's refusal to enter the study.

A total of 420 pedicle screws were inserted into the subaxial spine during this study. When screws were inserted in other vertebral bodies (C1–C2 and the upper thoracic spine), then the correctness of their insertion was not evaluated in this study. Most often, screws were placed in C3, C4, C7 vertebral bodies (Table 2).

The screws were inserted according to the standard procedure based on anatomical landmarks without passive and active intraoperative navigation. External bone landmarks of the posterior vertebral elements (the center of the lateral mass, the center of the lower articular process, lateral notch, etc.) are the conventional markers for insertion. We applied the method of Karaikovic et al. [14] modified by Lee et al. [18], where the so-called lateral notch was the main anatomical bone landmark for localization of the screw insertion point . In the sagittal plane, the screws were typically oriented cranially at an angle of about 10° when inserted into C3—C4 vertebrae, strictly vertically (in the anteroposterior direction) when inserted into the C5 vertebra, and caudally at an angle of 10° when inserted into C6—C7 vertebrae. In the frontal plane, the screws were inserted at an angle of about 40—45° into the bodies of C3—C6 vertebrae and about 30—35° into the C7 vertebra [9, 13, 30]. In each case, the anatomy of the vertebrae, vertebral artery location, and screw insertion sites and angles were specified according to preoperative CT data. In 36 (37.1 %) cases with indications for posterior decompression of nerve roots or complex anatomical variants, microlaminotomy with direct palpation of the medial and superior walls of the vertebral pedicle with a probe was used. Intraoperative neuromonitoring was used in 25 (25.8 %) patients. In the case of cervicothoracic spine fixation, rods with transition diameter were typically used to connect the cervical and thoracic screws. In 9 cases, thoracic screws of 4.35 mm in diameter and standard 5.5 mm rods were used in the cervical spine to reduce the risk of rod breakage (Fig. 2). We believe that, in the case of sufficient size of the cervical vertebral pedicles, insertion of screws of this diameter is possible up to C3 vertebra.

**Table 1**

Nosological data of operated patients

| Cervical spine pathology | Patients, n (%) |
|---|---|
| Unstable injuries | 37 (38.2 %) |
| Cervical myelopathy with underlying multilevel degenerative spinal stenosis | 29 (29.9 %) |
| Tumors of various etiologies | 17 (17.5 %) |
| Congenital and acquired deformities | 10 (10.3 %) |
| Nonspecific spondylodiscitis | 4 (4.1 %) |

Mandatory preoperative examination of patients included X-ray of the cervical spine in the frontal, lateral, and 3/4 projections, functional radiographs, CT, MRI of the cervical spine, and, in the case of neurologic symptoms, electroneuromyography. Doppler ultrasonography of the brachiocephalic vessels and CT angiography of the cervical vessels were carried out, when detailed assessment of the location of vertebral arteries and characteristics of the blood flow was required.

We evaluated clinical data (dynamics of pain syndrome, neurological status, patients' quality of life), as well as the results of instrumental examination methods (X-ray, CT, MRI, ENMG). Universal scales were used to assess the functional outcomes: VAS (neck and arms), NDI before and after surgery. The quality of life was assessed using the EQ-5D questionnaire. Additionally, patients' state was preoperatively and postoperatively assessed using the scales specific for each particular nosology (SINS, JOA, Nurick, etc.).

Comparative analysis of the results of treatment for various pathologies was beyond the scope of this study, the main attention was paid to evaluation of fixation stability in the early and late periods and the correct screw positioning.

Surgical outcomes and the absence of signs of instability and migration of the inplant in the postoperative period were

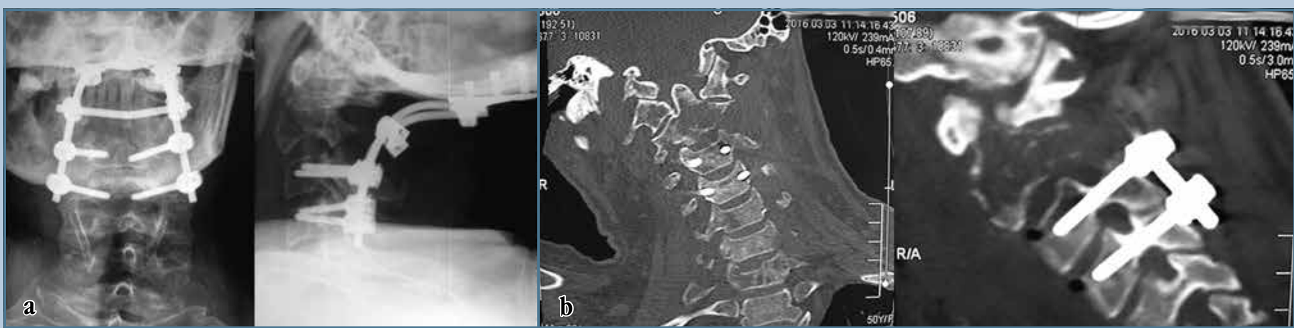


**Fig. 1**
Radiographs **(a)** of a patient with C2 vertebral body destruction with underlying metastatic kidney cancer and occipitospondylodesis in frontal and lateral projections and CT scans **(b)** in coronary and sagittal projections, which show transpedicular screws inserted to the bodies of C3 and C4 vertebrae

controlled using the standard radiography of the cervical spine in the frontal and lateral projections immediately after surgery, in 1, 3, 6, and 12 months, and then once a year throughout the follow-up period. Position of the implant, signs of screw migration and pull-out or radiolucency around the screws were evaluated based on X-ray images. According to CT performed immediately after surgery, correctness and accuracy of positioning of transpedicular screws implanted into the vertebral bodies was analyzed.

Currently, there is no unified generally accepted classification of the accuracy of transpedicular screw insertion in the cervical spine. Yoon et al. [31] suggested four-grade scale for evaluation of vertebral pedicle perforation: 0 — the screw is strictly within the vertebral pedicle; 1 — there is perforation of less than 25 % of the screw diameter; 2 — there is perforation 25 to 50 % of the screw diameter; 3 — the perforation is more than 50 % of the screw diameter. Grades 0 and 1 are regarded as correct screw position, 2 and 3 — incorrect. Zheng et al. [32] classified screw position into four grades, applying their own criteria: 1 — the screw is located inside the vertebral pedicle, the wall of the pedicle is intact; 2 — mild injury to the bone wall of the vertebral pedicle, but the screw is still located within the vertebral pedicle; 3 — there is perforation of the pedicle wall, but screw protrusion is less than 1 mm; 4 — perforation of pedicle wall with displacement by more than 1 mm. Taking into account the diameter of the screws inserted in the cervical spine (an average of 3–3.5 mm), the last classification is the most critical to the accuracy of screw insertion and, in our opinion, it is more applicable to assess the correctness of screw insertion using computer-assisted navigation.

Since the aforementioned classifications do not take into account clinical manifestations of incorrect screw insertion, and therefore there are no clear criteria, when they should be remounted, we used the classification proposed by Richter et al. [26], which classifies the screws inserted in the cervical spine into three groups. Group 1 includes the cases of correct screw insertion without perforation of pedicle wall or with perforation of less than 1.0 mm, group 2 — vertebral pedicle perforation of more than 1.0 mm, but without the need for screw remounting, group 3 — cases of pedicle perforation of more than 1.0 mm, when revision and remounting of the screw is required in connection with nerve root irritation or due to decrease in the biomechanical stability of the implant. This classification was used in our study to assess the correctness of transpedicular screw insertion in the cervical spine in all patients.

All operations were carried out under endotracheal anesthesia with muscular relaxation in the patient's prone position on the orthopedic table with head fixation in the soft head holder and with silicone bolsters under the shoulder girdle and pelvis. Skin preparation and preliminary labelling was followed by a median longitudinal incision. Dissection of the superficial fascia was followed by subperiosteal skeletonization of the muscles with separation of the vertebral arches up to the outer edge of the lateral mass. The level of surgical intervention was labelled under the control of image intensifier and high-speed burr was used to open the cortical plate at the site of planned screw insertion. Drilling site was determined based on anatomical landmarks, mainly the so-called lateral notch of the vertebral arch [14, 18]. Cortical layer was opened 2 mm medial to the lateral notch followed by formation of the screw channel using the cervical pedicle probe. Bone reaming with a drill was not used. The final site and angle of screw insertion was adjusted based on preoperative CT. The integrity of the walls of the formed channel was checked using a bulbous-end probe. When bone wall defects were discovered by a sudden advancement of the probe, the channel was formed in a new direction. Bleeding from the bone trabeculae was stopped with bone wax. The screw tap was not used in most cases; it was used only in the cases of sclerosal bone. Depth measurement was followed by screw insertion into the vertebral body, trying to perform bicortical fixation, especially when there were signs of osteoporosis. Laminoforaminotomy aimed at decompressing the neural structures of the spinal cord and other manipulations were

**Table 2**

Screw insertion level

| Screw insertion site | Screws, n (%) |
|---|---|
| C3 | 98 (23.3) |
| C4 | 93 (22.2) |
| C5 | 68 (16.2) |
| C6 | 74 (17.6) |
| C7 | 87 (20.7) |


**Fig. 2**
CT of a patient with transpedicular fixation of the cervicothoracic spine, wherein standard screws sized 4.35 mm in diameter are inserted in the vertebral bodies with 5.5 mm rods: **a** — axial scan; **b** — sagittal

performed when necessary, depending on the pathology. When screw insertion was technically complicated or reinsertion was required, mini-laminotomy was performed using 2.5 mm diamond burr or 2 mm Kerrison punch for direct visualization and palpation of the medial, superior, and inferior walls of the vertebral pedicle [8, 19, 20, 30, 31].

The operation was completed by installing the system with longitudinal rods, creating conditions for posterior fusion (in the absence of contraindications), and layer-by-layer wound suturing with active Redon drainage.

The data distribution was evaluated according to the Kolmogorov-Smirnov test. In connection with relatively small sampling, nonparametric statistics were used for statistical analysis. Median and quartile range (25—75 %) were calculated for quantitative values, qualitative characteristic were evaluated in fractions and percentages. The Mann-Whitney U-test was used to compare the values of independent samples; Wilcoxon pairwise comparison test was used for related samples. The result was considered significant at $p < 0.05$ for all methods.

## Results

On the average, pain syndrome as assessed by VAS regressed from 8.6 points before surgery to 3.2 points 1 year after surgery ($p = 0.025$) in the neck, from 7.6 to 1.9, respectively ($p = 0.01$), in the arms. Comparable improvement was also observed when analyzing the quality of life parameters: a year after the operation, the average EQ-5D score increased from 27 to 76 % ($p <0.05$), NDI score decreased from 34 to 11 points ($p = 0.01$), except for patients with primary oncological pathology, where there was no significant improvement in the quality of life, since these patients received palliative treatment ($p > 0.05$; Fig. 3).

According to the control radiographs, none of 97 patients showed signs of instability of the fixed department of the spine or migration of implants during the entire follow-up period. Extremely high reliability of transpedicular fixation of the cervical spine was evidenced by the fact that even four patients with continued growth of the primary tumor, which could not be totally resected, demonstrated no signs of cervical spine instability in spite of the progressive involvement of the osseous vertebral structures located at the area of osteosynthesis, which enabled us to proceed with systemic pharmacotherapy and radiation therapy. All patients could move independently immediately after the operation and required no additional external orthoses. Therefore, both immediate and long-term fixation stability was achieved in 100% of cases.

When assessing the accuracy of transpedicular screw insertion according to postoperative CT, 295 (70.2 %) out of 420 implanted screws were classified into group 1 (Richter), 120 (28.6 %) — into group 2, 5 (1.2 %) — into group 3, where revision and reinsertion of the implant was required. Screw malpositioning was mainly associated with perforations of the lateral wall (72 (57.6 %) cases out of 125), more rarely — inferior and superior walls (Table 3). There was low incidence of injury to the medial wall, which, in our opinion, is due to its thickness and also to the fact that we avoided screw insertion at large angles in the frontal plane.

A total of 125 cases of pedicle wall perforation were observed in 38 patients, and only 4 patients had clinical signs of root irritation, which necessitated surgical revision (Fig. 4).

Among 72 cases of perforation of the lateral wall of the vertebral pedicle, there were no cases of vertebral artery injury, which would require its ligation. In five cases, bleeding with scarlet blood arose during canal preparation for screw insertion, which was stopped using bone wax and screw insertion into the formed canal.

In addition to these complications, one case of deep surgical site infection was observed in a patient with initial spondylodiscitis of C5—C6 vertebrae. Revision of the surgical site, debridement, and wound washing led to healing without the implant removal.

In summary, positive results of treatment were achieved in 92 (94.8 %) patients, which is indicative of high reliability and effectiveness of transpedicular screw insertion in the cervical spine without the use of intraoperative navigation.

We exemplify the aforementioned data by the case of female patient M., 23 years old, who suffered from persistent pain syndrome (VAS score 8 points in the neck and 5 points in the arms) without neurological disorders. NDI score was 28 points. A multimodal examination (X-ray, CT, MRI of the cervical spine, osteoscintigraphy, oncological examination) showed pathological fracture of the C4 vertebral body with underlying space-occupying mass complicated by instability and kyphotic deformity with posterior displacement of the C3 vertebra and dynamic spinal stenosis (Fig. 5, 6). The SINS score (14 points) was indicative of pronounced spinal instability and absolute indications for cervical spine stabilization.

Selective angiography in projection of the C4 vertebra showed the area of pathological hypervascularization with multiple small branches of the left vertebral artery. Preoperative biopsy was not carried out, since it was decided to perform intraoperative express biopsy. The patient underwent a single two-staged operation.

The first stage included corporectomy of C4 through the anterior approach with removal of the tumor, vertebral pedicles, and anterior tubercles of the transverse processes, isolation of the vertebral arteries on both sides, decompression of the dural sac, anterior corporodesis using an interbody mesh cage filled with bone cement, and fixation with C3—C5 plate. Osteoclastoma was diagnosed based on the express biopsy, which was later confirmed by histological examination.

The second stage after patient's repositioning included transpedicular spondylosynthesis C3—C5 with a 4-screw system, extended laminectomy of C4 vertebra with removal of the superior and inferior articular processes and the remaining elements of the transverse processes on both sides (Fig. 7, 8).

Decrease in the severity of pain syndrome as assessed by VAS was observed

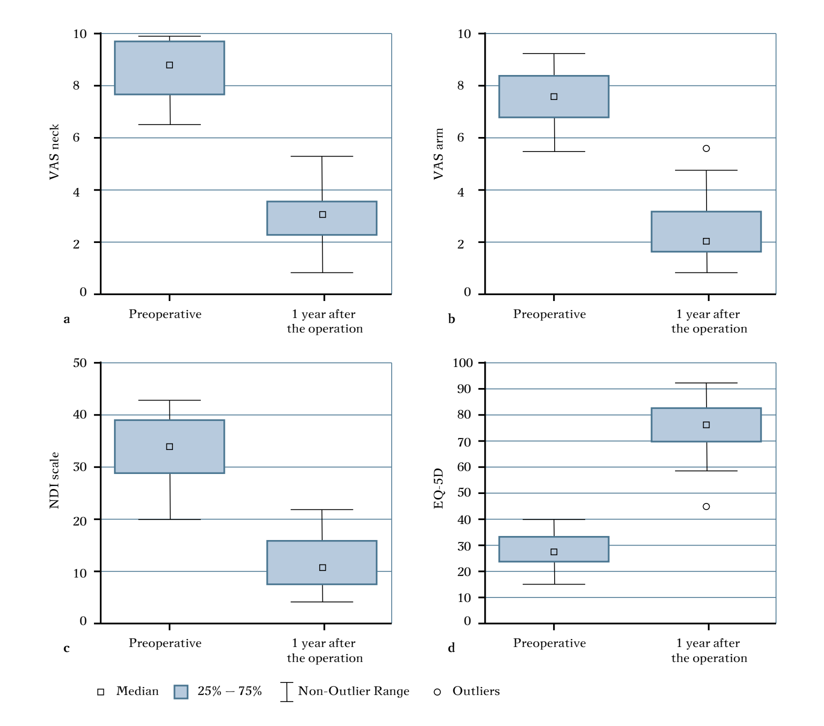


**Fig. 3**
Dynamics of the main parameters before the operation and 1 year after the operation: **a** — pain in the neck as assessed by VAS; **b** — pain in the arms; **c** — NDI; **d** — quality of life according to EQ-5D

after the operation: up to 2 points in the neck and up to 0 points in the arms. NDI decreased to 7 points (almost complete recovery). The patient was followed up for three years after the operation. No tumor recurrence was observed, the structure was stable, complete regression of pain syndrome was observed.

## Discussion

Transpedicular fixation of the cervical spine with subaxial screw insertion is one of the recent trends in spinal surgery, which rapidly develops since the 1990s. Panjabi et al. [22] studied the 3D anatomy of the cervical vertebrae and demonstrated the possibility of inserting screws into the vertebral pedicles for fixation purposes. The first successful operations with transpedicular screw insertion in the lower lumbar vertebrae were described in 1994 by Abumi et al. [5], who reported the results of treatment of 13 patients with subaxial trauma; they also were the first who described anatomical landmarks for screw insertion [5, 6]. Unfortunately, the landmarks were rather indistinct, but the possibility of performing such operations with 100% bone block formation without loss of fixation stability in the absence of serious complications stimulated further rapid development of the method [6, 27, 29]. In cervical surgery, most surgeons still prefer to insert screws into the lateral masses, as opposed to the thoracic and lumbar spine, where transpedicular screw insertion has become the gold standard for stable fixation of the spine in the past decades [1–4, 11, 12, 17], which is explained by complex relationships in the cervical spine, small size of cervical vertebral pedicles and wide variability of vertebral artery location [7, 9, 13, 17, 20–22]. At the same time, numerous studies show high efficacy, safety, and advantages of transpedicular fixation [11, 12, 16, 24, 27]. Numerous experimental studies specified the points and direction of the screw insertion, and techniques improving the safety and accuracy of their positioning [8, 14, 18–20, 26, 29, 32]. The development of computer technologies, as well as passive and active navigation techniques significantly improved the accuracy of screw positioning and reduced the risk of perforation of pedicle walls during insertion [10, 15, 19, 23, 25, 26, 28]. But these techniques cannot solve all the problems. In addition to high cost of equipment, there are some technical issues associated with the possibility of malpositioning in the case of occasional displacement of recording sensors, increase in the duration of operations, etc. [28, 30].

We used the traditional method of screw insertion based on anatomical landmarks without the use of navigation equipment. The accuracy of free-hand screw insertion as assessed by postoperative CT was lower in our study than with the use of intraoperative navigation according to literature data. However,

**Table 3**
Screw malposition

| Groups according to Richter et al. [25] | Perforation site of the vertebral pedicle wall, n (%) | | | |
|---|---|---|---|---|
| | Medial | Lateral | Superior | Inferior |
| Group 2 (120 screws) | 4 (3.2) | 70 (56.0) | 16 (12.8) | 30 (24.0) |
| Group 3 (5 screws) | 1 (0.8) | 2 (1.6) | 2 (1.6) | 0 (0.0) |
| Total (125 screws) | 5 (4.0) | 72 (57.6) | 18 (14.4) | 30 (24.0) |


**Fig. 4**
Postoperative CT. axial scan. shows the screw in C3 vertebral body on the left perforating the lateral wall of the pedicle to the depth of about 1.8 mm; perforation of the medial wall of the pedicle to the depth of 1 mm (on the right)

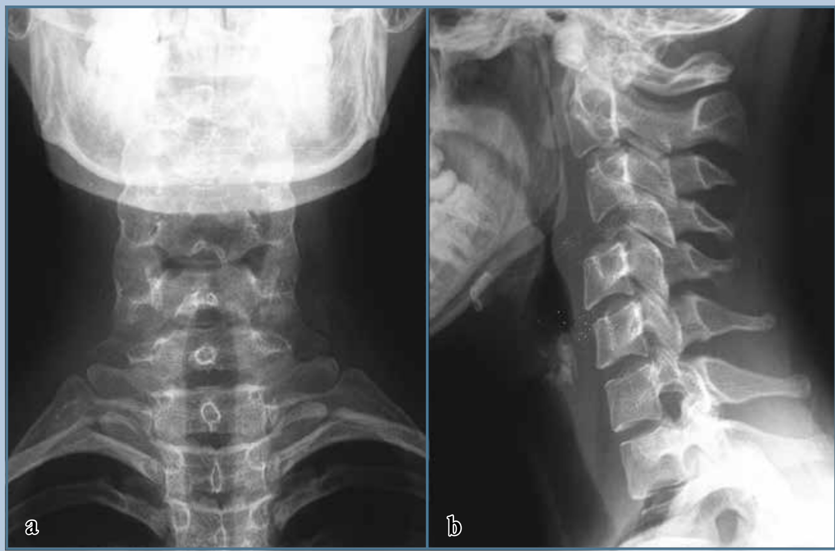


**Fig. 5**
Radiographs of patient M., 23 years old, with pathological fracture of C4 vertebra and cervical spine deformity: **a** — direct projection; **b** — lateral projection

this did not significantly affect functional and clinical outcomes: positive outcomes were obtained in 95% of cases with 100 % stability of the spine along with low incidence of indications for revision surgery, which is indicative of the effectiveness of the applied technique and prove that small perforations of the vertebral pedicles as shown by CT play no clinical role.

## Conclusion

Free-hand transpedicular screw insertion is a safe and effective technique providing reliable fixation in the subaxial cervical spine, even in the case of not completely correct screw position. In the case of accurate preoperative planning based on comprehensive radiological examination, the method can be quite widely used in clinics, where computer-assisted navigation is not available. It should be noted that simple, informative, and easily reproducible Richter method for assessing the correctness of screw placement cannot be the only argument for making decisions on revision surgery; decisive criteria can be obtained by comparing the results of X-ray examination with clinical complaints.

*The study was not sponsored. The authors declare no conflict of interest.*

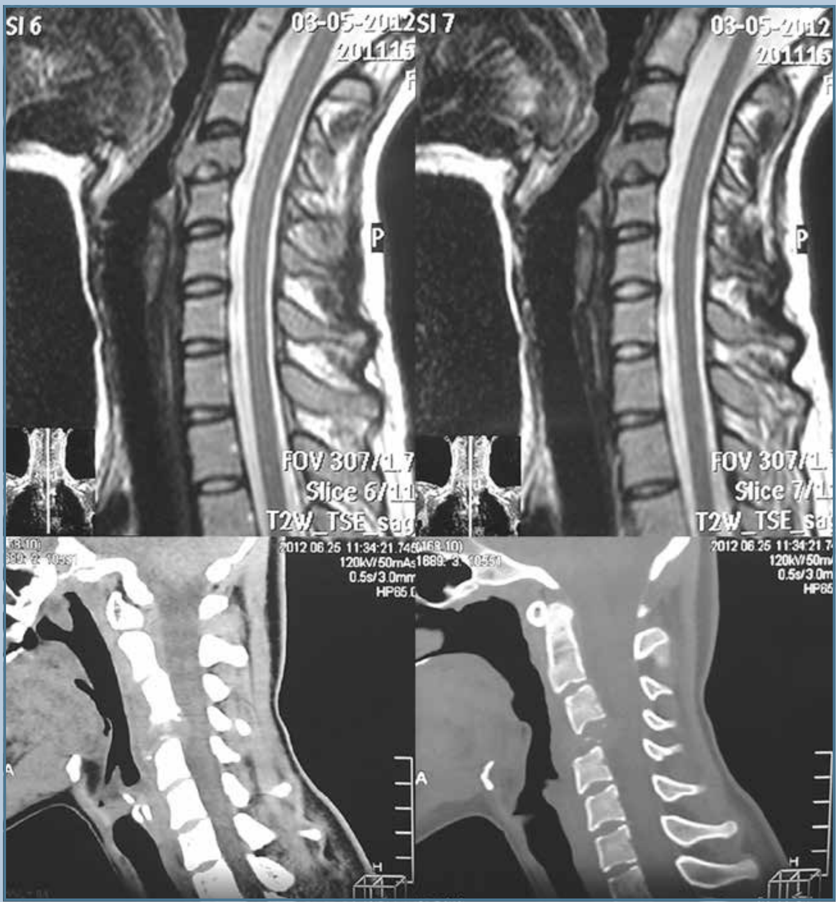


**Fig. 6**
MRI and CT scans of the cervical spine of patient M., 23 years: complete destruction of C4 vertebral body, which is totally replaced with tumor tissue

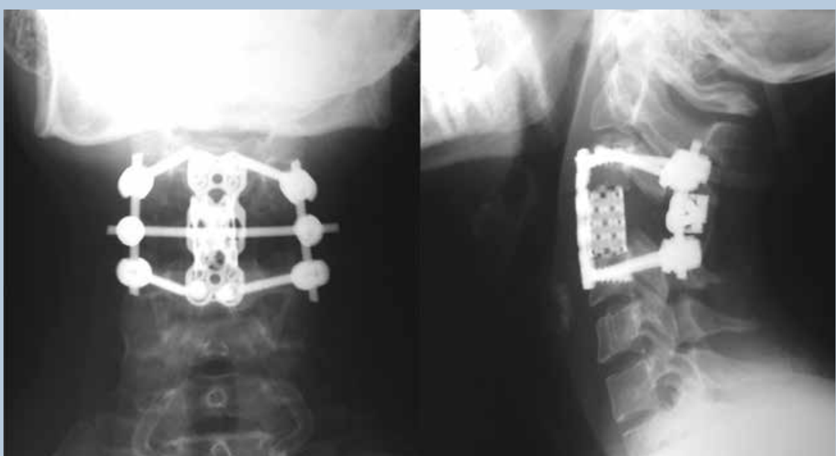

**Fig. 7**
X-ray image of patient M., 23 years, in the frontal and lateral projections after two-staged surgical treatment

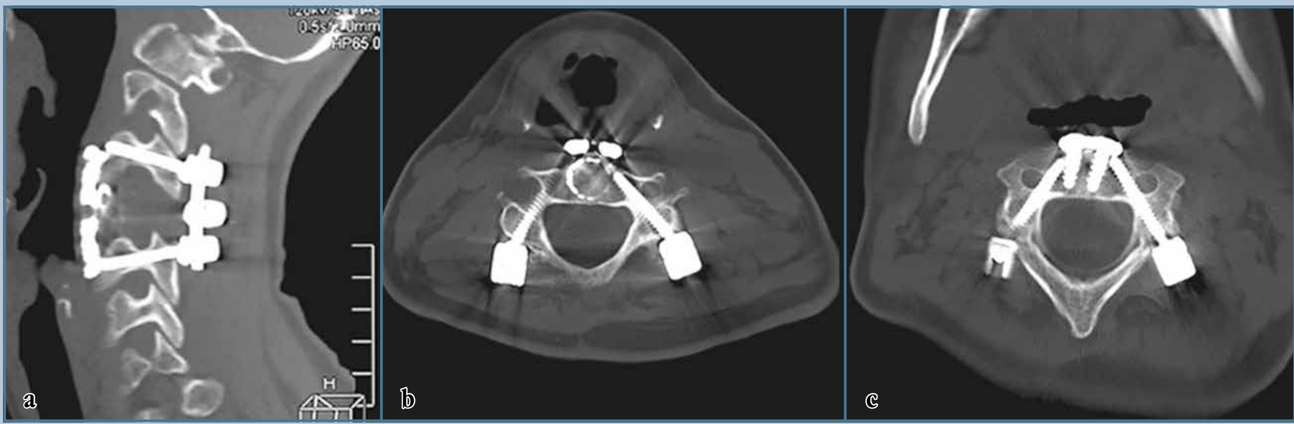

**Fig. 8**
CT scan of patient M., 23 years old, after two-stage surgical treatment: sagittal **(a)** and axial sections at the level of C3 **(b)** and C5 **(c)** vertebrae; total removal of the C4 vertebral body, the screws pass strictly within the pedicles

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**Address correspondence to:**
Dokish Mikhail Yuryevich,
Vreden Russian Research Institute of Traumatology and Orthopaedics,
Akademika Baikova str., 8, St. Petersburg, 195427, Russia
drdokish@mail.ru

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*Shamil Shamsudinovich Magomedov, MD, PhD, head of the Department No. 12, Vreden Russian Research Institute of Traumatology and Orthopaedics, Akademika Baikova str., 8, St. Petersburg, 195427, Russia; dr.shamil@mail.ru;*
*Mikhail Yuryevich Dokish, MD, PhD, neurosurgeon of the Department No. 12, Vreden Russian Research Institute of Traumatology and Orthopaedics, Akademika Baikova str., 8, St. Petersburg, 195427, Russia; drdokish@mail.ru;*
*Aleksandr Pavlovich Tatarintsev, neurosurgeon of the Department No. 12, Vreden Russian Research Institute of Traumatology and Orthopaedics, Akademika Baikova str., 8, St. Petersburg, 195427, Russia; alexandr98ru@yandex.ru.*