EPIDURAL FIBROSIS AND ITS ROLE IN THE STRUCTURE OF COMPLICATIONS IN REPEATED SURGICAL INTERVENTIONS ON THE LUMBAR SPINE

A.P. Zhivotenko[1], V.A. Sorokovikov[1,2], C.N. Larionov[1], I.A. Shurygina[1]
[1]Irkutsk Scientific Centre of Surgery and Traumatology, Irkutsk, Russia;
[2]Irkutsk State Medical Academy of Postgraduate Education – Branch Campus of the Russian Medical Academy of Continuing Professional Education, Irkutsk, Russia

Objective. To conduct a multifactorial assessment of the risks of intraoperative damage to the dura mater (DM) in patients who underwent primary and repeated interventions on the lumbar spine.

Material and Methods. A retrospective comparative analysis of data from two groups of patients who underwent repeated ($n = 144$) and primary ($n = 153$) surgery for degenerative diseases of the lumbar spine was conducted. All surgeries were performed by two experienced surgeons using a standard posterior approach, intraoperative fluoroscopy, microsurgical techniques and binocular magnification. Intraoperative (presence of adhesions, damage to the dura mater, duration of surgery, blood loss, approach and stabilization) and clinical and anamnestic data (gender, age, body mass index, diagnosis, blood transfusion and revisions) were analyzed. Damage to the dura mater was assessed intraoperatively, during revision and based on MRI data. Statistical analysis was performed using the binary logistic regression model.

Results. In repeated surgeries, epidural fibrosis was observed in 92.36% of patients, which significantly increased the risk of dura mater injury as compared to primary surgeries (15.2% vs. 1.9%; $p < 0.001$). According to multivariate analysis, the extent of surgical access does not have a statistically significant effect on dura mater injury. The presence of fibrosis increases the risk of injury by 4 times, while spine stabilization reduces it by 6 times. The effect of surgery duration on the risk of dura mater injury was not statistically proven. The main limitation of the study is the insufficient postoperative MRI screening, which may lead to the underestimation of the incidence of complications.

Conclusion. Epidural fibrosis is a key risk factor for damage to the dura mater during revision surgery. Its prevention is a pressing issue in surgery for lumbar spine dorsopathies.

Key Words: damage to the dura mater; complications; epidural fibrosis; failed back surgery syndrome; repeated surgical interventions; revision surgery.

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Surgical treatment of patients with degenerative disc diseases always involves risks of repeated surgery and recurrence of pain [1–4]. The efficiency of primary surgeries rarely exceeds 50%, and pain recurrence in re-operated patients is associated with epidural fibrosis, which is diagnosed in 95.6% of cases during epiduroscopy, whereas traditional MRI detects it in only 16.1% of cases [5–7]. The differences between the results of introspective technologies and real-time imaging are confirmed by Dessouky et al. [8], according to whom the widespread introduction of new diagnostic techniques, such as magnetic resonance neurography (MRN), in 40–67% of patients improves treatment outcomes by changing treatment strategies and, accordingly, reducing the frequency of repeated surgeries. Conversely, Amirdelfan et al. [9] demonstrated the limited efficacy of both drug treatment and repeated surgeries for failed back surgery syndrome (FBSS). However, active rehabilitation and stimulation techniques have demonstrated better outcomes [6, 10, 11]. Thus, spinal cord stimulation has a longer-lasting effect than both drug treatment and repeated surgery [11]. It is equally important that repeated surgeries not only reduce patient satisfaction but also increase the risk of intraoperative complications because of technical challenges associated with epidural fibrosis, which obstructs access to the surgical site and increases the injury risk of procedures.

The authors of this study have previously published data from a retrospective analysis of the frequency and structure of complications in patients who underwent repeated and primary surgery [12]. A disadvantage of the study was the incomparability of the groups in terms of surgical technique, which required extended and additional statistical processing of the data to determine the strength of influence and interrelationship of key risk factors for dura mater injury. Therefore, an additional analysis was conducted to quantify the odds ratio (OR) for each key factor in our data set using a binary logistic regression model.

The objective is to conduct a multifactorial assessment of the risks of intraoperative damage to the dura mater (DM) in patients who underwent primary and repeated surgeries on the lumbar spine.

Material and Methods

The design of the study is a retrospective comparison of two groups of patients with evaluated parameters who underwent surgery for degenerative pathology of the lumbar spine (Fig. 1). The study included 144 patients who underwent repeated surgery between 2010 and 2020 and 153 patients who underwent primary surgery in 2015. The surgery was performed by two experienced surgeons using a posterior approach to the spinal canal. The procedure involved intraoperative fluoroscopic control, decompression of the spinal canal under binocular optics with 3.5-fold magnification, and the use of microsurgical instruments and electro-optical converter during the placement of the pedicle screws.

The following parameters were obtained from the medical records:

• intraoperative indicators: according to dictated detailed procedure reports, there were signs of cicatrical adhesions in the epidural space, evidence of impaired integrity of the DM, duration of the surgery, blood loss, type of surgical approach to the spinal canal (translaminar, hemilaminectomy, laminectomy), use of stabilization transpedicular systems or their omission;

• clinical and medical history data: gender, age, body mass index (BMI), nosological form of the disease, use of blood transfusion, reasons for surgical postoperative wound revision;

• MRI scans in the postoperative period: MRI signs of DM injury were evaluated.

MRI scans of patients who underwent recommended routine outpatient follow-up after discharge from the hospital were retrospectively chosen from the database of the Irkutsk Scientific Centre of Surgery and Traumatology using their identification data (surname, name, and patronymic as well as the date of birth).

DM injury was recorded at three stages: intraoperatively, during wound revision, or based on the findings of postoperative MRI scans. The injury was considered confirmed if it was recorded at any of these stages.

The study was approved by the local ethics committee of the Irkutsk Scientific Centre of Surgery and Traumatology (protocol No. 1 as of January 22, 2019).

Statistical analysis. Statistical data processing was performed using Statistica 10.0 software. Data are given as quantitative and percentage ratio, mean values, standard deviations (M ± SD), and median (25; 75) in groups. The differences between the groups were evaluated using Pearson's chi-squared test and the Mann–Whitney U test. Multivariate analysis was performed using a binary logistic regression model to assess the risk of DM injury in the presence of confounders in groups of patients who underwent repeated and primary surgery. The models were built using the R programming language version 4.3.3 in RStudio version 2023.12.1 Build 402.

Results

The comparison of the indicators of the analyzed groups showed their similarity in terms of gender and age; nevertheless, differences in the nosological forms of degenerative pathology were noted: degenerative stenosis of the spinal canal (ICD-10 codes M99.0, M99.5, M48.0) was more common in patients who underwent repeated surgery, while intervertebral disc herniation (M51.1) was more common in patients undergoing primary surgery.

Repeated surgeries were marked by a significantly higher frequency of intraoperative epidural fibrosis (92.36%) and DM injury (15.2%) compared to primary surgeries (1.9%). Moreover, repeated surgeries were associated with longer surgical duration, greater blood loss volume, and, consequently, more frequent blood transfusions. Statistical analysis ($p < 0.001$) confirmed significant differences in the frequency of DM injury (Fig. 2).

There were no statistically significant differences in the frequency of repeated surgeries when comparing the groups ($p = 0.409$): revision was required in 8.33% (12 out of 144) of patients with repeated surgeries and in 5.88% (9 out of 153) with primary surgeries. Meanwhile, there were differences between the groups in terms of the reasons for these surgeries: apart from hematomas (50.00%; 6 cases), the re-operated group included cases of cerebrospinal fluid leakage (16.67%; 2 cases), pseudomeningocele (16.67%; 2 cases), and wound suppuration (16.67%; 2 cases), while in the group of patients undergoing primary surgery, hematomas (77.78%; 7 cases) and the need for additional decompression with fixation correction (22.22%; 2 cases) dominated.

Since repeated surgeries are more traumatic than primary ones, patients were divided into subgroups to level the difference between comparable groups. The classification was made according to the type of surgical approach (translaminar, hemilaminectomy, or laminectomy) and the presence/absence of transpedicular stabilization systems during surgery.

The data analysis on instrumental stabilization revealed differences between the groups in the frequency of isolated transpedicular fixation (TPF) system use, with no differences in the frequency of TPF and cage combination: thus, in repeated and primary surgeries, TPF was performed in 106 and 136 (73.61% and 88.89%) cases, respectively ($p < 0.0001$), while TPF with a cage was performed in 34 and 57 (32.08% and 41.91%) surgeries ($p = 0.1171$). These outcomes prompted the formation of a “stabilization” subgroup. Further analysis was conducted to identify differences between these subgroups in terms of the following parameters: intraoperative blood loss, surgery duration, and frequency of DM injury. Statistical analysis showed significant differences ($p < 0.001$) for patients with instrumental stabilization of the spine in all parameters studied. Signifi-

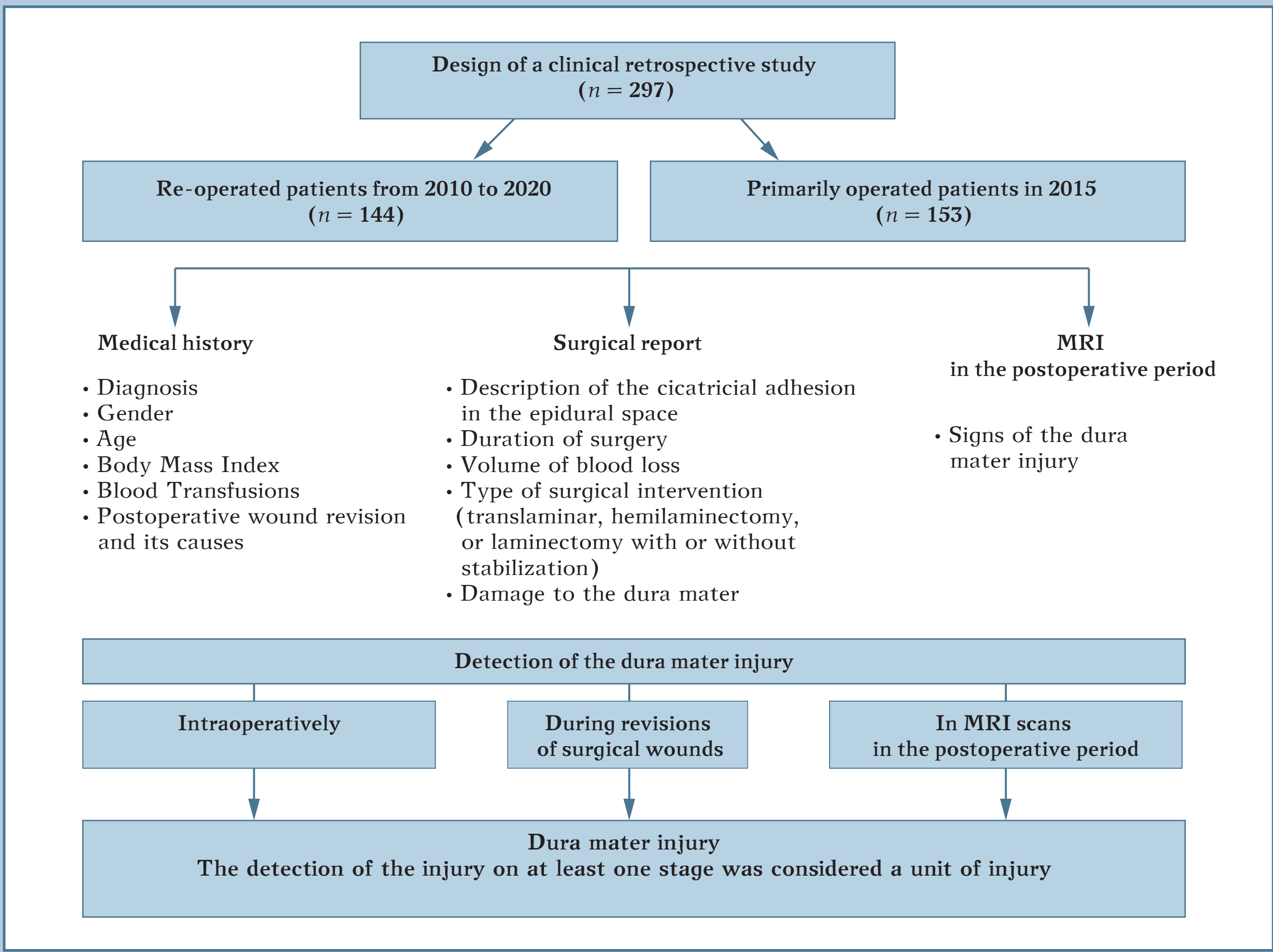

Fig. 1
Study scheme

cant differences were also found in the subgroups with hemilaminectomy and laminectomy (Tables 1, 2).

According to the data obtained, it can be concluded that epidural fibrosis, as a frequent complication of previous surgery, should be considered an important predictor of complications in repeated surgeries, including intraoperative injury to the DM, extended time of surgery, and increased blood loss volume. During repeated surgeries, injury to the DM was recorded in 16 cases. During two of the four repeated surgeries, the resulting DM defects were not diagnosed intraoperatively, which resulted in the formation of a pseudomeningocele. Analysis of postoperative MRI scans revealed signs of DM injury in six patients who underwent repeated surgeries. Two cases represent particular interest: despite wound revision performed earlier due to hematoma, there were no DM defects found intraoperatively, but an MRI scan revealed a radiculocele (Fig. 3). The obtained outcomes confirm a statistically significant association between repeated surgeries and an increased risk of DM injury ($p < 0.001$).

The main limitation of the study was the unavailability of systematic postoperative MRI screening. Follow-up MRI studies were performed only in some patients after repeated and primary surgeries – 49 and 36 (34.03% and 23.53%), respectively. The absence of statistically significant differences between the groups ($p = 0.405$) made it possible to predict the likelihood of DM injury with the expansion of MRI follow-up. Among 297 cases, intraoperative injury to the DM was recorded in 19, while among 85 postoperative MRI, signs of defect were found in 6 cases. Calculations showed that, according to MRI data, the overall probability of DM injury was 7.06% (≈15 patients): 0.00% in the primary surgery group and 12.24% (≈12 patients) in the repeated surgery group.

Another significant limitation of the study was the impossibility of analyzing the extent and degree of epidural fibrosis as a result of the unavailability of preop-

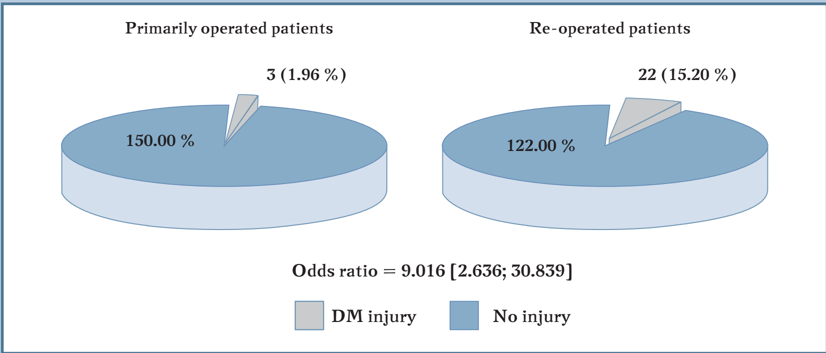

Fig. 2
Dura mater (DM) injury in groups

erative MRI data, even considering the limited sensitivity and specificity of this verification technique [7, 8], as well as the insufficient detailed information in the dictated detailed procedure reports and retrospective data analyzed.

Depending on the estimated limitations of reliability, additional multivariate analysis was performed using a binary logistic regression model to evaluate the risk of DM image in the presence of confounders in groups of patients who underwent repeated and primary surgery.

If the response is binary (in our case, DM injury is binary and assumes two values: 0 – no injury, 1 – injury present), logistic regression models are used to study the effect of factors on the response. A regression model is an equation where the dependent variable is shown as a function of independent variables (factors, predictors). The logistic regression model is distinguished from the regression model by using a transformation of the regression equation with a logistic function. It is done so as to obtain only two values as a response: 0 and 1.

Logistic regression predicts not a specific number but the probability that an event will occur. In order to convert this probability into a clear-cut answer of "yes" (1) or "no" (0), a cutoff threshold is used. If the probability is more than 50%, the answer is "yes"; if less, "no". OR is used to understand the effect of each factor on probability. Therefore, OR is a simple and understandable way to measure the strength and direction of each factor's influence on the outcome of interest.

The aim is to investigate the relationship between DM injury and concomitant factors, including cicatricial tissue, the extent of surgery (type of approach to the spinal canal), stabilization, and surgery duration. A distinctive feature of the characteristics "presence of cicatricial tissue" and "presence of stabilization" is their dichotomous nature – the values of the characteristics are reflected at two levels: 0 and 1. The type of surgery is a categorical variable and can include three values: 0 – hemilaminectomy; 1 – laminectomy; 2 – translaminar approach. The surgery duration is a quantitative variable (surgery time in minutes). The dichotomous nature of the signs-factors, as well as the sign-response, determined the choice of logistic regression as a mathematical-statistical tool for modeling the probability of DM injury development depending on the values of the signs-factors. The models are designed to predict the risk of DM injury.

A logistic regression model was used to analyze the relationship between the extent of surgery (type of approach to the spinal canal) and the risk of DM injury in groups classified according to whether they underwent primary or repeated surgery on the lumbar spine. For this purpose, a group of patients who had undergone primary surgery (153 individuals) was first identified,

Table 1
Blood loss volume, surgery duration, and dura mater injury in subgroups of patients with and without stabilization

Parameters	Stabilization		p	Without stabilization		p
	re-operated ($n = 106$)	primarily operated ($n = 136$)		re-operated ($n = 38$)	primarily operated ($n = 17$)	
Blood loss, ml	352.50 ± 269.50 250 [150; 500]	191.18 ± 134.56 200 [100; 200]	<0.000[2]	241.32 ± 216.36 150 [150; 300]	155.88 ± 160.94 50 [100; 200]	0.035[2]
Surgery duration, min	137.40 ± 48.00 132 [100; 160]	100.00 ± 23.89 95 [80; 115]	<0.001[2]	82.89 ± 25.62 75 [60; 100]	65.88 ± 21.52 60 [55; 65]	0.009[2]
Dura mater injury, n (%)	15 (14.15)	2 (1.60)	<0.001[1]	7 (18.42)	1 (5.88)	0.192[1]

[1] Pearson's chi-squared test χ^2; [2] Mann—Whitney U-test.

Table 2
Blood loss volume, surgery duration, and dura mater injury in the subgroups of hemilaminectomy, laminectomy, and translaminar approach

Parameters	Hemilaminectomy		p	Laminectomy		p	Translaminar approach		p
	re-operated (n = 41)	primarily operated (n = 85)		re-operated (n = 93)	primarily operated (n = 58)		re-operated (n = 10)	primarily operated (n = 10)	
Blood loss, ml	232.9 ± 191.9 150 [150; 200]	170.00 ± 136.54 150 [100; 200]	0.026[2]	380.9 ± 278.4 300 [200; 500]	230.2 ± 133.8 200 [150; 250]	<0.001[2]	155 ± 130.1 125 [100; 150]	85 ± 78.35 50 [50; 100]	0.045[2]
Surgery duration, min	88.65 ± 28.12 85 [75; 100]	91.41 ± 21.71 85 [75; 100]	0.32[2]	142.6±48 140 [110; 160]	109 ± 24.7 105 [90; 125]	<0.001[2]	82 ± 23.83 85 [70; 90]	63.5 ± 24.84 57.5 [50; 60]	0.064[2]
Dura mater injury, n (%)	5 (12.2)	2 (2.4)	0.024[1]	17 (18.28)	0	<0.001[1]	0	1 (10)	0.305[1]

[1] Pearson's chi-squared test χ^2; [2] Mann–Whitney *U*-test.

and a logistic regression model was developed.

The resulting model outlines the relationship between the extent of the surgery and the probability of DM injury. The significant free term a_0 = 3.725 indicates that, regardless of the extent of the surgery, DM injury in the group of primary patients is extremely rare. The free term OR is calculated for a value of factor X_1 = 0 (i.e., approach to the spinal canal during hemilaminectomy). The other types of spinal canal approach surgery had no significant effect on the response. As can be seen from the coefficients and their significance, none of the factor values are relevant; consequently, in the group of patients who underwent primary surgery, no statistical correlation was found between the extent of surgery and the presence of DM injury. The free term OR is 0.024; confidence interval (CI): [0.004; 0.076] (Table 3).

In the group of patients who underwent repeated surgery (144 patients), a logistic regression model was also constructed to clarify the relationship between DM injury and the extent of surgery.

The model coefficients and their relevance are provided in Table 4.

This group, like the group of patients who underwent primary surgery, shows no statistically significant correlation between the extent of surgery and the presence of DM injury. The value of the free term a_0 = 1.9741 (OR = 0.139; CI: [0.048; 0.323]) indicates that DM injury is significantly more common in the re-operated group. Comparing the free term OR in the primary and

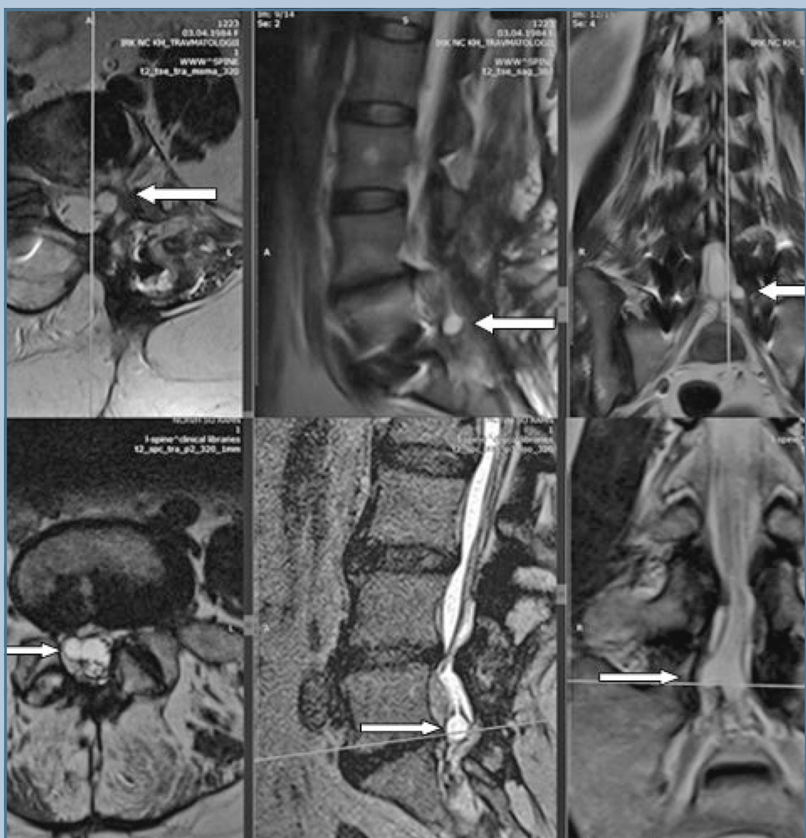

Fig. 3
MRI in axial, sagittal and frontal planes on T2-weighted image: the arrow indicates the radiculocele

re-operated groups, it can be concluded that DM injury occurs approximately 6 times more frequently in the re-operated group than in the primary surgery group at the zero value of the factor level (i.e., upon approach to the spinal canal during hemilaminectomy).

In regression models, including logistic regression, the inclusion of correlated signs in the model should be avoided. In our case, the dichotomous signs "primary/repeated" and "presence/absence" of cicatricial tissue (epidural fibrosis) are strongly correlated. Therefore, to determine the degree of correlation between cicatricial tissue and DM injury for each surgery extent, a logistic regression model was developed for the entire sample: the groups of patients who underwent primary and repeated surgeries were combined into a single group. The sample size was 297 people.

The model coefficients and their significance assessment are listed in Table 5.

The model coefficients provide evidence that in the absence of cicatricial tissue and an approach to the spinal canal during hemilaminectomy, injury to the DM occurs quite rarely (OR = 0.020; CI: [0.005; 0.056]). Moreover, the type of surgical approach to the spinal canal does not make a big difference to DM injury. It is the presence or absence of a cicatricial tissue that really matters. According to the model, the occurrence of cicatricial tissue increases the risk of DM injury by almost 9 times (OR = 8.775; CI: [2.788; 38.897]). This effect is statistically significant. The CI for OR is illustrated in Fig. 4.

The obtained values indicate that there is no statistically significant correlation between the extent of the surgery and injury to the DM, although there may be a correlation between injury to the DM and the presence or absence of cicatricial tissue.

Since surgery extent was not statistically correlated with DM injury in any model, a study was conducted to identify statistical correlation between DM injury and factors such as the presence/absence of cicatricial tissue, the presence/absence of stabilization, and surgery duration. The model coefficients and their significance assessment are listed in Table 6.

The presence of such a factor as the surgery duration (time approaching 0) does not have a significant effect on DM injury. All coefficients in the model were statistically significant. The presence of cicatricial tissue is strongly correlates with DM injury. The value of the coefficient $a_1 = 1.37$ (OR = 3.942; CI: [1.184; 17.921]), which indicates that in the presence of cicatricial tissue, injury to the DM occurs approximately 4 times more often. The presence of a stabilization system decreases the probability of DM injury (coefficient value $a_2 = 1.881$ (OR = 0.152; CI: [0.044; 0.512]) by approximately 6 times. Nevertheless, this result should be considered cautiously, since it is a consequence of complex interactions between factors and different case selection in the primary and repeated surgery groups, the severity of fibrosis, and technical aspects of the surgical approach. It is possible that stabilization does not directly reduce the risk of mechanical injury to the DM, although it correlates with a complex set of factors. During primary surgery, transpedicular stabilization technically advances the decompression stage, allowing the surgeon to use stable support structures that are not prone to cicatricial tissue and to avoid aggressive exposure of the dural sac and nerve roots when placing cages during neural structure traction. The surgery duration, despite being statistically significant (p-value = 0.00012), does not have a significant effect on DM injury (OR = 1.021; CI: [1.011; 1.033]). The model visualization is depicted in Fig. 5.

Discussion

The core issue with retrospective studies of this patient group is the complexity of organizing postoperative MRI scans, which results in an underestimation of the frequency of DM injuries. In order to eliminate this limitation, a two-stage approach is possible: retrospective analysis with prospective data collection and widespread use of postoperative MRI scans. This will clarify the nature of dura mater injuries during repeated surgery on the lumbosacral spine in patients with degenerative pathologies, identify subclinical defects (e.g., radiculocele) that remain hidden during standard intraoperative revision, and perform a correlation analysis between the surgical

Table 3

Indicators of the logistic regression model in the group of primary operated patients depending on the type of approach to the spinal canal

Factor	Coefficient	95% CI	OR	p-value
a_0, free term	−3.725	−5.529; −2.573	0.024	1.92e-07*
Laminectomy	−16.840	NA; 373.267	0.000	0.994
Translaminar approach	1.528	−1.596; 3.971	4.611	0.230

95% CI — 95% confidence interval; OR — odds ratio; * p < 0.001.

Table 4

Indicators of the logistic regression model in the group of re-operated patients depending on the type of approach to the spinal canal

Factor	Coefficient	95% CI	OR	p-value
a_0, free term	−1.9741	−3.042; 1.130	0.139	3.53e-05*
Laminectomy	0.4766	−0.537; 1.649	1.611	0.384
Translaminar approach	−15.5920	NA; 56.704	0.000	0.990

95% CI — 95% confidence interval; OR — odds ratio; * p < 0.001.

technique, the surgery's extent, and the structure of DM injury. The extensive use of postoperative MRI is essential for the early detection of subclinical DM injuries (radiculocele, pseudomeningocele), analysis of fibrosis structure, and correlation of morphological changes concerning clinical symptoms.

The results of the study showed that epidural fibrosis has clinical significance: it considerably complicates repeated surgery on the spine, thus increasing the risks of intraoperative DM rupture, bleeding, and nerve root injuries (due to pronounced anatomical deformities in the area of cicatrical adhesion), being a key trigger of FBSS, and remaining one of the complex problems in spinal surgery [13–17]. The incidence of FBSS reaches 30–46% after fusion and 19–25% after microdiscectomy [5]. Moreover, 50% of cases of FBSS require repeated surgery, forming a vicious circle of "complication reoperation new complication", leading to the development of chronic postoperative pain syndrome, the etiology of which includes structural factors (epidural fibrosis) and functional mechanisms (neurogenic inflammation, peripheral/central sensitization, activation of microglia cells) [11, 12, 18–21]. Therefore, prevention requires individual selection of anti-fibrotic protection techniques (considering past medical history and the extent of surgery) and multimodal analgesia with attention to the neuropathic component of pain. Therefore, the prevention of epidural fibrosis is a priority that includes the development of bioactive materials for intraoperative use and is a critically important area of research. Its adoption will reduce the frequency of intraoperative complications, decrease the risk of chronic postoperative pain syndrome, and improve long-term outcomes, especially in patients who require multiple revisions.

Table 5

Indicators of the logistic regression model in the joint group of primary and re-operated patients depending on the type of approach to the spinal canal

Factor	Coefficient	95% CI	OR	*p*-value
a_0, free term	3.932	5.391; 2.886	0.020	2.3e-10*
Presence of cicatricial tissue	2.169	1.025; 3.661	8.755	0.000858*
Laminectomy	0.098	0.846; 1.130	1.104	0.842
Translaminar approach	0.272	3.260; 1.612	0.762	0.809

95% CI — 95% confidence interval; OR — odds ratio; * $p < 0.001$.

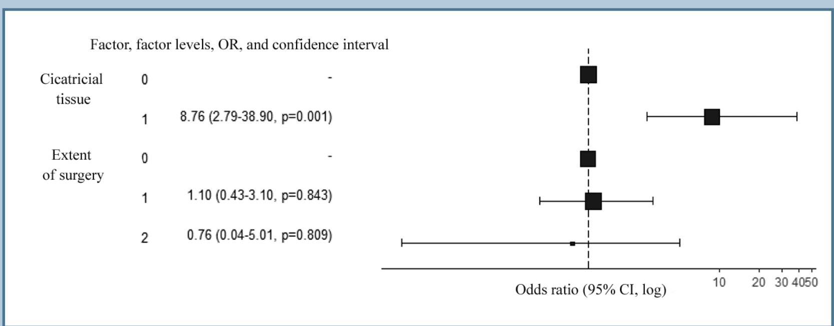

Fig. 4
Odds ratio (OR) and confidence intervals for factors of the dura mater injury in the presence of an epidural cicatricial tissue and the extent of surgery (type of approach to the spinal canal) in groups of primary operated and re-operated patients

Conclusion

Epidural fibrosis is a key risk factor for DM injury during repeated surgery. Postoperative MRI to detect subclinical DM injury (radiculocele) is essential for objective evaluation of the FBSS frequency and the mechanisms of chronic postoperative pain. The development and practical implementation of intraoperative materials designed to prevent postoperative epidural fibrosis is still a crucial issue in surgery for lumbar dorsopathies, especially when repeated surgical interventions are required, which are associated with a higher risk of intraoperative complications and adverse outcomes. Therefore, it is advisable to include postoperative MRI examination in clinical recommendations for the treatment of degenerative disc diseases.

The study had no sponsors. The authors declare that they have no conflict of interest.
The study was approved by the local ethics committee of the institution.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

Table 6

Indicators of the logistic regression model in the joint group of primary and re-operated patients depending on the presence/absence of cicatricial tissue and stabilization and surgery duration (time)

Factor	Coefficient	95% CI	OR	*p*-value
Constant	−4.57078	−6.217; −3.243	0.010	7.82e-10***
Presence of cicatricial tissue	1.37170	0.169; 2.886	3.942	0.04061*
Stabilization	−1.88106	−3.126; −0.669	0.152	0.00241**
Surgery time	0.02122	0.011; 0.033	1.021	0.00012***

95% CI — 95% confidence interval; OR — odds ratio;
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

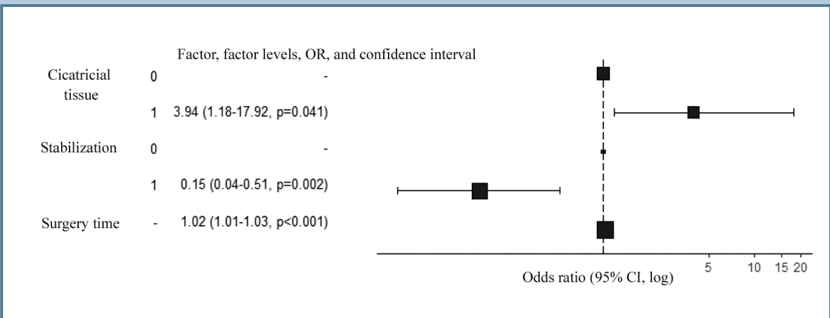

Fig. 5

Odds ratio (OR) and confidence intervals for factors of the dura mater injury in the presence of an epidural cicatricial tissue, stabilization and surgery duration in groups of primary operated and re-operated patients

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Address correspondence to:
Zhivotenko Aleksandr Petrovich
Irkutsk Scientific Centre of Surgery and Traumatology,
1 Botsov Revolyutsii str., Irkutsk, 664003, Russia,
sivotenko1976@mail.ru

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Aleksandr Petrovich Zhivotenko, junior researcher at the Research Clinical Department of Neurosurgery, Irkutsk Scientific Centre of Surgery and Traumatology, 1 Botsov Revolyutsii str., Irkutsk, 664003, Russia, eLibrary SPIN: 8016-5626, ORCID: 0000-0002-4032-8575, sivotenko1976@mail.ru;
Vladimir Alekseyevich Sorokovikov, DMSc, Prof., Director, Irkutsk Scientific Centre of Surgery and Traumatology, 1 Botsov Revolyutsii str., Irkutsk, 664003, Russia; Head of the Department of Traumatology, Orthopedics and Neurosurgery, Irkutsk State Medical Academy of Postgraduate Education – Branch Campus of the Russian Medical Academy of Continuing Professional Education, 100 Yubileiny Microdistrict, Irkutsk, 664049, Russia, eLibrary SPIN: 8379-4458, ORCID: 0000-0002-9008-6383, vasorokovikov@mail.ru;
Sergey Nikolaevich Larionov, DMSc, leading lesearcher; Head of the Scientific and Clinical Department of Neurosurgery, Irkutsk Scientific Centre of Surgery and Traumatology, 1 Botsov Revolyutsii str., Irkutsk, 664003, Russia, eLibrary SPIN: 6720-4117, ORCID: 0000-0001-9189-3323, snlar@mail.ru;
Irina Aleksandrovna Shurygina, DMSc, Professor of RAS, Deputy Director for Science, Irkutsk Scientific Centre of Surgery and Traumatology, 1 Botsov Revolyutsii str., Irkutsk, 664003, Russia, eLibrary SPIN: 6745-5426, ORCID: 0000-0003-3980-050X, irinashurygina@gmail.com.