ORIGINAL SURGICAL TECHNIQUE OF UNSTABLE ATLAS FRACTURE OSTEOSYNTHESIS: CASE SERIES ANALYSIS

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Objective. To evaluate the effectiveness of the original technique of surgical treatment of unstable fractures of the atlas.
Material and Methods. The study included 8 patients with isolated unstable Gehweiler type III B atlas fractures (Jefferson fracture) operated on using original surgical technique of osteosynthesis. Two-part fractures were present in five patients, and three-part fractures – in three patients. Dickman's type I transverse ligament injury was observed in 2 cases, and that of type II – in 6. All patients underwent osteosynthesis through the posterior approach using the developed method for eliminating atlantoaxial instability.
Results. In the postoperative period, a decrease in the VAS pain intensity by 5–7 points (on average 6.6) was noted. Control examination confirmed consolidation of the atlas fractures in all patients. The average value of the anterior atlantodental interval after surgery did not exceed 3.10 ± 0.54 mm. The amplitude of head rotation reached 145.00° ± 8.29°. Complications included surgical site infection in one case and cerebrospinal fluid leakage in another.
Conclusion. The described original surgical technique of reconstructing the transverse ligament function during osteosynthesis makes it possible to eliminate instability, while avoiding the rotation block in the atlantoaxial joint, which improves the functional outcomes of surgical treatment. The presented results indicate the effectiveness of the method and allow considering the proposed new technique of atlas osteosynthesis as a method of choice in the surgical treatment of unstable C1 fractures with Dickman's type I and II transverse ligament injury. Further studies on sufficient clinical material are necessary for a reliable assessment of the method.
Key Words: atlas fracture; osteosynthesis of atlas fractures; atlantoaxial instability.
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Atlas fractures represent 2–13 % of all cervical spine fractures [1–5]. In 1822, Cooper made the first report of an atlas fracture based on autopsy data. In 1920, Jefferson described a burst fracture of the atlas that was later named after him [2]. Only 33 % of atlas fractures are isolated injuries. Mostly they coexist with other spinal injuries, including 40–44 % of C2 vertebral fractures [1, 3, 4, 6]. According to recent studies, injury rates have a bimodal age distribution with an initial insignificant peak in the second to third decade of life followed by an exponential increase, reaching a maximum after the age of 80 years old. Atlas fractures in the elderly are a consequence of falling from height of their own body, whereas in younger people the dominant reason is high-energy injuries mostly caused by traffic accidents. The ratio of men to women with atlas fracture is 1.3 : 1.0 [7]. Neurological complications are rarely observed in isolated atlas fractures because of the specific structure of the first cervical vertebra [1–4, 6]. Most atlas fractures are stable injuries. Unstable injuries include a burst fracture in which excessive axial force splits the vertebra at two, three, or four points, resulting in lateral displacement of one or both lateral masses with concomitant transverse ligament rupture, corresponding to type 3B according to Gehweiler classification. The typical Jefferson fracture with the formation of four fragments is extremely rare. Burst fractures with the formation of two or three ring fragments are much more frequently observed [8]. Injury of the transverse ligament in the form of a direct rupture of the ligament (type I according to Dickman et al.) or its avulsion together with a bone fragment from its attachment to the lateral mass (type II) is the reason for atlantoaxial instability [1–6, 8–12].

The evolution of surgical techniques for the treatment of unstable C1 vertebral fractures is focused on minimizing the scope and traumatic nature of procedures and improving functional outcomes. Reduction of the fragments and elimination of atlantoaxial instability have become the fundamental principles of the modern concept of surgical treatment of unstable atlantoaxial fractures. One such technique is osteosynthesis of atlas ring fragments performed through a posterior approach [13–17].

The objective is to evaluate the effectiveness of the original technique of surgical treatment of unstable fractures of the atlas.

Material and Methods

The outcomes of osteosynthesis of isolated unstable atlas fractures of Gehweiler type IIIB through the posterior approach using the developed procedure of atlantoaxial instability elimination (patent application No. 2024117013) were analyzed. Eight patients (5 males and 3 females) aged 27–48 years (mean age 37.3 years old) were included in the study. Two-fragment fractures were found in five patients, and three-fragment fractures in three patients. There were two cases of transverse ligament injury type I according to Dickman et al., and six cases of type II. Five patients suffered atlas fractures because of a fall from height, and three patients were involved in traffic accidents. At the time of surgery, all the injuries were acute. Clinical symptoms and their course in the postoperative period, duration of surgery and blood loss volume, adequacy of reduction, stability of the operated spinal segments, fracture consolidation time, and restoration of head rotation were analyzed.

The clinical picture was characterized by pain syndrome with intensity from five to seven points according to VAS and limitation of head movements. There were no neurological disorders in all patients.

Verification of the diagnosis was in accordance with the findings of MRI, CT, transoral and functional spinal radiograph that are standard techniques in such cases.

All patients underwent osteosynthesis of atlas fractures through the posterior approach using the developed technique to eliminate atlantoaxial instability.

Surgical technique. The surgery was performed in the prone position of a patient with fixation of the head in a Mayfield headframe. The approach was performed through a midline incision with a length of about 5–7 cm. The posterior arch and lateral masses of the atlas and the spinous process and the C2 vertebral arch were skeletonized. A technical aspect of this procedure is to control bleeding from the venous plexus surrounding the Arnold nerve. For this reason, skeletonization of the lateral mass was performed subperiosteally, starting from the lower margin of the atlas arch. In case of intense bleeding from the venous plexus, it can be stopped easily by bipolar coagulation and tamponade with hemostatic dressings. Using a low-speed drill, holes were made in the lateral masses, and polyaxial screws were inserted. A rod was fixed to the head of the screw placed in the dislocated lateral mass. Fracture reduction was achieved by contraction between the screws. The rod was then locked in the head of the screw on the contralateral side. Subsequently, a loop of steel wire or strong lavsan thread was used to fix the rod to the spinous process of the C2 vertebra in the maximal head extension (Fig. 1).

On day 2 or 3 after surgery, a CT examination was performed to control the reduction and instrumentation position. Immobilization with a head supporter was performed for two months. Patients were examined every 2 months for the first 6 months, and functional spinal radiograph and CT scans were performed 4 and 6 months after surgery to control the condition of bone fusion and stability of the operated spinal segment, as well as to measure the amplitude of head rotation. The final evaluation of the recovery of rotational head movements in the majority of patients was performed after 12 months.

Results

The mean follow-up period was 15.75 ± 5.14 months (12 to 24 months). The main information about the patients and the surgical outcomes is given in the Table. The duration of surgery ranged from 60 to 120 min (mean 88.70 ± 18.15 min), and the blood loss volume ranged from 70 to 150 ml (mean 96.20 ± 25.95 ml). During the follow-up period, pain intensity decreased by 5–7 points (mean 6.6). Postoperative radiological parameters of total lateral displacement of the lateral atlas masses (1.28 ± 1.02 mm, range: 0.0-3.0 mm) that were measured according to the method of Spence et al. were considerably less than the preoperative (7.17 ± 0.60, range: 6.2–8.1 mm) parameters. According to functional spinal radiography, the anterior atlantodental interval values (3.10 ± 0.54 mm, range: 2.0-4.0 mm) after surgery were also significantly different from preoperative ones (5.07 ± 0.99 mm, range: 4.0–7.1 mm). The control examination in all cases verified the fusion of unstable atlas fractures. The mean consolidation time was 5.25 ± 0.96 months. The amplitude of head rotation in patients who underwent atlas osteosynthesis reached 145.00° ± 8.29° one year after surgery (Fig. 2, 3). No integrity disruptions of the instrumentation elements, including the cerclage wire, were observed.

One patient suffered from the surgical site infection, which was successfully managed with continuous flow drainage. The cerebrospinal fluid leakage found in one patient in the postoperative period was eliminated by lumbar drainage for seven days.

Discussion

The assessment of transverse ligament integrity is crucial in determining the treatment strategy for atlas fractures. If the transverse ligament is ruptured, atlantoaxial instability is present [1–6]. Dickman et al. identified two types of ligament injury: rupture along the ligament corresponded to type I; avulsion of the transverse ligament with a bone fragment from the fixation site to the lateral mass corresponded to type II [9, 10]. It is possible to objectively visualize the rupture in some cases in the acute period of injury using MRI. In cases of neglected atlas fractures, MRI loses its diagnostic value. Radiological computer tomography provides an opportunity to verify injury to the transverse ligament in case of its avulsion from the attachment site. In the case of type I rupture by Dickman et al, radiological computer tomography has no diagnostic value.

In this context, techniques for indirect assessment of transverse ligament integrity are of great relevance. One of them is the “Rule of Spence.” Spence et al., modelling true Jefferson fractures in a series of experiments with cadaver

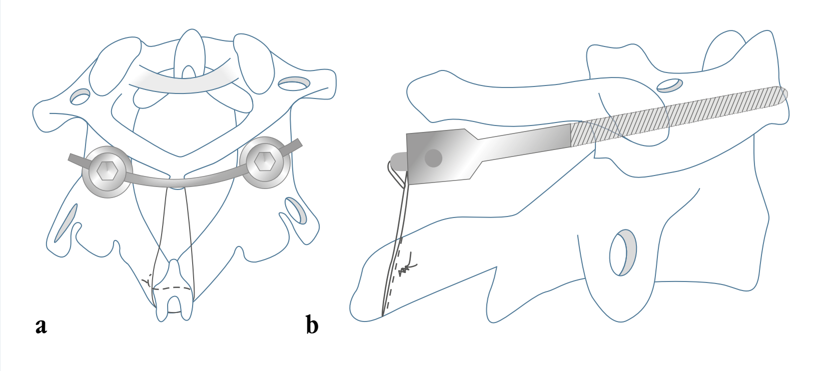

Fig. 1
Scheme of surgical intervention, posterior view **(a)** and lateral view **(b)**: osteosynthesis of an unstable atlas fracture with two screws inserted into the lateral masses and the rod fixed between screws in the transverse direction, with a cerclage wire stretched between the rod and the C2 spinous process to reconstruction of the function transverse ligament

blocks, have found that rupture of the transverse ligament is associated with a mean distraction force of 580 N and a mean total displacement of the lateral atlas masses relative to the articular axis surfaces of 6.9 mm [18].

Nevertheless, Dickman and Sonntag indicated that the study conditions were not suitable for the clinical mechanism of injury, as the experiment neglected the distraction resistance forces exerted by soft tissues and muscles that were nonexistent in cadaveric blocks. Using MRI, they evaluated the integrity of the transverse ligament, arguing that it was more objective than measuring the total displacement of the lateral atlas masses on spinal radiography. According to their series of experiments, it was found that the "Rule of Spence" failed to verify transverse ligament injury in 60% of cases [9, 10].

Heller et al. [19] suggested that the mean total displacement of the lateral atlas masses in the "Rule of Spence" should be increased to 8.1 mm because of an 18% distortion of the object size transfer in spinal radiography.

Nowadays, a number of authors criticize the reliability of this technique for the diagnosis of injury to the transverse ligament of the atlas, pointing out that there is no clear correlation between the figures of total displacement of the lateral masses and the fact of a transverse ligament rupture [3–5, 9, 10, 17].

Thus, in our series of cases, the total displacement of the lateral atlas masses in three patients was less than 6.9 mm with verified avulsion of the transverse ligament from the attachment site together with the bone fragment (type II according to Dickman et al.), which also proves against the absolute specificity of the "Rule of Spence." Moreover, a change in the anterior atlantodental interval on functional spinal radiograph was observed in all patients indicating the great diagnostic value of this examination technique. Therefore, only a comprehensive evaluation of radiological computer tomography, MRI, as well as functional and transoral spinal radiograph data can verify a transverse ligament rupture of type I by Dickman et al.

The treatment strategy of unstable atlas fractures is still a matter of debate. Conservative treatment was prevalent until the end of the twentieth century. Prolonged immobilization with cervical collars of various modifications or halo vests is a painful ordeal for patients, seriously affecting the quality of life and not guaranteeing, as practice has shown, a positive outcome [3, 4, 11, 12]. Thus, according to a multicenter study conducted by Dvorak et al. [20], conservative treatment of unstable fractures because of vicious union of the atlas ring resulted in the development of such long-term consequences as post-traumatic osteoarthritis and instability. The most unfavorable outcomes were found in patients with a total displacement of lateral atlas masses equal to 7 mm. Segal et al. [21] found a direct correlation between the degree of fragments displacement and the incidence of nonunions.

From the early 2000s, the treatment strategy for unstable atlas fractures has been revised considering the previous experience [2–4, 11–17, 22–28]. Active implementation of surgical techniques has been observed. This is greatly facilitated by the development of modern medical technologies.

Nowadays, the range of surgical techniques for unstable atlas fractures includes occipital cervical fusion, posterior C1–C2 vertebral fixation with screws according to Harms, transarticular fixation according to Magerl, and open reduction and osteosynthesis of C1 vertebral fragments from posterior and transoral approach.

Occipital cervical fusion is a traditional surgical technique for the treatment of unstable atlas fractures. However, in addition to the unnecessarily high volume and traumatic nature of the procedure, it has a negative consequence on head mobility. For this reason, craniocervical fixation in C1 vertebral fractures is not practically used nowadays. Currently, the scope of occipital cervical fusion is limited to comminuted fractures of the lateral atlas mass and the consequences of C1 vertebral fractures [15, 17].

In 2001, Harms and Melcher [22] described posterior screw fixation of the C1–C2 vertebrae for the treatment of injuries and diseases of the upper cervical spine, which is also used in the surgical treatment of unstable atlas fractures of Gehweiler type III B. Among other things, the technique provides instrumental correction of dislocations and atlantoaxial instability [22]. Contraction between the rods of the instrumenta-

Table

Main information about patients and surgical treatment outcomes

Pati-ents	Gen-der	Age, years	Injury mecha-nism	Type of transverse ligament injury according to Dickman et al.	Surgery duration, min	Blood loss volume, ml	VAS, points		Total divergence of the lateral masses of the atlas, mm		Anterior atlantodental interval, mm		Head rotation amplitude after surgery, degrees	Compli-cations	Duration of bone fracture consoli-dation, months	Follow-up period, months
							before surgery	after surgery	before surgery	after surgery	before surgery	after surgery				
1	F	41	Fall	II	80	120	6	0	8.1	0.8	7.1	3.6	140	–	6	12
2	M	27	TA	II	110	100	6	1	7.1	2.0	5.2	3.0	130	–	6	12
3	M	40	Fall	II	90	70	6	0	6.2	1.1	6.2	4.0	145	SSI	4	18
4	M	38	Fall	II	75	70	7	1	6.6	0.0	4.8	3.2	150	Cerebro-spinal fluid leakage	4	24
5	M	31	TA	II	60	80	7	1	6.8	1.0	4.4	2.0	150	–	4	12
6	F	47	Fall	I	80	100	6	0	7.2	0.0	4.0	2.8	160	–	6	12
7	M	27	TA	II	95	80	5	0	7.9	3.0	4.7	3.0	140	–	6	24
8	F	48	Fall	I	120	150	5	0	7.5	2.4	4.2	3.2	145	–	6	12
Arithmetic mean ± standard deviation					88.70 ± 18.15	96.20 ± 25.95	6.00 ± 0.70	0.37 ± 00.48	7.17 ± 0.60	1.28 ± 1.02	5.07 ± 0.99	3.10 ± 0.54	145.00 ± 8.29	–	5.25 ± 0.96	15.75 ± 5.14

SSI — surgical site infection; TA —traffic accident.

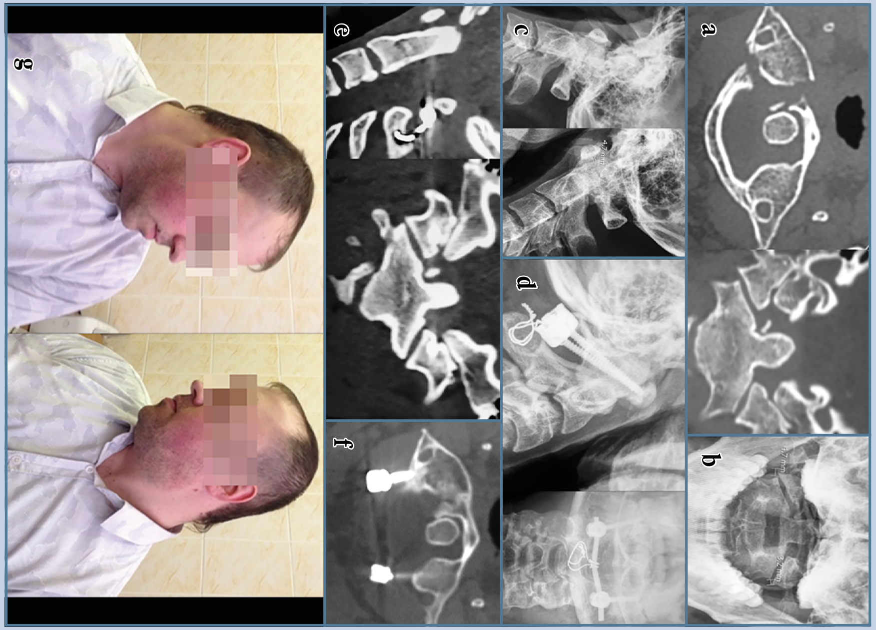

Fig. 2

Examination results of patient before and after surgical treatment: **a** – CT in axial and frontal planes shows a two-fragment unstable atlas fracture of Gehweiler type III with avulsion of the transverse ligament from the lateral mass (injury of type II according to Dickman et al.); **b** – transoral spinal radiographs shows lateral displacement of the lateral atlas masses with the total value of 7.9 mm; **c** – functional spinal radiographs in the position of extension and flexion of the cervical spine show atlantoaxial instability with an increase in the Cruveilhier joint space to 4.7 mm in the head tilt position; **d** – control radiographs immediately after surgery in lateral and frontal planes, osteosynthesis of the atlas fracture was performed with reconstruction of the transverse ligament function with cerclage wire; **e** – control CT immediately after surgery in the sagittal and frontal planes, anatomical relationships in the atlantoaxial joint are restored; **f** – control CT in the axial plane 12 months after surgery, bone fusion of the atlas fracture; **g** – photographs of the patient 12 months after surgery with head turns to the left and right, restoration of the head rotation amplitude to physiological parameters

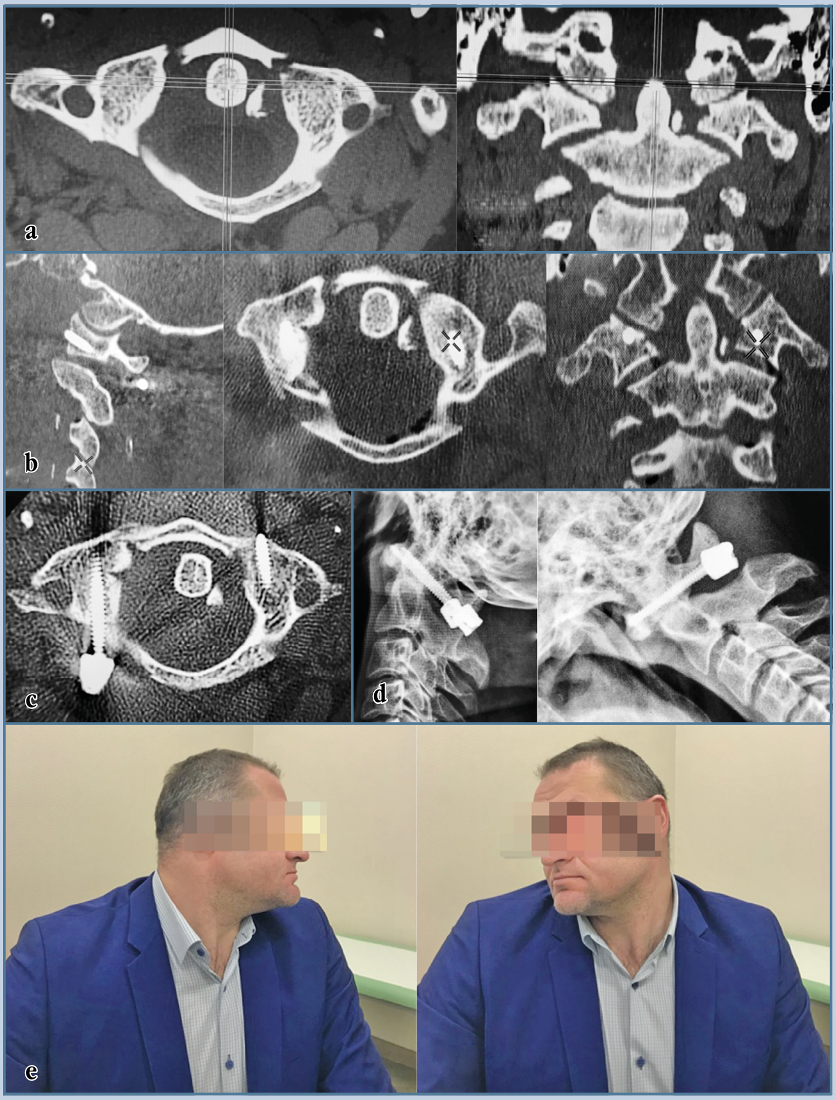

Fig. 3
Examination results of patient before and after surgical treatment: **a** – CT in axial and frontal planes show a three-fragment unstable atlas fracture of Gehweiler type III with avulsion of the transverse ligament from the lateral mass (injury of type II according to Dickman et al.); **b** – CT in the sagittal, axial and frontal planes immediately after surgery show osteosynthesis of the atlas fracture with reconstruction of the transverse ligament function with lavsan; **c** – control CT in the axial plane 6 months after surgery shows bone fusion of the atlas fracture; **d** – functional spinal radiographs in the position of extension and flexion of the cervical spine show no atlantoaxial instability; **e** – photographs of the patient 6 months after surgery with head turns to the left and right, restoration of the head rotation amplitude to physiological parameters

tion with an application of a connector can help to reduce fragments using this technique [11, 12]. According to a number of authors [3, 4, 23], fixation of the C1–C2 vertebrae is reasonable in unstable atlas fractures with injury of the transverse ligament of type I according to Dickman et al., when its integrity cannot be fully restored [3, 4, 6, 9–11]. The obvious disadvantage of instrumentation fixation of the C1–C2 vertebrae is the motor block in the atlantoaxial joint, which substantially limits the amplitude of head rotation.

The technique of transarticular fixation of the C1–C2 vertebrae, described in 1987 by Magerl et al., has not been widely used in the surgical treatment of unstable atlas fractures because of the complex nature of screw placement into the dislocated lateral mass and associated complications [3, 24].

In 2004, Ruf et al. [25] were the first to introduce osteosynthesis of unstable atlas fractures from a transoral approach. The advantages of this technique over the Harms and Magerl fixation of the C1–C2 vertebrae are the possibility of complete reduction with restoration of congruence of the articular surfaces of the atlanto-occipital and atlantoaxial joints, as well as preservation of the head rotation amplitude. The high risk of approach-related complications, primarily infectious complications, the complexity of the procedure, and the need to use special instrumentation have become an impediment to the widespread introduction of transoral osteosynthesis into clinical practice [12, 14, 23, 26]. Nonetheless, this concept has resulted in a paradigm shift in the development of surgery for unstable atlas fractures.

In 2006, Böhm et al. [13] described a combined osteosynthesis that involved the reduction of the fragments using contraction of screws connected by a rod and placed in a bicortical position posteriorly into the lateral atlas masses, followed by transoral strapping of the screw ends with a cerclage wire, essentially establishing a new technique for the surgical treatment of unstable C1 fractures performed from a posterior approach.

The osteosynthesis of C1 vertebral fragments through the posterior approach, which has been introduced into practice, is, in our opinion, the most appropriate technique for surgical treatment of unstable atlas fractures. Its main advantages are the possibility of complete reduction with restoration of congruence of the articular surfaces of the atlanto-occipital and atlantoaxial joints, preservation of mobility of the upper cervical spine, and minimal scope and traumatic nature of the procedure. It is also necessary to note that osteosynthesis of unstable atlas fractures is performed using standard screw instrumentation for the cervical spine, which is an important advantage of this technique. At the same time, this does not solve the problem of atlantoaxial instability associated with transverse ligament rupture. According to a number of authors [15–17, 23, 26, 27], restoration of anatomical relations in the atlanto-occipital and atlantoaxial joints and consolidation of atlas fractures, along with cicatrization of the capsular ligaments, compensate for the functional insufficiency of the transverse ligament of the atlas and prevent instability at the C1–C2 level in the postoperative period. Others believe that osteosynthesis of unstable atlas fractures is indicated only in cases of transverse ligament injury of type II by Dickman et al. In this case, in their opinion, the anatomical integrity of the transverse ligament is restored because of consolidation of the bone fragment at the avulsion site from the lateral atlas mass, thus avoiding the development of atlantoaxial instability in the postoperative period [3, 4, 11, 12, 28].

The correct fusion of the capsular ligaments of the atlantoaxial joint after osteosynthesis of an unstable C1 fracture is impossible even with minimal mobility, which cannot be completely eliminated with external immobilization in the postoperative period. The issue of atlantoaxial instability during osteosynthesis of Gehweiler type IIIB atlantoaxial fractures through a posterior approach prompted us to restore the function of the transverse ligament using a cerclage wire or lavsan thread stretched between the rod and the C2 spinous process in the maximal head extension position. This technique provides an opportunity to eliminate the anterior translation of the atlas during head flexion and promotes full cicatrization of the capsular ligaments, thus preventing atlantoaxial instability. At the same time, a loop of wire or lavsan thread fixed to the rod does not block rotation at the atlantoaxial joint to the same extent as posterior screw fixation of the C1–C2 vertebrae.

Conclusion

Open reduction and stable fixation of the fragments ensure restoration of the anatomical integrity of the atlas ring and congruence of the articular surfaces of the atlanto-occipital and atlantoaxial joints, which distinguishes osteosynthesis of C1 vertebral fractures of Gehweiler type IIIB through posterior approach from other techniques. Preservation of rotation movements in the upper cervical spine is an obvious advantage of this technique. The original technique for reconstruction of transverse ligament function during osteosynthesis described in this article provides an opportunity to eliminate instability while avoiding rotation block in the atlantoaxial joint, which improves functional surgical outcomes.

The presented outcomes demonstrate the efficiency of the technique and suggest that the proposed original technique of atlas osteosynthesis should be considered the treatment of choice for unstable C1 fractures with transverse ligament injury of types I and II according to Dickman et al. Nevertheless, further studies on sufficient clinical cases are required for a reliable assessment of the technique.

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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.

References

1. **Fiedler N, Spiegl UJA, Jarvers JS, Josten C, Heyde CE, Osterhoff G.** Epidemiology and management of atlas fractures. Eur Spine J. 2020;29:2477–2483. DOI: 10.1007/s00586-020-06317-7
2. **Ryken TC, Aarabi B, Dhall SS, Gelb DE, Hurlbert RJ, Rozzelle CJ, Theodore N, Walters BC, Hadley MN.** Management of isolated fractures of the atlas in adults. Neurosurgery. 2013;72 Suppl 2:127–131. DOI: 10.1227/NEU.0b013e318276ee2a
3. **Kandziora F, Chapman JR, Vaccaro AR, Schroeder GD, Scholz M.** Atlas fractures and atlas osteosynthesis: a comprehensive narrative review. J Orthop Trauma. 2017;31 Suppl 4:S81–S89. DOI: 10.1097/BOT.0000000000000942
4. **Kandziora F, Scholz M, Pingel A, Schleicher P, Yildiz U, Kluger P, Pumberger M, Korge A, Schnake KJ.** Treatment of atlas fractures: recommendations of the Spine Section of the German Society for Orthopaedics and Trauma (DGOU). Global Spine J. 2018;8(2 Suppl):5S–11S. DOI: 10.1177/2192568217726304
5. **Kopparapu S, Mao G, Judy BF, Theodore N.** Fifty years later: the “rule of Spence” is finally ready for retirement. J Neurosurg Spine. 2022;37:149–156. DOI: 10.3171/2021.12.SPINE211188
6. **Kakarla UK, Chang SW, Theodore N, Sonntag VK.** Atlas fractures. Neurosurgery. 2010;66(3 Suppl):60–67. DOI: 10.1227/01.NEU.0000366108.02499.8F
7. **Matthiessen C, Robinson Y.** Epidemiology of atlas fractures – a national registry-based cohort study of 1537 cases. Spine. 2015;15:2332–2337. DOI: 10.1016/j.spinee.2015.06.052
8. **Hays MB, Alker GJ Jr.** Fractures of the atlas vertebra. The two-part burst fracture of Jefferson. Spine. 1988;13:601–603.
9. **Dickman CA, Greene KA, Sonntag VK.** Injuries involving the transverse atlantal ligament: classification and treatment guidelines based upon experience with 39 injuries. Neurosurgery. 1996;38:44–50. DOI: 10.1097/00006123-199601000-00012
10. **Dickman CA, Sonntag VK.** Injuries involving the transverse atlantal ligament: classification and treatment guidelines based upon experience with 39 injuries. Comment. Neurosurgery. 1997;40:886–887. DOI: 10.1097/00006123-199704000-00061
11. **Kim MK, Shin JJ.** Comparison of radiological and clinical outcomes after surgical reduction with fixation or halo-vest immobilization for treating unstable atlas fractures. Acta Neurochir (Wien). 2019;161:685–693. DOI: 10.1007/s00701-019-03824-5
12. **Shin JJ, Kim KR, Shin J, Kang J, Lee HJ, Kim TW, Hong JT, Kim SW, Ha Y.** Surgical versus conservative management for treating unstable atlas fractures: a multicenter study. Neurospine. 2022;19:1013–1025. DOI: 10.14245/ns.2244352.176
13. **Böhm H, Kayser R, El Saghir H, Heyde CE.** [Direct osteosynthesis of instable Gehweiler Type III atlas fractures. Presentation of a dorsoventral osteosynthesis of instable atlas fractures while maintaining function]. Unfallchirurg. 2006;109:754–760. In German. DOI: 10.1007/s00113-006-1081-x
14. **Jo KW, Park IS, Hong JT.** Motion-preserving reduction and fixation of C1 Jefferson fracture using a C1 lateral mass screw construct. J Clin Neurosci. 2011;18:695–698. DOI: 10.1016/j.jocn.2010.08.033
15. **Bransford R, Falicov A, Nguyen Q, Chapman J.** Unilateral C-1 lateral mass sagittal split fracture: an unstable Jefferson fracture variant. J Neurosurg Spine. 2009;10:466–473. DOI: 10.3171/2009.1.SPINE0870
16. **Bransford R, Chapman JR, Bellabarba C.** Primary internal fixation of unilateral C1 lateral mass sagittal split fractures: a series of 3 cases. J Spinal Disord Tech. 2011;24:157–163. DOI: 10.1097/BSD.0b013e3181e12419
17. **Koller H, Resch H, Tauber M, Zenner J, Augat P, Penzkofer R, Acosta F, Kolb K, Kathrein A, Hitzl W.** A biomechanical rationale for C1-ring osteosynthesis as treatment for displaced Jefferson burst fractures with incompetency of the transverse atlantal ligament. Eur Spine J. 2010;19:1288–1298. DOI: 10.1007/s00586-010-1380-3
18. **Spence KF Jr, Decker S, Sell KW.** Bursting atlantal fracture associated with rupture of the transverse ligament. J Bone Joint Surg Am. 1970;52:543–549. DOI: 10.2106/00004623-197952030-00013
19. **Heller JG, Viroslav S, Hudson T.** Jefferson fractures: the role of magnification artifact in assessing transverse ligament integrity. J Spinal Disord. 1993;6:392–396. DOI: 10.1097/00002517-199306050-00004
20. **Dvorak MF, Johnson MG, Boyd M, Johnson G, Kwon BK, Fisher CG.** Long-term health-related quality of life outcomes following Jefferson-type burst fractures of the atlas. J Neurosurg Spine. 2005;2:411–417. DOI: 10.3171/spi.2005.2.4.0411
21. **Segal LS, Grimm JO, Stauffer ES.** Non-union of fractures of the atlas. J Bone Joint Surg Am. 1987;69:1423–1434. DOI: 10.2106/00004623-198769090-00017
22. **Harms J, Melcher RP.** Posterior C1–C2 fusion with polyaxial screw and rod fixation. Spine. 2001;26:2467–2471. DOI: 10.1097/00007632-200111150-00014
23. **Rajasekaran S, Soundararajan DCR, Shetty AP, Kanna RM.** Motion-preserving navigated primary internal fixation of unstable C1 fractures. Asian Spine J. 2020;14:466–474. DOI: 10.31616/asj.2019.0189
24. **Elliott RE, Tanweer O, Boah A, Morsi A, Ma T, Frempong-Boadu A, Smith ML.** Outcome comparison of atlantoaxial fusion with transarticular screws and screw-rod constructs: meta-analysis and review of literature. J Spinal Disord Tech. 2014;27:11–28. DOI: 10.1097/BSD.0b013e318277da19
25. **Ruf M, Melcher R, Harms J.** Transoral reduction and osteosynthesis C1 as a function-preserving option in the treatment of unstable Jefferson fractures. Spine. 2004;29: 823–827. DOI: 10.1097/01.brs.0000116984.42466.7e
26. **Niu HG, Zhang JJ, Yan YZ, Yang K, Zhang YS.** Direct osteosynthesis in the treatment of atlas burst fractures: a systematic review. J Orthop Surg Res. 2024;19:129. DOI: 10.1186/s13018-024-04571-9
27. **Shatsky J, Bellabarba C, Nguyen Q, Bransford RJ.** A retrospective review of fixation of C1 ring fractures - does the transverse atlantal ligament (TAL) really matter? Spine J. 2016;16:372–379. DOI: 10.1016/j.spinee.2015.11.041
28. **Ames CP, Acosta F, Nottmeier E.** Novel treatment of basilar invagination resulting from an untreated C-1 fracture associated with transverse ligament avulsion. Case report and description of surgical technique. J Neurosurg Spine. 2005;2:83–87. DOI: 10.3171/spi.2005.2.1.0083

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