TRANSPEDICULAR SCREW FIXATION OF THE CERVICAL SPINE: LITERATURE REVIEW AND CLINICAL DATA

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An analysis of key publications devoted to transpedicular fixation of the cervical spine has been carried out. The installation of transpedicular screws in the cervical spine is a technically challenging procedure, the frequency of screw deviation from the optimal trajectory remains high even with the use of modern intraoperative technologies, and there is a risk of serious life-threatening complications. The use of this technique allows achieving reliable three-column stabilization of the cervical spine through only posterior approach, which is the preferred or only possible option for a limited group of patients. According to literature data, screw displacement beyond the pedicle borders occurs, on average, in 15–20 % of cases, while clinically significant complications occur in 4–5 % of cases. Among 32 operated patients, one severe neurologic complication caused by vertebral artery compression by the screw was noted. Of the 79 installed screws, 18 (22.79 %) cases of lateral pedicle wall perforation were observed. There were no cases of the fixator instability, infection and radiculopathy due to compression by the screw.
Key Words: pedicle screw fixation, cervical spine stabilization, posterior cervical spine fixation.

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Currently, transpedicular fixation is the gold standard in stabilizing the thoracic and lumbar spine. Until recently, this method has been used only to a limited extent for treatment of the cervical section disorders due to technical complexity of the procedure and high risk of severe intraoperative and postoperative complications [8]. In addition, reliable stabilization of the cervical spine can be achieved using lateral mass screw fixation or hook fastening to vertebral arches. However, the number of operations for various spine disorders increases every year, including revision surgeries and those associated with correction of severe deformities. Such interventions increase the demand for reliability of the fixing elements, which increases the interest in transpedicular fixation of the cervical spine.

The introduction of transpedicular fixation for cervical spine disorder into clinical practice began at the end of the last century. A paper by Japanese authors [1] published in 1994 described the use of transpedicular fixation in treatment of 13 patients with traumatic injuries of the cervical spine. In all cases, it was possible to achieve the formation of a bone block, there were no complications related to screw insertion. This led to the conclusion that experienced surgeon performing such operation with careful observance of the technique described by the authors, can achieve the same reliable three-column stabilization through posterior approach, as that h achieved in transpedicular fixation in the thoracic and lumbar spine.

Later, Abumi et al. [2] published a number of works assessing the safety of the installation of transpedicular screws in the cervical spine. They analyzed the experience of treatment of 180 patients, who had 712 screws installed for traumatic and non-traumatic injuries of the cervical spine. They reported only 6.7 % of cases, where screws protruded from the pedicles; two patients had radiculopathy associated with the compression of the spinal nerve roots by a screw and in one case there was an intraoperative damage to the vertebral artery. These results allowed the authors to conclude that this operation is safe for various lesions of the cervical spine. Nevertheless, due to the risk of damage to the neural elements and the vertebral artery, the installation of transpedicular screws in the cervical spine is still considered a risky procedure and is used only by a limited number of surgeons specializing in cervical spine surgery [5].

There are very few publications devoted to this issue. A search in e-Library system did not return any results for “transpedicular fixation of the cervical spine” query, while searching in English-language databases identified only a few dozens of articles for “pedicle screw fixation of the cervical spine” query, and the number of clinical studies was in single digits. Therefore, we set ourselves the task of analyzing the literature data on the transpedicular fixation of the cervical spine, comparing them with the experience from our clinic and assessing the feasibility of using this method in the treatment of patients with injuries and diseases of the cervical spine.

Surgery techniques

We found descriptions of four surgical techniques for installation of transpedicular screws in the cervical spine. The first one is described in the works of Abumi et al. [1] and is based on a clear assessment of anatomical landmarks and tactile sensations of the surgeon. Only X-ray images in the lateral projection are taken intraoperatively to determine the direction of the screw in the sagittal plane. The landmark for inserting a screw at the C2 level is the cranial edge of the arch, while the upper medial border of the pedicle is accessible to visual inspection and palpation with a tool (the angle of screw insertion is usually 15–25°). At the C3–C7 level, the points of insertion of the screws are located lateral to the center of the lateral mass, next to the lower edge of the lower articular process of the overlying vertebra at the level of incisure of the lateral vetebral notch. X-ray in lateral projections is used to assess the direction of the screw. The angle of insertion is 25–45°, while the angle of inclination of the screw in the horizontal plane can be significantly less than the angle of deflection of the vertebral pedicle. This is possible due to the fact that vertebral pedicles in the cervical region are short. The direction of the screws at the level of C5-C7 is parallel to the upper closing plate, and at the C2-C4 level it is oriented to the cranial closure plate. A burr is used to perforate the cortical bone and form a recess allowing manipulation of a probe; a probe is then used to form a channel that passes through the pedicle into the body of the vertebra, then a tap and a screw are subsequently guided along the formed channel (Fig. 1).

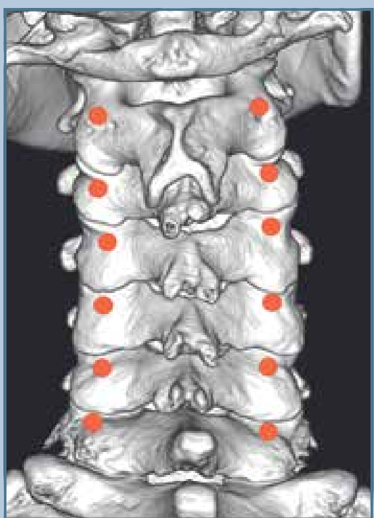

Fig. 1
Entry points for installation of the screws

In 2010, Zheng et al. [20] proposed slightly different reference points for screw insertion based on an anatomical study: C3 – outer edge of lateral mass, 4 mm caudally to the facet, C4–C6 border of middle and outer quarter of lateral mass, 3 mm caudally to the facet, C7 – middle of lateral mass, 2 mm caudally to the facet.

In 2006, Yukawa et al. [19] described the introduction of screws using X-ray in an oblique projection, the so-called method of looking at the pedicle axis (Fig. 2). In this case, the X-ray is directed in such a way as to clearly visualize the cortical plates of the vertebral pedicle (Fig. 2), which makes it possible to guide the screw along the vertebral pedicle, which reduces the risk of its perforation. In addition, this method visualizes the pedicles of lower cervical vertebrae, which are usually inaccessible to lateral X-ray, as well as the upper and lower border of the pedicles of the contralateral side.

The works of Ludwig et al. [14] describes the installation of screws with the use of laminoforaminotomy. In this case, before installing the screw, a foramen is formed in the lateral sections of the arch and the medial parts of the facet, similar posterior foraminotomy. The borders of the pedicle, the dural sac and the outgoing root are visualized through this foramen and therefore the screw can be safely inserted under a clear visual control of the vertebral arch root boundaries. This surgery technique (Fig. 3) is recommended by the AO Foundation (www2.aofoundation.org).

The development of modern imaging techniques in spinal surgery affected the technique of transpedicular fixation of the cervical spine, and the methods of installing screws using computer navigation systems were described and investigated [9]. However, a number of studies have shown that the use of navigation systems in this operation does not improve the accuracy of screw installations, and in some cases even reduces it [14]. The data obtained can be attributed to the complexity of using navigation systems in the cervical spine, which, in turn, is explained by high mobility of the cervical vertebrae. Nevertheless, according to the data of other authors [7, 9, 13], the use of navigation systems increases the accuracy and safety of transpedicular fixation in the cervical region.

Clinical and biomechanical studies

A number of biomechanical studies have shown that the stability of transpedicular screws is much higher than that of screws in lateral masses [6, 10, 11]. For example, pedicle screw pull-out strength was 677 N, whereas that required to pull-out screws from lateral masses – only 355 N. The range of motion in lateral flexion was 0.86° ± 0.31° in the segment fixed with transpedicular screws, and 1.43° ± 0.62° in segments with lateral mass screw fixation (P = 0.037). In the flexion/extention test, the decrease in mobility after fixation of the intact segment was 95.4 ± 9.4 % for transpedicular screws and 70.5 ± 9.8 % for lateral mass screws (P = 0.010). Kotani et al. [10] compared anterior locking plates and posterior locking systems. It has shown that the posterior locks are more resistant to axial loads, as well as to bending and rotating.

Some authors [12, 16] suggest using translaminar screws as an alternative to transpedicular fixation in the transitional zones (at the C2 level and in the cervicothoracic transition of C7–T2). This method of installing screws allows avoiding the risk of damage to the vertebral artery and does not require wide skeletonization of the facet joints. It should be noted that laminar screws can be used in the subaxial zone (C3–C6) only in a limited group of patients (37–89 %, depending

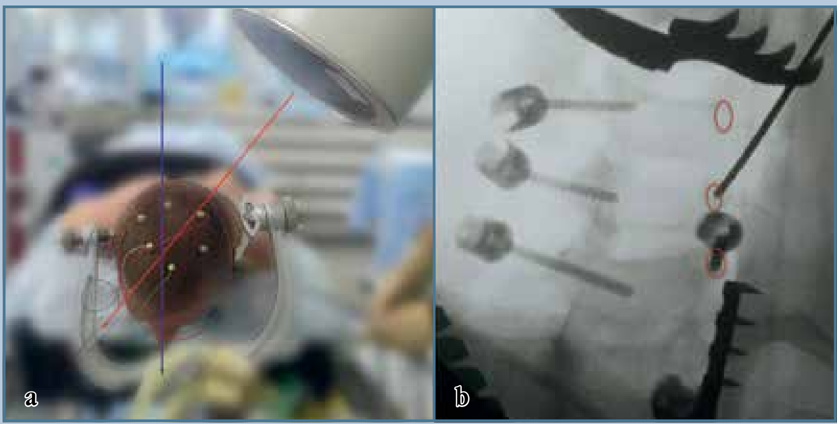

Fig. 2
Pedicle axis view: **a** – the direction of the X-ray is indicated by a red line; **b** – screws are installed on the left side, a side view of the pedicles; on the right side, the circles indicate axial sections of the roots of the vertebrae arches

Fig. 3
Laminoforaminotomy scheme: blue color, resected structures, green color, projection of the vertebrae pedicles

on the level) [4]. Therefore, this method of fixation requires coupling of screws, the fixing points of which are not on the same line. It leads to technical difficulties when installing longitudinal rods and requires additional modeling or use of connectors, which can reduce the reliability of the system. Clinical and biomechanical studies have shown that laminar fixation provides lesser stability than transpedicular fixation, especially for three-column lesions [12].

We have conducted the analysis of medical publications in PubMed, Web of Science, e-Library databases using the following key words: transpedicular fixation in the cervical spine, complications, veretebral artery damage, radiculopathy, screw displacement. The inclusion criteria were postoperative CT control of the position of the screws with assessment of perforation percentage of the pedicle cortical walls, as well as analysis of the complications associated with the use of transpedicular fixation.

Five studies have been selected for in-depth analysis. Table 1 shows the outcomes of these studies [2, 5, 8, 15, 17, 18].

According to literature data, screw displacement beyond the pedicle borders occurs, on average, in 15–20 % of cases, while clinically significant complications occur in 4–5 % of cases.

As noted by all authors, the perforation most often occurs in the lateral cortical wall of the pedicle (from the side of the vertebral artery), which is explained by its smaller thickness [18]. As can be seen from Fig. 4, which shows the axial section through the C5 vertebra at the level of the pedicles, the spinal cord lies fairly freely in the vertebral canal (in the absence of pronounced stenosis of the canal), so the displacement of the screw into the lumen of the spinal canal is rarely accompanied by compression of the spinal cord and damage to the dural sac. The displacement of the screws into the lumen of the vertebral artery is not always associated with the clinical manifestations, which can be attributed to high plasticity of the vessel, reserves of the vertebral artery lumen in the lateral mass of the vertebra, compensation due to contralateral blood flow and arterial anastomoses. Most authors recommend pre-operative planning to investigate the blood flow in the vertebrobasilar basin and, in case of dominance of one of the vessels, to avoid installing screws from this side.

In a number of cases, radiculopathy associated with compression of the rootlet was noted. When guiding the screws one should take into account that in the cervical region the outgoing root is attached to the upper wall of the pedicle, and not to the lower wall, as in the thoracic and lumbar regions. This anatomical feature must be taken into account when guiding the screw, clearly orienting it in the sagittal plane using X-ray images in the lateral projection (Fig. 5).

Analysis of relationships between the incidence of screws displacement and the position of the vertebra and the pathological process for which the surgery was performed revealed that C4 is the most common level for critical displacement of the screw [8, 15, 17]. The anatomical study of the angle of deviation of the pedicle in the axial plane has shown that at this level the angle of deviation of the pedicle is the largest (on average 50.2°, C5 – 48.1°), which explains the need to guide the screws with the greatest deviation angle in the horizontal plane [3]. This is associated with a number of technical difficulties and Abumi et al. [1] recommend in some cases to guide the screws through additional sections with significant indentation from the line of main central approach.

Clinical data

Transpedicular fixation in the cervical spine has been used for several years in the neurosurgical department of the

Table 1
Complications of transpedicular fixation of the cervical spine

Author	Patients, n	Screws, n	Pathologies	Displacement of screws (I), %	Displacement of screws (II), %	Displacement of screws (total), %	Radiculopathy, n	Damage to the vertebral artery, n	Infection, n	Fixator instability, n	Total complications, n
Kast et al. [8]	26	94	Different	21.0	9.0	30.0	2	0	0	0	7.6
Abumi et al. [2]	180	712	Different	Not assessed		6.7	2	1	2	0	2.7
Yukawa et al. [18]	144	620	Trauma	9.2	3.9	13.1	1	1	0	4 (no spondilosys)	4.2
Uehara et al. [17]	129	579	Non-traumatic	6.1	18.6	24.7	3	0	0	0	2.3
Nakashima et al. [15]	84	390	Non-traumatic	15.4	4.1	19.5	2	3	1	11	20.2
Hojo et al. [5]	283	1065	Different	9.6	5.3	14.9	0	2	0	0	0.7

I – screw displacement less than 50 % of the diameter, II – screw displacement more than 50 % of the diameter.

Privolzhsky Federal Research Center. The decision to use this method is taken individually in each specific case. The main indications for transpedicular fixation are: decrease in bone density, impossibility of fixation to lateral masses (if they are destroyed as a result of trauma or inflammatory process), the need for correction of significant deformities; limited fusion length in young patients; tracheostomy. Given these criteria, transpedicular fixation was used in 32 patients and 79 screws were installed. In 23 cases, the operation was performed for patients with traumatic spine injuries, in 3 cases for tumor lesions of the cervical vertebrae, in 4 for unstable cervical vertebrae due to rheumatoid arthritis, and in 2 for degenerative diseases of the cervical spine.

The most common level for screw introduction was C2 vertebra (28 patients), followed by C3 (4), C4 (2), C5 (3), C6 (4), C7 (5).

There were no cases of the fixation instability, infectious complications and radiculopathy as a result of compression by the screw in the postoperative period in any of the operated patients. There were also no cases of intraoperative damage to the vertebral artery accompanied by arterial hemorrhage.

Control CT revealed lateral pedicle wall perforation in 18 (22.79 %) cases. There was no medial perforation of walls of vertebral arch roots. In most patients, the deviation of the screw from the axis of the pedicle with perforation of the walls of the vertebral artery canal was asymptomatic and did not require repeated interventions and therapy. One patient developed a blood circulation disorder in the basin of the left posterior cerebral artery in the postoperative period, which required revision intervention with the removal of the screw and installation of the screw in the lateral mass.

Clinical case

Patient G., 23 years old, sustained an injury when falling from a height. A complicated comminuted unstable fracture of C4, C5, C6 vertebrae was diagnosed. Neurological group D by ASIA, C6: A4F2, C5: A1, C4: A1 (M0N1) according to AO classification. Posterior instrumental fixation was performed at the C4–C7 level using transpedicular screws. Visual impairment of quadrant hemianopsia type was observed in the early postoperative period. CT angiography revealed compression of the vertebral artery by the screws at the C4–C5 level. CT of the brain revealed a zone of ischemia in the basin of the posterior cerebral artery on the left. The revision intervention was performed, including re-installation of the screws at these levels in the lateral masses of the vertebrae. Control CT two weeks after the revision intervention revealed reverse development of the ischemia zone, while the clinical presentation demonstrated complete regression of the neurologic symptoms. In the long-term period, the clinical outcome is preserved; there are no signs of increase in the spinal deformity. The patient returned to his previous work 3 months after the discharge from the hospital (Fig. 6).

Fig. 4
Axial section of cervical vertebra: SC – spinal cord; VA – vertebral artery

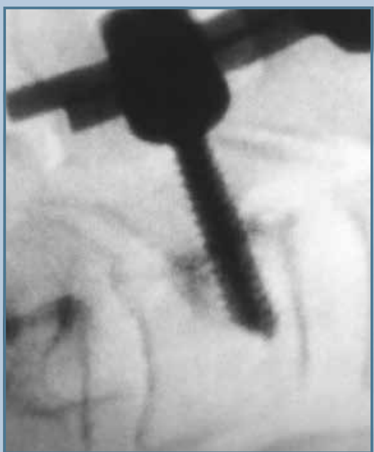

Fig. 5
X-ray in the lateral projection

Conclusion

Transpedicular fixation in the cervical spine allows achieving reliable three-column stabilization, which is extremely important in patients with poor bone quality, with marked fractures of lateral masses of vertebrae, and with gross deformities. The reliability of this fixation method has been demonstrated by the results of the conducted studies, most of which showed no cases of fixation instability.

According to biomechanical studies, this method of fixation outperforms both the fixation to lateral masses and the anterior stabilization using plates.

Complicated spinal injuries requires posterior approach, since it can be performed without additional risks in patients with a tracheostomy, and reliable three-column stabilization can be achieved from a single posterior approach.

Limitations to the application of the technique are mostly technical in nature. However, the installation of transpedicular screws in the cervical region is associated with the risk of damage to such anatomical structures as the spinal cord, spinal nerve roots and vertebral arteries, which can lead to severe perioperative complications and a severe neurologic deficit. From our experience, the risk of damage and compression of the vertebral artery is the most significant one, therefore, measures should be taken to prevent this complication both pre- and intraoperatively.

Therefore, despite the development of intraoperative imaging techniques, transpedicular fixation in the cervical spine remains a technically challenging operation and should be used in carefully selected patients after detailed examination and scrupulous assessment of possible risks.

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Table 2
Frequency of screw displacement by the fixation level, n

Study	C2		C3		C4		C5		C6		C7	
	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2
Kast et al. [8]	13.0	0.0	31.0	8.0	32.0	21.0	7.0	14.0	9.0	0.0	21.0	0.0
Uehara et al. [17]	0.0	6.7	10.2	8.2	18.6	14.0	18.8	3.1	7.4	2.4	2.2	2.2
Nakashima et al. [15]	16.0	4.0	21.0	7.0	24.7	1.1	16.7	5.1	7.6	1.3	4.8	8.1

G1 — screw displacement less than 50 % of the diameter, G2 — screw displacement more than 50 % of the diameter.

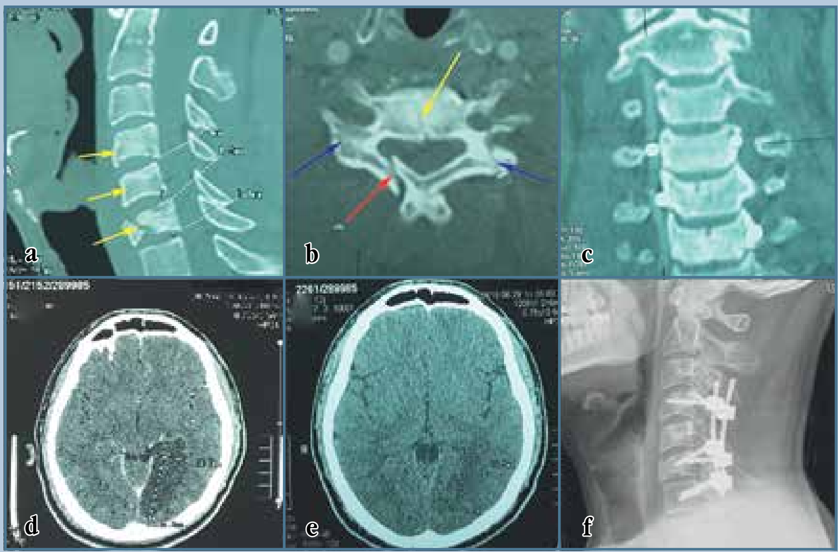

Fig. 6
Data of the patient G., 23 years old, with a complicated comminuted unstable fracture of C4, C5, C6 vertebrae: **a, b** – CT before the surgery, yellow arrows indicate damage to the vertebral bodies, red arrows, damage to the arches, blue arrows, damage to the facets; **c** – angiography after surgery; **d** – CT of the brain, ischemia is visible; **e** – CT of the brain 2 weeks after the second surgery; **f** – X-ray 12 months after discharge from the hospital

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