ON THE ISSUE OF PREDICTORS OF COMPLICATIONS OF SURGICAL TREATMENT OF PATIENTS WITH SPINAL CORD INJURY IN THE LOWER THORACIC AND LUMBAR SPINE

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Objective. To determine the predictors of complications of surgical treatment of patients with spinal cord injury (SCI) in the lower thoracic and lumbar spine using various options for performing decompression and stabilization surgeries.

Material and Methods. A total of 240 patients with spinal cord injury in the lower thoracic and lumbar spine were operated on in 2010–2021. All patients were divided into 3 groups depending on the tactical option of surgical treatment performed. In Group 1, patients (n = 129) underwent two-stage surgical intervention through combined approach: the first stage included transpedicular fixation (TPF) supplemented with posterior decompression options and the second stage – fusion through anterior approach, in Group 2 (n = 36) – TPF and decompression through posterior approach, and in Group 3 (n = 75) – one-stage surgical intervention including TPF, decompression and fusion through extended posterior approach. An analysis of surgical complications was carried out, and factors that increase the likelihood of their development were identified. Comparison of groups according to quantitative indicators was carried out using single-factor analysis of variance (with normal distribution), and Kruskal-Wallis test (with distribution other than normal). Comparison of percentages in the analysis of multifield contingency tables was performed using Pearson's χ^2 test.

Results. A total of 130 cases of postoperative complications were identified that corresponded to the grade 2 or 3 of the Clavien – Dindo classification, including respiratory, infectious processes in the surgical site, iatrogenic neurological complications, intraoperative damage to the dura mater, and instability of metal fixation. In two-stage surgery through combined approaches, the most common were respiratory complications (17.1 %), intraoperative damage to the dura mater (9.3 %) and surgical site infection (7.0 %). Predictors of these complications included the severity of preoperative neurological deficit of ASIA grade A or B, the patient's preoperative condition corresponding to the average risk of death according to the modified SOFA score, and the performance of extended laminectomy. In isolated TPF with reposition and stabilization without fusion, the most common complication was instability of metal fixation in the long-term period (47.1 %), the predictors of which were incomplete reposition of the fractured vertebral body and performing two-segment TPF. In one-stage decompression and stabilization interventions with TPF and fusion through the extended posterior approach, the most common complications were intraoperative damage to the dura mater (26.7 %), respiratory complications (18.7 %), infectious processes in the surgical site (10.7 %), iatrogenic neurological complications (12.0 %), and instability of metal fixation (16.1 %). Predictors of these complications were the severity of the patient's condition before surgery, corresponding to the average risk of death according to the modified SOFA score, neurological deficit of type D or rapidly regressing neurological deficit of type C, A or B according to ASIA scale, and bisegmental fusion when the injury was located at the lumbar level.

Conclusion. Analysis of the causes of complication development contributes to their prevention, and can also form the basis for algorithms to choose tactics and technology for performing decompression and stabilization operations.

Key Words: thoracic and lumbar spine, injury, surgical treatment, complications, predictors.

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The issue of choosing the optimal surgical option for spinal cord injury (SCI) in the lower thoracic and lumbar spine still remains a matter of debate. As a rule, known options for surgical treatment of these injuries are classified depending on the approaches used: anterior surgical interventions, posterior, including extended posterior approaches, and surgeries through combined approaches [1]. All of them ultimately provide positive immediate and long-term treatment outcomes [2–4], but they vary in technical complexity, nature and rate of emerging complications.

Papers on unsatisfactory outcomes of surgical treatment are much less common than ones showing positive outcomes [5]. Complications are usually associated with errors in preoperative planning, inappropriate choice of surgical strategy and/or technical errors [6, 7]. Complications often result in revision surgeries, which are distinguished by increased complexity, high morbidity, and surgical risk [8]. An important challenge in modern spine surgery is the assessment of the causes of complications, the identification of risk factors for their development and the elaboration of measures aimed at their prevention.

The objective is to determine the predictors of complications of surgical treatment for patients with spinal cord injury (SCI) in the lower thoracic and lumbar spine using various options for performing decompression and stabilization surgeries.

Material and Methods

A total of 240 patients with acute spinal cord injury in the lower thoracic and lumbar spine were operated on in 2010–2021.

Inclusion criteria:

– unstable single-level 1–2-segment injuries of the lower thoracic and lumbar spine from T9 to L5;

– the incidence of traumatic vertebrogenic neurological deficit;

– fractures with LSC (Load-Sharing Classification scale) score of 6 or more [9];

– patients aged 18–60 years.

Exclusion criteria:

– multilevel spinal injury;

– multiple trauma with a questionable and unfavorable prognosis for life;

– osteoporosis;

– pathologic fractures;

– Charlson Comorbidity Index of more than 5 points.

All patients were divided into 3 groups depending on the tactical option of surgical treatment performed:

– Group 1 (n = 129). Patients in this group underwent two-stage surgical intervention through a combined approach: the first stage included transpedicular fixation (TPF) supplemented with posterior decompression options, and the second stage was fusion through anterior approach. The time interval between the stages was at least 5 days;

– Group 2 (n = 36). Patients in this group underwent one-stage surgical intervention: TPF and decompression through the posterior approach;

– Group 3 (n = 75): one-stage surgical intervention: TPF, decompression and fusion through an extended posterior approach.

The AO Spine Thoracolumbar injury classification system was used to define the morphology of the injury [10]. Type A3 fractures were found in 5 (3.9 %) patients in Group 1, in 4 (11.1 %) patients in Group 2 and in 5 (6.7 %) patients in Group 3. Patients with A4 injuries predominated in all groups: 52 (40.3 %) in Group 1, 19 (52.8 %) patients in Group 2 and 34 (45.3 %) patients in Group 3. Type B distraction injuries in all patients were combined with vertebral body compression fractures of type A3 or A4. Type B2 (A3) fractures were registered in 13 (10.1 %) cases in Group 1, in 2 (5.6 %) cases in Group 2 and in 7 (9.3 %) cases in Group 3. Type B2 (A4) fractures predominated among distraction injuries and accounted for 42 (32.5 %) cases in Group 1, 8 (22.2 %) cases in Group 2 and 14 (18.7 %) cases in Group 3. Type B1 and B3 injuries were not found. Type C injuries were found in 17 (13.2 %) patients in Group 1, in 3 (8.3 %) patients in Group 2 and in 15 (20.0 %) patients in Group 3 (Fig. 1).

There were no statistically significant differences between the groups when analyzing the types of fractures ($p = 0.217$).

All patients included in the study suffered from SCI associated with vertebromedullary conflict and neurological deficit of differing grades according to the ASIA scale. Grade A according to the ASIA: 19 (14.7 %) patients in Group 1, 4 (11.1 %) patients in Group 2 and in 22 (29.3 %) patients in Group 3. Grade B was detected in 15 (11.6 %) patients in Group 1, in 4 (11.1 %) patients in Group 2 and in 10 (13.3 %) patients in Group 3. Grade C: in 35 (27.1 %) patients in Group 1, in 6 (16.7 %) patients in Group 2 and in 14 (18.7 %) patients in Group 3. Grade D: in 60 (46.5 %) patients of Group 1, in 22 (61.1 %) patients of Group 2 and in 29 (38.7 %) patients of Group 3 (Fig. 2).

There were no statistically significant differences in the distribution of injured persons in the groups according to the severity of the neurological deficit ($p = 0.069$). All patients included in this study were operated on for emergency indications in the acute phase of SCI. Moreover, in all three groups, patients with neurological deficit corresponding to types A and B according to Frankel, as well as those with type C with unstable neurological status, were taken to a neurosurgical in-patient department no later than 8 hours from the moment of injury. Corticosteroids were not administered to any of our patients due to the lack of consensus on this issue and the existence of guidelines suggesting that this component should be excluded from the medication of patients with SCI in the preoperative period [11–14].

The preoperative analysis of the findings of radiologic imaging included the identification of the main spondylometric parameters of the injured spinal motion segments: traumatic bisegmental local kyphosis (degrees), the vertical dimension of the injured vertebral body (% of the required) and the value of traumatic spinal stenosis (%). Cobb method was used to define the angle of bisegmental local kyphosis. Prior to the surgery it averaged 12.97° ± 7.75°, 11.56° ± 8.17° and 13.68° ± 7.93°, respectively, in groups 1, 2 and 3 (Fig. 3). There were no statistically significant differences between the groups when analyzing the values of local traumatic kyphosis ($p = 0.413$).

Traumatic spinal stenosis at the fracture level in the study groups ranged from 20 to 100 %. The median for this indicator was 47.8 % in Group 1, 40.0% in Group 2 and 48.0 % in Group 3.

There were no statistically significant differences between the groups when analyzing the values of traumatic spinal stenosis ($p = 0.102$).

Of the total number of patients, 142 (59.2 %) suffered from isolated SCI and 98 (40.8 %) had SCI as part of multisystem or concomitant injuries. A concomitant injury was observed in 47 (36.4 %) patients in Group 1, in 15 (41.7 %) patients in Group 2 and in 36 (48.0 %) patients in Group 3 (Fig. 4).

The severity of a multisystem or concomitant injury did not exceed 22 points according to the NISS. However, in all cases, the SCI was the most severe injury. The severity of concomitant injuries ranged from 1 to 3 on the AIS score [15]. There were no statistically significant differences in the incidence of multisystem or concomitant injuries in the groups, as well as in their structure (p = 0.095; Table 1). Therefore, the groups do not significantly differ from each other in terms of the key initial parameters.

The immediate and long-term surgical outcomes with a follow-up period of at least 24 months were studied in all three groups. The following were the main criteria for assessing the outcomes: regression of vertebrogenic post-traumatic neurological deficit, quality of the achieved correction of anatomical correlations and retention of values of the achieved correction in the long-term follow-up period. The ASIA scale was used to systematize neurological deficit. As for orthopedic correction in injured spinal motion segments, it was systematized according to the magnitude of bisegmental kyphosis and the degree of elimination of spinal stenosis. Moreover, the analysis of the outcomes considered intraoperative parameters (surgery duration, intraoperative blood loss) and the peculiarities of the hospital stage (duration of inpatient treatment, duration of stay in intensive care units (ICU) and the need for blood transfusions). Methods of descriptive statistics were used to systematize the data.

The comparison of groups by quantitative indicators was performed using the techniques of parametric and nonparametric statistics: univariate analysis of variance (in case of a normal distribution) and Kruskal – Wallis test (in case of a distribution other than normal). The Pearson's chi-squared test was used to compare the percentages in the analysis of multi-way contingency tables.

Positive treatment outcomes were obtained in all groups. There were no statistically significant differences between the groups in terms of the degree of regression of the neurological deficit. In Group 1, regression by one degree occurred in 74 (60.2 %) patients, by two degrees in 29 (23.6 %) patients and by three degrees in 6 (4.9 %) patients. There was no progress in neurological status as a result of treatment in 11.3 % of patients. In Group 2, regression by one degree occurred in 26 (72.2 %) patients and by two degrees in 6 (16.7 %) patients. There was no progress in neurological status as a result of treatment in 11.1 % of cases. In Group 3, regression by one degree occurred in 42 (59.2 %) patients, by two degrees in 12 (16.9 %) patients and by three degrees in 1 (1.4 %) patient. There was no progress in neurological status as a result of treatment in 22.5 %. Traumatic spinal stenosis was also effectively eliminated in all three groups. In Group 1, the value of stenosis correction was 31.0 %; in Group 2, it was 30.0 %; and in Group 3, it was eliminated in all patients by means of circumferential decompression. Complete correction of post-traumatic kyphotic deformity was achieved in all groups due to the high corrective ability of TPF in the acuity of injury. The mean value of residual segmental kyphosis in the early postoperative period was in the range of 0.8–2.9°, with subsequent loss of correction in the long-term period varying from 4.2° in Group 1 to 8.8° in Group 2. We do not provide a detailed analysis of the treatment outcomes in this paper. Furthermore, the data on the outcomes is presented in the section "Material and Methods," since the objective of the study is to determine the predictors of complications of surgical treatment for patients with spinal cord injury (SCI) in the lower thoracic and lumbar spine.

In accordance with the set objective, an analysis of the complications of surgeries that occurred in all groups was performed, and factors increasing the incidence of their development were identified. In our paper, we did not analyze the complications caused by defects in the care and rehabilitation of patients with SCI, which do not depend on the particularities of surgeries. Also, we did not cover the complications directly predetermined by the injury of the spinal cord and/or roots in SCI or collateral damage in a multisystem or concomitant injury. Complications were subdivided into intraoperative, early (occurring during inpatient treatment and up to 3 months after surgery) and late (occurring 3 months or more after surgery). Iatrogenic injury to the dural sac was attributed to intraoperative complications. Among the early ones were respiratory complications and infectious processes at the surgical site. Late complications include cases of loss of correction of more than 10° and the develop-

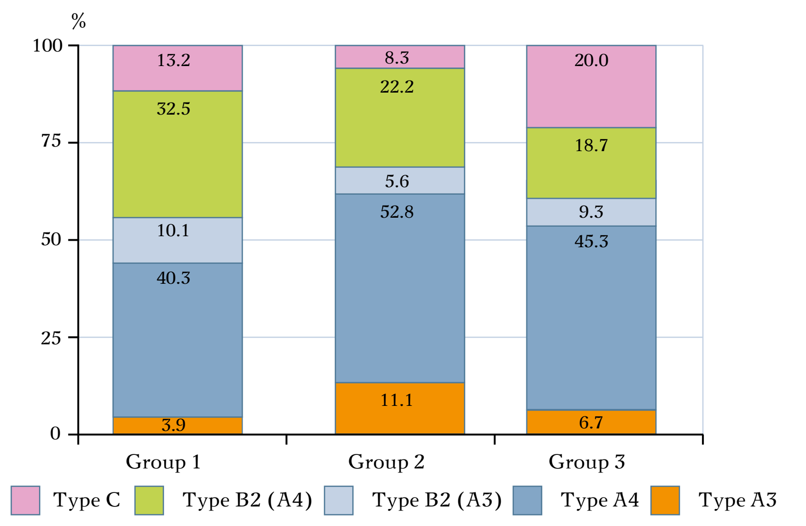

Fig. 1
Distribution of patients in groups by type of fracture

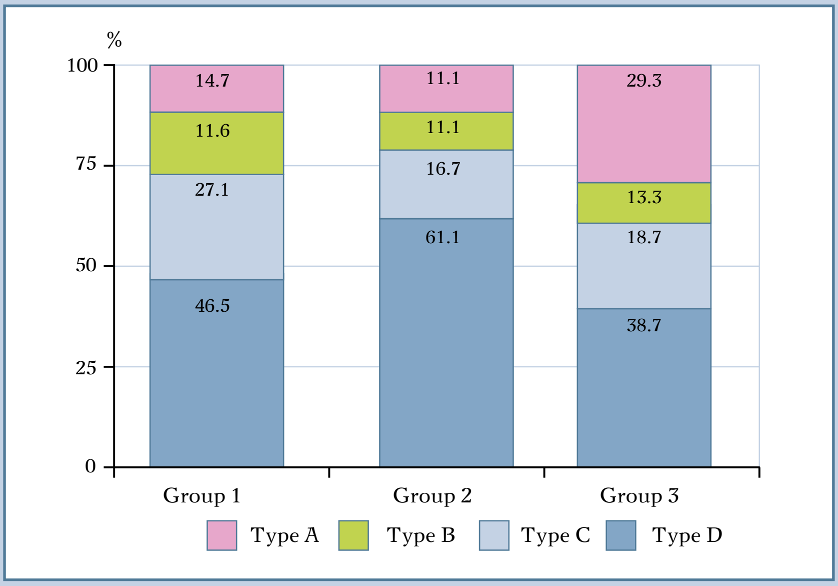

Fig. 2
Distribution of patients in groups according to the severity of neurological deficit according to the ASIA scale

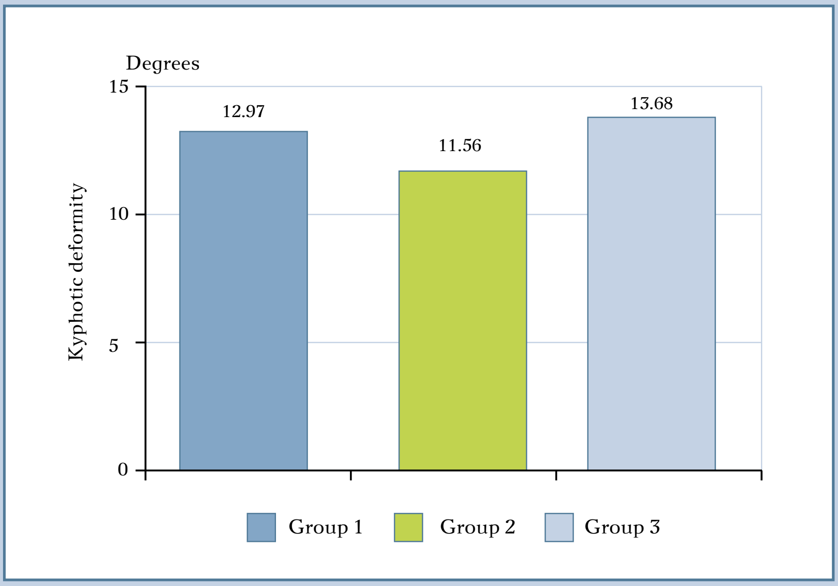

Fig. 3
Traumatic local kyphosis in study groups

ment of instrumentation instability. The strategy and technical options of surgical treatment were analyzed to influence the incidence of surgical complications in patients with SCI of the lower thoracic and lumbar spine, which were the grounds for the identification of three comparison groups. Furthermore, the severity of the preoperative neurological deficit and its progress in the preoperative period, the severity of a patient's preoperative condition, the site of injury, the type of fracture, the duration of the surgery, the intraoperative blood loss volume, the performed or non-performed laminectomy, the fusion extension (1 or 2 spinal motion segments), and the length of the ICU stay following surgery were all taken into consideration. During the hospital stay of the patients included in the study, there were no infection episodes or violations of infection control, both in the neurosurgical units and in the ICU. The ASIA scale was used to define the severity of the initial neurological deficit and its progress in the preoperative period. The type of fracture was assessed according to the AO Spine classification. The severity of the patient's condition before surgery was evaluated using the modified SOFA (Sequential Organ Failure Assessment) scale [16]. A regression analysis was conducted with the building of univariate and multivariate models to determine the contribution of the above factors to the likelihood of developing certain complications in all three groups. Therefore, multiplicative predictors have been determined to be statistically significantly associated with the development of these complications for each of the three surgical treatment options. The optimal values of quantitative features for predicting the outcome were estimated using ROC analysis. Statistical data processing was done using the IBM SPSS Statistics v21.0 software. The differences were considered statistically significant at p was <0.05.

Results

A total of 130 cases of complications of decompression and stabilization surgeries were identified that corresponded to the grade 2 or 3 of the Clavien – Dindo classification [17] and were considered serious complications according to the criteria of Schwab et al. [18] (Table 2).

We analyzed the dependence of the incidence of these complications associated with surgical treatment on the presence of factors listed in the section "Material and Methods", which characterize the initial condition of patients and some peculiarities of the treatment. Table 3 shows the identified influence

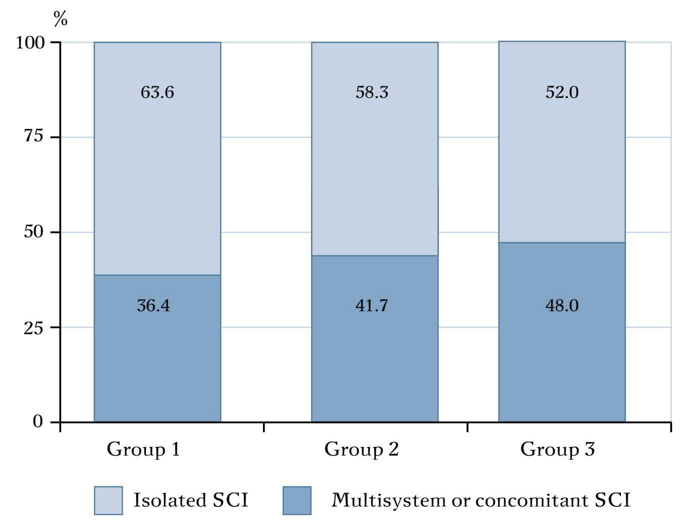

Fig. 4
Percentage of isolated spinal cord injury (SCI) and SCI as part of multisystem or concomitant injury in the study groups

Table 1
Collateral injuries in multisystem and concomitant injury in the studied groups of patients, n (%)

Collateral injuries	Group 1	Group 2	Group 3
Intracranial injury	11 (23.4)	3 (20.0)	13 (36.1)
Thoracic injury	25 (53.2)	5 (33.3)	24 (66.7)
Abdominal injury	16 (34.0)	6 (40.0)	8 (22.2)
Skeletal injury	39 (83.0)	11 (73.3)	24 (66.7)

of the studied parameters characterizing the initial condition of patients, as well as the influence of some technical features of surgeries on the risk of complications in all three groups of patients.

Patients of Group 1 who underwent two-stage surgical treatment for SCI of lower thoracic and lumbar localization through combined approach had the following most common complications: respiratory (17.1 %), including hemo- or hydrothorax, pneumothorax (8.5 %), atelectasis (7.0 %) and pneumonia (1.6 %). In addition to respiratory complications, intraoperative damage to the dura mater (9.3 %) and surgical site infection (7.0 %; Table 2) were common.

According to the statistical analysis using the binary logistic regression technique, the following has been established: the significant predictor of respiratory complications in the early postoperative period in Group 1 was the thoracic injury corresponding to score 2 or more on the AIS scale that increased the likelihood of these complications by 5.11 times (95 % CI: 1.88–13.91; $p = 0.001$). Nevertheless, this predictor proves to have a statistically significant effect on the risk of developing respiratory complications only in a univariate analysis. If there were no thoracic injuries, the predictor of respiratory complications in the early postoperative period was the severity of the patient's condition before surgery, corresponding to the average mortality risk according to the modified SOFA scale, which increased the likelihood of these complications by 6.87 times (95 % CI: 1.77–26.60; $p = 0.005$; Table 3). The effect of this parameter on the risk of pulmonary complications is higher than the presence of thoracic injury when building a multivariate model. All respiratory complications that manifested after the delayed anterior stage of surgical treatment (10.9 %) were associated with thoracotomy. The severity of the preoperative neurological deficit corresponding to grade A or B according to the ASIA increased the likelihood of developing respiratory complications in the early postoperative period after anterior surgeries by 17.37 times (95 % CI: 5.19–58.15; $p < 0.001$). Laminectomy increased the likelihood of iatrogenic damage to the dura mater by 53.67 times (95 % CI: 3.10–930.69; $p < 0.001$) and the risk of surgical site infection by 6.5 times (95 % CI: 1.29–32.69; $p = 0.023$). Other rather rare complications, such as neurological ones in the form of iatrogenic deterioration of vertebrogenic neurological deficit by 1–2 grades on the ASIA scale (0.8 %), instrumentation instability (2.9 %) and complications specific for anterior approach, such as cerebrospinal fluid leakage into the chest cavity and constant pain in the surgical site (1.6 %), did not show a statistically significant dependence on the studied parameters. Respiratory complications after thoracostomy and antibacterial therapy were eliminated and they did not unfavorably affect the treatment outcomes. Neurological complications were transient. In 4.7 % of cases surgical site infectious complications were an indication for debridement and subsequent vacuum therapy in the immediate postoperative period. In all cases, the stability of the TPF was preserved. There was no adverse effect on the treatment outcomes.

Thus, predictors statistically significantly associated with the development of respiratory complications are the severity of preoperative neurological deficit of the ASIA grade A or B, the severity of the patient's preoperative condition corresponding to the average mortality risk according to the modified SOFA score and collateral thoracic injury corresponding to score 2 or more on the AIS scale. The performance of laminectomy for SCI in the lower thoracic and lumbar spine during the posterior stage of surgical treatment increases the risk of intraoperative damage to the dura mater and the development of complications due to surgical site infections. Therefore, it is advisable to prefer indirect repositioning decompression of the dural sac based on the effect of ligamentotaxis. Other analyzed parameters did not affect the risk of complications in patients of Group 1 when using the staged surgical treatment (Table 3).

In Group 2, the most common complication with the use of isolated TPF with reposition and stabilization without fusion is the loss of achieved correction in injured spinal motion segments of more than 10° and/or instability of instrumentation in the long-term follow-up period (47.1 %; Table 2). Moreover, there were 2 cases of surgical site infection (5.5 %), pneumonia (5.5 %) and iatrogenic liquorrhea (5.5 %), which were eliminated in the early postoperative period. The instability of the TPF was an indication for repeated surgeries in the long-term period in 75.0 % of cases.

The predictors statistically significantly associated with the development of instability were identified using the binary logistic regression technique. It is a short-segment (two-segment) TPF and an incomplete reposition of the fractured vertebral body (Table 3). The building of a multivariate model showed that the four-segment eight-screw TPF decreases the risk of destabilization in the long-term period by 11.34 times compared to the two-segment four-screw TPF (95 % CI: 0.009–0.91; p = 0.041). Using ROC analysis, the optimal indicator of the degree of restoration of the height of the damaged vertebra was identified, at which it is possible to predict the stability of TPF in the long-term follow-up period. It was 78.0 %, with a sensitivity of 72.2 % and a specificity of 87.5 %. Restoring the vertical dimension of the injured vertebra to less than 78.0% of its proper size increases the risk of instability by 27.95 times (95 % CI: 2.80–279.50). Therefore, according to our data, in case of successful repositioning with TPF in conditions of four-segment eight-screw fixation, it is feasible to refrain from fusion. The cases of infectious processes at the surgical sites (n = 2; 5.5 %), pneumonia (n = 2; 5.5 %) and liquorrhea (n = 2; 5.5 %) did not reveal a significant dependence on the studied parameters.

In Group 3, single-stage decompression and stabilization surgeries from extended posterior approaches were used. The most common complications were intraoperative damage to the dura mater (26.7 %), respiratory complications (18.7 %), infectious processes at the surgical site (10.7 %), loss of correction of more than 10° with instability of metal fixation (16.1 %), as well as neurological complications in the form of iatrogenic deterioration of vertebrogenic neurological deficit by 1–2 grades on the ASIA scale (12.0 %; Table 2). In most cases, neurological complications regressed within 2–3 months to the initial status. The deterioration was irreversible only in two cases (22.2 %). Wound infectious and respiratory complications were eliminated in the early postoperative period and did not affect the obtained outcomes. The loss of correction in the injured spinal motion segments with instrumentation instability in all 16.1 % of cases was an indication for repeated surgeries in the long-term follow-up period.

A regression analysis of the data collected was performed, and the multiplicative predictors were determined that were statistically significantly associated with the development of these complications. It included the severity of a patient's condition before surgery corresponding to the average mortality risk according to the modified SOFA scale, collateral thoracic injury corresponding to score 2 or more on the AIS scale, a minor neurological deficit of grade D or a rapidly regressing neurological deficit of grade C on the ASIA scale, bisegmental fusion if the injury is localized at the lumbar spine, the severity of a preoperative neurological deficit of grade A or B according to the ASIA (Table 3).

The bisegmental fusion in the lumbar spine increased the risk of intraoperative damage to the dura mater by 8.79 times (95 % CI: 2.67–28.59; p < 0.001), the risk of developing iatrogenic neurological complications by 6.08 times (95 % CI: 1.11–33.38; p = 0.038) and the risk of instrumentation instability by 10.86 times (95 % CI: 2.05–57.46; p = 0.005). A minor neurological deficit of grade D or a rapidly regressing neurological deficit of grade C on the ASIA scale increase the risk of iatrogenic deterioration of neurological status by 1–2 grades on the ASIA scale by 6.08 times (95 % CI: 1.11–33.38; p = 0.038), which was not detected in other groups. The severity of the patient's condition in the preoperative period, corresponding to the average mortality risk according to the modified SOFA scale, and collateral thoracic injury corresponding to score 2 or more on the AIS scale increased the risk of respiratory complications by 12.87 times and 7.00 times, respectively (95 % CI: 2.86–57.97; p = 0.001; 95 % CI: 1.9–25.6; p = 0.003). In case of the comparable severity of the patients' conditions corresponding to the average mortality risk according to the modified SOFA scale, Group 3 had a 1.87 times higher risk than Group 1 with two-stage surgery.

The severity of preoperative neurological deficit of ASIA grade A or B, as well as the severity of a patient's condition prior to surgery, which corresponds to the average mortality risk according to the modified scale, are the predictors of complications for two strategic and technical surgical treatment options used concurrently in groups 1 and 3. Moreover, the severity of a patient's condition before surgery, corresponding to the average mortality risk on the SOFA scale, as the predictor of complications in Group 3 has a significantly greater impact on the risk of complications than in Group 1 (Table 2). Meanwhile, the severity of preoperative neurological deficit of ASIA grade A or B as the predictor of complications is more relevant in Group 1 than in Group 3. Concomitant thoracic injury, defined as score 2 or more on the AIS scale, is the predictor of respiratory complications solely in a univariate analysis, with no statistically significant difference between patient groups in its effect on the development of respiratory complications. It means that the thoracic injury corresponding to the AIS score 2 or more predetermines the development of respiratory complications in the early postoperative period, regardless of the chosen surgical option.

Such studied characteristics as the type of AO Spine fracture, the surgery duration, the blood loss volume, and the duration of stay in the ICU after surgery did not have a statistically significant effect on the development of complications in any of the comparison groups.

Discussion

During the analysis of foreign literature, attention is drawn to the disparity of data on the incidence of complications when using various options for surgical treatment of SCI in the lower thoracic and lumbar spine.

For example, Jiang et al. [19] reported a statistically significantly higher complication rate when using anterior decompression through anterior approaches (20 %) than when using posterior options (9 %); $p < 0.05$. Stancic et al. [20] provide similar data in their study, in which the overall incidence of surgical complications was 23.1 % during the anterior approach and 8.3 % during the posterior approach.

Meanwhile, a number of authors report that there are no significant differences in the incidence of complications between anterior and posterior options of surgery. Thus, according to Jiang et al. [21], when performing posterior decompression, the complication rate was 25.86 %, and with anterior decompression, it was 29.17 % ($p = 0.676$). In addition, in a number of systematic reviews and meta-analyses, there were no differences in the incidence of complications between posterior and anterior options of surgical treatment [3, 4]. Wang et al. [22] conducted a randomized study to compare the surgical outcomes of anterior, posterior and combined surgeries and found that the complication rate was 4.5 %, 13.0 % and 9.5 %, respectively, with no statistically significant difference.

The opposite results were shown by Wood et al. [23] in a randomized controlled trial. The incidence of surgical complications after anterior fusion was 5.0 %, while with posterior procedures it reached 50.0 %. Hitchon et al. [24] reported the rate of repeated surgeries at 5.3 % after anterior ones and 20.0 % after posterior decompression.

According to a number of authors [25–29], the complication rate for circumferential decompression through extended posterior approaches ranges from 8.0 to 42.9 %. In a randomized study by Lin et al. [30] comparing isolated anterior decompression and circumferential decompression through extended posterior approaches, it is reported that there is no statistically significant difference in the rate of complications.

In a study by Reinhold et al. [31], including 733 patients operated on using isolated anterior, posterior or combined approaches, 56 (7.7 %) patients had intraoperative complications and

Table 2

Complications of surgical interventions in the treatment of patients with spinal cord injury in the lower thoracic and lumbar spine, n (%)

Complications	Group 1 (n = 129)	Group 2 (n = 36)	Group 3 (n = 75)	Total
Intraoperative				
Iatrogenic liquorrhea	12 (9.30)	2 (5.50)	20 (26.7)	34
Early				
Respiratory (total), including:	22 (17.10)	2(5.50)	14 (18.7)	36
— hemo- and/or hydrothorax	9 (7.00)	—	8 (10.7)	17
— pneumothorax	2 (1.55)	—	—	2
— segmental pneumonia	2 (1.55)	2(5.50)	6 (8.0)	8
— lobar lung atelectasis	9 (7.00)	—	—	9
Infectious (total), including:	9 (7.00)	2 (5.50)	8 (10.7)	19
— superficial SSI	5 (3.90)	—	—	5
— deep SSI	4 (3.10)	2 (5.50)	8 (10.7)	14
Neurological	1 (0.80)	—	9 (12.0)	10
Late				
Specific complications of the anterior approach (total), including:	2 (1.60)	—	—	2
— cerebrospinal fluid leakage into the chest cavity	1 (0.80)	—	—	1
— hypotonia of the muscles of the anterior abdominal wall	1 (0.80)	—	—	1
Instability of instrumentation	3 (2.90)	16 (47.10)	10 (16.1)	29

SSI — surgical site infection.

Table 3

Predictors of complications during surgical treatment of patients with spinal cord injury of the lower thoracic and lumbar spine using various tactical options

Predictors of complications	Multiplicity of increase in the risk of complications		
	Group 1	Group 2	Group 3
Severity of preoperative neurological deficit of the ASIA grade A or B	Respiratory complications — by 17.37 times	No significant impact	Respiratory complications — by 10.86 times
The severity of the patient's condition before surgery, corresponding to the mean risk of death according to the modified SOFA scale	Respiratory complications — by 6.87 times	No significant impact	Respiratory complications — by 12.87 times; infectious complications — by 32.08 times
Collateral thoracic injury corresponding to score 2 or more on the AIS scale	Respiratory complications — by 5.11 times	No significant impact	Respiratory complications — by 7.00 times
Minor neurological deficit of grade D or rapidly regressing neurological deficit of grade C according to the ASIA scale	No significant impact	No significant impact	Iatrogenic deterioration of neurological status — by 6.08 times
Two-segment fusion with injury to lumbar spine	No significant impact	—	Intraoperative damage to the dura mater — by 8.79 times; iatrogenic neurological complications — by 6.08 times; instability of metal fixation — by 10.86 times
Short length of metal fixation (2 spinal motion segments)	No significant impact	Fixation of 4 spinal motion segments compared to 2 spinal motion segments reduces the likelihood of developing instability by 11.34 times	—
Restoration of the vertical dimension of the injured vertebral body to less than 78 %	—	Increases the risk of developing instability by 27.95 times	—
Performing a laminectomy	Intraoperative damage to the dura mater — by 53.67 times; infectious complications — by 6.50 times	—	No significant impact

69 (9.4 %) had postoperative complications. Meanwhile, 39 (5.3 %) patients required repeated surgeries. The rate of intraoperative complications was significantly higher when using combined approaches (n = 34; 10.7 %) than posterior ones (n = 22; 5.9 %); p = 0.021. In the long-term follow-up, complications were noted in 52 (9.1 %) patients after posterior (n = 39), anterior (n = 4) and combined (n = 9) surgeries. Repeated surgeries were required in 2.5 % of cases.

Summarizing the literature data on combined surgeries, it can be noted that the great majority of authors show a statistically significantly higher complication rate when using staged surgical procedures rather than performing isolated posterior options, including extended approaches [32–36].

Conventionally, complications after surgical treatment are divided into intraoperative and postoperative, which can be early (up to 2 weeks) and late (2 weeks after) [37].

The most common intraoperative complications in posterior surgeries are malpositioned pedicle screws. According to the literature [7, 38, 39], the frequency of screw malposition in conventional placement techniques ranges from 5 to 41 % in the lumbar spine and from 3 to 55 % in the thoracic spine. According to A.G. Aganesov et al. [40], the screw malposition of more than 4 mm is a risk factor for the development of vascular and neurological complications.

The second most common intraoperative complication is damage to the dura mater; its incidence ranges from 11.6 to 47.0 % [41–44]. According to Pham et al. [27], while performing circumferential decompression and fusion through extended posterior approaches, this indicator can reach 100.0 %. According to the number of authors, the predictors of dura mater rupture at the laminectomy stage are a vertebral arch fracture, the value of traumatic stenosis at the damage level of more than 50 %, an increase in the intervertebral space of more than 20 %, diastasis between fragments of a fractured vertebral arch of more than 2.5 mm, multilevel spinal injuries and concomitant SCI [41, 44–46].

According to the majority of authors [20, 22, 23, 26, 27, 47], the most common complications of the early postoperative period after TPF and posterior decompression are surgical site infectious complications, the incidence of which ranges from 4.3 to 22.2 %, and during the performance of circumferential decompression and fusion through the extended posterior approaches, it reaches 29.0 %. Meanwhile, a number of authors indicate that male gender, the presence of coronary heart disease, diabetes mellitus, obesity, the degree of anesthetic risk (ASA) and intake of NSAIDs are independent predictors of the risk of infectious complications [48, 49]. In the paper by V.M. Khaidarov et al. [50], a considerable attention is paid to the issue of predicting the risk of developing local purulent and inflammatory complications in spine surgery. The authors identify 17 prognostic criteria, 12 of which are defined at the preoperative stage, 4 – during surgery and 1 – in the postoperative period. As a result of the analysis, the authors proposed a mathematical model for predicting the risk of developing infectious complications and designed an algorithm for the prevention of surgical site infections.

It is considered that surgeries performed through combined approaches have a number of disadvantages: long surgery duration, high volume of blood loss, high injury rate of approaches, impaired lung function, risk of damage to internal organs and large vessels and the technical difficulty of performing the anterior stage [1, 34].

According to a few data points [51, 52], dura mater rupture in anterior decompression is much less common than in posterior surgeries; it ranges from 4.4 to 10.0 %. In rare cases, this can result in such a specific complication as cerebrospinal fluid leakage into the chest cavity [53]. A dura mater rupture after anterior decompression occurred in 1 (0.7 %) case in our study in the group of combined surgeries. This complication was managed to be eliminated by placing an external lumbar drainage system and performing multiple pleural punctures.

The most common postoperative complications of combined surgeries are respiratory, which is associated with the performance of anterior approaches. According to the literature, the rate of pulmonary complications [33, 34, 54, 55] ranges from 18.8 to 29.0 %. The most common respiratory complications in these studies are lobar lung atelectasis, pneumonia, hemo- and/or hydrothorax, and pneumothorax. In a prospective randomized trial by Lin et al. [30], it was proven that patients who underwent the anterior stage (thoracotomy) had significantly lower rates of pulmonary ventilation function in the postoperative period. The complication rate was 52.5 % in a study by Schnake et al. [54], which included 80 patients who underwent combined surgeries. Moreover, the authors note that after the posterior stage the complication rate was 13.0 %, while after anterior approaches it was 39.5 %. Out of them, 26.25 % were associated with thoracotomy.

The incidence of infectious complications when using combined approaches in the study by Wang and Liu [22] was 9.5 %; and according to A.K. Dulaev et al., it was 15.8 % [2]. In the study by Schnake et al. [54], all infectious complications occurred after the posterior approach.

In the study of K.O. Borzykh et al. [56], the overall complication rate when performing staged combined surgeries was 14.2 %; 3.3 % of them were intraoperative complications and 10.9 % were postoperative complications. Meanwhile, infectious and respiratory complications were most common in the postoperative period after the posterior stage.

Specific complications of anterior approaches include chronic pain syndrome at the surgical site, neuropathic body pain and weakness of the abdominal muscles. According to the literature [2, 35, 57], the incidence of post-thoracotomy pain syndrome ranges from 5.0 to 58.8 %.

Neurological complications in the surgical treatment of injuries to the lower thoracic and lumbar spine are quite rare. According to A.A. Grin' et al. [58], spinal cord injuries associated with surgical treatment are noted at up to 2.1 %. Single articles describe the deterioration of the neurological status in the postoperative period. However, they are more often described in papers dedicated to circumferential decompression and fusion through extended posterior approaches [25, 29, 59]. It corresponds to our data, where neurological complications in the group of single-stage posterior circumferential decompression were found in 9 (12.0 %) patients.

One of the rare causes of neurological deficit deterioration after surgical treatment is a spinal cord stroke. In a systematic review by Shlobin et al. [60], the incidence of this complication is up to 0.75 %. According to a number of authors [60, 61], risk factors for its development are vertebrectomy, anterior and especially left sided anterior approaches, fusion through extended posterior approaches and intra- or postoperative hypotension.

The most common complications after surgical treatment of injuries to the thoracic and lumbar spine in the long-term follow-up period are instability of instrumentation and recurrence of kyphotic deformity [62–64]. In the randomized controlled trial by Wood et al. [23], it was reported about the frequency of destabilization of the instrumentation and pseudoarthrosis after TPF and posterior decompression in 27.7 % of cases, compared to 5.0 % after anterior fusion. In a systematic review and meta-analysis by Tan et al. [65], the frequency of instrumentation destabilization after anterior fusion was 3.7 %, compared to 11.4 % in TPF. Nevertheless, there was no statistically significant difference ($p = 0.066$). Many other authors [3, 4, 66] also reported that there was no significant difference between anterior and posterior surgeries in terms of the loss of achieved correction. Meanwhile, some researchers [31, 36, 67] concluded that surgeries through combined approaches had significantly lower rates of loss of deformity correction compared to posterior surgeries. Nevertheless, the magnitude of this difference is often less than 10° and is statistically significant, still it has no clinical relevance.

In the Russian literature, much attention is paid to the analysis of the reasons for the development of instrumentation instability and secondary deformities after TPF. Most authors highlight the strategic and technical errors of primary surgical treatment, resulting in destabilization and the development of secondary deformities [5–7, 37, 62, 63]. Technical errors include disruption of spine correction techniques, defects in screw placement and violations of spinal instrumentation system mount technoque.

The intraoperatively diagnosed malposition of the pedicle screw often requires its replacement. Reinsertion of a screw reduces the stability of the transpedicular fixation system. In this case, the authors recommend performing vertebral cement augmentation or using a larger screw [5, 68–70].

Violations in the technique of kyphotic deformity correction include attempts to restore the sagittal profile by excessive lordozing of rods and excessive distraction at the level of the injured spinal motion segment [62, 71]. At the same time, the refusal of a full correction of posttraumatic deformity is noted in 15.7 % of cases [63]. According to many authors [63, 72, 73], residual kyphotic deformity is the statistically significant predictor of increased risk of destabilization.

According to Russian authors [5, 62, 63], one of the main tactical errors resulting in unsatisfactory surgical outcomes after SCI is the refusal to perform anterior fusion. In the paper by A.K. Dulaev et al. [63], only 3 out of 22 patients with indications for anterior fusion were treated. This resulted in a recurrence of kyphotic deformity in 21.1 % of cases.

A.E. Bokov et al. [74] analyzed the factors affecting the stability of instrumentation in patients with injuries to the lower thoracic and lumbar spine. According to their data, the performance of anterior fusion and intermediate fixation (with fixation of the injured vertebra) statistically significantly decrease the risk of destabilization. Residual kyphotic deformity, as well as laminectomy with resection of facet joints, increased the risk of instability. The extension of fixation did not affect the incidence of complications.

Therefore, despite the achievements of modern spine surgery, the errors and complications in the surgical treatment of SCI in the lower thoracic and lumbar spine remain an acute concern. The analysis of the reasons for the development of complications contributes to their prevention. It can also act as a foundation for algorithms for choosing strategies and technologies for performing decompression and stabilization surgeries.

Limitations of the study: a relatively small number of case studies; the presence of a retrospective part of the study (2010–2016); a significant difference in the number of follow-ups in the study groups; changing conditions of surgical services for patients with SCI during the period of history taking (increasing experience and number of surgeons performing procedures, changing quality of equipment in operating rooms); the presence of a considerable number of factors that cannot be reliably accounted for and analyzed, yet have the potential to influence the development of complications (experience and accuracy in the functioning of middle-level medical personnel, the quality of treatment of equipment and wards of patients in ICU and neurosurgery units, etc.).

It is unlikely that the latter of these limitations will be overcome in the future. Nonetheless, the presented study graphically illustrates the data on the frequency and structure of complications of surgeries in patients with SCI in the lower thoracic and lumbar spine. It may also have pointed the way to reducing the incidence of surgery complications in this category of patients.

Conclusion

1. In two-stage surgical treatment of patients with SCI of lower thoracic and lumbar localization using combined approaches, respiratory complications (17.1 %), intraoperative damage to the dura mater (9.3 %) and surgical site infection (7.0 %) are the most common. The predictors of these complications are the preoperative neurological deficit severity of the ASIA grade A or B, the patient's condition before surgery corresponding to the average mortality risk on the SOFA scale and the performance of an extended laminectomy.

2. The most common complication with the use of isolated TPF with reposition and stabilization without fusion is the instability of instrumentation in the long-term period (47.1 %). The predictors of this complication are incomplete reposition of the fractured vertebral body and performing two-segment TPF.

3. In one-stage decompression and stabilization interventions with TPF and fusion through the extended posterior approach, the most common complications are intraoperative damage to the dura mater (26.7 %), respiratory complications (18.7 %), infectious processes in the surgical site (10.7 %), iatrogenic neurological complications (12.0 %), and instability of instrumentation (16.1 %). The predictors of this complication are the severity of the patient's condition before surgery corresponding to the average mortality risk according to the modified SOFA scale, a minor neurological deficit of grade D or a rapidly regressing neurological deficit of grade C on the ASIA scale, bisegmental fusion if the injury is localized at the lumbar spine, and the severity of a preoperative neurological deficit of the ASIA grade A or B.

The study had no sponsors. The authors declare that they have no conflict of interest. The study was approved by the local ethics committees of the institutions. All authors contributed significantly to the research and preparation of the article.

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