BILATERAL OSTEOPLASTIC DECOMPRESSION LAMINOPLASTY WITH SIMULTANEOUS FORAMINOTOMY TO TREAT MULTILEVEL CERVICAL STENOSIS

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Objective. To analyze surgical technique and possibilities of using bilateral laminoplasty technique with simultaneous foraminotomy for extended stenosis of the cervical spine.

Material and Methods. The analysis included results of surgical treatment of 26 patients (18 males and 8 females, mean age 60.2 ± 1.3 years) operated on by the method of bilateral laminoplasty with simultaneous foraminotomy from January 2016 to April 2020. Pre- and postoperative clinical condition of patients was assessed, including using VAS, JOA and Nurick scales. An objective assessment of stenosis degree (linear dimensions, areas, volume of the stenotic spinal canal) was performed using standard measuring tools of the RadiAnt DICOM Viewer software. To assess the statistical significance of the obtained results, nonparametric Wilcoxon-T and Mann – Whitney-U tests were used. Differences were considered significant at $p < 0.05$.

Results. Upon admission to the hospital, all patients had specific neurological symptoms with varying degree of pain, myelopathic and radicular symptoms. According to neurovisualisation, the average number of involved in the process levels (stenotic) was 3.2 ± 0.1, (the average length of stenosis was 5.1 ± 0.2 cm). In the postoperative period, all patients showed positive dynamics in the form of a decrease in the severity of neurological disorders and pain (from 7.2 ± 0.1 to 5.07 ± 0.1 according to VAS, $p < 0.001$). The manifestations of myelopathy decreased according to Nurick scale from 2.08 ± 0.71 to 1.84 ± 0.10 points ($p < 0.05$). According to MRI data, the average area of the dural sac objectively increased from 1.25 ± 0.30 cm^2 to 2.26 ± 0.27 cm^2 ($p < 0.001$), and the volume of spinal canal in the area of stenosis increased from 7.2 ± 0.2 cm^3 to 13.4 ± 0.1 cm^3 ($p < 0.001$). Patients were mobilized on the 2nd day after surgery. The duration of inpatient treatment ranged from 4 to 17 days (on average, 7.1 ± 0.4 days). Intraoperative complications were not observed in the presented series. Mild postoperative complications were detected only in two out of 26 operated patients.

Conclusion. Bilateral laminoplasty with simultaneous foraminotomy using titanium miniplates and osteoinductive material has a number of advantages and can be the surgery of choice in the treatment of patients with extended cervical stenosis complicated by myelopathy and radicular pain syndrome.

Key Words: spinal stenosis, myelopathy, cervical spine, bilateral laminoplasty, foraminotomy.

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Cervical spine stenosis complicated by myelopathy is a progressive degenerative disorder, as well as one of the most common causes of spinal cord dysfunction [1, 2]. An early diagnosis and surgical treatment are critical aspects of preventing irreversible changes in the spinal cord [1–4]. Thus, it is essential to choose the most effective method for the treatment of extended cervical stenosis caused by degenerative changes [1–3, 5]. Surgery is the only possible way to decompress the spinal canal contents [1, 2, 4, 6]. The standard laminectomy in cases of extended multilevel stenosis is often associated with secondary complications. They include the formation of a pronounced epidural cicatrical adhesion process, kyphotic deformity and the axial pain development. It also considerably limits the possibilities of further surgical correction of neurological signs of myeloishemia and neuropathic pain syndrome using the functional neurosurgery techniques [5,7]. The laminoplasty techniques have recently been considered to be more and more effective [5, 6]. It has got several modifications but two techniques were mostly used: by Nakashima and Kurokawa [8, 9]. According to many authors, the most effective technique is the open-door by Hirabayashi, which we chose to initially use in the treatment of extended cervical stenosis [2, 8, 10]. However, patients often suffer from radicular pain syndrome caused by compression of the nerve root in the intervertebral foramen, in addition to the myelopathy symptoms. In our opinion, the open-door technique does not provide an effective solution to this problem [11, 12]. For the elimination of compression of the spinal cord roots, an additional foraminotomy was performed using the bilateral laminoplasty. A penetrating bilateral cutting of the vertebral arches at three or more levels, followed by the removal of the bone flap, enables to perform foraminotomy adequately and safely from any side and at any level.

The aim of the investigation is to analyze surgical technique and possibilities of using bilateral laminoplasty technique with simultaneous foraminotomy for extended stenosis of the cervical spine.

Material and Methods

The analysis included results of surgical treatment of 26 patients (18 males and 8 females), of 45-72 years (mean age 60.2 ± 1.3 years, median – 60.5 years) operated on by the method of bilateral laminoplasty with simultaneous foraminotomy at the Department of Spinal Neurosurgery of the Federal Neurosurgical Center (Tyumen). All the surgeries were performed by one team in January 2016 – April 2020.

The local ethics committee of the Federal Neurosurgical Center has approved the study. All patients or their representatives have signed consent to perform the necessary diagnostic and therapeutic measures in a neurosurgical hospital in accordance with the legislation of the Russian Federation.

We analyzed clinical cases of spondylogenic cervical stenosis with the presence of three or more levels of spinal cord compression complicated by myelopathy, as well as the presence of radicular pain syndrome. The criteria for patients' enrollment in the study group were the following: persistent lordosis in the cervical spine and the lack of conservative therapy efficacy. The exclusion criteria were less than three levels of stenosis, the presence of kyphosis with an angle of more than 15°, signs of segmental instability, no signs of myelopathy, and a positive and long-lasting effect of conservative therapy. Also, the patients suffering from severe comorbidity, acute inflammatory diseases, mental illnesses and conditions that prevent understanding of the treatment plan were excluded.

A full clinical examination was performed in all patients at the preoperative stage. A neurosurgeon and a neurologist independently obtained complaints and case history, and performed a clinical and neurological examination. An objective assessment of the clinical condition and neurological status of patients was performed using scales and questionnaires in the pre- and postoperative periods (after 2–3 months). A 10-point VAS scale was applied to assess the severity of the pain syndrome [13]. For the functional status assessment of patients and the neurological recovery dynamics, the Nurick Cervical Myelopathy Scale (Nurick grade) and the modified scale of the Japanese Orthopedic Association (JOA score) were used.

MRI and CT of the cervical spine were performed in all patients as the main instrumental diagnostic method before the surgery and in the postoperative period. The following parameters were assessed: the spinal motion segment condition, the presence or absence of signs of segmental instability, kyphosis of the cervical spine, the spinal cord position, ossification of the posterior longitudinal ligament, the presence of anterior and posterior subarachnoid spaces.

RadiAnt DICOM Viewer (ver. 2020.1.1) closed polygon and open polygon tools were used for an objective assessment of the stenosis degree. The average linear dimensions and cross-sectional areas of the dural sac, as well as the spinal canal volume in stenosis were calculated on cross-sectional MRI scans. A linear characteristic of the stenosis severity was calculated for the anteroposterior section of the spinal canal in the pre-and postoperative periods. The anterior reference point was the dorsal surface of the compression factor (ossified longitudinal ligament, disc herniation, marginal osteophytes), and the posterior point was the spinous process base. The closed polygon tool of the RadiAnt DICOM Viewer software was used to calculate the average stenosis area. The spinal canal volume in the stenosed area was additionally measured.

Isotropic three-dimensional MR images were used for MR volumetry (3D fast spinecho sequences, Cube). The volume measurement of the stenosed area to determine the spinal canal stenosis severity provides an integral assessment of the efficacy of decompression surgery in multi-level stenoses.

The nonparametric Wilcoxon signed-rank test and Mann-Whitney U–test were used to evaluate the statistical significance of the obtained results. The differences were considered significant at $p < 0.05$. The results are presented in the form M ± m, where M is an arithmetic mean, and m is a standard error of the mean.

Surgical technique. In all cases, the surgeries were performed under endotracheal anesthesia. The patient was placed in a lying or sitting position on a modulable spinal table. This procedure allowed to get rid of neck folding. It is especially important in obese patients. Silicone rollers were placed under the bone protrusions. The torso was fixed with a belt (Fig. 1).

The hair was shaved above the occiput level. Before the complete fixation of the patient on the surgery table, the electrodes for neuromonitoring were placed. In order to provide operative approach, bone anatomical landmarks (spinous processes) were palpated. A posterior longitudinal incision of the skin and subcutaneous tissue was made along the abdominal midline. The spinous processes were skeletonized with the preservation of the interosseous and supraspinous ligaments. It is essential to skeletonize the soft tissues laterally as much as possible (optimally up to the middle of the lateral mass) when performing the approach. It preserves the muscles as much as possible, which minimizes blood loss (non-vascular area) and further reduces axial pain in the neck. In order to stave off the instability, if possible, we kept the muscles fixed to the spinous process of C2 [14]. The next surgery stage consisted in cutting through the vertebral arches on both sides (Fig. 2).

This procedure with the elevation of the bone flap was the most crucial because of the injury risks of the dura mater, the dural sac mobilization and possible bleeding from the spasmodic lateral veins. Through-cutting was performed on both sides in the lateral part of the vertebral arch, where it passes into the facet joint. An ultrasound bone scalpel Misonix was used to perform the cut. The yellow ligament was incised to displace the plate during laminoplasty. In order to avoid voluminous epidural bleeding at this surgery stage, the extra care was taken. Then the interosseous ligaments were incised at the levels above and below the bone flap. The yellow ligament was fully cut off along the entire length of the lamina of vertebral arch, followed by temporary removal of the bone flap. If there were indications like radiculopathy, a foraminotomy was additionally performed (in the presented clinical series, this surgery stage was performed in all cases). Using a high-speed Stryker drill and Kerisson 2.3 mm bone pliers, parts of the arches and joints were cut and removed in the area of the corresponding root along the entire length until the outlet from the intervertebral foramen at all interested levels (Fig. 3).

After the bone flap was removaed, the laminar plates were modeled (Fig. 4).

We used both already modeled laminar plates with a thickness of 0.6 to 10.0 mm (it is not recommended to use a smaller plate thickness due to the fracture risk), which are supplied with the tools, or standard plates for laminoplasty. Plate for each patient was modeled intraoperatively and individually. It is not advised to insert plates that failed to be modeled more than three times due to the loss of the metal's physical properties. During the microplate fixation with screws, the insertion site was completely skeletonized, leaving only the external cortical surface. The modeled plates were initially fixed to the mobilized arches with screws of 6 or 8 mm. Later, when the plates were screwed to all the arches, the entire complex was placed in its original position and began to be fixed for the facet joints (Fig. 5a). A key point is the fixation of the plates to the joints to form a diastasis. It will allow the increase of the spinal canal volume. This manipulation is done by the correct modeling of the plates. The diastasis between the arches and the facet joints should not exceed 10 mm (preferably 5–7 mm, depending on the baseline of the spinal canal stenosis and clinical manifestations). After the bone flap was fixed by plates for better osteogenesis in the places of cutting, miniplates were processed in the area of the formed diastasis by osteoinductive material (Fig. 5b).

At this surgery stage it is essential to avoid getting the osteoinductor into the spinal canal. It can result in the compression of the neurovascular structures. The wound closure was performed at the final surgery stage. For minimizing the axial pain development, the neck muscles were stitched with three apposition sutures, followed by the suturing of aponeurosis, subcutaneous adipose tissue. After that, an intradermal suture was performed.

Results

During admission, all patients reported typical neurological symptoms with varying degrees of pain, myelopathic and radicular symptoms. Radiculopathy and conduction disorders were found in all patients of the study group. Compression was most often revealed in C5 and C6 spinal cord roots. Six patients had pelvic organ dysfunction and 7 had trophic disorders (Table 1).

The pain syndrome severity according to VAS before the surgery was 7.2 ± 0.1 points. All patients had an average value of motor disorders according to the Nurick scale 2.1 ± 0.14 and JOA scale – 11.3 ± 0.38. According to the MRI data of the cervical spine, all patients were diagnosed with multilevel stenosis of the spinal canal with the myelopathy formation. Twenty one patients had 3 levels of compression, 4 patients - 4 levels, and one patient had 5 levels. The average number of involved (stenosed) levels was 3.2 ± 0.1 (the average extension of stenosis was 5.1 ± 0.2 cm).

All patients reported an improvement in their neurological status in the postoperative period: a decrease in pain, an increase in muscle sensitivity and strength. According to the VAS indicators, there was a decrease in the pain syndrome in the cervical spine and upper extremities to 5.07 ± 0.10 ($p < 0.001$). There was also a positive dynamic on the Nurik myelopathy scale (a decrease in the average score from 2.08 ± 0.71 to 1.84 ± 0.10; $p < 0.05$). When using the modified JOA scale, the average score remained virtually unchanged and amounted to 11.5 ± 0.4 ($p = 0.36$).

A control MRI scan showed a significant increase in both linear and volumetric dimensions of the spinal canal in all patients in the postoperative period (Table 2).

Therefore, a high efficiency of the performed surgery is assessed by the presented clinical scales and neuroimaging data. The analysis of the intraoperative technical characteristics of surgeries and the specificity of the postoperative period found that the average duration of surgery was 175.2 ± 6.3 minutes (from 115 to 265 minutes, median – 177.5 minutes), the blood loss volume was 192.3 ± 20.8 ml (from 50 to 500 ml, median – 175 ml), the activation of patients was on the 2nd day after surgery, the hospital stay length varied from 4 to 17 days (on average, 7.1 ± 0.4 days, median – 6 days).

Intraoperative complications were not found in the presented stages of surgery. Only in 2 (7.7 %) of the 26 operated patients were found postoperative complications. The development of an intermuscular hematoma as well as wound edge dehiscence occurred in the early postoperative period in the first case. These complications were associated with overweight, diabetes mellitus, and hypertension. The local and systemic antibacterial therapy after revision with primary surgical treatment of the wound and excision of its edges promoted to a favorable healing of the postoperative wound by a secondary intention. An epidural hematoma formation was the second complication in the postoperative period. The hematoma was removed during the revision. Then a meticulous hemostasis was performed. Finally, the wound was sutured and a vacuum drain tube was inserted. The patient was discharged with recommended medication. No negative changes were observed. The check-up scans of patients showed no signs of dislocation, migration of implants or elements of the posterior support system, as well as the spinal canal restenosis processes.

The technique performance is shown in the following clinical case study.

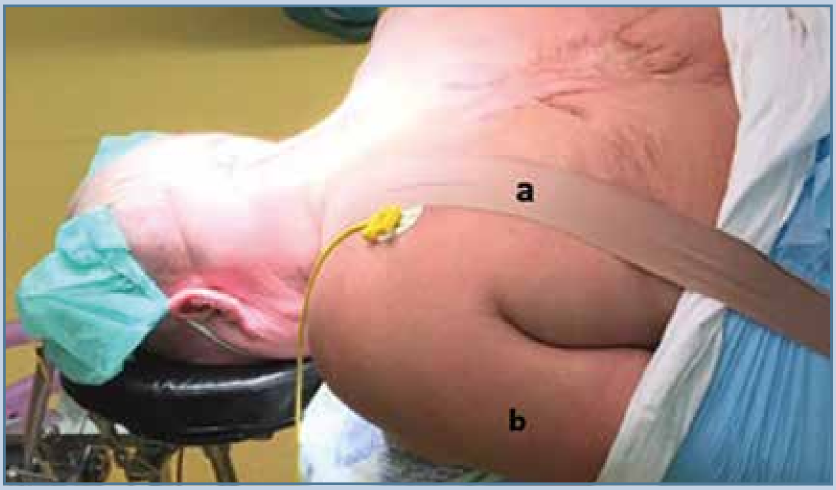

Fig. 1
Patient positioning on the surgical table: **a** – a patch to get rid of neck folding; **b** – the arms are pressed along the torso

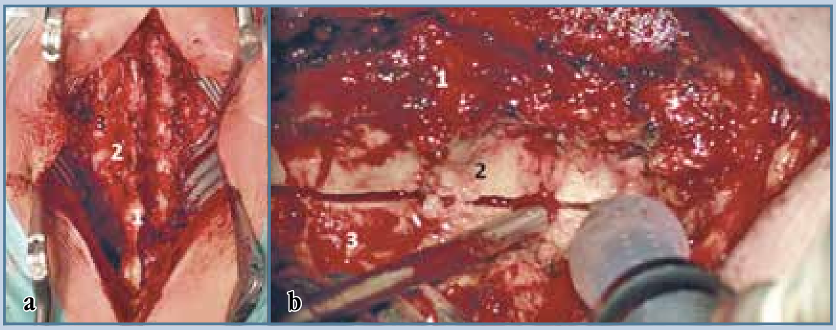

Fig. 2
Midline incision, vertebral arch skeletonization **(a)** and through-sawing of the arches from both sides using an ultrasonic bone scalpel Misonix **(b)**: *1* – spinous processes; *2* – a vertebral arch; *3* – a joint area

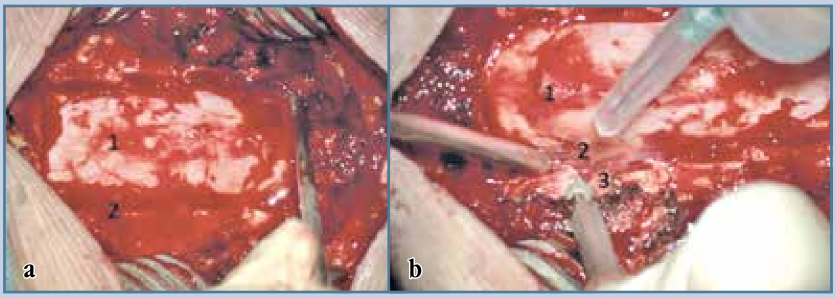

Fig. 3
The stage of temporary bone flap removal **(a)** a foraminotomy **(b)**: *1* – a dural sac; *2* – a root formation area; *3* – a high-speed drill

A clinical case study. A 67-year-old patient, Sh., was admitted with complaints of intermittent dizziness, cervical spine pain radiating to the right arm, numbness in both upper extremities, and a gait disturbance. The neurological status was dominated by the radiculopathy symptoms along the C5, C6 roots on the right, neck pain, hypesthesia and paresthesia in the innervation zone of the roots C4, C5, C6, and C7 on both sides. The tendon reflexes D = S were retained in the upper extremities and reinforced in the lower extremities. VAS – 7 points, JOA – 14 points, and Nurick – 2 points.

The MRI scan showed an extensive spinal canal stenosis at the level of C3–C7 with myelopathy at the level of C4–C5. Average cross-sectional area of the dural sac (from C3 to C7) was 1.25 ± 0.03 cm^2, the stenotic volume of the spinal canal area (C3–C7) was 9.5 cm^3 (Fig. 6, 7).

The diagnosis was made on the basis of complaints, physical examination results, the neurological status, and MRI scan of the cervical spine: degenerative damage to the spine; facet joints osteoarthritis; spinal canal stenosis at the level of C3–C7; myelopathy at the level of C4–C5; radiculopathy along C5, C6 on the right.

The patient underwent an osteoplastic decompressive laminoplasty under neurophysiological control at the level of C3–C7, foraminotomy of C5, C6 on the right, and bone flap fixation by laminoplasty plates.

The patient had positive changes in the postoperative period in the form of radicular pain syndrome as well as neck pain regression (VAS: 5 points). No changes were reported using the Nurick and JOA scales.

In the postoperative period, the average cross-sectional area of the dural sac increased to 2.19 ± 0.01 cm^2, according to the MRI scans ($p < 0.001$); the spinal canal volume was up to 16.4 cm^3 (Fig. 7, 8).

Multi-layer spiral CT results: the location of the plates and the bone flap was satisfactory (Fig. 9).

The patient was discharged on the 8th day under the doctor's supervision at the place of residence.

Discussion

The surgical treatment of a multilevel degenerative cervical stenosis is a complex and multi-stage challenge. This technique is the most effective in terms of permanent changes prevention in the spinal cord [5, 18]. The selection of the proper treatment strategy, including the analysis of the indications for surgery, the technique of the surgical aid and its scope, is still being discussed in the literature. [1, 5, 6, 15–19]. It is known that early surgical treatment has a significant advantage in terms of clinical outcomes [4, 15, 20].

The main goal is decompression of the spinal canal contents. There are 2 main approaches: anterior and posterior. Each of these approaches were at various development stages at different times. The choice of the decompression technique depends on many factors, namely: the number of stenotic segments, ossification of the posterior longitudinal ligament, the severity of spondylosis, kyphotic deformity, etc. As for the posterior approach, it all started with a laminectomy. This technique provides a complete decompression of the spinal canal contents and perfect visualization of neurovascular structures. Nevertheless, there are disadvantages of this technique: the formation of segmental instability and kyphotic deformity [9, 7, 21]. Therefore, the posterior decompression has undergone a number of changes. Currently, laminectomy followed by spinal fusion is widely used. The fixation is performed as transpedicular or lateral mass fixation. The expensive stabilizing systems intended to prevent the development of kyphotic deformity of the spine accelerate the degenerative process at adjacent segments. These findings were observed in a number of cases [7]. There is also a risk for fracture of screws used for spinal stabilization. This is an additional agressive factor for neurovascular structures.

It was Oyama who first described cervical laminoplasty in 1973.

Today, 2 main laminoplasty techniques are used: according to the type of open door, where only one side is sawn slightly, and to the type of French door, where spinous processes are sawed and forced apart. The literature sources describe complications associated with restenosis, migration of the fractured arch, and allografts [9]. Additionally, these techniques do not allow to fully visualize the neurovascular structures and safely perform hemostasis from varicose epidural veins. The bilateral laminoplasty technique, as in the case of laminectomy, provides an opportunity to fully visualize the neurovascular structures and avoid all of the above factors. More-

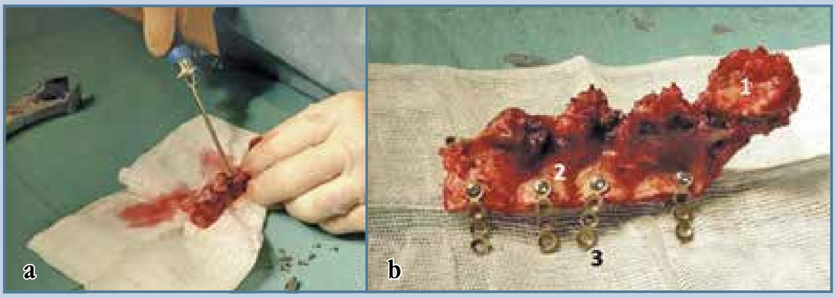

Fig. 4
Modeling of miniplates, fixing them to a bone flap **(a)** and a bone flap (ready for insertion; **b**): *1* – a spinous process; *2* – a vertebral arch; *3* – a titanium miniplate

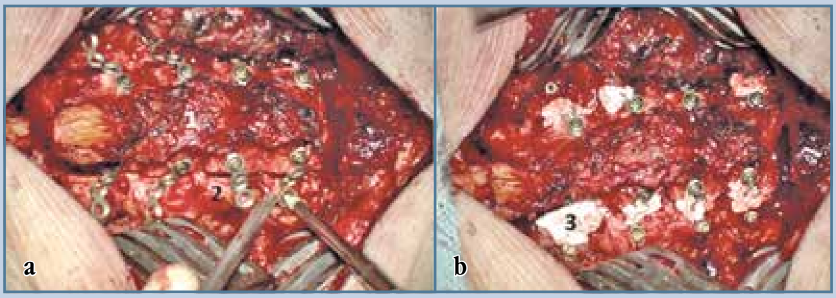

Fig. 5
The bone flap is fixed to the facet joints **(a)** and the osteoinductive material is applied to the miniplates **(b)**: *1* – a spinous process; *2* – a facet joint; *3* – an osteoinductive material

Table 1
The patients distribution (n = 26) according to the frequency of neurological disorders

Symptoms	Patients, n (%)
Radiculopathy	26 (100.0)
Superior paraparesis	3 (11.5)
Quadraparesis	9 (34.6)
Pelvic disorders	6 (23.1)
Trophic disturbances	7 (27.0)
Combination of symptoms	18 (69.2)

Table 2

Assessment of the linear and volumetric dimensions of the spinal canal via MRI scans in the pre- and postoperative periods

Characteristics	Before the operation	After the operation
Average cross-section size of the spinal canal, cm	0.90 ± 0.10	1.52 ± 0.08*
The average area of the spinal canal, cm^2	1.25 ± 0.30	2.26 ± 0.27*
The average spinal canal volume, cm^3	7.20 ± 0.20	13.40 ± 0.10*

*$p < 0.001$.

over, it allows to safely perform foraminotomy at the levels of interest.

Osteoinductive material contains chemical compounds attracting primitive stromal cells as well as immature bone cells and inducing their proliferation and differentiation into osteoblast cells [22]. Lauweryns et al. [23] compared the use of bone allograft and osteoinductive material ABM/P-15 (Anorganic Bone Mineral). It contains P-15 peptides that attract immature stromal cells. The study findings revealed that the inorganic mineral osteinductive materials containing the P-15 peptide are not worse in properties than the material from their own bone in terms of bone tissue formation. In this clinical group, we used the osteoinductive material i-Factor, which is also ABM/P-15 (Anorganic Bone Mineral). A patent for the invention is provided for this bilateral laminoplasty technique [24].

Conclusion

The technique of bilateral osteoplastic decompressive laminoplasty with simultaneous foraminotomy using osteoinductive material, if indicated, may be efficiently used in the treatment of extended stenosis of the cervical spine complicated by myelopathy and radicular disorders. It enables to significantly increase the transverse size of the spinal canal, the cross-sectional area of the dural sac and considerably decrease the radicular pain syndrome. Moreover, this method can reliably increase the volume of the spinal stenosis canal Nevertheless, additional comparative studies are required in the form of a retrospective analysis of the treatment findings of patients of two groups: those who underwent traditional open-door laminoplasty and those after bilateral laminoplasty.

The study had no sponsorship. The authors declare no conflict of interest.

Fig. 6
MRI of the cervical spine of the 67-year-old patient Sh.: **a** – sagittal plane; **b** – axial plane, cross-sectional area calculation of the dural sac in the Radiant Dicom Viewer software

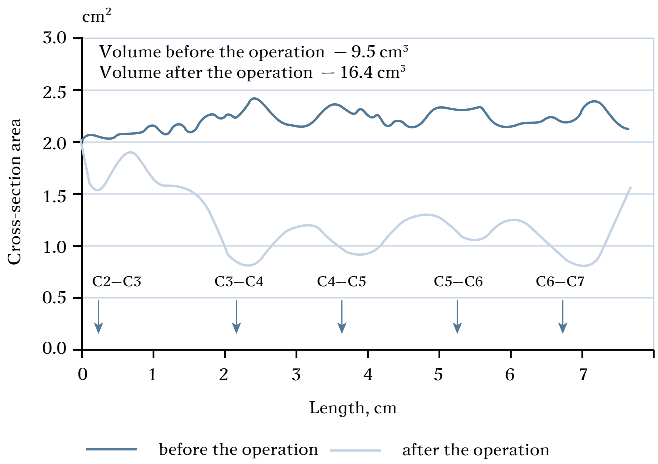

Fig. 7
The cross-sectional area of the spinal canal of the cervical spine in the 67-year-old patient Sh., at the levels of C3–C7 (the results of the 3D fast spin-echo MRI sequence were used for evaluation)

Fig. 8
MRI of the cervical spine of the 67-year-old patient Sh, on the 5th day after surgery: **a** – sagittal plane; **b** – axial plane: the condition after osteoplastic decompressive laminoplasty at the level of C3–C7, fixation with laminoplasty plates; no signs of central spinal stenosis

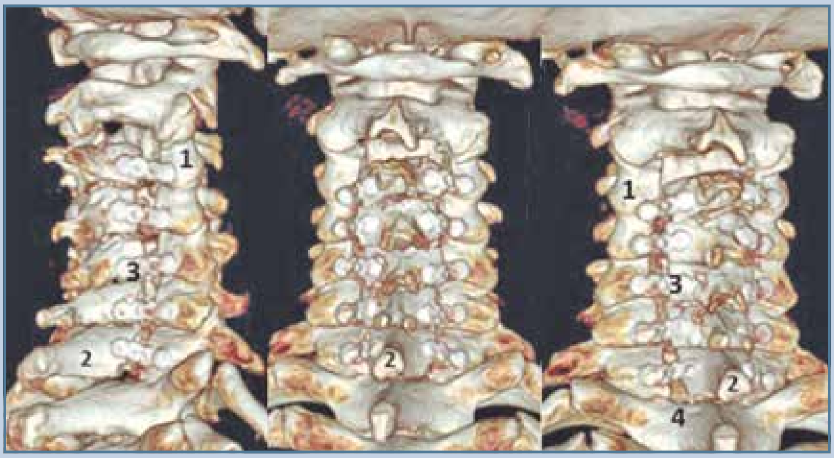

Fig. 9
3D-CT-volumetric reconstruction of the cervical spine: the condition after osteoplastic decompressive laminoplasty at the level of C3–C7, fixation with laminoplasty plates (*1* – a facet joint; *2* – a spinous process; *3* – a titanium miniplate; *4* – a persistent diastasis)

References

1. **Truumees E, Herkowitz HN.** Cervical spondylotic myelopathy and radiculopathy. Instr Course Lect. 2000;49:339–360.
2. **Boogaarts HD, Bartels RHMA.** Prevalence of cervical spondylotic myelopathy. Eur Spine J. 2015;24 Suppl 2:139–141. DOI: 10.1007/s00586-013-2781-x.
3. **Wang LN, Wang L, Song YM, Yang X, Liu LM, Li T.** Clinical and radiographic outcome of unilateral open-door laminoplasty with alternative levels centerpiece miniplate fixation for cervical compressive myelopathy: a five-year follow-up study. Int Orthop. 2016;40:1267–1274. DOI: 10.1007/s00264-016-3194-3.
4. **Yoon ST, Raich A, Hashimoto RE, Riew KD, Shaffrey CI, Rhee JM, Tetreault LA, Skelly AC, Fehlings MG.** Predictive factors affecting outcome after cervical laminoplasty. Spine. 2013;38(22 Suppl 1):S232–S252. DOI: 10.1097/BRS.0b013e3182a7eb55.
5. **Ma L, Liu FY, Huo LS, Zhao ZQ, Sun XZ, Li F, Ding WY.** Comparison of laminoplasty versus laminectomy and fusion in the treatment of multilevel cervical ossification of the posterior longitudinal ligament. A systematic review and meta-analysis. Medicine (Baltimore). 2018;97:e11542. DOI: 10.1097/MD.0000000000011542.
6. **Lin X, Cai J, Qin C, Yang Q, Xiao Z.** Comparison of clinical outcomes and safety between laminectomy with instrumented fusion versus laminoplasty for the treatment of multilevel cervical spondylotic myelopathy. Medicine (Baltimore). 2019;98:e14651. DOI: 10.1097/MD.0000000000014651.
7. **Nasto LA, Muquit S, Perez-Romera AB, Mehdian H.** Clinical outcome and safety study of a newly developed instrumented French-door cervical laminoplasty technique. J Orthop Traumatol. 2017;18:135–143. DOI: 10.1007/s10195-016-0440-9.
8. **Nakashima H, Kato F, Yukawa Y, Imagama S, Ito K, Machino M, Ishiguro N.** Comparative effectiveness of open-door laminoplasty versus French-door laminoplasty in cervical compressive myelopathy. Spine. 2014;39:642–647. DOI: 10.1097/brs.0000000000000252.
9. **Kurokawa R, Kim P.** Cervical laminoplasty: the history and the future. Neurol Med Chir (Tokyo). 2015;55:529–539. DOI: 10.2176/nmc.ra.2014-0387.
10. **Su N, Fei Q, Wang B, Li D, Li J, Meng H, Yang Y, Guo A.** Long-term outcomes and prognostic analysis of modified open-door laminoplasty with lateral mass screw fusion in treatment of cervical spondylotic myelopathy. Ther Clin Risk Manag. 2016;12:1329–1337. DOI: 10.2147/TCRM.S110340.
11. **Kothe R, Schmeiser G, Papavero L.** Open-door laminoplasty: What can the unilateral approach offer? Oper Orthop Traumatol. 2018;30:3–12. DOI: 10.1007/s00064-017-0527-3.
12. **Lee DH, Cho JH, Hwang CJ, Lee CS, Kim C, Ha JK.** Multilevel posterior foraminotomy with laminoplasty versus laminoplasty alone for cervical spondylotic myelopathy with radiculopathy: a comparative study. Spine J. 2018;18:414–421. DOI: 10.1016/j.spinee.2017.08.222.
13. **MacDowall A, Skeppholm M, Robinson Y, Olerud C.** Validation of the visual analog scale in the cervical spine. J Neurosurg Spine. 2018;28:227–235. DOI: 10.3171/2017.5.SPINE1732.
14. **Riew KD, Raich AL, Dettori JR, Heller JG.** Neck pain following cervical laminoplasty: does preservation of the C2 muscle attachments and/or C7 matter? Evid Based Spine Care J. 2013;4:42–53. DOI: 10.1055/s-0033-1341606.
15. **Fehlings MG, Wilson JR, Kopjar B, Yoon ST, Arnold PM, Massicotte EM, Vaccaro AR, Brodke DS, Shaffrey CI, Smith JS, Woodard EJ, Banco RJ, Chapman JR, Janssen ME, Bono CM, Sasso RC, Dekutoski MB, Gokaslan Z.** Efficacy and safety of surgical decompression in patients with cervical spondylotic myelopathy: results of the AOSpine North America prospective multi-center study. J Bone Joint Surg Am. 2013;95:1651–1658. DOI: 10.2106/JBJS.L.00589.
16. **Gibson J, Nouri A, Krueger B, Lakomkin N, Nasser R, Gimbel D, Cheng J.** Degenerative cervical myelopathy: a clinical review. Yale J Biol Med. 2018;91:43–48.
17. **Blizzard DJ, Caputo AM, Sheets CZ, Klement MR, Michael KW, Isaacs RE, Brown CR.** Laminoplasty versus laminectomy with fusion for the treatment of spondylotic cervical myelopathy: short-term follow-up. Eur Spine J. 2017;26:85–93. DOI 10.1007/s00586-016-4746-3.
18. **Sherman BP, Lindley EM, Turner AS, Seim HB 3rd, Benedict J, Burger EL, Patel VV.** Evaluation of ABM/P-15 versus autogenous bone in an ovine lumbar interbody fusion model. Eur Spine J. 2010;19:2156–2163. DOI: 10.1007/s00586-010-1546-z.
19. **Lauweryns P, Raskin Y.** Prospective analysis of a new bone graft in lumbar interbody fusion: results of a 2- year prospective clinical and radiological study. Int J Spine Surg. 2015;9:2. DOI: 10.14444/2002.
20. **Rhee JM, Register B, Hamasaki T, Franklin B.** Plate-only open door laminoplasty maintains stable spinal canal expansion with high rates of hinge union and no plate failures. Spine. 2011;36:9–14. DOI: 10.1097/BRS.0b013e3181fea49c.
21. **Liu X, Min S, Zhang H, Zhou Z, Wang H, Jin A.** Anterior corpectomy versus posterior laminoplasty for multilevel cervical myelopathy: a systematic review and meta-analysis. Eur Spine J. 2014;23:362–372. DOI:10.1007/s00586-013-3043-7.
22. **Pasku D, Katonis P.** Congenital defects of the atlas: an insidious malformation. J Spinal Res Found. 2009;4:29–31.
23. **Lauweryns P, Raskin Y.** Prospective analysis of a new bone graft in lumbar interbody fusion: results of a 2-year prospective clinical and radiological study. Int J Spine Surg. 2015;9:2. DOI: 10.14444/2002.
24. **Sufianov AA, Sufianov RA, Nabiev DN, Zajtsev MK, Cherkasov AV.** Method of laminoplasty at level of cervical spine. Patent RU 2726057 C1. Appl. 01.11.2019, publ. 08.07.2020. Bul. 19. In Russian.

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