PREDICTING THE LOSS OF CORRECTION AFTER ISOLATED ANTERIOR STABILIZATION IN THE SURGICAL TREATMENT OF SUBAXIAL CERVICAL DISLOCATIONS

A.D. Lastevsky[1], V.L. Lukinov[2], V.V. Rerikh[1, 3]

[1]Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia

[2]Institute of Computational Mathematics and Mathematical Geophysics SB RAS, Novosibirsk, Russia

[3]Novosibirsk State Medical University, Novosibirsk, Russia

Objective. To identify factors leading to the loss of correction and re-dislocation of the vertebrae after isolated anterior reconstruction and stabilization in the surgical treatment of subaxial cervical dislocations.

Material and Methods. A retrospective cohort STROBE-type study was carried out using data of 175 patients with dislocations of vertebrae in the subaxial cervical spine who were operated on in 2010–2019. The key parameters of the study were the relevant indices of the cervical sagittal balance and morphological characteristics of the injury: thoracic inlet angle (TIA), T1 vertebra slope, neck tilt, regional cervical C2–C7 lordosis, fracture of the vertebral body, and fracture of the articular process at the level of dislocation. Statistical analysis of the obtained data was carried out in the RStudio program.

Results. At preoperative TIA value of 74.5°, the risk of correction loss corresponds to 28 %. In the group with TIA < 74.5° and that with TIA ≥ 74.5°, the risk of correction loss is 17.3 % (95 % CI: 7–37 %) and 85.7 % (95 % CI: 60–96 %), respectively. With an increase in TIA by 10°, the chance of recurrence increases by 23.3 times. The effect of the articular process fracture on the loss of correction is equivalent to an increase in TIA by 10°, namely, it increases the chance of recurrence by 20.7 times. The parameter "duration of injury" has an effect on the loss of correction, but it is statistically insignificant ($p > 0.05$).

Conclusion. The parameter of the cervical sagittal balance, thoracic inlet angle, as well as the fracture of the articular process at the level of injury are statistically significant factors that determine the initial stability in isolated anterior surgical reconstruction and stabilization of the lower cervical spine for Allen type 3 flexion-distraction injuries.

Key Words: anterior cervical discectomy and stabilization, anterior spinal fusion, cervical sagittal balance, dislocations of cervical vertebrae, recurrent dislocation, re-dislocation, loss of correction, flexion-distraction injury.

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Bilateral dislocations of the cervical vertebrae are rather destructive injuries of the spine, especially in terms of the development of serious neurological consequences [1, 2]. They present three-column injuries characterized by gross morphological deformities that result from hyperflexion and distraction at the subaxial cervical spine and in most cases lead to severe neurological complications. These injuries are mainly found in young people (predominantly males); they are characterized by bilateral dislocations and most frequently located at C6–C7 [3–5]. The main causes of dislocations are road accidents, falls from a height, sports and cycling injuries [3–5].

The publications on the methods of treating dislocations of the cervical vertebrae are sparse; all of them emphasize the lack of a unified strategy for the surgical treatment of traumatic dislocations of the subaxial cervical spine [6–9]. Some authors favor anterior stabilization in the case of a neurologically intact scenario [5, 8, 10]. Others recommend using a combined approach in case of neurological deficit with disc herniation and anterior stabilization in the absence of hernia [6]. Japanese authors prefer isolated posterior procedure [11, 12]. A number of authors recommend a combined approach for patients with bilateral subaxial dislocations regardless of the degree of neurological deficit [6, 7, 13]. There are some discrepancies in the publications that tend to favor the anterior surgical technique [5, 14]. These articles state that the effectiveness of anterior stabilization in bilateral dislocations is high, while the percentages of re-dislocation and fixation failure are low [5, 14]. An alternative point of view is presented in the studies that focus on rather high rates (up to 25 %) of the failure of isolated anterior approach, as well as high risks of re-dislocation and unfavorable long-term functional outcomes [4, 15–17]. Literature data indicate the absence of a unified strategy for the surgical treatment of subaxial cervical dislocations. Publications on the effectiveness of isolated anterior stabilization are controversial.

We have not found any modern studies on the prediction of adverse outcomes in the treatment of subaxial cervical dislocations.

The aim of the study is to identify factors leading to the loss of correction and re-dislocation of the vertebrae after isolated anterior reconstruction and stabilization in the surgical treatment of subaxial cervical dislocations.

The scientific hypothesis is that certain characteristics of the sagittal cervical balance and morphological features of injury impose a significant effect on the induction of re-dislocation, i.e., the loss of the achieved correction after isolated anterior stabilization in Allen stage 3 flexion-distraction injuries at C6–C7 [18].

The study presents a retrospective cohort STROBE-type analysis [19].

Material and Methods

The material for the study was medical history, radiographs, MRI and MSCT data of 175 patients operated on for subaxial cervical dislocations at Novosibirsk Research Institute of Traumatology and Orthopedics n.a. Y.L. Tsivyan in 2010–2019. Group 1 (n = 16) included patients with signs of loss of the achieved correction. The criteria for correction loss were the following: segmental kyphosis of ⩾ 11° (according to Cobb) and segmental vertebral translation (shift) ⩾ 3.5 mm at the level of stabilized segment [16]. All patients in this group had bilateral fracture dislocations. They underwent isolated anterior stabilization with an interbody cage made of porous titanium nickelide and a third generation cervical plate via dynamic fixation. Injuries at the C6–C7 level prevailed in this group (63.6 % of cases). Of them, 72.7 % corresponded to stage 3 distractive flexion injuries according to the classification by Allen et al. [18]. Using these data as a basis, we determined the inclusion criteria for the control group patients. The criteria included bilateral injuries, Allen stage 3 flexion-distraction traumas, injuries at C6–C7, isolated anterior stabilization with a 3rd generation plate using dynamic fixation, monosegmental injuries, no loss of correction (re-dislocation) in the postoperative period, as well as the patient's age of 15 years and older. Exclusion criteria were the following: Allen stage 1, 2, and 4 flexion-distraction injuries, multisegmental injuries, diffuse idiopathic skeletal hyperostosis (Forestier's disease), ankylosing spondylitis (Bekhterev's disease), and the age younger than 15 years.

Analysis of the general sample performed using the above-mentioned criteria allowed us to define Group 2 (control; n = 21). In both the studied groups, the degree of injury and verification of instability were determined using the classification system [18], which describes the stages of a flexion-distraction injury. Neurological deficit was assessed using the ASIA score [20]. The treatment results were analyzed using clinical and radiological data obtained upon admission of the patient, immediately after surgery, and three months after treatment. The presence or absence of sclerosis or bone resorption was assessed using MSCT scans of the cervical spine at the sites of contacts of the porous material with the adjacent vertebral bodies included in the fixation. Fusion grade was classified according to Tan et al. [21]. The following significant parameters of the cervical sagittal balance were evaluated: thoracic inlet angle (TIA) and regional C2–C7 cervical lordosis (CL) [22, 23]. The analysis was performed using morphological characteristics of the injury: the presence or absence of a fracture of at least one articular process, the presence or absence of a fracture of the caudal vertebra, as well as the signs of osteoporosis according to the MSCT data. In addition, the groups were compared by age, length of hospital stay, and duration of injury.

Descriptive characteristics are presented as median [first quartile; third quartile] for continuous parameters (age, length of hospital stay, duration of injury, segmental angle, shift, and TIA; Table 1 additionally shows mean ± standard deviation); number of cases, percent [lower bound of the 95 % CI; upper bound of the 95 % CI] for binary data (gender and related factors with calculation of the confidence intervals (CIs) using Wilson's formula); number of patients per category (percentage) for categorical data in relation to the cause of injury and the degree of baseline neurological deficit according to the ASIA grading system.

No continuous values of age, hospital stay, duration of injury, segmental angles, displacement, and TIA were found for the groups with and without loss of correction (Table 1). The variables had a normal distribution according to the Shapiro – Wilk test and comparable variances as shown by the Fisher's F-test. The nonparametric Mann – Whitney U test was used to compare the groups with each other. The distribution bias was calculated with the 95 % confidence interval for the bias. Binary and categorical variables were compared using the two-tailed Fisher's exact test. Effect sizes for the binaries to be compared were calculated as odds ratio with a 95 % CI.

Predictors of the loss of correction were identified using logistic regression models. Univariate models were used to determine individual predictors of the loss of correction. Prior to constructing multivariate models, collinear covariates were obtained by calculating Pearson's correlation coefficients using the original multivariate models, including covariates with the achieved level of significance of $p < 0.300$ in univariate models. For additional control, the forward–backward algorithm using the Akaike information criterion (AIC) was applied to determine the optimal multivariate logistic regression models. The forward and backward probabilities turned out to be equal. For the formula of the multivariate model of logistic regression, ROC analysis methods were used to calculate the optimal cut-off threshold for the probability of the loss of correction in terms of sensitivity and specificity. Next, the following qualitative prognostic indicators were assessed using the 95 % CI: sensitivity, specificity, apparent prevalence, true prevalence, positive predictive value, negative predictive value, as well as positive and negative likelihood ratio. Predictive scores for different logistic regression models were compared using the McNemar test, weighted generalized score statistic, and diagnostic likelihood regression model (regtest).

Statistical hypotheses were tested with a critical level of significance set up at $p = 0.05$, i.e., the difference was considered statistically significant at $p < 0.05$.

All statistical calculations were performed in the RStudio software (v. 1.2.5001) with the R language (v. 3.6.1).

Results

Both groups are mainly represented by males: the M : F ratio is 14: 2 and 17 : 4 for Groups 1 and 2, respectively. The average age is 54 [40.75; 65.25] years in Group 1 and 54 [40.75; 65.25] years in Group 2 ($p = 0.283$). There were no significant differences between the segmental angle values and shift values at the damaged segment before and after surgery (Table 1).

Thirteen (81.3 %) patients in Group 1 had recurrent dislocation at the first outpatient visit within three months after surgery. In three (18.7 %) patients, dislocation recurrence was detected before discharge from the hospital. For this reason, additional posterior stabilization was performed in two cases, and one patient underwent revision surgery with extension of the anterior fusion. Grade I fusion according to Tan et al. [21] with loss of correction was observed in all patients of Group 1 in the long-term period.

The groups differed in the CL parameter before and after surgery (although statistically insignificantly). At the same time, statistically significant differences in the TIA values were noted. However, the preoperative and postoperative values of this parameter were almost identical (Table 1). TIA values did not alter upon changing body position in space [24].

Comparison of the morphological features of injury using the two-tailed Fisher's exact test revealed no statistically significant differences between the groups (Fig. 1).

There were also no statistically significant differences in the following parameters between the groups: the cause of injury and the degree of neurological deficit (Fig. 2, 3).

Using the method of logistic regression, we identified predictors that statistically significantly affect the success of re-dislocation at the damaged C6–C7 segment (Table 2).

According to the univariate analysis, such variables as age, hospital stay length, segmental angle, shear displacement, and CL were not defined as statistically significant parameters affecting the recurrence of dislocation at the level of injury.

Having constructed an optimal multivariate model of logistic regression, we identified significant multiplicative predictors of dislocation recurrence:

– preoperative TIA ($p = 0.021$); an increase in preoperative TIA by k degrees raises the likelihood of recurrence 1.65k-fold [1.22k; 3.17k], provided that all other parameters of joint fracture remain equal;

– fracture of the articular processes ($p = 0.054$); fracture of the articular processes or one of them on at least one side increases the chances of recurrence 20.66-fold [1.68; 1,046.08], provided that all other parameters of preoperative TIA are equal.

The formula for the resulting multivariate model for predicting the loss of correction (recurrent dislocation) is as follows:

$$R = \frac{e^z}{1+e^z}, (^*),$$

where R (recurrence) is the risk (probability) of recurrence; $z = -24.3471 + 0.3143^*\text{TIA} + 3.0282^*$ stands for joint fracture; e^z is the exponent raised to the power of z; TIA denotes TIA value in degrees; joint fracture is assumed equal to "1" for patients with a joint fracture and "0" in the opposite case.

The ROC analysis determined a balanced TIA value in terms of sensitivity and specificity, which amounted to 74.5° (Fig. 4).

We analyzed the predictive models using the parameters "TIA" and "TIA + articular process fracture" (Fig. 5). The graph shows that the sensitivity of the second model is higher.

In their study, Lee et al. [24] established that TIA equals 69.5° ± 8.6° (range, 54.9° to 96.5°) in asymptomatic patients. Based on this data, we simulated the prognosis of recurrence for TIA values of 70.0° and 74.5°. The prediction results are presented in Table 3.

To determine the prognosis of dislocation recurrence, a more balanced TIA value (74.5°) was used. The risk of relapse has been shown for patients with TIA > 74.5°. No relapse was predicted for individuals with TIA ⩽ 74.5°.

Such parameters as TIA and fracture of the articular process were used as a model for determining the risk of recurrence. The values of these indicators differ significantly in both groups. Using the multivariate logistic regression formula based on the TIA values and the presence of an articular process fracture, we determined the risk of recurrence. It turned out to be 28 %.

A relapse and the absence of relapse were predicted for patients with a risk of recurrence exceeding 28 % and below this value, respectively. The prognostic model is presented in Table 4.

Sensitivity is a more important parameter than specificity in clinical practice. Therefore, we rejected the trivariate model for prediction of recurrence (TIA + articular process fracture + injury duration). The predicted risk of recurrence was more than 54 % in this model; in addition, the model was less sensitive (Table 5). The sensitivity value was 0.87 [0.60; 0.98].

The trivariate model including the parameter "injury duration" requires additional studies and, thus, a greater number of patients in the comparison groups.

A bivariate model for prediction of recurrence (TIA + joint fracture) was adopted and proposed. It has a sensitivity value of 0.94 [0.70; 1.00] and a predicted risk of recurrence greater than 28 % (Table 5).

High sensitivity values in the model predicting the risk of recurrence indicate a significant predictive value of the proposed predictors of re-dislocation.

Discussion

It should be noted that, when analyzing modern domestic and foreign stu-

Table 1

Comparison of the parameters between patients with loss of correction (Group 1) and patients without loss of correction (Group 2)

Parameter	General group (n= 37)	Group 1 (n= 16)	Group 2 (n= 21)	Mann-Whitney U-test	
	Median [IQR] Mean ± SD	Median [IQR] Mean ± SD	Median [IQR] Mean ± SD	Difference [95 % CI]	p-level
Age, years	48.0 [34.00; 62.00] 47.84 ± 17.61	54.0 [40.75; 65.25] 51.31 ± 15.51	46.0 [31.00; 59.00] 45.19 ± 19.00	-7.00 [-20.0; 6.0]	0.283
Hospital bed days	14.0 [11.00; 20.00] 20.70 ± 16.89	12.5 [10.00; 21.00] 22.06 ± 22.81	16.0 [13.00; 20.00] 19.67 ± 10.98	3.00 [-2.0; 7.0]	0.237
Injury duration	2.5 [0.88; 6.50] 6.36 ± 11.26	4.5 [1.00; 10.25] 10.24 ± 15.74	1.5 [0.50; 4.25] 3.27 ± 3.91	-2.00 [-6.0; 0.2]	0.159
Local segmental kyphosis before surgery, deg.	11.0 [19.00; 5.00] 12.27 ± 9.30	6.5 [19.25; 2.00] 10.38 ± 10.63	12.0 [19.00; 9.00] 13.71 ± 8.20	4.53 [10.0; 2.0]	0.149
Local segmental curvature (lordosis) after surgery, deg.	-6.0 [-2.00; -10.00] -6.22 ± 4.70	-7.5 [2.50; 10.25] -7.00 ± 5.07	-5.0 [-2.00; -9.00] -5.62 ± 4.43	-1.00 [-5.0; 2.0]	0.479
Anterior shift before surgery, mm	6.0 [5.00; 8.00] 6.11 ± 2.28	5.0 [4.00; 6.25] 5.38 ± 1.96	7.0 [5.00; 8.00] 6.67 ± 2.39	2.00 [0.0; 3.0]	0.061
Anterior shift after surgery, mm	0.0 [0.00; 0.00] 0.08 ± 0.36	0.0 [0.00; 0.00] 0.12 ± 0.50	0.0 [0.00; 0.00] 0.05 ± 0.22	0.00 [0.0; 0.0]	0.845
C2–C7 lordosis before surgery, deg.	12.0 [6.00; 22.00] 14.3 ± 11.24	12.5 [6.00; 21.25] 15.12 ± 11.71	12.0 [3.00; 24.00] 13.67 ± 11.11	-1.00 [-9.0; 6.0]	0.854
C2–C7 lordosis after surgery, deg.	18.0 [7.00; 27.00] 17.24 ± 12.30	15.5 [8.00; 28.00] 19.17 ± 13.66	18.0 [4.00; 24.00] 16.14 ± 11.67	-4.00 [-11.0; 8.0]	0.537
TIA before surgery, deg.	70.0 [62.00; 78.00] 69.84 ± 11.25	79.0 [74.00; 84.25] 78.19 ± 8.18	63.0 [58.00; 70.00] 63.48 ± 8.91	-15.00 [-21.0; -9.0]	<0.001*
TIA after surgery, deg.	71.5 [62.00; 81.00] 72.00 ± 11.26	81.0 [77.50; 85.50] 80.87 ± 6.44	62.0 [58.00; 71.00] 64.18 ± 8.40	-17.00 [-23.0; -10.0]	<0.001*

TIA — thoracic inlet angle.

dies on the treatment of dislocations of the cervical vertebrae, the major attention is drawn to the inconsistency of the terminology, i.e., a series of definitions are used to describe the same morphological type of injury. Nevertheless, dislocations of the cervical vertebrae are referred to as cervical facet dislocation in the English-language literature: bilateral facet dislocation in the case of bilateral injury and unilateral facet dislocation in the case of unilateral trauma [1, 25]. Fracture-dislocations account for up to 36.3 % of all traumas of the cervical spine [26]. According to different authors [14, 16], fractures of articular processes in dislocations of the subaxial cervical vertebra occur in 44.4–54.0 % of cases. Vertebral body fracture at the level of dislocation is detected in 17–19 % of cases [14, 16]. According to the researchers, these factors should be considered unfavorable, since they make it difficult to achieve the stability after anterior surgery. At least half of the spinal cord injuries accompanied by complete or incomplete neurological deficits results from fracture-dislocations at C5–C6 and C6–C7 segments [25]. Bilateral fracture-dislocations are more deleterious to the spinal cord [1]. There were slightly fewer fractures of the articular processes among the patients in our study. In addition, the number of fractures of the adjacent vertebral body in our research was close to that in the literature data; while neurological deficit was present in 43.2 % of cases. Knowing the pathobiomechanics of the formation of bilateral fracture-dislocation of the subaxial spine is extremely important. It provides the basis for understanding the degree of damage to the stabilizing osteoarticular system, which, in turn, allows the surgeon to provide a pathogenetic approach when planning an operation. There are two opinions in the literature regarding this matter. The first one is supported by researchers who believe that bilateral fracture-dislocations of the cervical spine are the result of excessive flexion caused by axial compression applied with eccentricity to the head [1]. Other researchers believe that dislocation occurs in sharp deceleration of the trunk movement at the moment when the head continues to experience acceleration [27]. Such movement is considered as forced hyperflexion of the cervical spine with the chin moving towards the chest [27]. Transformation of the views of biomechanical researchers observed in the literature can be traced in the modern clinical classification of subaxial cervical injuries. Dislocations of the cervical vertebrae are classified as type C (translational injuries) according to this classification. Previous morphological

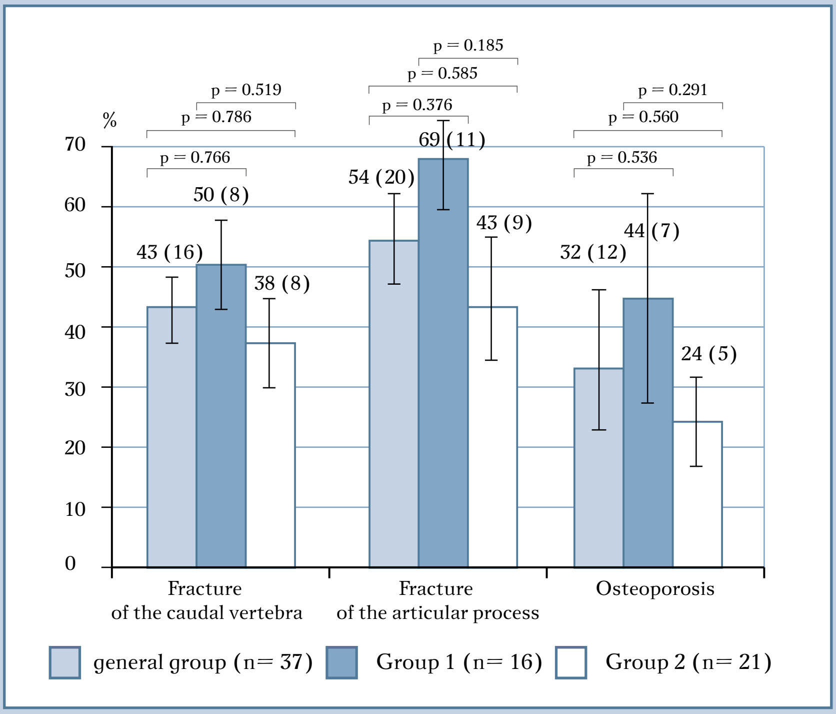

Fig. 1
Differences between the groups in morphological characteristics of the injury

classification systems define this type of trauma as type B (flexion-distraction injuries) [18, 26, 28], which still has not lost its significance.

Modern concepts of surgical treatment of dislocations of the subaxial cervical spine are based on the idea that surgery should provide the earliest possible decompression of the spinal cord, elimination of spinal deformity, and reliable anterior, posterior or combined stabilization [7, 8]. Spinal cord decompression is achieved by reducing the dislocation using any of the existing closed or open techniques while restoring the clearance of the spinal canal [8, 26]. According to modern domestic and foreign clinical guidelines, either anterior [29, 30], posterior [32, 31] or combined [8, 33–35] stabilization of the injured spinal segment is required after successful reduction of dislocations of the cervical vertebrae, elimination of deformity, restoration of the clearance of the spinal canal, and decompression of the spinal cord. The question arises about the factors that would determine the risk of success or failure of a certain surgical intervention.

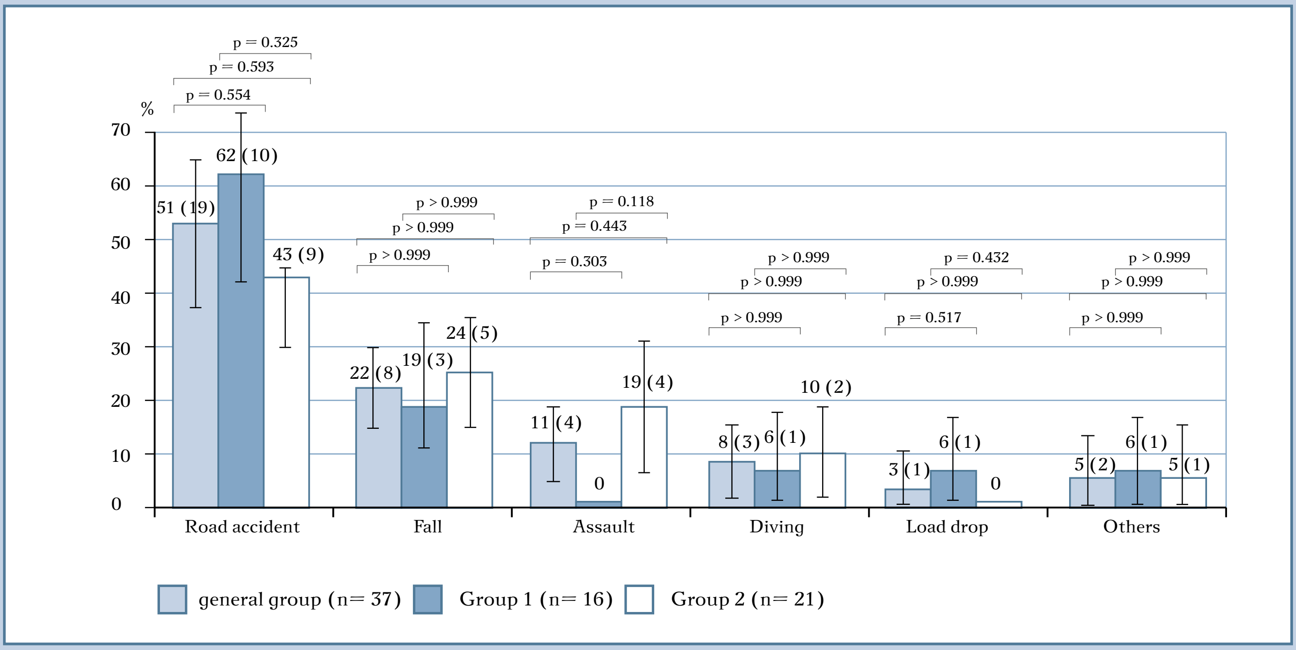

Fig. 2
Differences between the groups in a cause of injury

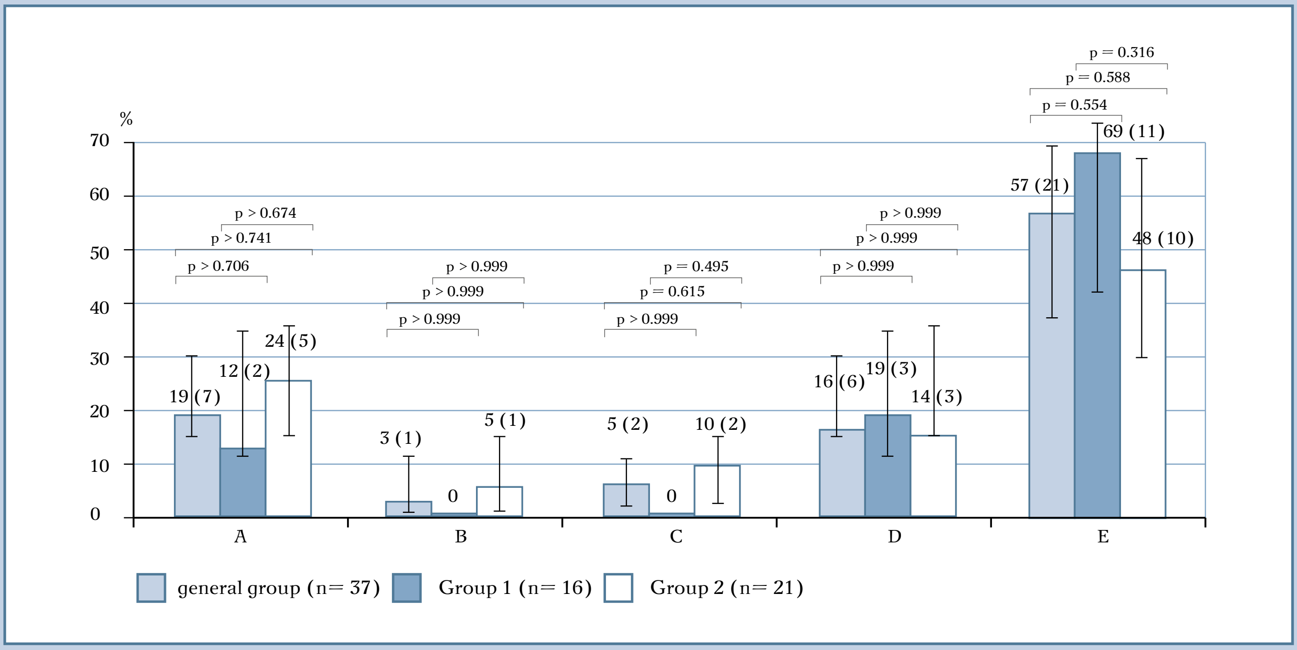

Fig. 3
Differences between the groups based on the degree of initial neurological deficit according to the ASIA scale

Table 2
Re-dislocation predictors

Covariates	Univariate models		Multivariate model (TIA + articular process fracture)		Multivariate model (TIA + articular process fracture + injury duration)	
	OR [95 % CI]	p	OR [95 % CI]	p	OR [95 % CI]	p
TIA before surgery	1.23 [1.10; 1.43]	0.001*	1.37 [1.14; 1.88]	0.011*	1.70 [1.24; 3.32]	0.020*
Articular process fracture	2.93 [0.77; 12.29]	0.122	20.66 [1.68; 1046.08]	0.054	93.96 [2.60; 54944.92]	0.051
Injury duration	1.10 [0.99; 1.31]	0.171	–	–	1.52 [1.08; 2.79]	0.058

TIA – thoracic inlet angle.

In 1982, Allen et al. [18] described the stages of flexion-distraction injuries: flexion subluxation with intact articular processes and widening of the interspinous space (stage 1); unilateral dislocation (stage 2); bilateral dislocation with up to 50 % displacement of the vertebral body anteriorly (stage 3); spondyloptosis (floating vertebra), a rare injury in living people (stage 4). Clinicians are faced with the loss of the achieved correction in certain types of flexion-distraction injuries in the long-term period after anterior stabilization. Many authors attribute such a phenomenon to the morphological features of injury: the type of fracture of the articular processes and vertebral bodies [16], osteoporosis, the degree of kyphosis [36] and translation, as well as the severity of damage to the ligamentous structures [37]. Henriques et al. [15] believe that the tension band mechanism is implemented in anterior cervical stabilization. The mechanism is considered to be due to the integrity of the posterior longitudinal ligament [15]. In the case of an intact ligament, fixation with the anterior cervical plate allows achieving relative stability in the fusion area, which provides the expected level of adequate stabilization of the spinal segment in a controlled position.

In the case of flexion-distraction injuries of Allen stages 1 and 2 [18] with integrity of the posterior longitudinal ligament, the tension band mechanism is important in achieving the initial stability and complete fusion. Injuries of stages 3 and 4, on the contrary, are accompanied by rupture of both the posterior longitudinal ligament and deep muscles, as well as inter- and supraspinal ligaments. In

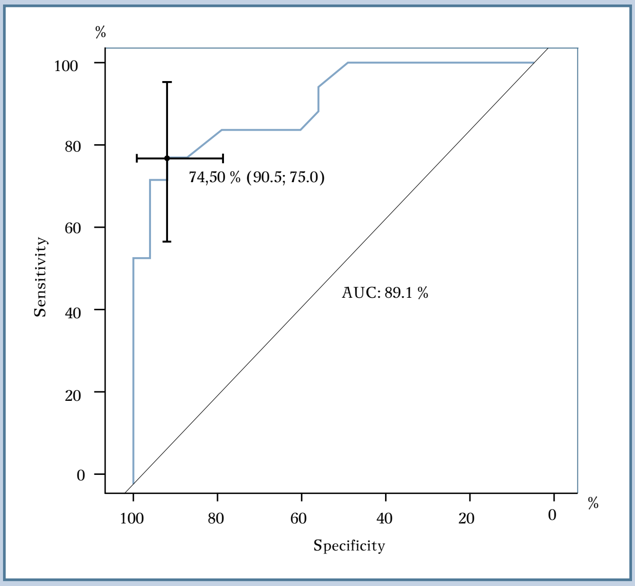

Fig. 4
ROC curve of the thoracic inlet angle

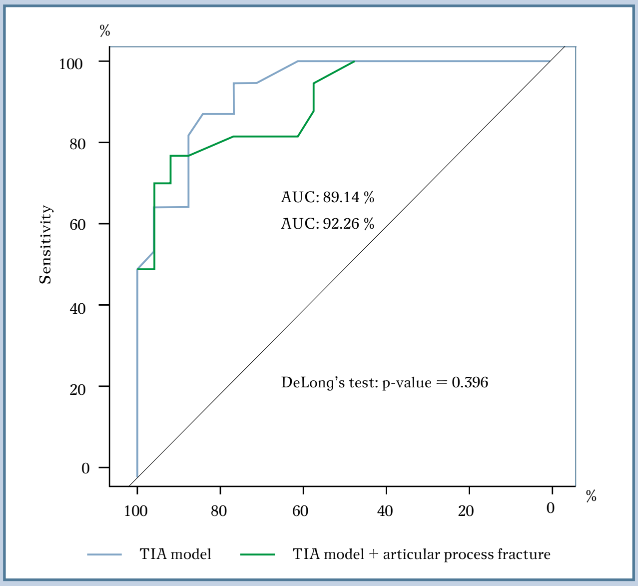

Fig. 5
ROC curves for the models of thoracic inlet angle (TIA) and TIA + articular process fracture

Table 3
Conjugacy for predictive models of recurrence for thoracic inlet angle (TIA) of 70.0° and 74.5°

Parameter	TIA – 70.0°			TIA – 74.5°		
	relapse+	relapse-	total	relapse+	relapse-	total
Prognosis+	13	5	18	12	2	14
Prognosis-	3	16	19	4	19	23
Total	16	21	37	16	21	37

TIA – thoracic inlet angle.

Table 4
Conjugacy for predictive models of recurrence for TIA + articular process fracture and TIA + articular process fracture + injury duration

Parameter	TIA + articular process fracture (28 %)			TIA+ articular process fracture + injury duration (54 %)		
	relapse+	relapse-	total	relapse+	relapse-	total
Prognosis+	15	5	20	13	1	14
Prognosis-	1	16	17	2	19	21
Total	16	21	37	15	20	35

TIA – thoracic inlet angle.

such cases, the momentary axis of rotation is shifted closer to the plate, and the tension band mechanism does not work. This, in turn, leads to the loss of correction followed by re-dislocation. For this reason, anterior fixation is ineffective in 50 % of cases with stage 3 flexion-distraction injuries.

Our observations indicate that the specificities of the relationship between the cervical vertebrae play one of the leading roles in the success of re-dislocation in conditions of isolated anterior stabilization in flexion-distraction injuries. These specificities are characterized by certain values of the parameters of the cervical sagittal balance. There are relevant indicators that fully reflect the essence of biomechanical relationships between the spinal motion segments. They include T1 vertebra slope, TIA, and neck tilt (NT) (Fig. 6) [22, 38].

There is still no consensus among researchers on the acceptable values of CL. Numerous studies in asymptomatic volunteers show variable results [38]. According to Hardacker et al. [39], normal C1–C7 CL equals 40.0° ± 9.7°, while the subaxial cervical spine provides about 15 % of the total value of CL. According to a meta-analysis by Guo et al. [40], the average degree of the C2–C7 lordosis in asymptomatic volunteers is

Table 5

Comparison of the models for predicting the recurrence of re-dislocation

Parameter	Model 1: TIA (70.0°)	Model2: TIA (74.5°)	Model 3: TIA + articular process fracture (28 %)	Модель 4: TIA + articular process fracture + injury duration (54 %)	Comparison
	value [95 % CI]	value [95 % CI]	value [95 % CI]	value [95 % CI]	p level
Case incidence	0.49 [0.32; 0.66]	0.38 [0.22; 0.55]	0.54 [0.37; 0.71]	0.40 [0.24; 0.58]	1–2: 0.134 1–3: 0.683 1–4: 0.289 2–3: 0.041* 2–4: >0.999 3–4: 0.131
Actual incidence	0.43 [0.27; 0.61]	0.43 [0.27; 0.61]	0.43 [0.27; 0.61]	0.43 [0.26; 0.61]	–
Sensitivity	0.81 [0.54; 0.96]	0.75 [0.48; 0.93]	0.94 [0.70; 1.00]	0.87 [0.60; 0.98]	1–2: 0.317 1–3: 0.157 1–4: >0.999 2–3: 0.083 2–4: 0.317 3–4: 0.564
Specificity	0.76 [0.53; 0.92]	0.90 [0.70; 0.99]	0.76 [0.53; 0.92]	0.95 [0.75; 1.00]	1–2: 0.083 1–3: >0.999 1–4: 0.102 2–3: 0.083 2–4: 0.564 3–4: 0.046*
Positive predictive value	0.72 [0.47; 0.90]	0.86 [0.57; 0.98]	0.75 [0.51; 0.91]	0.93 [0.66; 1.00]	1–2: 0.118 1–3: 0.729 1–4: 0.103 2–3: 0.207 2–4: 0.519 3–4: 0.061
Negative predictive value	0.84 [0.60; 0.97]	0.83 [0.61; 0.95]	0.94 [0.71; 1.00]	0.90 [0.70; 0.99]	1–2: 0.704 1–3: 0.163 1–4: 0.743 2–3: 0.137 2–4: 0.269 3–4: 0.708
Positive likelihood ratio	3.41 [1.53; 7.60]	7.88 [2.05; 30.32]	3.94 [1.81; 8.55]	17.33 [2.54; 118.30]	1–2: 0.131 1–3: 0.729 1–4: 0.144 2–3: 0.218 2–4: 0.529 3–4: 0.089
Negative likelihood ratio	0.25 [0.09; 0.70]	0.28 [0.12; 0.65]	0.08 [0.01; 0.56]	0.14 [0.04; 0.51]	1–2: 0.704 1–3: 0.184 1–4: 0.743 2–3: 0.164 2–4: 0.273 3–4: 0.710

*statistically significantly different values.
Values were compared using the McNemar test, two-tailed Fisher's exact test, and the Weighted Generalized Score (WGS) test;
TIA is the thoracic inlet angle.

about 13° and higher in males. According to the data of other studies [38, 41], parameters of the sagittal cervical balance strictly correlate with the indices of the functional capacity of patients assessed using different scales.

According to Lee et al. [22], TIA, T1 slope, and NT are the parameters that define the correlation between sagittal cervical and thoracolumbar relationships. A study of healthy volunteers revealed the following values of TIA, T1 slope, and NT: 69.5° ± 8.6°, 25.7° ± 6.4°, and 43.7° ± 6.1°, respectively [24]. The authors determined that TIA is a morphological parameter, which means that it is constant and does not alter upon changing the position. TIA presents the sum of the NT and T1 slope values. Clinical studies revealed a strong direct correlation between TIA and T1 slope (Pearson's coefficient, 0.694) [22]. High values of TIA and T1 slope significantly correlate with increased CL at C2–C7 and vice versa [24]. Studies have shown that, in asymptomatic volunteers, NT corresponds to an average of 44°, which determines the optimal energy expenditure in cervical muscles. Lower TIA values result in a smaller T1 slope value in order to maintain the physiological NT value, which, in turn, leads to a decreased CL.

Despite the fact that the degree of CL varied in our study, its severity had no significant relationship with the absence or occurrence of re-dislocations.

The key element is the following inverse correlation observed in our study: increased TIA in a patient (due to his constitution) contributes to the greater T1 slope value and, therefore, produces a need for increased CL. This results in the formation of translational (shear) loads in the cervicothoracic spinal junction. From our standpoint, this leads to the loss of the achieved correction (re-dislocation) in the early period after surgical treatment (reduction) only in the case of anterior stabilization in patients with dislocations of the lower cervical vertebrae.

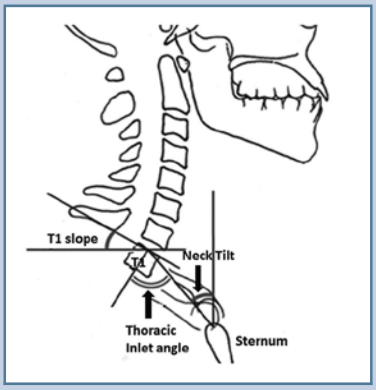

Fig. 6
The scheme for determining the parameters of the cervical sagittal balance: T1 slope is the slope angle of the first thoracic vertebra T1; TIA is the thoracic inlet angle; NT is neck tilt

Conclusion

Isolated anterior surgical reconstruction and stabilization of the spine using modern dynamic cervical plates in subaxial dislocations of the cervical vertebrae are accompanied by the loss of the achieved correction in 9.1 % of cases (95 % CI: 5.7–14.3 %). In Allen stage 3 flexion-distraction injuries at C6–C7, the risk of correction loss is 43.2 % (95% CI: 28.7–59.1 %). TIA, as well as the fracture of the articular process at the level of injury, are statistically significant factors that determine the initial stability in isolated anterior surgical reconstruction and stabilization of the lower cervical spine in Allen stage 3 flexion-distraction injuries. The risk of correction loss for preoperative TIA value of 74.5° amounts to 28 %. In groups with TIA < 74.5° and TIA ⩾ 74.5°, the risks of correction loss are 17.3 % (95 % CI: 7–37 %) and 85.7 % (95 % CI: 60–96 %), respectively ($p < 0.001$; RA = 4.9; 95 % CI: 2.0–12.3 %). With a 10° growth in the TIA value, the likelihood of recurrence increases 23.3-fold. The effect of a fracture of the articular process on the loss of correction is equivalent to an increase in TIA by 10°, i.e., it raises the chances of recurrence by 20.7 times. The parameter "duration of injury" has an impact on the loss of correction after surgery; however, it is statistically insignificant ($p > 0.05$).

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Address correspondence to:
Rerikh Viktor Viktorovich
Novosibirsk Research Institute of Traumatology
and Orthopedics n.a. Y.L. Tsivyan,
17 Frunze str., Novosibirsk, 630091, Russia,
clinic@niito.ru

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Alexey Dmitrievich Lastevsky, Head of orthopedic trauma department, researcher of the Research Department of Spine Pathology, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0001-5917-1910, Lastevskiy@mail.ru;
Vitaliy Leonidovich Lukinov, PhD in Physics and Mathematics, senior researcher, Head of the Laboratory of numerical analysis of stochastic differential equations, Institute of Computational Mathematics and Mathematical Geophysics SB RAS, 6 Academica Lavrent'eva prospect, Novosibirsk, 630090, Russia, ORCID: 0000-0002-3411-508X, vitaliy.lukinov@gmail.com;
Viktor Viktorovich Rerikh, DMSc, Head of the Research Department of Spine Pathology, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia; Professor of traumatology and orthopedics in Novosibirsk State Medical University, 52 Krasny pr., Novosibirsk, 630091, Russia, ORCID: 0000-0001-8545-0024, clinic@niito.ru.