OPTIONS FOR SURGICAL TREATMENT OF CHRONIC C2 ODONTOID FRACTURES

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The paper presents a review of three clinical cases of treating patients with chronic fractures of the odontoid process of C2 vertebra using various combinations of surgical techniques. In all cases, complete decompression of the spinal cord and stabilization of the upper cervical segment of the spine were achieved. A decrease in the range of motion in the cervical spine was observed, which did not affect patient satisfaction. A gradual regression of the neurological status and increase in muscle strength were recorded. Comparative analysis of the neurological status was carried out before and after surgical treatment. When assessing the general condition of patients using the index of disability due to pain in the neck (NDI), an improvement in the quality of life was noted. These data show the opportunities and peculiarities of methods for treating patients with chronic C2 odontoid fractures.

Type of publication: description of clinical cases. Evidence level: IV.

Key Words: chronic fracture of the C2 odontoid process, transoral approach, custom-made plate for C2 vertebra, craniovertebral surgery.

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The choice of a treatment option for chronic odontoid fracture with displacement of fragments and spinal cord compression is a challenge that requires the operating team to accurately understand the craniovertebral region anatomy and have sufficient tactical and surgical experience, technical equipment, and appropriate anesthesia and resuscitation support. The issue has been rarely addressed in the literature [1–11]. The article describes the approach for surgical treatment of the patients using a transoral stabilization technique proposed by the authors as well as the treatment outcomes.

We analyzed treatment outcomes in three patients with chronic odontoid fractures. The treatment option was chosen individually for each patient, depending on the features and duration of injury and the instrumental examination findings. Different combinations of surgical techniques were used.

The patients underwent clinical and radiological (plain and functional X-ray, CT, MRI) examinations and assessment of quality of life using the neck disability index (NDI).

Case 1. A 53-year-old male patient M. presented to the Priorov National Medical Research Center of Traumatology and Orthopedics with complaints of occipital and back neck pain and numbness. More than a year ago, the patient fell from his own height backwards, after which a neck pain developed. He did not seek medical care. A year later, the patient noted neck pain aggravation, numbness in the left upper and lower extremities, and weakness in the left hand. Later, numbness and weakness in the right upper and lower extremities developed.

Local findings at admission: the cervical spine was fixed with a Schantz collar; after removing the collar, the head was slightly tilted to the left. Lateral turns and forward and backward bending of the head were limited; palpation revealed tenderness of the paravertebral points in the C1–C2 projection.

An examination by a neurologist revealed slight paresis (up to 4 points) in the finger flexors and extensors; no lower extremity paresis was detected. Gait was stiff, with a spastic component in the right lower extremity. There were fasciculations in the suprascapular muscles; the trapezius muscles were hypotrophied, their function was preserved. The patient had high tendon reflexes with an extended area. There was a slight Rossolimo reflex in the hands, foot clonus, and bilateral Babinski signs. Sensation impairments: C2, C3, and C4 hypesthesia on both sides. There were paresthesias in the hands and toes and increased thermal sensation in the extremities. There were no deep sensitivity disorders. The findings included cervical compression-ischemic myelopathy at the C2–C3 level: tetrapyramidal syndrome, mild upper distal paraparesis, and sensory disorders (Frankel grade C; Nurick grade 3; JOA score of 12).

Radiographs of the cervical spine in two projections revealed an ununited odontoid fracture with anterior displacement, chronic dislocation of the C1 vertebra, and posttraumatic kyphotic deformity of the craniovertebral junction.

Contrast-enhanced CT findings: an ununited odontoid fracture; anterior displacement of the C1 arch and odontoid process; angular kyphosis. The adjacent surfaces of bone fragments were indurated; their contours were smoothed; the diastasis between them was up to 6 mm; there were no signs of consolidation. The spinal canal at the C2 level was deformed and markedly narrowed; the reserve subdural space was markedly reduced. There was an hourglass deformity of the contrast-enhanced dural sac (Fig. 1).

MRI findings: kyphotic deformity of the cervical spine with the apex at the C2 level. The C2 vertebra was deformed in the odontoid process region; the odontoid fragment and C1 vertebra were anteriorly dislocated with deformation of ligamentous apparatus and a 180° turn around the coronal axis. The spinal canal at the C1–C2 level was markedly narrowed (up to 3 mm in the anteroposterior direction) and deformed by dislocation of the C1 vertebra and odontoid process fragment. At the C1–C2 level, there was myelopathy and a partial CSF block with spinal cord deformity.

Given the duration of injury and the severity of deformity, the patient underwent multi-stage surgical treatment.

The first stage included application of a halo-apparatus and gradual halo-traction. Slight deformity correction was achieved.

After 10 days, the second stage was performed which included C1 laminectomy for decompression and occipital fusion with instrumentation (Fig. 2).

A control CT examination revealed that the C0–C3 segment was stabilized with instrumentation, and its position was satisfactory. Anterior atlas subluxation retained due to atlantoaxial joint subluxation. There was a post-resection defect of the posterior atlas arch. The central atlantoaxial joint space was little if any visualized.

After 3 weeks, the patient underwent the third stage that included tracheostomy, transoral resection of the anterior C1 hemiarch, resection of the odontoid process and C2 vertebral body, and anterior decompression of the spinal cord (Fig. 3).

Neurological status on the first postoperative day: there was improvement in the form of an increase in muscle strength to 4–5 points in the upper extremities and to 4 points in the lower extremities, there were no sensation disorders.

An examination by a neurologist 2 weeks after surgery revealed regression of tetraparesis, restoration of muscle strength, and reduced spasticity (Frankel grade D; Nurick grade 1; JOA score of 16).

In the early postoperative period, there was wound disruption on the posterior pharyngeal wall. The patient consulted an otorhinolaryngologist; the wounds were treated by antiseptic solutions. The patient's condition improved on treatment; wounds healed by secondary tension.

Further, the patient was followed-up on an outpatient basis. Clinical and radiological examination at 3, 6, and 12 months demonstrated that the instrumentation system was stable; there was no worsening of the neurological status.

Case 2. A 55 year-old male patient G. presented with complaints of cervico-occipital pain and weakness in the upper and lower extremities. According to the medical history, the patient was injured in a road accident. Clinical and radiological examinations revealed a C2 vertebra fracture as well as simple T3 and T6 vertebral fractures. The patient was treated conservatively at the place of residence (immobilization with a Philadelphia collar). A year after the accident, progressive weakness in the upper and lower extremities developed. The patient self-presented to the Burdenko Neurosurgical Institute.

Local findings at admission: the patient moved independently; gait was unsteady; the cervical spine was fixed with a Philadelphia collar; muscle strength in the upper and lower extremities was reduced to 2–3 points; there were no vascular disorders.

Neurological status: the patient had upper right-sided monoparesis (3 to 4 points) and progressive lower paraparesis (2 to 3 points) (Frankel grade C; Nurick grade 3; JOA score of 9).

X-ray findings: the patient had a malunited fracture, with the odontoid process being displaced posteriorly. MRI revealed spinal canal stenosis at the C2 level and cervical myelopathy signs (Fig. 4a). According to CT myelography, there was a malunited odontoid fracture (Anderson and D'Alonzo type III [12]) with spinal canal stenosis. The odontoid process fragment was displaced posteriorly 6.9 mm (Fig. 4b).

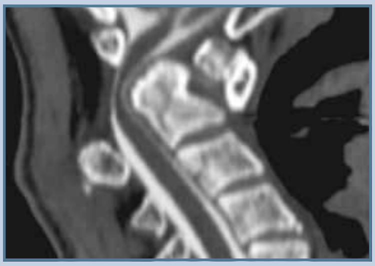

Fig. 1
CT scan with myelography of a 53-year-old male patient M. with a chronic odontoid fracture (Anderson and D'Alonzo type II), chronic C1 dislocation, and severe posttraumatic kyphotic deformity of the craniovertebral junction: the vertebral canal at the C2 level is deformed and markedly narrowed; there is an hourglass narrowing of the contrast-enhanced dural sac

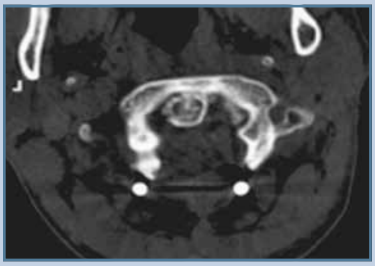

Fig. 2
CT cross-section at the C1 laminectomy level in the 53-year-old male patient M. after the second surgical stage

One-step surgical treatment was decided to be performed. For planning the surgical intervention, a stereolithographic model of the cervical spine was fabricated, and a C1–C2 vertebral resection area and spinal cord decompression limits were modeled. A custom-made plate was prepared for the C1–C2 fixation (Fig. 5). The patient underwent tracheostomy, transoral removal of the anterior C1 arch and displaced odontoid process, spinal cord decompression at the C1–C2 level, and C1–C2 fixation with the custom-made plate (Fig. 6). This technique was protected by a patent [13].

CT examination after surgery: spinal canal was decompressed at the level of stenosis; the metal plate position was correct. The postoperative period was without complications; cervico-occipital pain was completely relieved; neurological symptoms regressed (Frankel grade E; Nurick grade 3; JOA score of 12). Further, the patient was followed-up on an outpatient basis. The patient was followed-up for 6 years: according to the clinical and radiological findings, the metal system was stable; there was no worsening in the neurological status.

Case 3. A 25-year-old female patient Zh. presented with complaints of a head tilt, recurrent pain and lack of motion in the cervical spine, restricted walking, and cramps in the lower extremities.

According to the medical history, the patient had polytrauma due to a road accident. She was treated in the neurosurgical department at the place of residence with a diagnosis of concomitant injury (moderate brain contusion, traumatic subarachnoid hemorrhage); a left occipital condyle fracture with spinal cord compression; spinal cord hemorrhage; a closed fracture of the left clavicle; a pubic and ischial fracture without displacement. There were clinical signs of tetraplegia. The patient underwent surgical treatment that included tracheostomy and transoral removal of a left occipital condyle fragment. Neurological disorders regressed to the paresis level, more in the left lower extremity. At the next stage, occipital fusion with a shape memory plate was performed (Fig. 7a). The patient received courses of rehabilitation treatment. She was discharged in satisfactory condition for outpatient follow-up care. The patient applied to the Center of Traumatology and Orthopedics 4 years after injury.

Local findings at admission: the patient moved independently; gait was spastic-paretic, supported by crutches or walkers; the head was tilted to the left with a turn to the right; there was an old postoperative scar extending from the occipital bone to the C5 vertebra, without signs of inflammation; palpation along the spinous processes and paravertebral points was non-tender, muscles were tense, more on the left; cervical spine motion was restricted; motion in the upper extremities was constrained; left shoulder joint abduction was restricted to 90°; there were no vascular disorders.

In the neurological status, there was spastic tetraparesis, less pronounced in the upper extremities; strength in the arm and leg muscles was 4 and 2 points, respectively; superficial and deep sensitivity was preserved; she satisfactorily performed coordination tests. There was vertebrogenic cervicalgia (Frankel grade C; Nurick grade 4; JOA score of 8).

Radiographic findings in the cervical spine in two projections: the condition after surgical treatment; occipital fusion with a shape memory plate. There was a head tilt. The patient underwent CT of the cervical spine, which revealed rota-

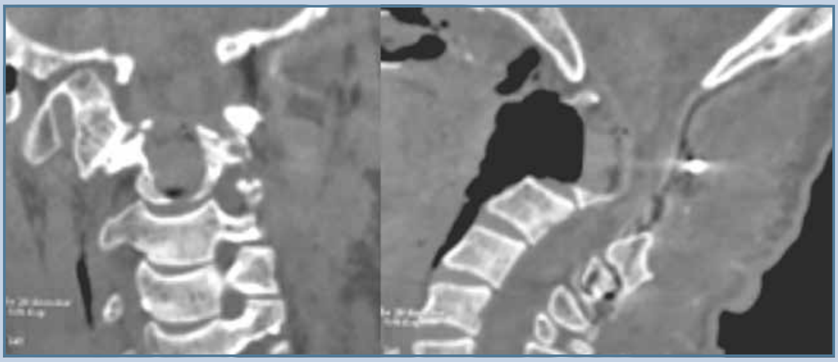

Fig. 3
CT scans of the 53-year-old male patient M. after the third stage of surgical treatment: anterior decompression at the C1–C2 level

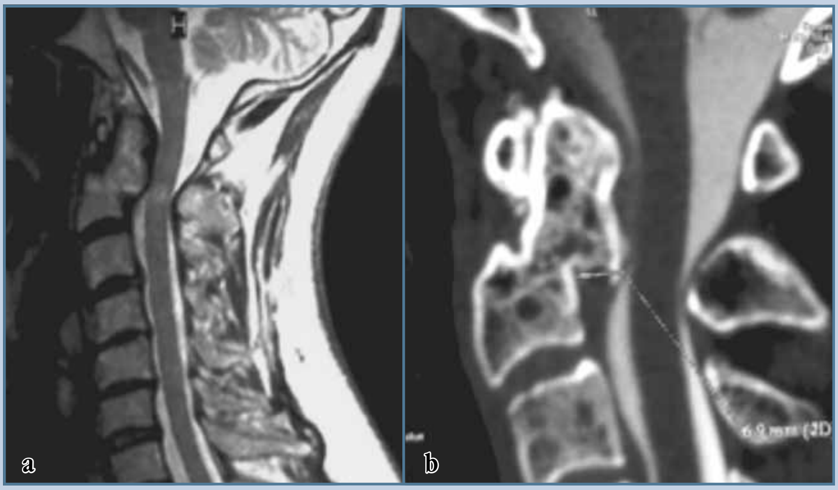

Fig. 4
MRI scan **(a)** of a 55-year-old patient G.: spinal canal stenosis at the C2 level, signs of cervical myelopathy; CT scan **(b)**: a malunited C2 fracture (Anderson and D'Alonzo type III) with C2 deformity and spinal canal stenosis at this level; an odontoid process fragment is displaced 6.9 mm posteriorly

tional dislocation of the atlas to the left with atlantoaxial joint ankylosis in the vicious position; ankylosis of the atlanto-occipital joints;condition after surgical treatment; moderate spinal canal stenosis at the odontoid process level (Fig. 7b).

Clinical diagnosis: sequelae of severe polytrauma; a malunited C1–C2 fracture (atlantoaxial joint ankylosis); posttraumatic osseous torticollis; spinal canal stenosis at the odontoid process level; cervical myelopathy; tetraparesis.

Given the clinical, radiological, and neurological findings, multi-stage surgical treatment was decided to be performed.

The first stage included application of a halo-apparatus, removal of metal instrumentation, posterior release of the craniovertebral region, placement of screws into the C3, C4, and C5 lateral masses, and then gradual sequential correction of the head position in the halo-apparatus.

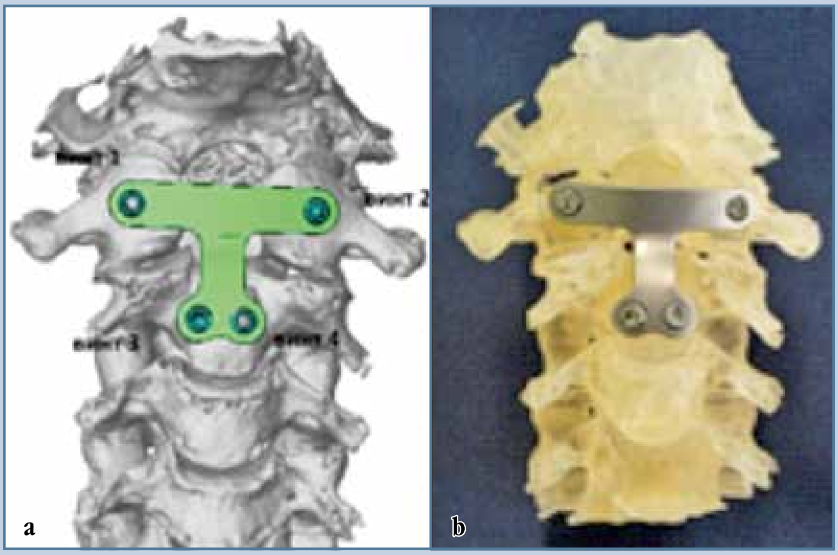

Fig. 5
Sketch of a custom-made plate **(a)** for the 55-year-old patient G., which was calculated based on CT data, and a stereolithographic model of the spine with the custom-made plate **(b)**

Fig. 6
Radiographs of the craniovertebral region in two projections of the 55-year-old patient G. after surgical treatment

The second stage, 2 weeks later, included tracheostomy, transoral resection of the odontoid process, release of the craniovertebral region, decompression of the neural structures at the C1–C2 level, and correction of cervical spine deformity in the halo-apparatus under neuromonitoring control (Fig. 8).

The third stage, after another 2 weeks, involved occipital fusion with instrumentation, posterior spinal fusion with a fibula bone graft, and removal of the halo-apparatus (Fig. 9).

Neurological status after surgery: there was improvement in the form of an increase in muscle strength in the upper and lower extremities up to 5 and 4 points, respectively. The head position improved (Frankel grade D; Nurickg rade 2; JOA score of 13). The postoperative period was without complications; the wound healed by first intention (Fig. 10). Tracheostomy was removed a day after surgery. The cervical spine was fixed in a headholder. The patient was activated; she was able to move independently. A follow-up examination at 3 months revealed a satisfactory position of the instrumentation system; there was no correction loss. After a 14-month follow-up, the instrumentation system was stable; a bone block was formed; the neurological status was unchanged.

Discussion

In the presented cases, we achieved complete spinal cord decompression and stabilization of the upper cervical spine segment. There was a decrease in the range of cervical spine motion, which did not affect patients' satisfaction, gradual regression in the neurological status, and an increase in muscle strength. However, one patient developed a complication in the form of wound edge failure on the posterior pharyngeal wall due to the anterior approach features. The area of surgical intervention was sanitized; the patient was fed through a nasogastric tube until the wound was healed. None of the complications affected the treatment outcome. Patients were fully satisfied with the achieved treatment outcome and reported an improvement in the quality of life. Comparative characterization of the neurological status before and after treatment is presented in Table 1.

According to the neck disability index (NDI), there was an improvement in the patients' quality of life (Table 2).

The odontoid process together with the transverse ligament of the atlas, alar ligaments, and anterior C1 arch is the most important component providing atlantoaxial complex stability [2, 6, 14].

Type I and III odontoid fractures are mainly treated conservatively using external immobilization of the cervical spine. Type II fractures often require surgical treatment due to the anatomical and physiological features of a high nonunion rate. Surgeons choose different approaches, depending on the fracture type. In the case of fresh non-comminuted fractures with a horizontal fracture plane, in the absence of fragment displacement, and without neurological symptoms, transcutaneous osteosynthesis of the odontoid process using a cannulated screw is performed. In other cases, applicability of this technique may be limited, and posterior spinal fusion is used, which includes C1–C2 transarticular fixation with Magerl screws, Harms screw fixation, translaminar fixation to the C1–C2 arches using hooks or wire, and a combination of these techniques. In cases of marked fragment displacement and spinal canal deformity with spinal cord compression, treatment includes multi-stage treatment options with reposition in the halo-apparatus and subsequent decompression/stabilization interventions, such as monosegmental fixation (by wire, hooks, screws using Magerl or Harms techniques, etc.) or occipital fusion.

Fig. 7
Radiographic image **(a)** of the craniovertebral region of a 25-year-old female patient Zh. after surgical treatment and a CT scan **(b)** demonstrating a malunited C1–C2 fracture, spinal canal stenosis, and cervical myelopathy

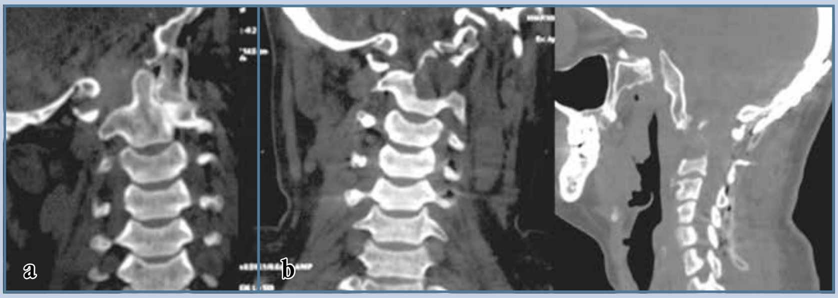

Fig. 8
CT scans of the craniovertebral region in the 25-year-old female patient Zh. before **(a)** and after **(b)** surgical treatment

Often, odontoid fractures are not properly diagnosed, especially in the absence of a neurological deficit, and patients do not receive adequate treatment. In some cases, repeated, even minimal, trauma can cause or increase atlas dislocation with the development of severe neurological complications, up to disability or death [2, 5]. The feature of chronic odontoid fractures is nonunion of the fracture with formation of a bone or fibrous block in the damaged segment in the vicious position.

Historically, surgical treatment of irreducible odontoid fractures with spinal canal stenosis most often involved only a posterior approach. However, this treatment was associated with a high rate of fracture reduction failure and, as a result, with the lack of regression of neurological complications, and even with their aggravation, up to a fatal outcome. Resection of only posterior elements with atlantoaxial fixation or occipital fusion does not always provide satisfactory spinal cord decompression and reduction in the atlantoaxial segment [15].

If fragment reposition and elimination of spinal canal stenosis are impossible during preoperative or intraoperative halotherapy, anterior transoral decompression is required. The transoral approach provides visualization of the C1–C2 segment, which enables resection of the atlantoaxial joint capsule, scars, and osteophytes as well as full spinal cord decompression after removal of the anterior atlas arch and odontoid process [16]. For example, in Case 1, the transoral decompression technique was used after an attempt of fracture reduction in the halo-apparatus and posterior craniocervical fixation.

The priority of anterior and posterior stages is a debatable issue and rather depends on the fracture type. Researchers [17, 18] recommend using the tran-

Fig. 9
Radiograph of the 25-year-old female patient Zh. : occipital fusion with metal instrumentation; posterior spinal fusion with a fibular bone autograft

Fig. 10
Appearance of the 25-year-old female patient Zh. before and after surgical treatment

Table 1
Comparative characterization of the patients'neurological status before and after surgical treatment

Patient	Nurick grade		Frankel grade		JOA score	
	before surgery	after surgery	before surgery	after surgery	before surgery	after surgery
Case 1	3	1	C	D	12	16
Case 2	3	3	C	E	9	12
Case 3	4	2	C	D	8	13

Table 2
Disability due to neck pain assessed using the NDI, score (%)

Patient	before surgery	after surgery
Case 1	17 (37.0)	12 (30.0)
Case 2	15 (33.3)	11 (26.0)
Case 3	24 (51.0)	18 (41.0)

soral decompression stage first to provide the best possible reduction, followed by the posterior reduction/stabilization stage. We have chosen the approach of primary posterior decompression and fixation followed by the anterior stage because we believe that this option is safer for manipulations during preparation to the anterior decompression stage; in particular, any repositioning maneuvers were inappropriate in the patient from Case 1.

Another treatment option for irreducible odontoid fracture is the use of single-stage transoral decompression/stabilization surgery using plates. Schmelzle et al. [19] first described surgery with plate placement. However, these plates lacked screw locking, which, as the authors indicated, later caused the need for the 2nd posterior stage. Ai et al. [17] presented a TARP technique that enables one-stage reduction of a fragment (odontoid process) after its mobilization and fixation with an anterior plate. Spinal stenosis is eliminated without removal of the odontoid process and is achieved by reduction of fragments; therefore, indirect spinal cord decompression is provided. This, on the one hand, minimizes the risk of dura mater injury and bleeding from the epidural veins, but, on the other hand, does not always provide full decompression of the spinal cord. In the described clinical cases, complete removal of the odontoid process enabled direct full decompression of the spinal cord and was not accompanied by intraoperative complications.

Given the development of additive technologies (3D-modeling and manufacturing of custom-made instrumentation systems), we started to use anterior transoral stabilization of the C1–C2 segment. This treatment option was successfully used in Case 2. Consideration of the anatomical features and type of the fracture in a particular patient during development of a custom-made plate [13] is important for long-term fixation stability. This approach enables implementation of both direct decompression of the neural structures and stabilization within one surgical session, which is undoubtedly an advantage. This technique has been approved in the foreign literature [20].

In Case 3, the patient complained mainly of an incorrect head position due to severe deformity of the craniovertebral region and a bone block formed between the lateral C1–C2 masses in the vicious position. Only the use of neuromonitoring and a halo-apparatus after resection of the anterior and posterior bone structures enabled correct positioning of the head with subsequent fixation.

Conclusion

The presented cases of nonunited/malunited odontoid fractures reflect the complexity and diversity of this pathology.

The use of a full range of modern diagnostic techniques and additive technologies enables comprehensive assessment of posttraumatic deformity of the craniovertebral region, planning of surgical stages, and manufacturing of custom-made instrumentation systems for fixation.

The choice of a treatment option is individual in each case and depends on both the features of posttraumatic changes in the fracture area and the neurological status.

The use of halo-traction and posterior and anterior decompression/stabilization surgery in the treatment of this category of patients provides good clinical outcomes.

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The authors declare no conflict of interest.

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