LONG-TERM RADIOLOGICAL RESULTS OF ANTERIOR CERVICAL FORAMINOTOMY

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Objective. To evaluate the intervertebral disc height and mobility of the operated segment in patients with cervical compression monoradiculopathy of degenerative etiology after anterior cervical foraminotomy (ACF) in the late postoperative period.

Material and Methods. The study included 50 patients (44 ± 9 years, 28–72 years) after ACF with a long-term postoperative period. The height of the operated and adjacent intervertebral discs was measured by the interbody distance and by Farfan method on CT scans before and after surgery. The mobility of the operated and adjacent segments was measured by the interspinous distance on functional radiographs. The follow-up period ranged from 3 to 93 months (mean 22 months).

Results. The height of the adjacent superior, operated and adjacent inferior intervertebral discs before surgery was 4.6 ± 0.9 mm, 4.6 ± 0.9 mm and 5.1 ± 0.9 mm and after surgery – 4.4 ± 0.9 mm, 2.8 ± 1.0 mm and 4.8 ± 0.9 mm, respectively. The mobility of the operated segment at the ACF level was 3.7 ± 2.4 mm, and of the adjacent superior and inferior segments – 7.1 ± 3.8 mm and 6.8 ± 2.4 mm, respectively. The mobility of the operated segment of 3 mm or more was detected in 38 (76%) patients (convincing mobility), and less than 3 mm – in 12 (24%) patients (questionable mobility). A combination of preserved disc (intervertebral disc height > 0 according to the Farfan method) and convincing mobility of the operated segment (≥3 mm) was detected in 25 (50%) patients. In 4 (8%) patients, the disc was preserved, but the segmental mobility was questionable. Disc collapse (intervertebral disc height = 0 according to the Farfan method) with questionable mobility of the operated segment was detected in 8 (16%) patients. In the remaining 13 (26%) cases, disc collapse was accompanied by convincing mobility of the operated segment.

Conclusion. The intervertebral disc and/or mobility of the operated segment were preserved in 84% of cases after ACF.

Key Words: anterior cervical foraminotomy; intervertebral disc height; segmental mobility; Farfan method.

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In degenerative changes of the cervical spine, compression of the cervical nerve root in the overwhelming majority of cases is caused by a soft lateral sequestrum of the intervertebral disc or uncoforaminal stenosis. The most widely used method of surgical treatment of compression cervical radiculopathies for several decades is ACDF (Anterior Cervical Discectomy and Fusion) [1]. Anterior Cervical Foraminotomy (ACF) was proposed as an alternative to ACDF with the goal of preserving the intervertebral disc and the mobility of the operated segment [2]. According to literature reviews, ACDF and ACF have comparable clinical efficacy of radicular decompression [1]. In the Pubmed and Google Scholar databases we found 32 articles presenting the results of ACF. In the majority of articles, the emphasis is placed on clinical results of ACF, while key radiological parameters, such as intervertebral disc height and mobility of the operated segment, are insufficiently presented or not investigated at all, whereas it is precisely these two radiological parameters that constitute the distinctive essence and expected advantage of ACF.

Objective of the study was to evaluate the height of the intervertebral disc and the mobility of the operated segment in patients with cervical compression monoradiculopathy of degenerative etiology after ACF in the long-term postoperative period.

Material and Methods

The study included 50 patients with cervical compression monoradiculopathy operated on in the years 2018–2024 at the St. Petersburg City Multi-Disciplinary Hospital No. 2.

Inclusion criteria for the study: primary operated patients aged 18 and older with cervical compression monoradiculopathy of degenerative etiology.

Exclusion criteria: cervical myelopathy, instability of the segment.

All patients underwent ACF at a single level. The diagnostic program included MRI, CT and functional radiographs of the cervical spine before surgery, after surgery before discharge and in the long-term observation period (from 3 months).

Before surgery, all patients signed voluntary informed consent for the use of investigation results for scientific purposes. The protocol of ethical review was not formalized, since the conducted investigations did not go beyond the standard pre- and postoperative methods of managing patients with this pathology.

In all cases, the Smith-Robinson approach to the cervical spine from the side of radiculopathy was applied using an operating microscope and microsurgical instruments. In all patients, the

author's (patent No. RU 2815702[1]) parauncial variant of ACF was performed (Fig. 1). This variant of ACF is a minimized modification of the approach according to Snyder and Bernhardt [3]. Monodissector is used to perform marginal resection of the longus colli muscle to the medial edge of the uncinate process, thereby forming a platform for the start of milling. The milling corridor (initially with a cutting burr with a diameter of 4 mm, then diamond) passes parallel to the uncinate process. The diameter of the milling corridor is 6–7 mm. With a 2-mm Kerrison rongeur, the posterior longitudinal ligament is removed. In foraminal stenosis, the uncinate process must be resected. In this case, the base of the uncinate process is filed down with a burr. At all times it is necessary to control the edge of the uncinate process with a spatula. The thinned uncinate process is broken off with a conchotome and removed. With a pistol-grip rongeur, the remnants of the uncinate process are removed. Usually, after removing the uncinate process, venous bleeding appears – this bleeds from the venous plexus of the vertebral artery. Venous bleeding is stopped with a soft tamponade using a gelatin sponge.

In soft compression (preforaminal sequestrum) and a wide intervertebral foramen according to CT data, uncoforaminotomy was not performed, but only a marginal resection of the posterior third of the uncinate process was conducted. In preforaminal sequestrum with intraforaminal extension, the intraforaminal part was removed using a microhook. In foraminal stenosis and a deeply located intraforaminal sequestrum, the parauncial variant of Anterior Cervical Foraminotomy was supplemented with complete and partial uncoforaminotomy respectively.

The height of the intervertebral disc was measured in two ways according to CT data (in the sagittal plane in the "bone window" mode, slice thickness 0.6 mm) in the RadiAnt Digital Imaging and Communications in Medicine Viewer by the interbody distance and by the Farfan method (Fig. 2). The Farfan method takes into account the lens-shaped structure of the vertebral bodies.

The mobility of the operated segment was measured in millimeters as the difference of the corresponding interspinous distances on functional radiographs. The interspinous distance was measured with a ruler on a negatoscope and corrected to the true value according to the anteroposterior dimension of the selected vertebral body according to CT data in the RadiAnt DICOM Viewer software.

Segment instability was determined according to the White and Panjabi criteria (displacement of more than 3.5 mm, inclination angle of more than 11°).

Statistical analysis of the data and plotting of the graph were performed in the program Statistica 6.0. For each of the three levels, two statistical parameters were determined: arithmetic mean and standard deviation.

Results

The average age of the patients was 49 ± 9 years (24–75 years), 23 (46%) men, 27 (54%) women.

The number of operations performed by levels was distributed as follows: C3–C4 – 1 (2%), C4–C5 –1 (2%), C5–C6 – 19 (38%), C6–C7 – 26 (52%), C7–T1 – 3 (6%). Preforaminal soft sequestrum – 33 (66%), intraforaminal soft sequestrum – 12 (24%), foraminal stenosis – 5 (10%). The parauncial approach without uncoforaminotomy was performed in 33 (66%) patients, with uncoforaminotomy – in 17 (34%). The average observation period was 22 months (3–93 months).

According to the Odom scale, an excellent result was obtained in 36 (72.5%) patients, good – in 9 (17.5%), poor – in 5 (10%). Complications occurred in three patients – Horner's syndrome, hoarseness of voice and instability. Horner's syndrome and hoarseness of voice completely regressed within 6 months. In the patient with instability, pains in the neck completely regressed within 6 months after ACF. One patient was operated on (ACDF) due to persistent pains in the cervical spine. No recurrences were revealed.

The height of the intervertebral disc for the adjacent upper, operated and adjacent lower vertebrae before surgery was 4.6 ± 0.9 mm, 4.6 ± 0.9 mm, 5.1 ± 0.9 mm, after surgery – 4.4 ± 0.9 mm, 2.8 ± 1.0 mm, 4.8 ± 0.9 mm respectively (Fig. 3). The decrease in the height of the adjacent higher, operated and adjacent lower intervertebral discs was 0.18 ± 0.7 mm, 1.8 ± 1.06 mm and 0.33 ± 1.02 mm, respectively. A decrease in intervertebral disc height of less than 1 mm was determined in 12 (24%) patients, from 1 to 2 mm – in 20 (40%), more than 2 mm – in 18 (36%).

When measuring the intervertebral disc height by the Farfan method, in 29 (58%) patients the disc was preserved (Farfan > 0; Fig. 4). In 19 (38%) patients, a disc collapse was revealed (Farfan = 0; Fig. 5). In 2 (4%) patients, a bone block was formed.

In patients with uncoforaminotomy (34%), the disc height decreased on average by 1.26 ± 0.69 mm, and in patients without uncoforaminotomy (66%) – by 2.11 ± 1.13 mm. Up to 50% of its height the disc loses in the first 3–6 months after the operation, subsequently the decrease in height occurs slower.

The mobility of the operated segment after ACF was 3.7 ± 2.4 mm. The mobility of the adjacent upper and adjacent lower segments was 7.1 ± 3.8 mm and 6.8 ± 2.4 mm, respectively. Thus, the mobility of the operated segment after ACF is half the mobility of the adjacent segments. A mobility of the operated segment of less than 3 mm was determined in 12 (24%) patients. Such mobility we consider doubtful taking into account the measurement error. Mobility of the operated segment ⩾3 mm was revealed in 38 (76%) patients (convincing mobility).

A comparison of the intervertebral disc height and the mobility of the operated segment is presented in Table.

[1]*Patent No. RU 2815702. March 20, 2024. Bulletin No. 8. Shulev Yu.A., Stepanenko V.V., Pechiborshch D.A. Method formicrosurgical access to intervertebral foramen in patients with cervical radiculopathy. Appl. 21.09.2023. Access mode: https://patents.google.com/patent/RU2815702C1/ru*

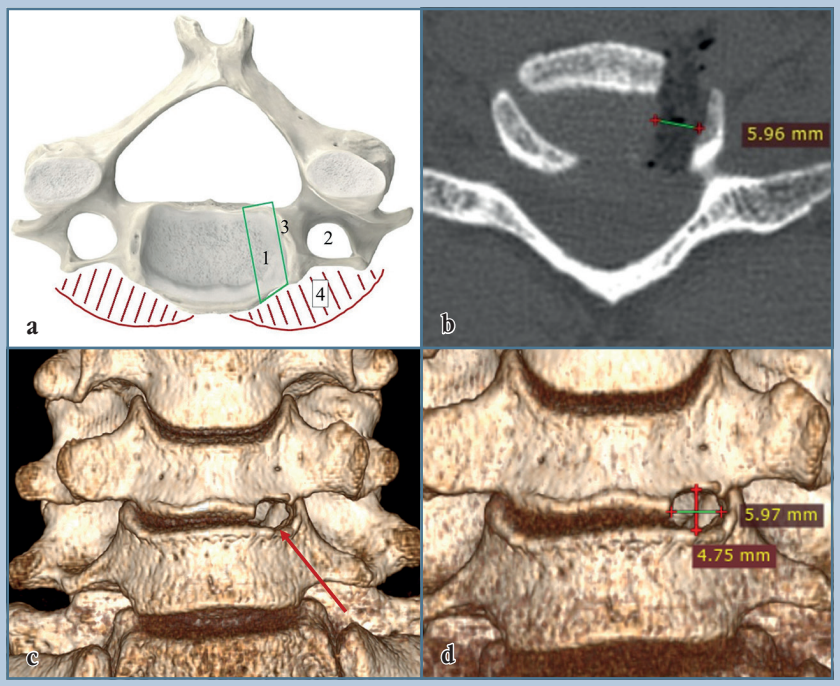

Fig. 1
Performing the parauncial variant of ACF (without uncectomy): **a** – schematic representation (*1* – entry point and boundaries of the milling corridor; *2* – intervertebral foramen; *3* – posterior third of the uncinate process; *4* – longus colli muscle); **b** – CT (axial slice); **c** – 3D CT, milling canal of ACF (indicated by arrow), anterior view; **d** – dimensions of the milling corridor

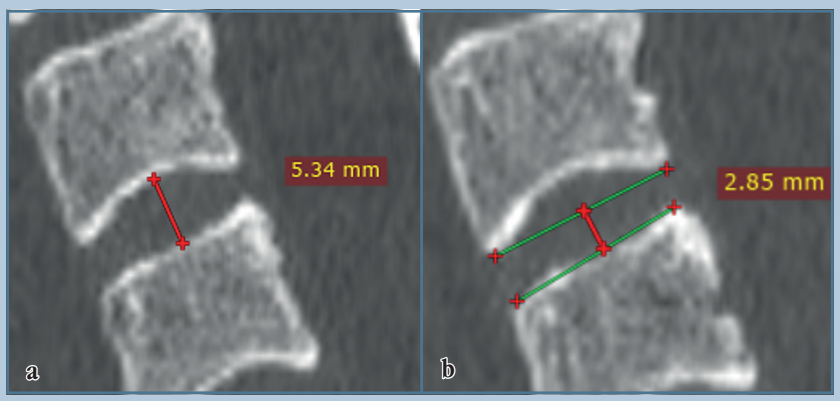

Fig. 2
Height of the intervertebral disc by interbody distance **(a)** and by Farfan method **(b)**

Discussion

Currently, in cervical compression radiculopathy in world practice, five surgical methods are applied: ACDF, Anterior Cervical Discectomy (ACD) without block, Anterior Cervical Foraminotomy (ACF), Posterior Cervical Foraminotomy (PCF) and Artificial Disc Replacement (ADR). Since the morphological substrates of compression are practically always located ventrally in relation to the cervical root, the anterior approach has an advantage over the posterior in the possibility of direct decompression. ACDF is considered the gold standard in the surgical treatment of compression cervical radiculopathies, however, the possible occurrence of adjacent segment syndrome became an incentive for the emergence of the concept of non-fusion surgery. The idea of non-fusion surgery began to develop in two directions of preserving the mobility of the operated segment – the natural way (ACF) and the artificial way (ADR). Since the general trend in neurosurgery is the striving to preserve anatomical structures and their functions, among the anterior approaches Anterior Cervical Foraminotomy seems the most attractive option.

The first attempt to preserve the mobility of the operated segment for the purpose of preventing adjacent segment syndrome was undertaken by Snyder and Bernhardt [3]. Their operation represented a partial Anterior Cervical Discectomy with the preservation of 2/3 of the intervertebral disc. The authors named their operation Anterior Cervical Foraminal Interspace Decompression (ACFID). With comparable clinical results to ACDF and ACFID, they demonstrated a decrease in the frequency of bone block formation from 60%, as with total ACD, down to 4%. The authors drew attention to the fact that all operated discs "significantly degenerated" due to surgical invasion.

It turned out that even minor surgical invasion of the cervical intervertebral disc triggers the process of its rapid degeneration up to disc collapse (disc height according to the Farfan method = 0). This phenomenon has received the name "needle puncture effect". "Needle puncture" is a classic method of provoking a degenerative cascade in the intervertebral disc in experimental animals. Biomechanical and biochemical reactions in the punctured disc are described depending on the diameter of the needle, the depth of needle penetration and the duration of the needle's

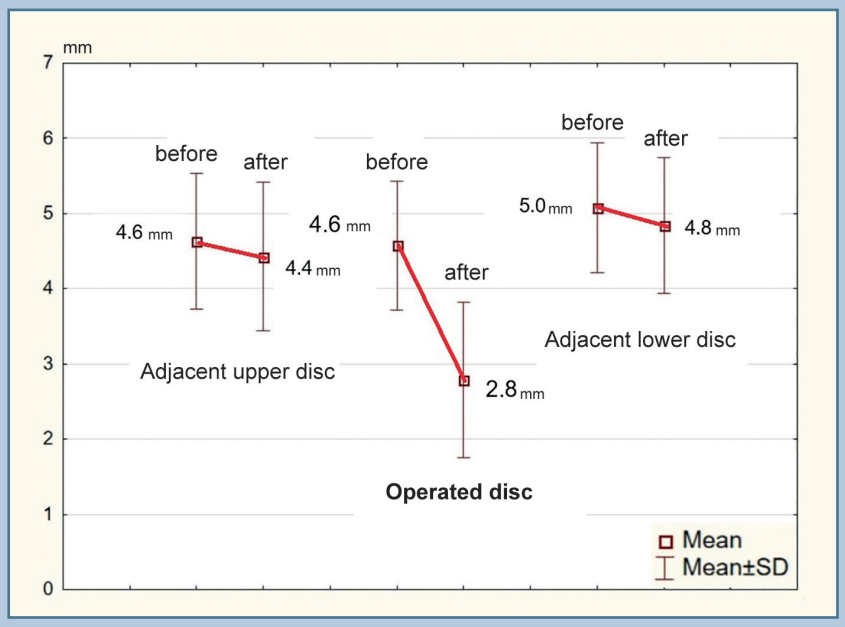

Fig. 3
Dynamics of the intervertebral disc height before and after ACF (according to the measurement method of interbody distance). Average values with standard deviations are presented

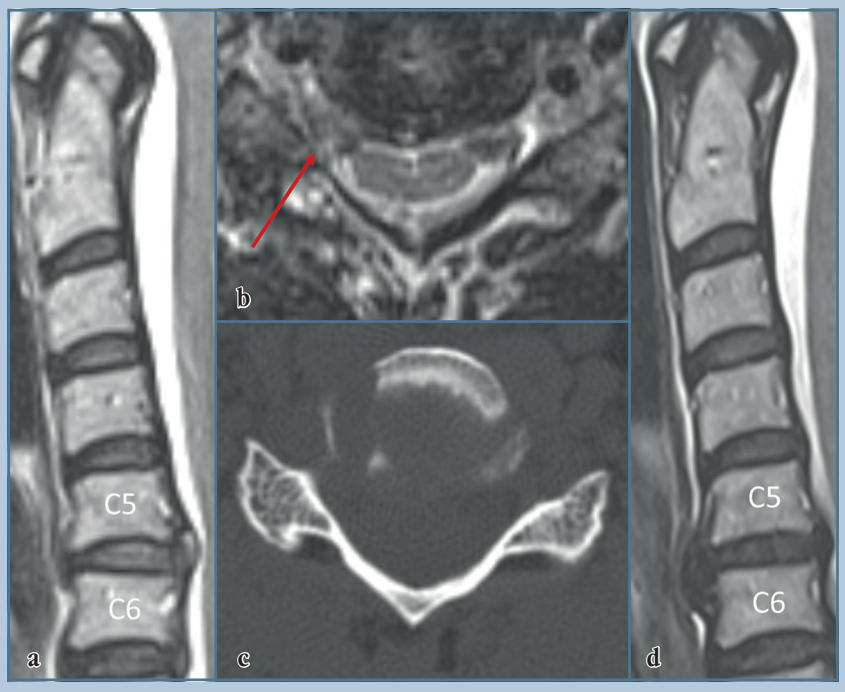

Fig. 4
The disc is preserved in patient K., aged 44, with a preforaminal sequestrum with intraforaminal extension of the C5–C6 vertebrae on the right (observation period 22 months): **a, b** – MRI before surgery; **c** – milling corridor on CT; **d** – postoperative MRI

presence in the disc in a wide variety of animals – from rats to cattle. Elliott et al. [4] on the basis of their own study, as well as an analysis of 23 articles on the influence of the ratio of the needle diameter to the disc height, came to the conclusion that such a ratio has significant importance for disc degeneration. The needle puncture effect was also shown on human cervical intervertebral discs with erroneous level marking in patients during ACDF [5].

In 1996, Jho [2] proposed the ACF operation and defined its concept: preservation of the natural mobility of the operated segment and its function through the minimum possible surgical trauma of the cervical disc from an anterior approach. Jho explains that for ACF, what is fundamental is not the resection of the uncovertebral joint, but the "integrity of the intervertebral disc". ACF according to Jho is "surgery of the intact disc" [2]. In the original variant (transuncal variant of ACF, "Jho procedure"), the approach passes in a very narrow corridor through the uncinate process between the vertebral artery and the intervertebral disc in order to minimize surgical invasion of the disc. Jho even suggested preserving the medial wall of the uncinate process as a protector of the intervertebral disc. On the other hand, the ACF variant according to Jho, being the most sparing in relation to the intervertebral disc, presents the greatest risks for the vertebral artery and sympathetic trunk. Subsequently, the original variant of ACF was modified into various compromise variants to move away from direct contact with the vertebral artery. Currently, ACF is a multitude of anterior minimally invasive milling approaches with a common end point – the posterior part of the uncinate process, which forms the medial wall of the intervertebral foramen (hence foraminotomy). This point is key, since having reached it, any factor of nerve root compression can be removed. The variants of ACF differ in various entry points and, accordingly, different trajectories. Each variant of ACF has its own balance of risks, the key ones of which are damage to the vertebral artery and sympathetic trunk on the

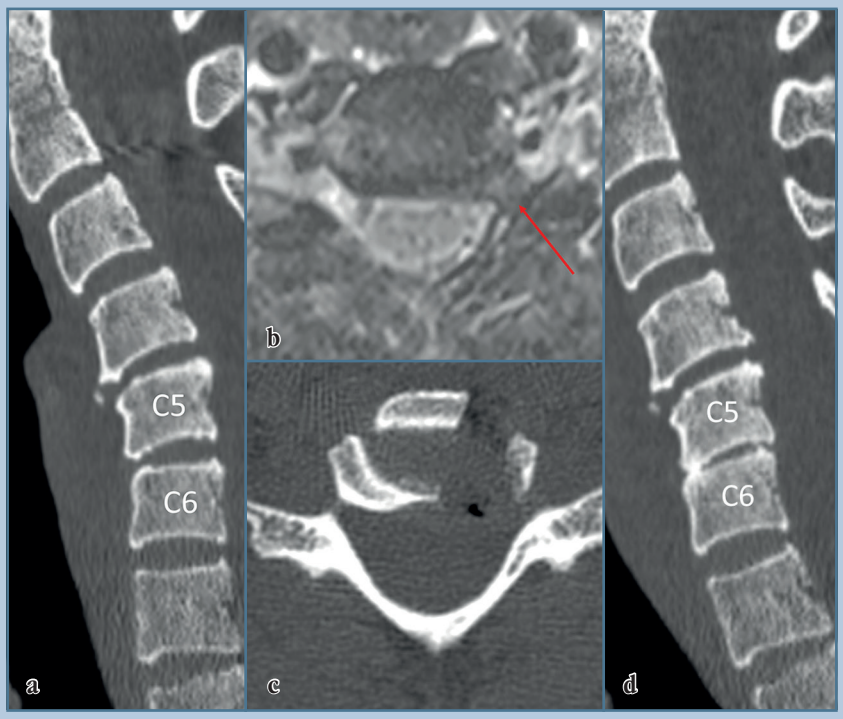

Fig. 5
Disc collapse in a 37-year-old female patient X., with a left-sided C5–C6 intraforaminal sequestration (follow-up period of 4 months): **a, b** – preoperative CT and MRI; **c, d** – postoperative CT

Table
Comparison of intervertebral disc height and mobility of the operated segment

Mobility of the operated segment	Disc preserved (Farfan >0)	Disc collapse (Farfan = 0)	Bone block
Convincing (≥3 mm)	25 (50 %)	13 (26 %)	0
Doubtful (<3 mm)	4 (8 %)	6 (12 %)	2 (4 %)

one hand and collapse of the intervertebral disc on the other. Jho distinguishes 3 variants of ACF: transuncal, upper transbody and lower transbody [2]. Han et al. [6] classify all variants of ACF into the classic transuncal and modifications of ACF. Ohtake et al. [7] distinguish three types of ACF: ACF Interspace Decompression (ACFID) (according to Snyder and Bernhardt) with an approach through the disc, transuncal type (according to Jho) and transvertebral type (according to Choi [8]).

We began applying ACF in 1999, to date more than 500 operations have been performed. Over the past 25 years, ACF in our neurosurgical department has undergone an evolution and currently represents an author's (parauncal) compromise variant – safer for the patient than ACF according to Jho, and less invasive for the intervertebral disc than ACFID according to Snyder.

The height of the intervertebral disc is a fundamental parameter in preserving the natural mobility of the segment, and a decrease in disc height is a key radiological criterion for disc degeneration [9]. A significant decrease in the disc height of the operated segment, according to our data, is the most characteristic radiological change after ACF. A decrease in the disc height of the operated segment shortly after ACF has already been described in the literature. Data on the dynamics of disc height before and after ACD are presented in 8 out of 32 works on the results of ACF, while in all articles measurements were carried out according to radiographs. The transuncal variant of ACF (Jho method), despite attempts to preserve the integrity of the disc, in the majority of patients leads to a significant decrease in the disc height of the operated segment – on average by 1 mm [6, 10–15].

Hong et al. [10] revealed a decrease in the disc height of the operated segment after the transuncal variant of ACF (40 patients) by 0.8 mm and the upper transbody variant of ACF (20 patients) by 0.3 mm. Measurements were carried out 3 months after surgery. The authors concluded that the upper transbody variant of ACF is better for preserving the disc than the transuncal one.

According to the data of Kim et al. [11], in 82 patients (97 transuncal ACF) the disc height of the operated segment after 3.1–8 years decreased on average by 1 mm. A change in disc height before ACF and in the immediate period after ACF was not revealed, however, in the majority of patients the disc decreased in height in the first 3 months after ACF. The decrease in disc height correlated with the degree of surgical invasion of the disc and with the diameter of the milling canal. According to the authors' data, a milling canal diameter of more than 4.7 mm is critical for disc degeneration. It was determined that the degree of disc invasion is of greater importance than the diameter of the milling canal as a cause of the decrease in disc height after ACF. The authors write: "To save disc height, we recommend avoiding any damage to it during ACF" [11].

Park et al. [12] performed ACF (transuncal variant) on 50 patients and revealed a decrease in disc height in all operated patients. Considering that

the height of adjacent discs after ACF decreased insignificantly compared to the operated one, the authors consider surgical invasion to be the main cause of significant disc degeneration in the operated segment. ACF in patients with a normal disc or with insignificant degenerative changes usually leads to a faster and more significant decrease in disc height than in patients whose disc has signs of moderate or severe degeneration. In connection with this, the authors recommend using PCF or ADR in patients with insignificant disc degeneration [12]. A. Gushcha believes that with a soft lateral sequestrum "the application of PCF is most appropriate". The author uses ACF for radicular compression by an osteophyte [16]. Cornelius et al. [17] also use ACF only for rigid radicular compression.

According to the results of the study by Han et al. [6], in 24 patients after ACF (transuncal variant), the disc height in the operated segment decreased on average by 1 mm at the final examination after 6.4–9.8 years. The degree of disc invasion during ACF correlates with a decrease in disc height, a decrease in its mobility, as well as the formation of osteophytes. The authors concluded that "intraoperative disc invasion during ACF could have been a trigger for disc degeneration [6]".

According to Son et al. [13], in 62 patients after ACF (transuncal variant), the disc height in the operated segment after a year decreased on average by 0.6 mm and by 1.06 mm at the final examination after 10.0–14.5 years. With the goal of minimizing surgical trauma to the disc, Choi et al. [8] proposed ACF in the variant of transbody approach (through the middle of the vertebral body). Despite all attempts to preserve the disc intact, the operated disc decreased in height by 0.4 mm according to radiographs predominantly in the first 3 months after ACF.

Kim et al. [14] conducted an analysis of the dynamics of disc height after ACF and PCF according to radiographs and came to the conclusion that the disc height after PCF during one year did not change significantly, whereas after ACF the disc height after 1 month, 6 months and 1 year decreased by 0.4, 0.6 and 0.6 mm respectively. Thus, according to Kim et al. [14], the disc height decreases in the first 6 months after ACF, subsequently the disc height stabilizes, while the most significant decrease in disc height occurs during the first month after ACF. The insignificant change in the disc height of the operated segment in all works after PCF indicates an important conclusion: a disc tear with the formation of a sequestrum does not provoke accelerated disc degeneration.

According to our data, after the parauncal variant of ACF, the intervertebral disc height in the operated segment decreased on average by 1.8 mm (according to CT results). The decrease in the disc height of the operated segment after ACF in patients with soft compression is more significant (2.1 mm) than in patients with foraminal stenosis (1.3 mm), which is due to more pronounced initial disc degeneration in foraminal stenosis. At the same time, the disc degenerates to the greatest extent in the first 3–6 months after ACF. This is consistent with the data of other authors [8, 10, 14]. In the literature, we did not encounter works where the intervertebral disc height before and after ACF was measured according to CT data.

In our series, a spontaneous bone block was revealed in 2 (4%) patients. The cause of the formation of a spontaneous bone block is complete disc degeneration with the formation of a fibrous fusion, which is subsequently fixed by marginal osteophytes [18]. Such an outcome is typical for ACD. The parauncal variant of ACF, as well as other trans-disc variants of ACF are essentially a miniature or minimalist ACD [19]. The highest occurrence of spontaneous block after ACF is presented in Pechlivanis et al. [20]: out of 96 patients, 2 years after ACF, a spontaneous block was revealed in 28.6% of patients. The authors concluded that uncoforaminotomy cannot preserve the motion segment in every patient. In the works of other authors, a spontaneous bone block in the long-term period after ACF was revealed in 1% [2], 4% [3], 10% [11], 10.1% of cases [12]. Thus, according to literature data, as well as the results of our study, ACF inevitably causes significant degeneration of the intervertebral disc of the operated segment, despite all attempts to minimize its surgical invasion.

The mobility of the operated segment after ACF can be caused by two different reasons. The first is the natural mobility of the segment due to relative preservation of the disc (Farfan > 0), the second is segment mobility during disc collapse (Farfan = 0) due to the formation of fibrous fusion [18]. Such mobility can be combined with instability of the operated segment. The mobility of the operated segment after ACF in the long-term period has been quantitatively measured only according to data from isolated studies. In these works, a significant decrease in the mobility of the operated segment compared to adjacent levels after ACF is shown [7, 12]. At the same time, the methods of measuring segment mobility in the works are different. We investigated the dynamics of mobility of the operated and adjacent segments by the method of measuring the interspinous distance according to functional radiographs data. This method, according to the opinion of Ohtake et al. [7], is the most accurate. We determined convincing mobility of the operated segment (⩾3 mm) in 31 (62%) patients, while the mobility of the operated segment turned out to be approximately half the mobilities of the adjacent segments. The significant decrease in the mobility of the operated segment, according to our data and literature data, is due to significant degeneration of the disc of the operated segment.

Considering the insignificant (0.2 mm) decrease in the height of adjacent discs in our series, most likely caused by natural degenerative changes, we believe that ACF does not have a significant impact on the degeneration of adjacent levels. A similar conclusion is made by other authors [7, 12, 13].

The clinical correlation of the revealed radiological changes is of interest. Many authors believe that neck and shoulder pain after ACF is caused by iatrogenic instability of the operated segment, although it is often not confirmed radiologically in accordance with the White-Panjabi criteria (displacement ⩾3.5 mm or angu-

lation >11 degrees). It is possible that the application of more sensitive scales, such as the Guigui scale (displacement >2 mm or angulation >5°), will be more accurate for the verification of instability of the cervical spine after ACF [21]. Some authors believe that uncectomy predisposes to instability after ACF. We did not reveal a correlation between significant neck pains after ACF and uncforaminotomy. Also, the only case of radiologically confirmed instability after ACF in our series was in a patient with a preforaminal sequestrum, who did not undergo uncoforaminotomy. According to our data, the appearance or intensification of neck and/or shoulder pains after ACF correlates with the collapse of the intervertebral disc of the operated segment. Other authors have also revealed a similar correlation [11]. However, clinical-radiological correlations are not the goal of this article and will be presented in detail in the next work.

Conclusion

ACF allows preserving the intervertebral disc in 58% of patients and convincing mobility in the operated segment in 76% of patients, while the disc is preserved in combination with convincing mobility in only 50% of patients. The mobility of the operated segment is reduced and amounted to approximately half of the mobility of adjacent segments. ACF in all patients leads to a significant decrease in the intervertebral disc height at the operated level (on average by 1.8 mm) in the period from 3 to 93 months (on average 22 months) after the operation. Thus, in 84% of cases after ACF, the intervertebral disc and/or mobility of the operated segment is preserved.

References

1. **Gao QY, Wei FL, Zhu KL, Zhou CP, Zhang H, Cui WX, Li T, Qian JX, Hao DJ.** Clinical efficacy and safety of surgical treatments in patients with pure cervical radiculopathy. *Front Public Health*. 2022;10:892042. DOI: 10.3389/fpubh.2022.892042
2. **Jho HD.** Failed anterior cervical foraminotomy. *J Neurosurg*. 2003;98(2 Suppl):121–125; discussion 125. DOI: 10.3171/spi.2003.98.2.0121
3. **Snyder GM, Bernhardt M.** Anterior cervical fractional interspace decompression for treatment of cervical radiculopathy. A review of the first 66 cases. *Clin Orthop Relat Res*. 1989;(246):92–99.
4. **Elliott DM, Yerramalli CS, Beckstein JC, Boxberger JI, Johannessen W, Vresilovic EJ.** The effect of relative needle diameter in puncture and sham injection animal models of degeneration. *Spine (Phila Pa 1976)*. 2008;33:588–596. DOI: 10.1097/BRS.0b013e318166e0a2
5. **Nassr A, Lee JY, Bashir RS, Rihn JA, Eck JC, Kang JD, Lim MR.** Does incorrect level needle localization during anterior cervical discectomy and fusion lead to accelerated disc degeneration? *Spine (Phila Pa 1976)*. 2009;34:189–92. DOI: 10.1097/BRS.0b013e3181913872
6. **Han C, Kim MH.** Extent of disc degeneration after single-level cervical anterior microforaminotomy analyzed with long-term radiological data. *J Korean Neurosurg Soc*. 2014;56:200–205. DOI: 10.3340/jkns.2014.56.3.200
7. **Ohtake Y, Hanakita J, Takahashi T, Minami M, Nakamura H, Kawaoka T.** Long-term radiological evidence of affected and adjacent segment disease after anterior cervical foraminotomy. *Neurol Med Chir (Tokyo)*. 2020;60:492–498. DOI: 10.2176/nmc.oa.2020-0053
8. **Choi G, Lee SH, Bhanot A, Chae YS, Jung B, Lee S.** Modified transcorporeal anterior cervical microforaminotomy for cervical radiculopathy: a technical note and early results. *Eur Spine J*. 2007;16:1387–1393. DOI: 10.1007/s00586-006-0286-6
9. **Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N.** Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine (Phila Pa 1976)*. 2001;26:1873–1878. DOI: 10.1097/00007632-200109010-00011
10. **Hong WJ, Kim WK, Park CW, Lee SG, Yoo CJ, Kim YB, Jho HD.** Comparison between transuncal approach and upper vertebral transcorporeal approach for unilateral cervical radiculopathy – a preliminary report. *Minim Invasive Neurosurg*. 2006;49:296–301. DOI: 10.1055/s-2006-954828
11. **Kim MH.** Clinical and radiological long-term outcomes of anterior microforaminotomy for cervical degenerative disease. *Spine (Phila Pa 1976)*. 2013;38:1812–1819. DOI: 10.1097/BRS.0b013e31827ddd9e
12. **Park YK, Moon HJ, Kwon TH, Kim JH.** Long-term outcomes following anterior foraminotomy for one- or two-level cervical radiculopathy. *Eur Spine J*. 2013;22:1489–1496. DOI: 10.1007/s00586-013-2712-x
13. **Son S, Kim WK, Lee SG, Ahn Y.** Long-term outcomes after microscopic anterior cervical foraminotomy with a minimum 10-year follow-up. *World Neurosurg*. 2019;122:e67–e80. DOI: 10.1016/j.wneu.2018.09.049
14. **Kim SJ, Seo JS, Lee SH, Bae J.** Comparison of anterior cervical foraminotomy and posterior cervical foraminotomy for treating single level unilateral cervical radiculopathy. *Spine (Phila Pa 1976)*. 2019;44:1339–1347. DOI: 10.1097/BRS.0000000000003081
15. **Klimov VS, Kelmakov VV, Clyde BL, Evsyukov AV, Loparev EA, Amelina EV, Bervitskiy AV, Ponomarenko AP, Rzaev JA.** Long-term clinical and radiological outcomes of anterior uncoforaminotomy for unilateral single-level cervical radiculopathy: retrospective cohort study. *Spine J*. 2021;21:915–923. DOI: 10.1016/j.spinee.2021.01.024
16. **Grigoryan YuA, Stepanyan MA, Onopchenko EV, Kadin LA, Khimochko EB, Lunina ES.** Microsurgical anterior foraminotomy in spondylogenic cervical radiculopathy (commentary by A.O. Gushcha). *Burdenko's Journal of Neurosurgery*. 2008;(2):31–35. EDN: JVBKZX
17. **Cornelius JF, Bruneau M, George B.** Microsurgical cervical nerve root decompression via an anterolateral approach: clinical outcome of patients treated for spondylotic radiculopathy. *Neurosurgery*. 2007;61:972–980; discussion 980. DOI: 10.1227/01.neu.0000303193.64802.8f
18. **Feiz-Erfan I, Klopfenstein JD, Bambakidis NC, Sonntag VK.** Surgical management of cervical disc disease: from no fusion to fusion and back again. *Clin Neurosurg*. 2005;52:331–337.
19. **White BD, Buxton N, Fitzgerald JJ.** Anterior cervical foramenotomy for cervical radiculopathy. *Br J Neurosurg*. 2007;21:370–374. DOI: 10.1080/02688690701441340
20. **Pechlivanis I, Brenke C, Scholz M, Engelhardt M, Harders A, Schmieder K.** Treatment of degenerative cervical disc disease with uncoforaminotomy – intermediate clinical outcome. *Minim Invasive Neurosurg*. 2008;51:211–217. DOI: 10.1055/s-2008-1080914
21. **Guigui P, Benoist M, Deburge A.** Spinal deformity and instability after multilevel cervical laminectomy for spondylotic myelopathy. *Spine (Phila Pa 1976)*. 1998;23:440–447. DOI: 10.1097/00007632-199802150-00006

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