Neurosurgical Review (2023) 46:247
https://doi.org/10.1007/s10143-023-02157-3

RESEARCH

Treatment of the two-level degenerative cervical disk diseases based on algorithmic anterior approach: a multicenter prospective study

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Received: 3 July 2023 / Revised: 4 September 2023 / Accepted: 12 September 2023
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Abstract

To analyze the effectiveness of an algorithmic anterior approach to the surgical treatment of patients with two-level cervical degenerative disk disease based on the preoperative clinical and imaging parameters. The study included 244 patients with two-level cervical degenerative disk disease. Three groups of patients were evaluated at 3 neurosurgical centers between 2016–2019. The prospective group (Group I, $n=126$) consisted of patients who were treated using an algorithm to decide whether they should be treated with a two-level Total Disk replacement (TDR), Anterior Cervical Discectomy and Fusion (ACDF) and hybrid technique. The control group (Group II, $n=118$) consisted of patients who underwent two-level anterior decompression with TDR, ACDF and hybrid stabilization between 2005–2015. Visual Analogue Scale (VAS) neck pain, VAS upper limbs pain, Neck Disability Index (NDI), SF-36, Macnab and Nurick scales were collected. Perioperative complications were identified. At 2 years of follow up Group I had significantly better clinical outcomes based on VAS neck pain score ($p=0.02$), VAS upper limbs pain ($p=0.04$), NDI score ($p=0.02$), SF-36 score ($p=0.01$), satisfaction with surgery on the Macnab scale ($p<0.001$) and outcome of surgery based on Nurick scale ($p<0.001$). Complication rate was lower in Group I, 6.3% compared to 24.6% in Group II, $p=0.0001$. The algorithmic anterior approach to the surgical treatment of patients with two-level cervical degenerative disk disease resulted in significant improvement of functional outcomes and a decrease in complications at a minimum 2 years of follow-up.

Keywords Cervical spine · Two-level degenerative disk disease · Total disk replacement · Anterior cervical discectomy and fusion · Hybrid stabilization · Surgical algorithm

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Published online: 18 September 2023

Introduction

Degenerative disk diseases of the cervical spine due to compression of the spinal cord and its roots are often accompanied by a clinically significant neurological deficit in the form of myelopathy or radiculopathy [1, 2]. Tactical and surgical approaches in the treatment of patients with two-level cervical degenerative disk diseases are ambiguous, in particular, when choosing a surgical approach and a stabilizing implant [3, 4]. The ambiguity of surgical tactics is largely related to the location of the compressive substrate in relation to the spinal cord, the presence and severity of morphological changes in the spinal cord, surgeon preference, the availability of implants for a medical institution, and the fact that the posterior approach is more traumatic and is associated with high risk of developing C5 nerve root palsy, axial neck pain, segmental instability and progressive cervical kyphosis compared with an anterior approach with stabilization [1–3].

Most often for anterior surgical interventions for two-level degenerative diseases of the cervical intervertebral discs, two-segment Anterior Cervical Discectomy and Fusion (ACDF), Total Disk Replacement (TDR), or a combination of both are used [5, 6]. The choice of surgical treatment depends of severity of degenerative changes in intervertebral disk (IVD) and facet joints (FJ), spinal alignment and preservation of segmental mobility [7, 8]. At the same time, an incorrectly chosen surgical method is associated with unsatisfactory results, adversely impacts the long-term outcomes [9, 10].

The study of the effectiveness of TDR, ACDF and hybrid surgery in patients with two-level cervical degenerative disk disease is reflected in a few publications [5, 11, 12]. The absence of unified clinical and instrumental criteria for the differentiated use of these surgical technologies was the impetus for the development of personalized surgical tactics in patients with two-level cervical degenerative disk disease. We had previously examined the causes of unsatisfactory outcomes following two-segment surgical interventions for TDR, ACDF and their combination in patients with two-level cervical degenerative disk disease. They had been treated in the first author's institution from 2005 to 2015 without any standardized protocol. A retrospective analysis of those patients found that those who had been treated with TDR did best if they had the following characteristics: degenerative changes were detected in IVD according to Pfirrmann C. I-III degree, in FJ according to Pathria M. I-II degree, segmental Range Of Motion (ROM) more than 8^0, Interbody Height (IH) more than 6 mm. On the other hand, the ACDF worked better in those with preoperative degenerative changes were detected in IVD according to Pfirrmann C. more than III degree, in FJ according to Pathria M. more than II degree, segmental ROM 8^0 or less, IH less than 6 mm. Based on these findings, we came up with an algorithm that took into account all of these factors. We have confirmed that the best clinical and instrumental outcomes are associated: in patients with symptomatic two-level cervical degenerative disk disease; anterior compression of the neural structures; C2–C7 lordotic angle > —7 degrees; absence clinical symptoms and signs of myelopathy; absence of MR cord signal change [13].

Given the above, we believe that a treatment algorithm aimed at improving clinical results would be of benefit to spine surgeons. Since 2016, we have been utilizing and prospectively investigating the effectiveness of an algorithmic approach to the surgical treatment of two-level degenerative cervical disk disease. The purpose of the study was to evaluate the results of using the proposed algorithm in a prospective group in order to confirm the feasibility of eliminating risk factors for the formation of unsatisfactory outcomes in this category of patients.

Materials and methods

Patients data

Prospective non-randomized multi-center cohort study was approved by the ethics committee of Irkutsk State Medical University (Protocol No. 3 dated 15.11.2016). Each patient gave voluntary consent to be included in the study. We developed an algorithm to guide the anterior treatment of two-level degenerative cervical disk disease and prospectively evaluated its efficacy with radiographic and clinical outcomes instruments. The prospective group underwent procedures in a non-randomized manner from 2016–2019 in the neurosurgical departments of 3 hospitals: Irkutsk (Russia), *Krasnoyarsk (Russia), Almaty (Kazakhstan)*. In order to minimize the influence on the treatment outcome of patient selection factors, the experience of the surgeon and the operating technique at the bases of the three departments, the outcomes from that database were utilized and a general research protocol was developed. This produced a uniform algorithmic approach that was agreed upon and approved by three operating surgeons – all heads of neurosurgical departments. Prior to the protocol development, none of the three centers had a uniform approach and all three centers noted improved outcomes, as one would expect.

Their outcomes were compared to historical controls who had been treated from 2005 to 2015 without any standardized protocol at the *Hospital 1*.

To minimize the influence of the surgeon's experience on the outcome of the operation, surgeons with at least 15 years of experience in surgery were included in the

study. In the historical group, the surgeon had 20 years of experience. In the prospective group, there were 3 main surgeons, with 17, 19 and 20 years of experience.

Inclusion criteria

At prospective group we utilized the algorithm for patients following inclusion criteria: symptomatic two-level cervical degenerative disk disease; anterior compression of the neural structures; C2–C7 lordotic angle > − 7 degrees; absence clinical symptoms and signs of myelopathy; absence of MR cord signal change.

Exclusion criteria

Isolated posterior or circumferential compression, asymptomatic two-level disease; single-level or multilevel degenerative cervical disk disease; C2–C7 lordotic angle < − 7 degrees; clinical manifestations of myelopathy without cord compression on MR; the presence of MR cord signal change; traumatic or inflammatory disease of the cervical spine; previous cervical operation; significant osteoporosis; instability.

Figure 1 outlines the algorithm that was utilized for the prospective study. TDR was limited to those with preservation of movements in the segment and minimal degeneration of the IVD and FJ due to the fact that in our

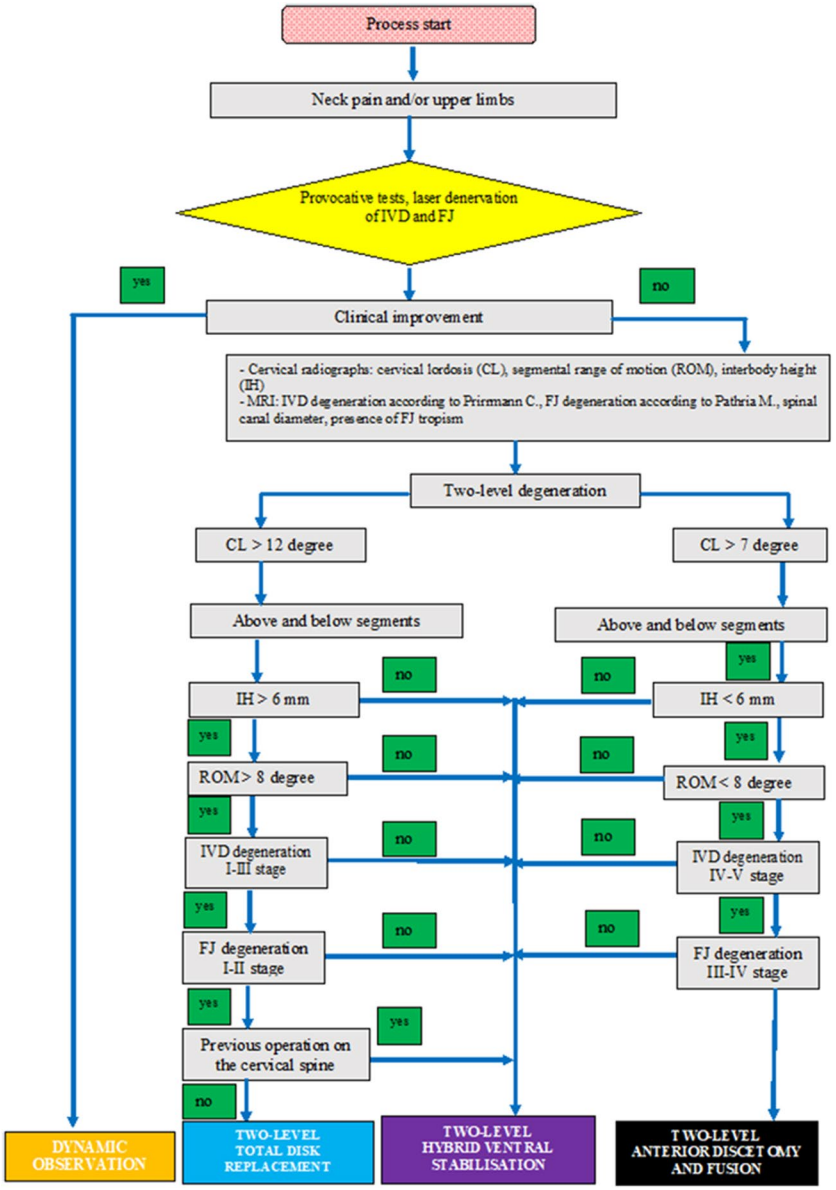

Fig. 1 Algorithm for the surgical treatment of patients with two-level cervical degenerative disk disease [13] (IVD—intervertebral discs, FJ—facet joints)

pilot retrospective study, those with severe degeneration of the IVD and FJ, presence of FJ tropism and spinal canal stenosis did better with a ACDF (Fig. 2).

Surgical technique

Surgical interventions were performed under general anesthesia, using optical magnification, and x-ray control. We used an anterior retropharyngeal approach to perform a two-level TDR, ACDF and hybrid technique.

Group I consisted of patients who were treated as per the algorithm outlined in Fig. 1. TDR was performed when degenerative changes were detected in IVD according to Pfirrmann C. I-III degree, in FJ according to Pathria M. I-II degree, segmental ROM more than 8^0, IH more than 6 mm. ACDF was performed when degenerative changes were detected in IVD according to Pfirrmann C. more than III degree, in FJ according to Pathria M. more than II degree, segmental ROM 8^0 or less, IH less than 6 mm.

Group II consisted of patients who had been treated with anterior two-levels cervical procedures during 2005–2015 without any defined protocol. To be included, they had to have 2-year follow-up.

Outcomes of the study

All patients in both groups had the following assessments preoperatively and at each post-operative visit: cervical lordosis (CL) on the plane X-rays, segmental ROM according to flexion–extension X-rays, 1.5 T MRI, CT, perioperative complications, Visual Analogue Scale (VAS) for cervical pain, VAS upper limbs, Neck Disability Index (NDI), SF-36 (Physical Component Score – PCS, Mental Component Score – MCS), Macnab and Nurick scales.

Statistical analysis

Data was entered into Microsoft Excel and Statistica 13.5. The distribution pattern was based on the Shapiro–Wilk, Kolmogorov–Smirnov and Lil'efors tests. Taking into account the presence of significant differences according to these tests ($p < 0.05$), the distribution was considered to be different from normal, in connection with which the assessment of the significance of the differences in the sample sets was made according to the criteria of nonparametric statistics; a level of $p < 0.05$ was considered as the lower confidence limit. The data

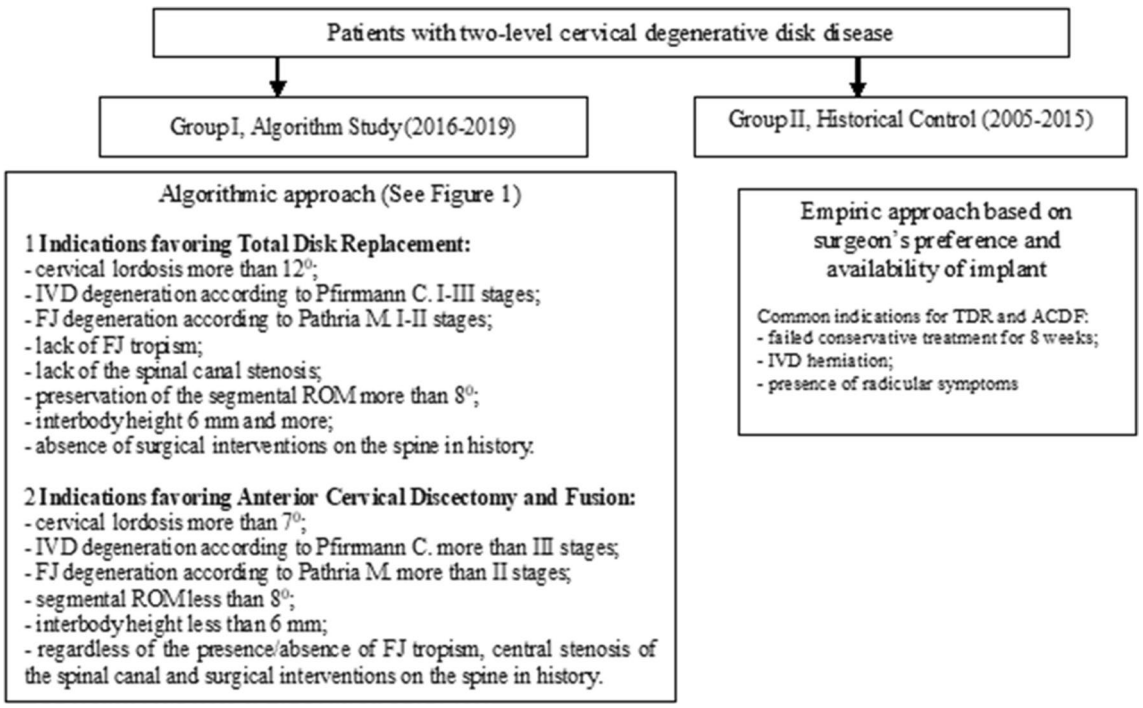

Fig. 2 Flowchart for study selection

were presented as the median, the values of the 1st and 3rd quartiles—Me (Q_{25}; Q_{75}). The following nonparametric statistics criteria were used: the Mann–Whitney test for intergroup comparison, Friedman's criterion for dependent samples, and Fisher's exact test for binomial parameters.

Results

At baseline, 281 patients with two-level cervical degenerative disc diseases were included in the study, in Group I are excluded 19 patients ($n = 17$—loss of follow-up; $n = 2$—refusal to participate in the study), in Group II are

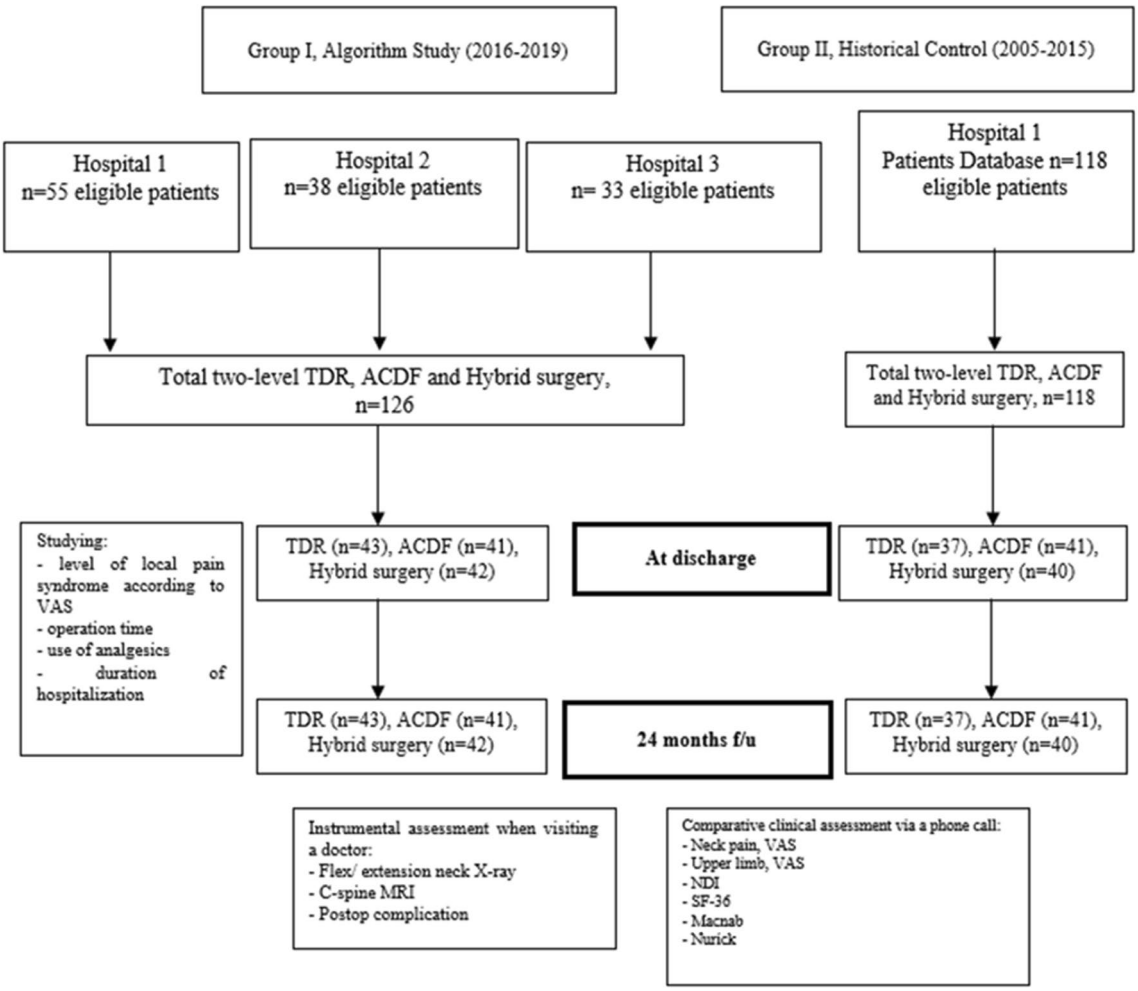

Fig. 3 A total of 244 patients underwent surgery for two-level cervical degenerative disk disease. Note: TDR – Total Disk Replacement; ACDF – Anterior Cervical Discectomy and Fusion; VAS – visual analogue pain scale; NDI – Neck Disability index; MRI – Magnetic resonance imaging

Table 1 Characterization of patients of the studied groups

Criteria		Group I ($n = 126$)	Group II ($n = 118$)	p
Age, years		41 (35; 53)	39 (32; 57)	0.25
Male / female ratio, *n, %*		75 (59.5)/ 51 (40.5)	75 (63.5)/ 43 (36.5)	0.30
Surgery level, *n, %*	C3-C4, C4-C5	9 (7.2)	11 (9.3)	0.46
	C4-C5, C5-C6	40 (31.7)	37 (31.4)	
	C5-C6, C6-C7	69 (54.8)	63 (53.4)	
	C6-C7, C7-T1	8 (6.3)	7 (5.9)	
Observation period, mon		29 (26; 33)	42 (32; 64)	–

excluded 18 patients ($n=13$—loss of follow-up; $n=4$—refusal to participate in the study; $n=1$—death unrelated to the operation (there were no postoperative complications)). There was a total of 244 patients with two-level cervical degenerative disk disease enrolled in the study (Fig. 3). Information about the patients included in the study is shown in Table 1. According to the studied characteristics, there were no intergroup differences revealed in gender, age and surgery level ($p>0.05$). The average follow-up was 29 months in Group I and 42 months in Group II.

Pre-operatively, in both Groups I and II, the majority of patients had radicular pain (96.8% and 98.3%, respectively, $p=0.42$), neck pain (94.4% and 93.2%, respectively, $p=0.64$), dermatomal loss of sensation (76.2% and 82.2%, respectively, $p=0.39$), and decreased deep tendon reflexes of the upper extremities (62.6% and 63.5%, respectively, $p=0.27$).

Preoperatively, there were no statistically significant differences ($p>0.05$) between the two groups in neck pain, upper limbs, NDI and SF-36. Post-operatively, there was a significant decrease in the severity of neck pain according to VAS from 81 mm (76; 95) to 8 mm (5; 12) ($p=0.002$) and pain in upper limbs according to VAS from 91 mm (76; 93) to 2 mm (0; 5) ($p=0.001$) in Group I, their NDI, SF-36 (PCS) and SF-36 (MCS) values improved post-operatively from 42 (40; 44) to 8 (6; 10) ($p=0.003$), from 28.72 (19.83; 36.54) to 55.29 (51.83; 57.29) ($p=0.001$) and from 32.21 (18.28; 38.99) to 57.66 (51.25; 59.22) ($p=0.005$) respectively. Group II also had a significant improvement in the severity of neck pain from 86 mm (81; 94) to 19 mm (10; 24) ($p=0.024$), pain in upper limbs from 89 mm (75; 92) to 8 mm (4; 12) ($p=0.001$), NDI improved from 44 (40; 48) to 15 (12; 20) ($p=0.023$), SF-36 (PCS) improved from 26.73 (20.36; 35.72) to 46.23 (44.56; 49.06) ($p=0.01$) and SF-36 (MCS) improved from 33.19 (19.82; 39.81) to 43.24 (41.39; 46.81) ($p=0.03$). At 2-year follow-up, there was a statistically significant difference in VAS neck pain, upper limbs, NDI scores and SF-36 between Group I and Group II ($p<0.05$) (Table 2).

Comparative analysis of preoperative radiological parameters in all subgroups of the prospective study group (TDR, ACDF, TDR + ACDF) showed statistically significantly higher CL and IH, as well as the segmental ROM, the degenerative changes of the IVD and FJ in the subgroups of two-level TDR and hybrid surgery compared with a retrospective cohort ($p<0.05$). The segmental ROM, the degenerative changes of the IVD and FJ in subgroups of two-level ACDF between the prospective and retrospective cohorts were comparable ($p>0.05$).

After 2 years of postoperative follow-up, in all subgroups of the prospective group (TDR, ACDF, TDR + ACDF), statistically significantly greater CL and IH, as well as segmental ROM, the degenerative changes of the IVD and FJ in the subgroups of two-level TDR and hybrid surgery according to compared with a retrospective cohort ($p<0.05$). The degenerative changes of IVD and FJ in subgroups of two-level ACDF between the prospective and retrospective cohorts were comparable ($p>0.05$) (Table 3).

Satisfaction with surgery on the Macnab scale after 24 months was better in Group I than II ($p<0.001$) (Table 4). Outcomes of surgery on the Nurick scale after 24 months was better in Group I than II ($p<0.0001$) (Table 4).

There was a statistically significantly higher complication rate in Group II than Group I ($p<0.00001$) (Table 5).

Discussion

Two-level cervical degenerative disease can be treated either anteriorly or posteriorly, depending upon various factors, including cervical alignment, extent of disease, the localization of compressive pathology, as well as surgeon preference [8, 14]. Many spine surgeons prefer a ACDF, TDR and their combination for treatment patients with two-level cervical

Table 2 Comparison between Groups I and II for VAS, NDI, Sf-36 scores pre-operatively and at 2 years post-operatively

Criteria	Group I ($n=126$)	Group II ($n=118$)	p
VAS, neck pain pre-operatively, mm	81 (76; 95)	86 (81; 94)	0.53
VAS, neck pain at 2 years post-operatively, mm	8 (5; 12)	19 (10; 24)	0.02
VAS, upper limbs pre-operatively, mm	91 (76; 93)	89 (75; 92)	0.29
VAS, upper limbs at 2 years post-operatively, mm	2 (0; 5)	8 (4; 12)	0.04
NDI score pre-operatively	42 (40; 44)	44 (40; 48)	0.47
NDI score at 2 years post-operatively	8 (6; 10)	15 (12; 20)	0.02
SF-36 (PCS) pre-operatively	28.72 (19.83; 36.54)	26.73 (20.36; 35.72)	0.44
SF-36 (PCS) at 2 years post-operatively	55.29 (51.83; 57.29)	46.23 (44.56; 49.06)	0.01
SF-36 (MCS) pre-operatively	32.21 (18.28; 38.99)	33.19 (19.82; 39.81)	0.26
SF-36 (MCS) at 2 years post-operatively	57.66 (51.25; 59.22)	43.24 (41.39; 46.81)	0.01

Table 3 Comparison between Groups I and II for radiological data pre-operatively and at 2 years post-operatively

Criteria		Group I ($n=126$)			Group II ($n=118$)		
		TDR ($n=43$)	ACDF ($n=41$)	Hybrid ($n=42$)	TDR ($n=37$)	ACDF ($n=41$)	Hybrid ($n=40$)
Cervical lordosis (CL) pre-operatively		12.7 (12.2; 13.5)*	7.6 (6.0; 8.2)*	11.9 (11.3; 13.3)*	6.6 (5.2; 7.1)	5.3 (4.9; 5.8)	6.1 (5.4; 6.8)
Cervical lordosis (CL) at 2 years post-operatively		14.2 (12.5; 16.4)*	11.3 (10.7; 12.6)*	13.6 (12.8; 15.1)*	10.8 (8.3; 11.4)	8.6 (6.7; 9.1)	9.9 (7.9; 10.6)
Segmental range of motion (ROM) pre-operatively	Upper segment	9.2 (8.7; 9.7)*	4.9 (4.0; 5.3)	8.9 (8.4; 9.5)*	6.3 (5.5; 6.9)	4.7 (4.1; 5.5)	6.2 (5.1; 6.6)
	Lower segment	9.3 (9.1; 9.8)*	4.8 (3.7; 5.4)	9.1 (8.3; 9.9)*	6.4 (5.2; 7.1)	5.1 (3.5; 5,8)	6.3 (4.8; 6.2)
Segmental range of motion (ROM) at 2 years post-operatively	Upper segment	9.1 (8.5; 9.5)*	–	– / 9.5 (8.9; 9.6)*	4.7 (4.2; 5.7)	–	– / 6.3 (4.7; 6.6)
	Lower segment	9.4 (8.4; 9.8)*	–	– / 9.2 (8.8; 9.7)*	4.9 (4.1; 5.9)	–	– / 6.4 (4.9; 6.8)
Interbody height (IH) pre-operatively	Upper segment	6.7 (6.2; 6.7)*	4.4 (3.7; 4.9)*	6.3 (6.0; 6.7)*	5.3 (3.9; 6.0)	2.7 (2.1; 3.0)	4.8 (3.0; 5.5)
	Lower segment	6.6 (6.2; 6.6)*	4.5 (3.4; 5.1)*	6.1 (5.8; 6.3)*	5.1 (3.8; 5.9)	3.5 (3.2; 4.1)	4.6 (3.2; 6.0)
Interbody height (IH) at 2 years post-operatively	Upper segment	6.7 (6.5; 6.9)*	6.2 (5.1; 6.5)*	6.6 (6.0; 6.8)*	5.6 (5.1; 5.8)	3.9 (3.3; 4.7)	5.5 (4.9; 5.8)
	Lower segment	6.7 (6.4; 6.9)*	5.9 (5.2; 6.3)*	6.3 (5.9; 6.5)*	5.5 (5.0; 5.9)	4.1 (3.5; 4.7)	5.7 (4.7; 5.9)
Intervertebral disk (IVD) degeneration pre-operatively	Upper segment	I (I;II)*	IV (III;V)	I (I;III)*	II (I;III)	III (III;IV)	II (I;III)
	Lower segment	I (I;II)*	IV (III;V)	I (I;III)*	II (I;III)	III (III;V)	II (I;III)
Facet joint (FJ) degeneration pre-operatively	Upper segment	I (I;II)*	III (III;IV)	I (I;II)*	II (I;III)	II (II;IV)	I (I;III)
	Lower segment	I (I;II)*	III (III;IV)	I (I;II)*	II (I;III)	III (II;IV)	II (I;III)
Facet joint (FJ) degeneration at 2 years post-operatively	Upper segment	I (I;II)*	III (III;IV)	I (I;II)*	II (II;III)	III (II;IV)	II (II;III)
	Lower segment	I (I;III)*	III (III;IV)	I (I;II)*	III (II;III)	III (III;IV)	II (II;III)

Note. * – $p < 0.05$

Table 4 Intergroup comparative analysis of the outcome of surgical treatment on the Macnab and Nurick scales at long-term postoperative follow-up

Criteria		Group I ($n=126$)	Group II ($n=118$)	p
Macnab scale	Excellent	81 (64.4%)	29 (24.6%)	< 0.0001
	Good	40 (31.7%)	51 (43.2%)	
	Satisfactory	5 (3.9%)	31 (26.3%)	
	Unsatisfactory	–	7 (5.9%)	
Nurick scale	Complete regression of symptoms	75 (59.5%)	33 (28%)	< 0.0001
	Improvement of neurological status	51 (40.5%)	59 (50%)	
	No changes	–	21 (17.8%)	
	Worsening of symptoms	–	5 (4.2%)	

degenerative disk disease, because they are less traumatic compared to dorsal decompression-stabilization techniques and have lower risks of reoperation compared to isolated decompression [15–17]. A poor choice of two-level anterior surgical procedures can result in unsatisfactory clinical results due to postoperative pain, heterotopic ossification, pseudoarthrosis and adjacent segment diseases [9, 10, 18]. To help prevent such poor pre-operative results, in 2015, we set out to develop a uniform algorithmic anterior approach to the surgical treatment of two-level cervical degenerative disk disease. Then we compared the results from this prospectively treated group to historical controls that had been treated at one of the hospitals to determine the impact of the algorithmic approach on surgical outcomes.

We have established that the algorithmic anterior approach, which standardizes surgical treatment, resulted in significant improvement of functional status at long-term follow-up, based on VAS pain scores, NDI, SF-36, Macnab scale and Nurick scores, compared to an unstandardized conventional approach based on surgeon preferences. Post-operatively, in Group I there

Table 5 Complications

Criteria	Group I ($n=126$)	Group II ($n=118$)	p
Intraoperative complications, n, %	2 (1%)	6 (5.3%)	0.031
Dural tears	–	1	
Dysphonia	1	2	
Dysphagia	1	3	
Early postoperative complications, n, %	3 (2.4%)	11 (9.3%)	0.026
Intramuscular hematoma	1	3	
Surgical site infection	1	2	
Venous thrombosis, Pulmonary embolism	–	1	
C5 palsy	1	5	
Long-term postoperative complications, n, %	3 (2.4%)	12 (10.2%)	0.015
Adjacent level disc herniation	1	3	
Heterotopic ossification	1	5	
Pseudoarthrosis	1	4	

was a significant decrease in the severity of neck pain according to VAS from 81 mm (76; 95) to 8 mm (5; 12) ($p=0.002$) and pain in upper limbs according to VAS from 91 mm (76; 93) to 2 mm (0; 5) ($p=0.001$) in Group I, their NDI, SF-36 (PCS) and SF-36 (MCS) values improved post-operatively from 42 (40; 44) to 8 (6; 10) ($p=0.003$), from 28.72 (19.83; 36.54) to 55.29 (51.83; 57.29) ($p=0.001$) and from 32.21 (18.28; 38.99) to 57.66 (51.25; 59.22) ($p=0.005$) respectively. There was also a decreased complication rate in Group I, 6.3% compared to 24.6% in Group II ($p=0.0001$), including for neurologic deficits, revision procedures, heterotopic ossification and pseudoarthrosis. We think that the algorithm per se does not eliminate the development of surgical complications, but we are confident that different procedures can affect the morbidity.

The presence of a difference in preoperative radiological parameters between the algorithmic group and the control group is due to the fact that the algorithmic approach implied a personalized choice of the method of surgical intervention with the exclusion of adverse factors for the development of unsatisfactory outcomes that were identified in the retrospective group [13]. To optimize postoperative outcomes in the prospective group, preoperative radiological parameters were chosen to select patients for the two-segment TDR, ACDF, or hybrid technique (Fig. 1). Subsequently, having received the best results in the prospective cohort, the hypothesis about the effectiveness of the proposed algorithm and the selected radiological criteria was confirmed.

The results of surgical treatment in our historical control group were comparable to what is in the literature. However, our results using the algorithmic approach appear to be better than the results reported in the literature regarding anterior cervical procedures [19–21]. Our results using an algorithmic approach to indicate the promise of using our proposed algorithm for choosing the type of anterior cervical procedure in patients with two-level degenerative disease of the cervical spine.

Limitation

Limitations of the study, potentially having the ability to influence its results, include: (1) heterogeneity of analyzed cohorts based on fact that a multi-center study were involved 3 institutions from 2 countries; (2) relatively short follow-up period, limited to a minimum two-year period; (3) this study does not address the superiority of either TDR, ACDF or hybrid technique, since we are simply determining if an algorithmic approach to choosing one versus the other can result in better outcomes and reduction of complications; (4) Group II had a longer follow-up period. This may be one reason why there were higher long-term complication rates in Group II, such as development of heterotopic ossification, pseudoarthrosis, adjacent segment disease, and progression of symptoms; (5) since the operations used for historical controls were performed from 2005–2015, prior to when the algorithm-based prospective study was done (2016–2019), it is possible that the surgeons gained more experience in the interim, contributing to some of the improved outcomes; (6) heterogeneity of the analyzed cohorts in terms of preoperative radiological parameters (CL, IH), due to the fact that strict radiological criteria were established in the algorithmic group for the use of two-segment TDR, ACDF or hybrid technique, which were associated with a good long-term clinical outcome [13].

Conclusions

We developed and prospectively tested, in a multicenter trial, an algorithm to guide us in the anterior treatment of two-level cervical degenerative disk disease. We found that it resulted in good clinical and radiological outcomes. In comparison to historical controls, there was a decrease in the complication rate, along with an

improvement in functional outcomes at minimum 2-years follow up period.

Authors' contributions Each author made significant individual contributions to this manuscript. VAB (0000-0003-4349-7101)*, AAK (0000-0002-6059-4344)* and MAA (0000-0002-3190-2395)* were the main contributors to the drafting of the manuscript. VAB, AAK, MAA, BMA (0000-0001-5458-0184), AVK (0000-0001-7709-5800) and NOA (0000-0002-4902-3874) performed the surgery, and patient follow-up, and gathered clinical data. AAK, MAA, AVK evaluated the data from the statistical analysis. VAB, AAK, MAA and BMA performed the literature search and review of the manuscript, and contributed to the intellectual concept of the study. *ORCID (Open Researcher and Contributor ID).

Data availability Data are available from the corresponding author (prof. Vadim A. Byvaltsev) for researchers who meet the criteria for access to confidential data.

Declarations

Ethical approval The study was approved by the Ethics Committee of Irkutsk State Medical University, protocol № 3, dated November 15, 2016.

Competing interests The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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