POSTERIOR INSTRUMENTATION OF THE CERVICAL SPINE IN CHILDREN: LITERATURE REVIEW

O.M. Pavlova, A.V. Burtsev, A.V. Gubin, S.O. Ryabykh
Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russia

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The paper presents a review of the current literature on instrumental fixation of the pediatric cervical spine and technical features of the application of described techniques in children. The posterior instrumental fixation of the cervical spine provides stability and increases fusion rates in children with cervical spine deformities or instability, and allows intraoperative reduction of vertebral displacements. A number of morphological and clinical studies proved the possibility of implantation of modern metal constructs in children. Given the small size of bone structures in children, each case requires careful preoperative planning, proper intraoperative positioning and strict adherence to surgical techniques.
Key Words: screw fixation of the cervical spine, spine surgery in children.

Please cite this paper as: *Pavlova OM, Burtsev AV, Gubin AV, Ryabykh SO. Posterior instrumentation of the cervical spine in children: literature review. Hir. Pozvonoc. 2017;14(3):32–39. In Russian.*
DOI: http://dx.doi.org/10.14531/ss2017.3.32-39.

Despite the wide nosological prevalence, the anatomical, functional, and biomechanical features of cervical spine pathology in children are very poorly represented in the international and domestic literature.

The greatest experience in treating cervical spine diseases in children has been accumulated by large multidisciplinary clinics dealing with a significant percentage of different age patients with spine pathology [5, 11, 15 20, 22, 31, 32, 36, 39, 40, 49, 52, 54], which provides valuable surgical experience despite a small number of surgical cases. Despite multicentre studies and large literature reviews devoted to this problem [8, 9, 25], there remain issues of choosing indications for surgical treatment, surgical techniques, implants, and geometry of implant positioning.

These factors motivated the authors to analyze a spectrum of nosologies and techniques for surgical correction of cervical spine diseases in children. The first part of this work reviews the literature on techniques and technical features of posterior instrumental fixation of the cervical spine in children. The second part will analyze outcomes in a monocentric cohort (47 patients).

The following types of stabilization surgery for the cervical spine in children have been described: non-instrumental fusion; wire or cable fixation; anterior plate fusion; occipitospondylodesis using an occipital plate fixed by screws to the occipital crest or squama; occipital condyle screw fixation [5]; C1 lateral mass screw fixation; anterior odontoid screw fixation [49]; C2 intralaminar, transpedicular, or interarticular screw fixation; C1–C2 transarticular screw fixation; C3–C6 lateral mass and transpedicular screw fixation; lateral mass screw fixation; C7 intralaminar and transpedicular screw fixation; combined screw and hook fixation.

Non-instrumental fusion and wire/cable fixation require prolonged immobilization and are associated with a large number of re-operations [4, 8, 9, 11, 14, 18, 22, 32, 49, 52, 54]. In addition, wire fixation results in more complications than screw fixation [22].

In the last six years, screw fixation of the cervical spine in children has become widespread [2, 6, 8, 10, 13, 16, 20, 23, 26, 29, 33, 35, 40, 42, 43, 47, 51, 53]. Application of screw constructs in the treatment of spine pathology enables creation of a reliable frame for further fusion [4, 13, 22, 43] as well as intraoperative segmental reduction of displacements [13, 33, 41, 43], avoids prolonged use of a halo-apparatus [4, 8, 9, 11, 13, 14, 18, 32, 43], and provides biomechanically reliable fixation because in the 3-column load distribution system, the vertebral bodies and anterior column bear 36 % of the load, and the posterior structures of the cervical spine bear a larger load (64 %).

Although there are studies proving safety of certain screw fixation types in children, each child should undergo high resolution thin-slice CT of the cervical spine before surgery because of potential individual variations in the size of vertebral structures.

C1 lateral mass fixation. In the past, C1 sublaminar wire fixation was traditionally used because it was considered to be the safest and simplest technique due to a relatively large diameter of the spinal canal at this level. However, wire fixation is unstable and allows for rotational movements in the C0–C1 and C1–C2 joints. In addition, from the clinical point of view, craniovertebral junction surgery is often associated with C1 decompressive laminectomy, which excludes the use of a wire. This initiated the search for new solutions and anatomical studies of C1, which revealed that C1 lateral mass screw fixation could be used in most patients.

The C1 lateral masses are quadrangular bone structures situated anteriorly and laterally to the spinal cord and closely associated with the vertebral arteries adjacent to the lateral masses.

There are three types of C1 lateral mass fixation with different screw entry points and trajectories: direct translaminar screw placement [45], insertion through a point under the lamina [12], and an intermediate variant of insertion [30]. The main cause to distinguish these techniques is long-term postoperative pain due to C2 radiculopathy upon a lower position of the screw head in C1, as well as the fact that the C1–C2 joint region is surrounded by the largest veins. The C2 nerve root sectioning in performing the Goel's technique to reduce postoperative pain was reported [35]. A case of C1 arch fracture during translaminar screw placement was reported [45]; for this reason, an intermediate variant of screw placement was proposed [30].

Our experience confirms that the entry point in most cases lies on the inferior edge of the C1 arch (Fig. 1), along the line of its transition into the lateral mass, and only rarely under the arch, which may be easily examined by preoperative CT. The ideal screw trajectory is directed medially at an angle of 10–16° and reaches a depth of 20 mm (Fig. 2) [5].

Aggressive bipolar coagulation of venous plexuses during approaching the entry point significantly simplifies screw placement. If the entry point is chosen below the C1 arch, it is necessary to identify the C2 nerve root before screw placement and avoid compression of the root by the screw head. The entry point never lies lateral to the line of the arch to the transition into the lateral mass. This line can be easily identified by probing the medial edge of the lateral mass with an elevator. Spinal cord injury is actually excluded when the screw is inserted through the correct point because the point is located laterally to the spinal cord and projected approximately to the center of its anteroposterior diameter (Fig. 2, 3).

CT morphometry of the cervical spine revealed that 3.5 to 10.0 mm screws may be safely inserted into the C1 lateral masses in most children over the age of 1.5 years [5, 10]. In this case, limitations in the screw size are mainly associated with the C1 lateral mass height [29].

In clinical series of patients who underwent this fixation procedure, there were the following complications: C1 posterior arch fracture [46], perforation of the spinal canal wall without spinal cord injury [53], and excessive venous plexus bleeding during dissection of the C1 entry point [53]. In other series, there were no complications [8, 13, 14, 52, 53].

C2 screw fixation. The C2 vertebra plays an important role in the cervical spine biomechanics: C2 can be used as a basis for occipitospondylodesis, connected to C1 in atlantoaxial instability, and serve as the upper base for fusion of the subaxial cervical spine. The use of wire and cable fixation at the C2 level is not recommended due to a relatively small diameter of the spinal canal.

There are several variants of C2 screw fixation: transpedicular [24], interarticular, and intralaminar [50] fixation. The fixation type is chosen based on the bone canal diameter and vertebral artery position. Biomechanical studies have demonstrated reliability of C2 intralaminar screw placement at rigid fixation [31]. The entry point for C2 intralaminar screw placement lies on the contralateral side of the spinous process and is displaced either caudally or rostrally on either side to enable a criss-cross screw insertion (Fig. 4). The entry point is marked with a burr and deepened in the rostrocaudal direction with a reamer. Perforation of the ventral arch surface and spinal canal wall is prevented by placing a dissector tip on the arch as a landmark.

CT morphometry of C2 revealed that intralaminar insertion of screws of up to 3.5 mm in diameter may be used in most patients older than two years of age; the main limitations are associated with the arch width, but not with its height, with the screw length being 14–20 mm, on average [10, 29, 51]. In clinical practice, this technique has demonstrated its reliability and safety in children [14, 17, 40, 42, 47].

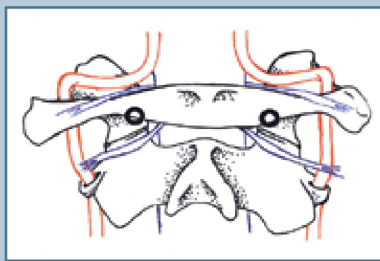

Fig. 1
Screw entry points for C1 lateral mass screw fixation; a relationship with the nerve roots, C1 arch, vertebral arteries, and spinal cord

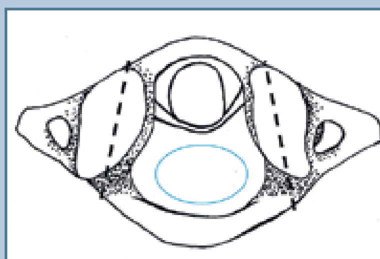

Fig. 2
The screw insertion trajectory for C1 lateral mass screw fixation; a relationship with the spinal cord

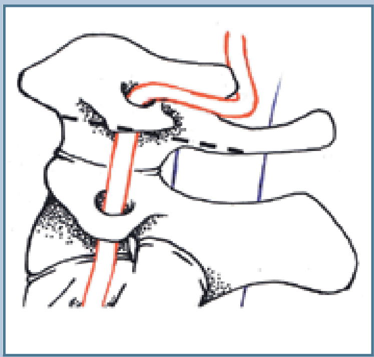

Fig. 3
The screw insertion trajectory for C1 lateral mass screw fixation; a relationship with the spinal cord and vertebral arteries

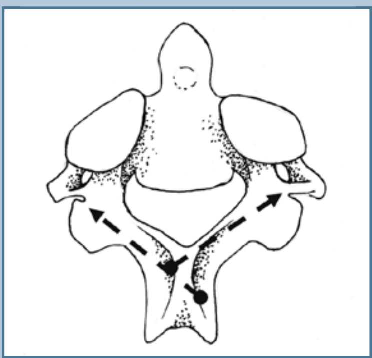

Fig. 4
The trajectory for C2 intralaminar criss-cross screw insertion

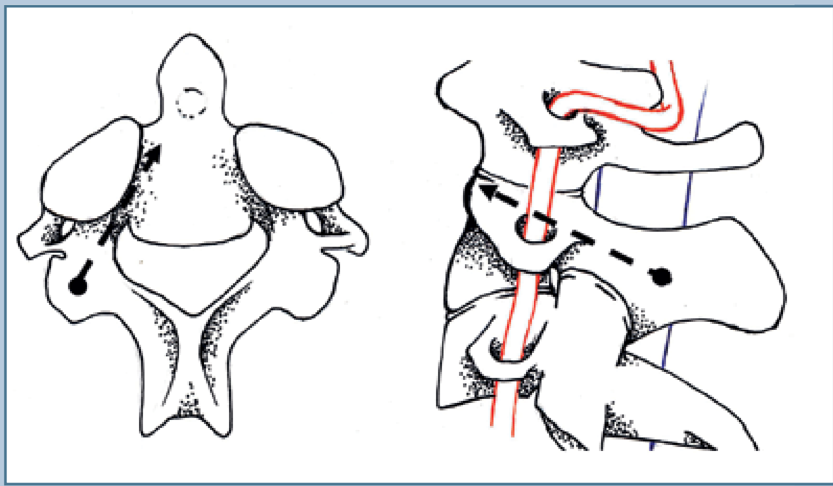

Fig. 5
The entry point and trajectory for C2 transpedicular screw insertion

The C2 lateral masses and pedicles inosculate in the bulk bone and are directly visualized during surgical dissection: the arch runs first lateral to the C2 isthmus and then turns upward and medially. As in the approach to C1, aggressive bipolar coagulation of venous plexuses surrounding the posterior C1–C2 structures and careful dissection of the posterior and medial portions of the isthmus are necessary for direct visualization of the screw trajectory.

There are descriptions of two screw trajectories differing by entry points and associated risks: a transpedicular trajectory and an interarticular trajectory to the superior articular portion of the C2 vertebra (Fig. 5, 6).

The entry point for interarticular screw placement lies caudally above the C2–C3 facet, along the midline of the articular surface (Fig. 7). The screw trajectory direction in the horizontal plane is determined by placing a dissector tip on the medial surface of the isthmus as a landmark. The screw direction in the sagittal plane is determined using fluoroscopic data; the screw length depends on the course of the vertebral artery and height of the C1–C2 joint and is identified in advance by CT.

The entry point for C2 transpedicular screw placement lies on the C2 isthmus, but superior and more lateral than for interarticular screw placement (Fig. 8). Because the screw trajectory in this case is directed more medially towards the C2 body, this carries a risk of perforating the spinal canal wall.

CT morphometry of the C2 vertebra showed that transpedicular 3.5 to 14.0 mm screw placement into C2 may be used in 40–70 % of children older than 2 years of age [10, 29], with the pedicle width and height being approximately the same. In clinical practice, C2 transpedicular and interarticular screw fixation has demonstrated reliability and safety in children [8, 13, 14, 17, 23, 26, 27, 37, 43, 46].

C1–C2 transarticular screw fixation. The C1–C2 transarticular screw fixation [34] is a firm, but technically complex fixation technique (Fig. 9). Classically, it is used for instability at the C1–C2 level but can serve as a base for occipitospondylodesis. The frequent problems associated with an incorrect trajectory in C1–C2 transarticular screw fixation are a very medial direction of the trajectory and an abnormal course of the vertebral artery when a sharply twisted medial trunk adjoins the C2 isthmus before entering the C1 transverse foramen [17].

Application of this fixation procedure in children is still a matter of debate. For example, according to CT morphometry of the C1–C2 vertebrae in 50 children aged 2–6 years, C1–C2 transarticular screw fixation was possible only in four of hundred sides, mainly because of a small size of the C2 isthmus and an abnormal course of the vertebral artery [10]. However, in a clinical series of 31 patients aged 4–16 years, transarticular screw fixation was performed without complications even in younger patients [3]; in a series of 67 patients aged 1.7–16 years who underwent 127 transarticular fixations, there were two trajectory-related complications: injury to the vertebral

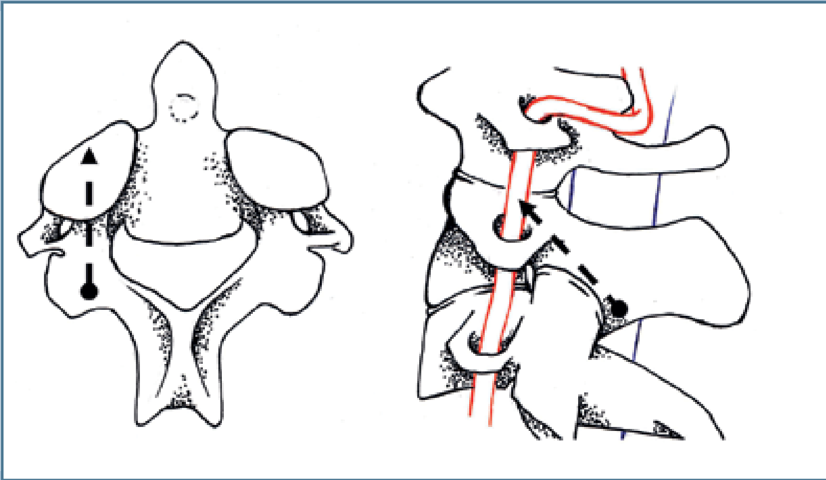

Fig. 6
The entry point and trajectory for C2 interarticular screw insertion

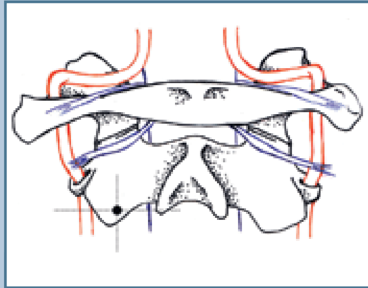

Fig. 7
The entry point for C2 interarticular screw insertion; a relationship with the nerve roots, vertebral arteries, and spinal cord

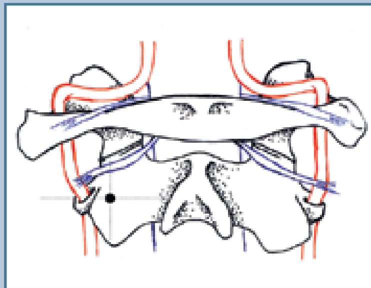

Fig. 8
The entry point for C2 transpedicular screw insertion; a relationship with the nerve roots, vertebral arteries, and spinal cord

arteries [11]. In addition, incorrect selection of the screw length (too long) was reported, which was not visualized by intraoperative fluoroscopy and required re-operation and replacement of the screw for a shorter one [17].

We have not applied this fixation procedure in our clinic, but do not exclude its application in individual pediatric patients.

Subaxial screw fixation. There are the following techniques of subaxial screw fixation of the cervical spine: transpedicular fixation [1], lateral mass fixation [38], and transarticular fixation [7, 44].

In children, transpedicular screw fixation and lateral mass screw fixation have been described. The C3–C7 lateral mass is a quadrangular bone structure that medially borders on the spinal canal and anteriorly adjoins the vertebral artery. There are several techniques of lateral mass screw insertion with variations in the entry point location and trajectory direction in the sagittal and horizontal planes [21, 38].

We have used the following placement procedure [21]: the entry point is located on the medial half of the horizontal line dividing the posterior surface of the lateral mass in half; the trajectory is deflected by 25° in the horizontal plane and by 45° in the sagittal plane (Fig. 10).

In most children older than 4 years, 3.5 to 10.0 mm screws can be safely inserted into the C3–C6 lateral masses [2, 10]. There are reports of complications associated with screw placement: C5 transient radiculopathy [15].

The C3–C6 transpedicular fixation with screws of 3.5 mm and more in diameter is limited by the pedicle height and can be used in less than a third of children [29, 48], but there is successful experience of C3–C6 transpedicular fixation with screws of 3 mm in diameter in children aged 6 years and older [37]. We have not used this fixation procedure at the C3–C6 level in children.

According to CT morphometry, C3–C6 intralaminar screw fixation is limited by the arch width and height and can not be used in most children [29].

The C7 intralaminar and transpedicular screw fixation and the C7 lateral mass screw fixation can be used in most children [29, 48].

Conclusion

Posterior instrumentation of the cervical spine is a technically challenging task that requires careful preoperative planning using thin-slice CT. The C1 lateral mass screw fixation can be used in almost all children. The choice of C2 screw fixation depends on the course of the vertebral arteries and the C2 isthmus size; in this case, transpedicular, intralaminar, and interarticular screw fixations provide a reliable basis for fusion and serve as a lever for reduction of the cervical vertebrae and correction of deformity. Lateral mass screw fixation is the method of choice for stabilization of the subaxial spine in children because transpedicular and translaminar screw fixations in children are unsafe and reasonable only at the C2 and C7 levels.

The study was performed without any financial support.
The authors declare no conflict of interest.

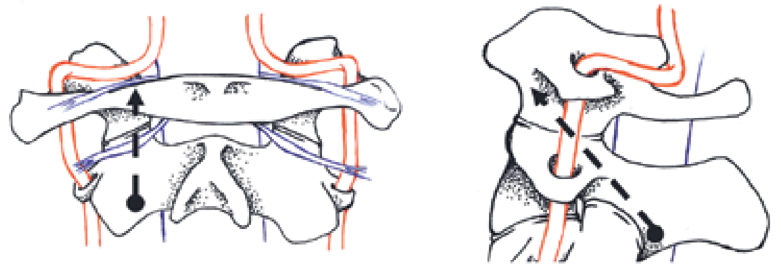

Fig. 9
The entry point and trajectory for C1–C2 transarticular screw insertion; a relationship with the nerve roots, spinal cord, and vertebral arteries

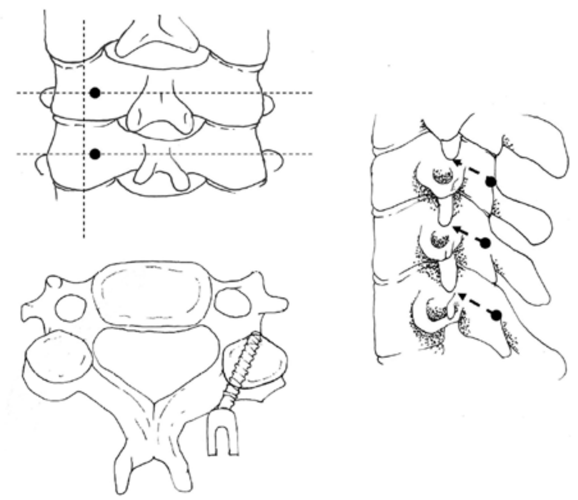

Fig. 10
The entry point and trajectory for C3–C7 screw insertion

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Address correspondence to:
Pavlova Olga Mikhailovna
Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics,
M. Ulyanovoy str., 6, Kurgan, 640014, Russia,
pavlova.neuro@mail.ru

Received 21.11.2016
Review completed 24.11.2016
Passed for printing 15.12.2016

Olga Mikhailovna Pavlova, neurosurgeon, orthopedist, junior researcher, Laboratory of Axial Skeletal Pathology and Neurosurgery, Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russia, pavlova.neuro@mail.ru;
Aleksandr Vladimirovich Burtsev, MD, PhD, orthopedist-vertebrologist, researcher, Laboratory of Axial Skeletal Pathology and Neurosurgery, Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russia, bav31rus@mail.ru;