C1-RING OSTEOSYNTHESIS AS A FUNCTIONALLY PRESERVING OPERATION FOR UNSTABLE ATLAS FRACTURES

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Objective. To analyze the dynamics of pain syndrome, quality of life and functional status of patients with unstable atlas fractures after C1-ring osteosynthesis.

Material and Methods. Study design: observational retrospective case series study (n = 15). The intensity of pain syndrome was assessed using the VAS scale before surgery, 3 days, and 3 and 6 months after surgery. The quality of life was assessed using the Neck Disability Index (NDI) before surgery, and 3 and 6 months after surgery. Functional status, as well as cervical spine range of motion (head turn left/right, flexion/extension) was assessed 3 and 6 months after surgery. The integrity of the atlas bone ring and the degree of fusion after fixation were assessed using axial CT scans; and the lateral mass separation was assessed using frontal CT scans. The criterion for transverse ligament injury was a separation of lateral masses of more than 8.1 mm.

Results. All patients had C1 fractures type 3B according to Gehweiler, out of them 7 patients (46.7 %) had traumatic injury to the atlas transverse ligament according to Dickman type 1, and 8 patients (53.3 according to Dickman type 2. The average age of patients was 40 years (12; 71), the male/female ratio was 2/1. In 7 patients (46.7 %), the cause of injury was diving, in 6 (40.0 %) it was a traffic accident, and in 2 (13.3 %) – a fall from a standing height. Observation of patients revealed a positive dynamics in the form of statistically significant regression of pain according to VAS before and 6 months after surgery from 6.8 (6.0; 8.0) to 1.0 (1.0; 0.0) points (Z = -3.434; p = 0.001). A positive trend was also noted in the form of a decrease in NDI scores and an improvement in the quality of life after 3 (Z = -3.411; p = 0.001) and 6 months after surgery (Z = -3.410; p = 0.001). The range of motion (turn left/right, flexion/extension) increased statistically significantly by the 6th month after C1-ring osteosynthesis, and its indicators were close to physiological ones. Postoperative CT scans showed positive dynamics in the form of statistically significant regression of the lateral mass separation from 10.4 mm (8.9; 11.4) to 2.2 mm (1.8; 2.6); Z = -3.408; p = 0.001. Complete fusion of the atlas fracture was observed after 12.5 months (8.5; 16.5).

Conclusion. Isolated posterior osteosynthesis of the atlas ring for Gehweiler type 3B injury using a repositioning compression maneuver under distraction conditions is physiologically justified. It is a reliable method of stabilization, ensures the restoration of congruence and the entire range of motion in the atlanto-occipital and atlantoaxial joints and stability of the occipital-atlantoaxial complex. This operation contributes to a considerable and long-term reduction in the intensity of pain syndrome and a significant improvement in the quality of life.

Key Words: C1 fracture, ring osteosynthesis, functionality, instability.

Please cite this paper as: *Basankin IV, Giulzatyan AA, Magomedov IM, Takhmazyan KK, Tomina MI, Malakhov SB, Afaunov AA, Porkhanov VA. C1-ring osteosynthesis as a functionally preserving operation for unstable atlas fractures. Russian Journal of Spine Surgery (Khirurgiya Pozvonochnika). 2024;21(3):6–13. In Russian.*
DOI: http://dx.doi.org/10.14531/ss2024.3.6-13.

The C1 vertebra is a significant contributor to the kinematics of the cervical spine. According to the study by Lindenmann et al. [1], the C1–C2 segment represents 63–73 % of axial rotation, 11–20 % of flexion/extension, and 12–17 % of lateral flexion of the cervical spine.

The incidence of C1 vertebra fractures accounts for 2–13 % of all cervical spine fractures and 1–2 % of all spinal injuries [2]. The mechanism of injury that causes damage to the atlas bone ring and the ligaments of the C1–C2 segment is axial load transmitted through the occipital condyles, resulting in traumatic expansion of the bone ring [3]. The stability of C1 vertebra fracture is related to the integrity of the transverse ligament of the atlas. If the ligament is structurally damaged, the fracture is unstable [4]. Treatment techniques for patients with unstable atlas fractures are diverse and can be conservative-invasive (use of a head supporter or Halo brace) or surgical (C1–C2 posterior fixation, C0–C2/C3 posterior fixation, C1 posterior osteosynthesis) [5].

Nowadays, there is a trend in the treatment of spinal cord injuries to preserve or restore the functionality of the spinal motion segment that considerably improves the quality of life of patients [6]. Therefore, functionally oriented surgeries for traumatic injuries of the axial part of the cervical spine are of great relevance [7, 8]. In case of traumatic injury to the C1 vertebra, C1-ring osteosynthesis is a functional preserving surgery [9].

The objective is to analyze the dynamics of pain syndrome, quality of life, and functional status of patients with unstable atlas fractures after C1-ring osteosynthesis.

Material and Methods

Study design: observational retrospective case series study (n = 15). The object of the study is patients with isolated unstable simple C1 fractures. The subject of the study is posterior C1-ring osteosynthesis, its efficiency, and its effect on the functionality of the cervical spine.

On admission to the neurosurgical inpatient department, the neurological status of the patients was evaluated using the Frankel scale; the intensity of the pain syndrome was evaluated using VAS before surgery, in 3 days, and after 3 and 6 months after surgery; the quality of life was evaluated using the Neck Disability Index (NDI) before surgery, and 3 and 6 months after surgery. Functional status as well as the range of motion of the cervical spine (turn left/right, flexion/extension) were evaluated in 3 and 6 months after surgery using the Protractor Online application (https://play.google.com/store/apps/details?id=com.exatools.protractor&pcampaignid=web_share).

In order to systematize C1 vertebra fractures, we used the Gehweiler classification according to the WFNS guidelines of 2020 [10]. Patients with C1 vertebra fractures of type 3B according to Gehweiler and transverse ligament injury of Dickman 1 type (ligament tear at the center) and Dickman 2 type (bone fragment avulsion from the C1 lateral mass along with the intact ligament) were included in the study. The integrity of the atlas bone ring and the degree of fusion after fixation were assessed using axial CT scans, and the lateral mass displacement (LMD) was assessed using frontal CT scans. The criterion for transverse ligament injury was a lateral mass divergence of more than 8.1 mm [11].

Technical aspects of the surgery

After an approach was performed, the screw was inserted in the C1 lateral mass under the atlas arch using standard trajectories. The heads of polyaxial screws were turned into a horizontal plane; then, a beam of suitable size and shape was modeled and inserted into the open tulip heads of the pedicle screws. After that, longitudinal head traction and simultaneous transverse compression of the atlas by the heads of the implanted screws were performed. Thereafter, the nuts were finally fixed, and the wound was sutured in layers.

The malposition of screws placed in C1 was evaluated by a CT scan performed in the postoperative period using the criteria of Hu et al. [12]: type I – the screw is within the bone tissue (perfect choice); type II – less than 50 % of the screw diameter damages the cortical layer (safe choice); type III – violation of the integrity of the transverse foramen or spinal canal independently of neurovascular complications (unacceptable choice).

Statistical analysis

The obtained clinical outcomes were processed using the IBM SPSS 16.0 software system. Numerical data are given as median (Me) and interquartile range [25; 75] or arithmetic mean ± standard deviation (M ± STD).

Since the number of patients in the general population was less than 50 and the distribution of numerical values in part of the sample differed considerably from the normal law of distribution (the hypothesis of normality of distribution was verified using the Shapiro-Wilk test), nonparametric methods of statistical analysis, Wilcoxon signed-rank test, were used, and the value of statistical significance $p < 0.05$ was considered as the lower limit of validity.

Results

The surgical outcomes of 15 patients with isolated C1 fracture who underwent surgery in the neurosurgical unit between 2018 and 2023 were analyzed. All patients had C1 fractures type 3B according to Gehweiler; 7 of them (46.7 %) had traumatic injuries to the transverse ligament of the atlas of Dickman 1 type, and 8 patients (53.3 %) had Dickman 2 type.

The mean age of patients was 40 years (12; 71); the male/female ratio was 2:1. In 7 patients (46.7 %), the cause of injury was diving, in 6 (40.0 %) it was a traffic accident, and in 2 (13.3 %) – a fall from a standing height. The median duration of surgery was 90 (77.5; 102.5) min, intraoperative blood loss was 200 (100; 250) ml, the length of hospital stay was 5 (5; 7) bed days, and the time between injury and surgery was 3 (2.0; 4.5) days.

There were no neurological disorders diagnosed in the pre- and postoperative periods. Observation of patients revealed a positive trend in the form of statistically significant regression of pain according to VAS before and 6 months after surgery from 6.8 (6.0; 8.0) to 1.0 (1.0; 0.0) points ($Z = -3.434$; $p = 0.001$). It should be emphasized that the pain in the period from 3 to 6 months was statistically insignificantly regressed ($Z = -1.134$; $p = 0.256$), and therefore the course of pain syndrome reduction was not followed in the future (Fig. 1). A positive trend was also noted in the form of a decrease in NDI scores and an improvement in the quality of life after 3 months ($Z = -3.411$; $p = 0.001$) and 6 months ($Z = -3.410$; $p = 0.001$) after surgery.

The range of motion in the cervical spine after 3 and 6 months after surgery is presented in the Table. It is worth pointing out that the range of motion (turn left/right, flexion/extension) increased statistically significantly by the 6th month after C1-ring osteosynthesis, and its indicators were close to physiological ones.

Postoperative CT scans showed a positive trend in the form of statistically significant regression of the atlas lateral mass divergence from 10.4 mm (8.9; 11.4) to 2.2 mm (1.8; 2.6); Wilcoxon T-test before and after surgery: $Z = -3.408$; $p = 0.001$. Screws were placed within the bone tissue in 14 (93.3 %) cases — type I according to Hu et al; in 1 (6.7 %) case — type II. Bicortical screw placement into the C1 lateral mass was observed in 8 (53.3 %) patients and monocortical – in 7 (46.7 %) patients. Complete fusion of the atlas fracture was observed after 12.5 months (8.5; 16.5; Fig. 2). Patients were activated in a Schanz rigid cervical collar one day after surgery. The postoperative period was smooth and unremarkable in all cases. Nonsteroidal anti-inflammatory drugs were administered in the postoperative period if relevant symptoms were available.

Discussion

The atlas is a sort of bone meniscus between the occipital condyles and the C2 lateral masses, which provides for the transition of movements from flexion-extension to rotation [3]. C1 vertebra fractures are most commonly observed in traffic accidents, diving, and fall from height. The axial vector of force exerted on the skull is transmitted downward through the occipital condyles to the atlas. With their unique wedge-shaped structure, the lateral masses convert the axial force vector into a horizontal one. This results in traumatic separation of the lateral masses from the relatively fragile area at the junction of the anterior and posterior arches and lateral displacement [13]. There are several classification systems for atlas fractures, among which the Jefferson, Dickman, Landell, Gehweiler, and AO Spine classification systems are the most widely used [14–18]. According to the 2020 WFNS guidelines, the Gehweiler classification that combines the Jefferson and Dickman classifications, should be used [10].

The integrity of the transverse ligament of the atlas is crucial in evaluating the stability of the atlas fracture. According to the Dickman classification, 2 types of ligament injuries are noted: Dickman 1 (ligament tear in the center) and Dickman 2 (bone fragment avulsion from the C1 lateral mass together with the ligament) [15]. Neurological deficit in patients with atlas fracture is rare because the lateral mass divergence increases the space available for the dural sac and spinal cord that prevents compression [19]. Therefore, stabilization of the fracture is the most crucial aspect of the treatment of traumatic atlas injuries.

Currently, there is consensus on the treatment of stable atlas fractures, yet the optimal treatment of unstable C1 fractures remains controversial. Historically, conservative treatment has been the procedure of choice for atlas fractures. In the study by Dvorak et al. [20], 22 patients with explosive unstable C1 fractures were treated in a conservative mode using various external orthoses (Minerva, Gilford, Philadelphia). According to the study, the quality of life and functional status of the patients did not improve within five years, and the majority of patients suffered from pain in the cervical spine. The authors do not recommend conservative treatment with rigid cervical collars as a treatment option for unstable atlas fractures [20]. Moreover, cervical spine immobilization for several months can result in pronounced discomfort and other complications, especially in elderly patients. At the same time, mechanical instability and incongruence of the atlanto-occipital and atlantoaxial joints can result in arthrosis and persistent pain in the cervical spine [21]. Kim and Shin [22] assessed the results of treatment of patients with unstable atlas fractures using a halo brace (1-year follow-up). According to their data, the fusion rate was 72.7 %, while in patients who underwent C1–C2 fixation, fusion was achieved in 100 % of cases. Therefore, the use of a halo brace is associated with risks of pseudoarthrosis in almost 30 % of cases [22].

Surgical techniques for stabilization and rigid fixation are now widely used and include C1–C2 and C0–C2 fixation. These fixation techniques promote biomechanical stability and guarantee a high rate of fracture fusion [23]. However, they restrict rotation in the C1–C2 segment and flexion/extension in the C0–C1 segment; the incidence of subaxial cervical spine disc degeneration may also increase [24]. Various techniques of C1-ring osteosynthesis have been proposed in the last decade to preserve mobility in the adjacent joints [25]. Some researchers promote transoral anterior C1-ring osteosynthesis [7, 26]. Nevertheless, because of the technical difficulties and disadvantages of implant placement through the contaminated oral cavity, more and more surgeons prefer posterior C1-ring osteosynthesis [25].

It should be mentioned that the existing techniques of isolated C1 osteosynthesis restore its integrity and stability while maintaining the intactness and mobility of the adjacent joints that, as a result of transverse coaptation of the C1 lateral masses, become close to anatomical congruence. It is completely clear that this type of surgery has functional advantages over the C1–C2 stabilization owing to the elimination of blockage of the specified segment. Currently, there is a sustainable paradigm that rigid monosegmental or bisegmental fixation with creation of conditions for bone block

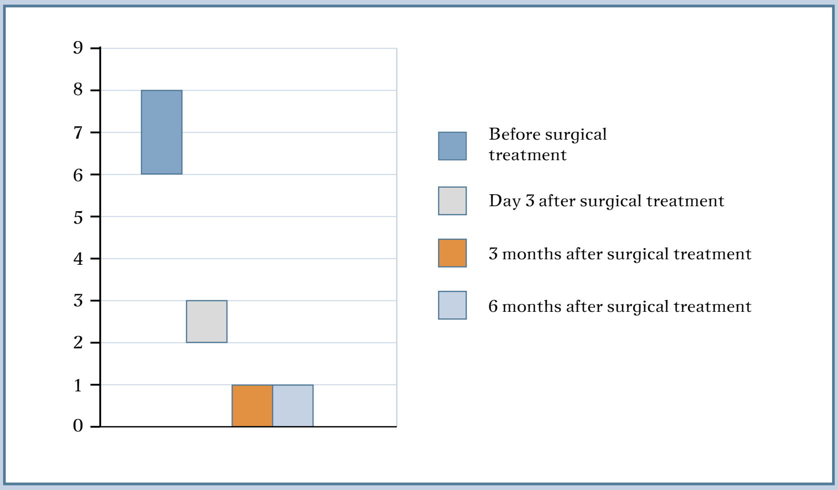

Fig. 1
Changes in pain syndrome over time according to VAS within 6 months after surgery

Table

Range of motion in the cervical spine 3 and 6 months after surgery

Motion	3 months after, degrees (Me) [25; 75]	6 months after, degrees (Me) [25; 75]	Wilcoxon T-test
Turn left	59 (59; 60)	68 (66; 69)	Z = -3.315; p = 0.001
Turn right	62 (59; 63)	70 (66; 73)	Z = -3.306; p = 0.001
Flexion	36 (35; 38)	46 (45; 47)	Z = -4.025; p < 0.001
Extension	40 (36; 42)	52 (50; 54)	Z = -3.529; p < 0.001

union is recommended for atlas bone injuries with transverse ligament rupture [27]. Biomechanical studies have cleared up the issue under study and have shown that the key to the choice of surgical strategy depends solely on the mechanism of injury to the transverse ligament and the surrounding capsular ligamentous complex in atlas burst fractures [28]. The extreme rotational or flexion loads in which the fracture and translation of the atlas happen result both in damage to the bone structures as well as to the ligamentous apparatus. It is very probable that other stabilizers (joint capsule, alar ligament, muscles) are damaged in addition to the transverse ligament of the atlas. In the case of excessive axial load with disruption of the integrity of the atlas ring, traumatic C1 lateral mass divergence occurs with rupture or separation from the transverse ligament attachment site; at the same time, the secondary stabilizers of the segment remain intact [29].

According to Koller et al. [30] and Shatsky et al. [31], preservation of the integrity of secondary stabilizers in the C1–C2 segment after injury, as well as successful C1-ring osteosynthesis with restoration of congruence of the joints, provide sufficient long-term stability of the injured area. In this case, fixation of the segments adjacent to the injured atlas is not biomechanically justified despite damage to the transverse ligament. This expansion of the surgical procedure does not provide additional stability but only limits the functionality of the injured area.

In 2022, Yan et al. [32] published a comparative analysis of the results (5-year follow-up) of treatment of 73 patients with unstable atlas fractures who underwent either C1–C2 fixation (n = 36) or C1-ring osteosynthesis (n = 37). The authors concluded that C1-ring osteosynthesis was superior to C1–C2 fixation in all of the parameters studied (duration of surgery, intraoperative blood loss, length of the hospital stay, exposure dose, neck pain, and functional status) [32].

Our study of patients with an unstable C1 fracture and transverse ligament rupture who underwent C1-ring osteosynthesis resulted in a 78.8 % coaptation of the C1 lateral masses (from 10.4 mm of the initial diastasis to mean 2.2 mm), thus bringing this parameter close to the anatomical values. During the dynamic follow-up of these patients, statistically significant regression of pain syndrome and NDI scores were observed. The time to fracture fusion was 12.5 months (8.5; 16.5). The range of motions (left/right rotation, flexion/extension) increased

Fig. 2

C1 vertebra fracture according to Gehweiler 3B (Dickman 2), lateral mass divergence is 9.1 mm **(a)**; complete fracture fusion 13 months after osteosynthesis of the C1-ring, lateral mass divergence is 1.5 mm **(b)**; functional radiographs of the patient's cervical spine show a range of motion closer to physiological **(c)** statistically significantly by 6 months after C1-ring osteosynthesis, and these parameters were close to the physiological standard.

Conclusion

Isolated posterior osteosynthesis of the atlas ring for Gehweiler type 3B injury using a repositioning compression maneuver under distraction conditions is physiologically justified. It is a reliable technique of stabilization that ensures the restoration of congruence and the entire range of motion in the atlanto-occipital and atlantoaxial joints and stability of the occipital-atlantoaxial complex. This surgery contributes to a considerable and long-term reduction in the intensity of pain syndrome and a significant improvement in the quality of life.

The study had no sponsors. The authors declare that they have no conflict of interest.
The study was approved by the local ethics committees of the institutions. All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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Received 29.07.2024
Review completed 08.08.2024
Passed for printing 22.08.2024

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