RISK FACTORS FOR DAMAGE TO THE DURA MATER IN THORACIC AND LUMBAR SPINE INJURY

A.G. Martikyan[1, 2], A.A. Grin[1, 3], A.E. Talypov[1], S.L. Arakelyan[4]
[1]N.V. Sklifosovsky Research Institute for Emergency Medicine, Moscow, Russia
[2]Hospital for War Veterans No. 2, Moscow, Russia
[3]A.I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russia
[4]City Clinical Hospital No. 13, Moscow, Russia

Objective. To clarify a significance of the risk factors for damage to the dura mater (DM) in fractures of the thoracic and lumbar spine.
Material and Methods. The study is based on the analysis of examination data and surgical treatment results of 350 patients with spinal cord injury (SCI). Fractures of the thoracic spine were observed in 124 patients, and those of the lumbar spine in 226. The study included 167 operated patients who underwent posterior decompression at the fracture level using laminectomy and transpedicular fixation of the injured spinal motion segment. There were two groups of patients: study group included 55 patients with DM rupture and control one — 112 patients without damage to the DM.
Results. Damage to the DM was found in 32.9 % of patients, the rupture was localized on the posterior surface of the dural sac. In patients with rupture of the dura mater, ASIA type A and B neurological disorders were significantly more common ($p = 0.00065$). The DM damage occurs significantly more often in patients with type C fracture according to the AOSpine classification, with multilevel spinal injuries and combined SCI (Injury Severity Score more than 27.58 ± 9.46 points). The most significant risk factors for the development of DM ruptures are narrowing of the spinal canal at the fracture level by more than 50 %, a fracture of the vertebral arch, an increase in the relative interpedicular distance of more than 20 %, and diastasis between the fragments of the arches by more than 2.5 mm.
Conclusion. The damage to the dura mater is a common complication of vertebral fracture. The prediction of dura mater rupture will allow optimizing surgical approach and improving the treatment outcome.
Key Words: spinal cord injury, risk factors for damage to the dura mater, damage to the dura mater, fracture of the vertebral arch, narrowing of the spinal canal.
Please cite this paper as: *Martikyan AG, Grin AA, Talypov AE, Arakelyan SL. Risk factors for damage to the dura mater in thoracic and lumbar spine injury Hir. Pozvonoc. 2022;19(1):31–38.*
DOI: http://dx.doi.org/10.14531/ss2022.1.31-38.

Surgical treatment of spinal cord injury (SCI) has the following objectives: to perform a full-fledged decompression of the neurovascular formations of the spinal column; to reduce and prevent vertebromedullar or vertebroradicular conflicts; to create an adequate bone block and to restore the supportability of the spinal column; and to restore normal cerebrospinal fluid circulation [1–3]. A crucial area of concern in spinal surgery is damage to the dura mater (DM) resulting in the formation of liquor fistulas and liquorrhea. The DM rupture can cause pseudomeningocele and infectious complications, considerably affecting the treatment outcomes.

The DM rupture caused by a vertebral fracture may contribute to the prolapse of neural structures into the DM defect and their compression by bone fragments at the fracture site. When there is no preoperative diagnosis, this can result in damage to these structures during surgical interventions. Most frequently, such injuries occur upon neurological disorders, splitting of the spinous process, and vertical laminar fractures with the displacement of lamina fragments [4–9].

According to various authors [4–16], SCI at the thoracic and lumbar levels in 7.7–64.0 % of patients is accompanied by DM rupture. The latter, as a rule, is verified during surgery while decompressing neural structures.

Today, spiral CT is the gold standard for defining bone pathology. This diagnostic technique permits accurate verification of various types of spinal injuries. CT promotes the diagnosis of even minor fractures of the posterolateral elements of the spinal canal walls that are not visible on MRI [3].

An MRI of the spine is performed to diagnose damage to soft tissue structures. The resolving power of MRI is insufficient to visualize minor DM ruptures that cause cerebrospinal fluid leakage. A DM damage less than 1 cm cannot be directly imaged on MRI [7, 11, 17, 18]. Lee et al. [19] believe that it is impossible to visualize the damage less than 4 cm in length.

Several studies have been conducted [4–8, 10–16, 19–22] to evaluate the risk factors for damage to DM in SCI. According to the authors, the most significant factors are a laminar fracture [5–10, 12, 19, 22], wider separation of the laminar fracture [6–8], narrowing of the spinal canal at the fracture level [6, 8, 19], and an increase in the interpedicular distance of the fractured vertebra [4, 6, 8, 19]. Patients with DM ruptures are more likely to develop neurological symptoms [6, 8, 19]. Nevertheless, there is no consensus among the authors on the prognostic significance of various risk factors [5, 7, 8, 10, 14, 15, 23]. Moreover, inattention to their detection at the preoperative stage results in diagnostic pitfalls and incorrect surgical approaches. Additionally, it may lead to complications and unfavorable outcomes.

The objective is to clarify the significance of the risk factors for damage to the dura mater (DM) in fractures of the thoracic and lumbar spine.

Material and Methods

Patients

The study is based on the analysis of examination data and surgical outcomes of 350 patients with spinal cord injury (SCI) treated in a neurosurgical emergency department from 2014 to 2018. Fractures of the thoracic spine were observed in 124 patients and those of the lumbar spine in 226. A total of 167 patients underwent decompressive laminectomy at the fracture level and transpedicular fixation of the spinal motion segment. Transpedicular fixation of the spinal motion segment and postural reduction of the spinal column without laminectomy was performed in 73 patients. The ability to support the spinal motion segment was restored in 84 individuals by anterior fusion and in 26 patients by vertebroplasty. The fracture level varied from T3 to L5 vertebra; most often, fractures were localized at the level of T12–L3 vertebrae. The terms of surgical intervention from the moment of injury ranged from 3 hours to 23 days. The prospective follow-up was from 3 to 18 weeks.

The DM rupture was detected only on the posterior and/or posterolateral surface of the dural sac. Patients who underwent posterior decompression with laminectomy and transpedicular fixation of the spinal motion segment at the fracture level were selected for analysis. The retrospective study included 167 patients. There were two groups of patients: study group included 55 patients with DM rupture and control one – 112 patients without DM rupture. The distribution of men and women: 101 : 66 (60.5 : 39.5 % = 1.53 : 1.00). The mean age of patients was 38 (min – 17, max – 80). Among them 115 (68.9 %) patients had lumbar spine fractures, and 52 (31.1 %) patients suffered from thoracic spine fractures.

Surgical technique

Patients were operated on in the neutral prone position without attempts of postural reduction. All individuals underwent laminectomy at the level of the fracture through an extended posterior approach. The neural structures located between the bone fragments of the fractured vertebra were released. The integrity of DM damaged areas was restored by suturing or dural plastic surgery. All surgeries were completed with transpedicular fixation of vertebrae adjacent to the damaged spinal motion segment. There was also the formation of a block of operated spinal motion segments.

Methods

The AOSpine classification was used to evaluate the type of spinal injury depending on the morphology and the mechanism of injury [24]. It must be pointed out that this classification has been developed mainly for injuries of the thoracic and lumbar spine.

Neurological disorders associated with spinal cord injury and nerve roots were rated on the ASIA scale [25]; the concomitant injury severity was evaluated on the ISS scale.

All patients underwent SCT of the spine both at admission and over time. The examination was performed on CTE and ZTX tomographs with a slice spacing of 2 mm. An objective assessment (linear dimensions, area, volume of the spinal canal stenosis) was conducted using standard measuring instruments of the RadiAnt Dicom Viewer software. Before the surgery, vertebral body, lamina and pedicles were measured to select the optimm size of the fixation devices.

During the CT data assessment, the position of the fragments, the degree of narrowing of the spinal canal, the presence of laminar fracture and the distance between the fragments of the fractured lamina, the interpedicular distance, and the localization of the fracture line were considered. The spinal canal diameter was measured in the anteroposterior direction as the distance between the middle of the posterior surface of the vertebral body and the middle part of the base of the spinous process at the dural sac border. In the case of vertebral dislocation, the canal dimension was measured in the part that has the most pronounced narrowing in the sagittal and axial planes.

The interpedicular distance on axial CT slices was defined as the maximum distance between the medial surfaces of the pedicles of the vertebra (Fig. 1).

The value of the interpedicular distance of the fractured vertebra was calculated using the following formula:

$(A + C)/2 - B / (A + C)/2$,

where A is the interpedicular distance above the fracture zone; B is the interpedicular distance at the fracture level; and C is the interpedicular distance below the injury area [26].

An essential characteristic of the clinical material was the evaluation of the luminal narrowing of the spinal canal at the level of injury. It was detected by a CT scan. The degree of narrowing of the spinal canal was assessed using a similar formula:

$(A + C)/2 - B / (A + C)/2$,

where A and C are the anteroposterior dimension of the spinal canal above and below the fracture zone, respectively; B is the anteroposterior dimension of the canal at the fracture level (maximum compression) [26].

The axial CT sections were used to evaluate the morphology of the laminar fracture. The laminar fractures were classified by anatomical integrity into complete and incomplete [9]. The greenstick fracture was attributed to incomplete ones (Fig. 2).

Statistical analysis

Statistical analysis of the obtained data and processing of materials was performed using SPSS Statistics 22 for Windows.

Parametric tests were used to compare quantitative attributes of a normal distribution. The non-parametric Mann – Whitney U-test was used to evaluate the statistical significance of the differences between the two groups having an abnormal distribution. The Pearson's chi-squared test was done to compare the proportions of qualitative attributes. The odds ratio (OR) was assessed. The Fisher's exact test was calculated for 2 × 2 tables when the expected number even in one group is less than 5. If $p \leqslant 0.05$, the analysis results were considered statistically significant.

Results

The DM damage was found in 55 (32.9 %) of 167 patients. Its absence was observed in 112 (67.1 %) patients. In all patients with DM rupture, it was found on the posterior and/or posterolateral surface of the dural sac. The dimension of a damaged section ranged from 2 to 38 mm, the area of a damage ranged 2 to 38 mm^2.

There was no statistically significant difference age between the patients with and without DM damages in age (37 y.o. (18; 73 y.o.) and 40 y.o. (17; 80 y.o.) in the study and control groups, respectively), the Mann–Whitney test: U = 2762; p = 0.32) and in gender (36 men and 19 women in the study group (65.5 and 34.5%) and 65 men and 47 women in the control group (58.0; 42.0 %); the Pearson's test: $\chi^2 = 0.85$; p = 0.357).

A combined SCI was observed in 110 (65.9 %) patients, it prevailed in the study group – 41 (74.5 %), and to a lesser extent in the control group 69 (61.6 %). A significant difference in the degree of the combined injury severity was found. Its average score on the ISS scale in the group of patients with DM rupture was 32.00 points, in the group without damage – 27.58 ± 9.46 points (the Mann – Whitney test: U = 982; p = 0.007).

The risk of DM rupture was higher in patients with multiple and multilevel spinal injuries, noted respectively in 31 (56.4 %) versus 40 (35.7 %) individuals in the groups (OR 2.32; 95 % CI 1.16–4.29; p = 0.01).

Fractures of the thoracic and lumbar spine in the groups occurred with almost the same frequency (the Pearson's test: $\chi^2 = 0.79$; p = 0.38). In the study group, 41 (74.5 %) patients had lumbar spine fractures, and 14 (25.5 %) patients had thoracic fractures. In the control group, the injuries of the lumbar vertebrae were found in 76 (67.9 %) patients; the thoracic spine injuries were found in 36 (32.1 %) patients.

Neurologically complicated injuries were observed in 114 (68.3 %) of the 167 patients. The risk of neurological complications in the study group was higher than in the control group: 46 (83.6 %) and 68 (60.7 %) patients, respectively (OR 3.31; 95% CI 1.47–7.43; p = 0.003).

Severe neurological disorders were significantly more common among patients with DM rupture. Spinal cord injuries of grades A and B on the ASIA scale were found in 15 (27.3 %) and 12 (21.8 %) people in the study group, respectively. It was statistically significantly less frequent in the control group: in 16 (14.3 %) and 9 (8.0 %) patients (for plegia of type A – OR 2.25; 95 % CI 1.02–4.98; p = 0.042; type B – OR 3.19; 95 % CI 1.25–8.13; p = 0.012). There was no significant difference in the groups in other types of spinal cord injuries with neurological disorder: for type C – 8 (14.5 %) and 13 (11.6 %) cases (the Pearson's test: $\chi^2 = 0.29$; p = 0.59); for type D – 11 (20.0 %) and 30 (26.8 %) cases (the Pearson's test: $\chi^2 = 0.92$; p = 0.34), respectively (Fig. 3).

The table shows the results of the analysis of risk factors for DM damage in SCI in the studied groups.

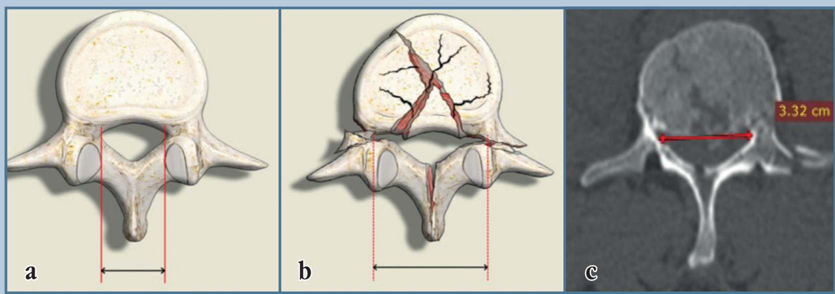

Fig. 1
Determination of the interpedicular distance on axial sections: **a** – the interpedicular distance for a vertebra without fracture; **b** – a burst compression fracture with an extension of the interpedicular distance; **c** – measurement of the interpedicular distance on CT (Dicom catalog)

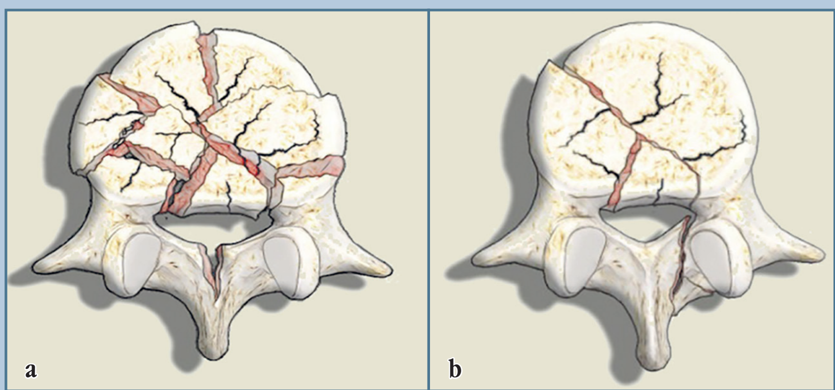

Fig. 2
Types of laminar fractures: **a** – incomplete type of laminar fracture (a greenstick fracture); **b** – complete type of laminar fracture

Type of fracture. In the study group, the compression comminuted fractures of types A3 and A4 according to the AOSpine classification were found in the groups in 19 (34.5 %) and 62 (55.4 %) patients; distraction injuries with compression comminuted fracture of the vertebral body and rupture of the posterior supporting structures (type B) were detected in 15 (27.3 %) and 26 (23.2 %) patients, respectively (the Pearson's test: $\chi^2 = 0.33$; $p = 0.57$).

The DM damage in the study group was significantly more often detected in patients with rotational injuries (type C) – 21 (38.2 %) individuals; in the control group – 24 (21.4 %; OR 2.26; 95 % CI 1.18–4.59) individuals (Fig. 4).

Narrowing of the spinal canal. The risk of DM damage significantly increased with narrowing of the spinal canal by more than 50 % (OR 16.05; 95 % CI 5.93–43.4; $p < 0.01$). Meanwhile, luminal narrowing of the spinal canal exceeding this indicator was found in 50 (90.9 %) of the patients in the study group, and 43 (38.4 %) patients in the control group.

Laminar fracture of the fractured vertebra. This is a significant risk factor for DM rupture (OR 10.21; 95 % CI 4.24–24.57; $p < 0.01$). It was significantly more common in the study group: 48 (87.3 %) cases; in the control group – 45 (40.9 %) cases.

There were no significant differences between the groups among the patients with fractured lamina and neurological disorders. In the case of DM damage, they were observed in 41 (85.4 %) out of 48 patients; in the group without DM rupture – in 32 (71.1 %) out of 45 (the Pearson's test: $\chi^2 = 2.82$; $p = 0.093$) patients.

Type of laminar fracture. There was no statistically significant difference in the type of laminar fracture between the groups (the Pearson's test: $\chi^2 = 0.89$; $p = 0.345$). Both groups showed a complete fracture type: 32 (66.7 %) patients in the study group and 34 (75.6 %) patients in the control group. In turn, a partial laminar fracture (greenstick fracture) was found in 16 (33.3 %) and 11 (24.4 %) patients in the groups, respectively.

The distance between the fractured laminar fragments. The risk of DM damage significantly grew with an increasing distance between the fractured laminar fragments. In the study group, the average distance between the laminar fragments was 3.31 ± 1.40 mm; in the control group – 2.33 ± 1.23 mm (OR 4.43; 95 % CI 1.85– 10.65; $p < 0.01$).

The relative value of the interpedicular distance. The relative value of the interpedicular distance made significant differences in the compared groups. In the group with DM rupture, the average relative value of the interpedicular distance was 21 %; in the group without DN damage – 11 % (OR 4.77; 95 % CI 2.33–9.76; $p < 0.01$).

Discussion

In 1980, Miller et al. [20] were the first to report on the ruptures of the DM posterior surface in case of injury to the thoracic and lumbar spine in combination with a laminar fracture of the fractured vertebra and damage to the spinal cord or strangulation of cauda equina roots between fragments of the fractured vertebra.

A classical pattern of the spinal fracture, accompanied by DM damage, is a burst compression fracture in the thoracic or lumbar regions and a vertical laminar fracture of a fractured vertebra. The authors noted a high probability of strangulation of the neural structures between the fragments of the fractured lamina and the development of neurological complications in these types of fractures [4–9, 12, 13, 16, 20, 21].

An essential predictive sign is a greenstick fracture of the anterior cortical laminar plate in case of vertebral fracture due to spinous process splitting. This type of injury was originally described by Denis [27]. In the case of a vertebral fracture with a laminar fracture, the dural sac contents are relocated posteriorly between the fragments of the fractured lamina. After the delitescence of the axial load and the restoration of the position of the fragments, the strangulation of the DM and cerebrospinal nerves is possible. This is especially typical for greenstick laminar fractures [4, 7].

There is a high frequency of greenstick laminar fracture in case of DM damage (100.0 %) in patients with injury to the thoracic and/or lumbar spine [4, 7]. Yet other researchers have pointed out the rare occurrence of a greenstick laminar fracture in case of DM damage (24.7–27.5 %) in contrast to the complete laminar fracture [6, 9].

According to our data, the combination of the vertebra body fracture and the laminar fracture of the fractured ver-

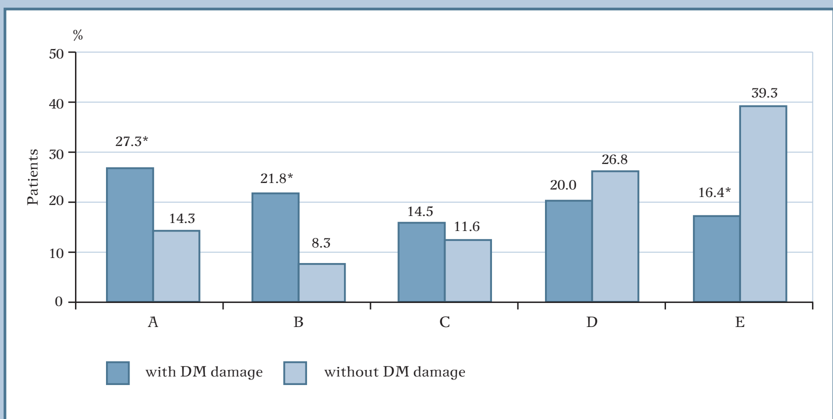

Fig. 3
Distribution of patients depending on the severity of spinal cord injury on the ASIA scale: * significant differences in groups; DM – dura mater

Table

Analysis of risk factors for dura mater damage in spinal cord injury

Factors	Study group (n = 55)	Control group (n = 112)	p	Odds ratio
Multiple and multilevel injuries, n (%)*	31 (56.4)	40 (35.7)	0.010	2.32
Neurological disorders, n (%)*			0.003	3.31
without disorders	9 (16.4)	44 (39.3)		
with disorders	46 (83.6)	68 (60.7)		
ASIA A	15	16	0.042	2.25
ASIA B	12	9	0.012	3.19
ASIA C	8	13	0.590	
ASIA D	11	30	0.340	
ASIA E	9	44	0.003	3.31
Interpedicular distance, %**	21	11	<0.010	4.77
Spinal stenosis, n (%)*			<0.010	16.05
less than 50 %	5 (9.1)	69 (61.6)		
more than 50 %	50 (90.9)	43 (38.4)		
Laminar fracture*, n (%)			<0.010	10.21
yes	48 (87.3)	45 (40.2)		
no	7 (12.7)	67 (69.8)		
The distance between the Laminar fragments, mm**	3.31 ± 1.40	2.33 ± 1.23	<0.010	4.43

* The Pearson's test; ** the Mann – Whitney test.

tebra is a significant risk factor for DM damage. This combination of injuries was noted in 87.3 % of the patients. In turn, there was no statistically significant difference between the fracture type of a laminar and DM rupture ($p > 0.05$). In the group of patients with the DM rupture, the complete type of the laminar fracture was two times more common in contrast to the greenstick fracture.

The mechanism of DM rupture and strangulation of nerve structures in burst compression fracture of vertebrae with a laminar fracture has not been fully investigated. According to Cammisa et al. [5], at the moment of injury, owing to the influence of axial force, vertebral body fragments are dislocated into the spinal canal. This causes the dilatation of the interpedicular space, which, in turn, is accompanied by a high frequency of laminar fracture. Pickett et al. [15] and Denis et al. [22] reported the following: in case of a burst compression fracture of a vertebra with a laminar fracture, the fragments of the vertebral body are displaced into the spinal canal. In this case, compression and dislocation of the dural sac occur in the posterior direction, and the rupture of the DM's posterior surface by the sharp borders of the fractured laminar fragments. A statistically significant relationship was shown by Xu et al. [6] between the detection rate of DM rupture at the laminectomy stage and the narrowing of the spinal canal by more than 50 % due to dislocation of a fractured vertebral body fragment into the spinal canal. This is typical for

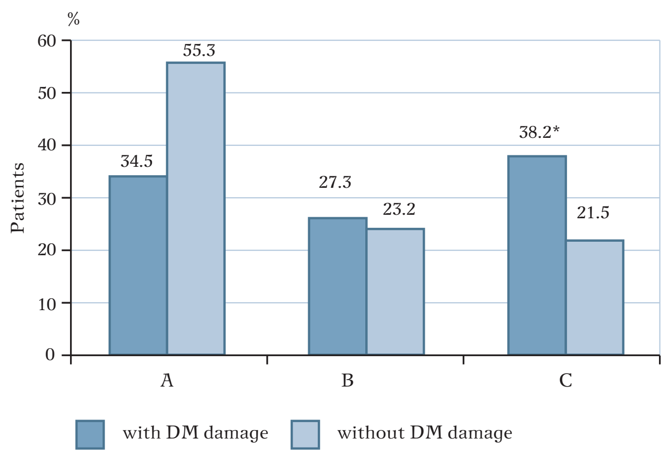

Fig. 4

The structure of spinal injuries in patients according to the AO Spine classification:
* significant differences in groups; DM – dura mater

patients with SCI at the lower thoracic and lumbar levels with laminar fracture of a fractured vertebra. According to these authors, two conditions are needed for DM rupture in SCI to occur: the combination of fractured lamina and the dislocation of the fractured vertebral body fragments into the spinal canal lumen.

According to our study, the dislocation of fragments into the spinal canal lumen and its narrowing by more than 50 % were risk factors for DM rupture.

Some researchers [4–8, 12, 20, 21] have attempted to establish a relationship between DM rupture and the development of neurological symptoms. Cammisa et al. [5] and Miller et al. [20] believe that a vertebral fracture in combination with a laminar fracture is accompanied by a neurological deficit with 100 % sensitivity and 74 % specificity. In addition, there is a DM rupture. According to Park et al. [8], these indicators are 100 % and 78 %, respectively. Nevertheless, the absence of neurological disorders in the case of laminar fracture does not exclude DM damage and/or strangulation of cerebrospinal nerves [7, 10, 12, 20].

Several authors [4, 6, 8, 19] consider an increase in the interpedicular distance according to CT findings to be another risk factor for DM rupture. According to Lee et al. [19], DM rupture in patients with the trauma of the thoracic and lumbar spine and laminar fracture of a fractured vertebra was detected at the average interpedicular distance equal to 28.7 mm. There was no DM damage at the interpedicular distance of less than 26.0 mm. According to Park et al. [8], when such a mechanism of injury, a DM rupture was detected at the average interpedicular distance equal to 32.4 ± 3.9 mm; at the distance of 28.4 ± 3.8 mm, DM damage was not detected ($p = 0.015$). According to our study, the risk factor for DM rupture is an increased relative value of the interpedicular distance ($p < 0.05$). It is vital to note that the greatest risk of developing damage occurred while the relative value of the interpedicular distance was more than 20 %.

An essential diagnostic criterion for DM rupture is the distance between the fragments of the fractured lamina. According to a study by Ozturk et al. [7] patients with DM rupture had an average distance of 4.35 mm ($p < 0.01$) between the fragments of the fractured lamina. In a similar study by Park et al. [8] the difference in the diastase of fragments in patients with rupture and without rupture of DM was 1.4 mm ($p = 0.002$). According to Xu et al. [6], the distance between the fragments of the fractured lamina was 3.3 ± 2.3 mm in patients with SCI and a laminar fracture accompanied by DM rupture; in the group of patients without DM rupture – 2.3 ± 1.6 mm ($p = 0.013$). We have obtained similar results: the average distance between the fractured laminar fragments in the study group was 3.31 ± 1.4 mm, in the control group – 2.33 ± 1.23 mm ($p = 0.0001$).

Conclusions

DM rupture occurs in 32.9 % of patients with fractures of the lumbar and thoracic spine. In all patients, the injury is located on the posterior and/or posterolateral surface of the dural sac.

Patients with a DM rupture are significantly more likely to have neurological disorders of types A and B on the ASIA scale with rotational fractures of type C.

The most significant risk factors for DM rupture are the following: narrowing of the spinal canal at the fracture level by more than 50 %, laminar fracture and diastase between the fragments of the lamina of more than 2.5 mm, an increase in the relative interpedicular distance of more than 20 %, multilevel spine damages, and combined SCI (ISS more than 27.58 ± 9.46 points).

Predicting a possible DM rupture will optimize the surgical approach and improve the treatment outcomes of the patients.

The study had no sponsors. The authors declare that they have no conflict of interest.

References

1. **Afaunov AA, Kuzmenko AV, Basankin IV.** Differentiated treatment in patients with traumatic vertebral canal stenosis at lower thoracic and lumbar levels. Innovatsionnaya meditsina Kubani = Innovative Medicine of Kuban 2016;(2):5–16.
2. **Grin' AA, Kordonskiy AYu, Lvov IS, Kaikov AK, Sytnik AV, Bogdanova OYu.** The timing in surgery of spinal trauma (a review). Russian journal of neurosurgery. 2018;20(3):81–90. DOI: 10.17650/1683-3295-2018-20-3-81-90.
3. **Krylov VV, Grin'AA, Timerbaev VKh, Genov PG, Efremenko SV, Grigor'eva EV, Nikitin SS, Kurenkov AL, Khit' MA.** Trauma of the Spine and Spinal Cord. Moscow, 2014.
4. **Aydinli U, Karaeminogullari O, Tiskaya K, Ozturk C.** Dural tears in lumbar burst fractures with greenstick lamina fractures. Spine. 2001;26:E410–E415. DOI: 10.1097/00007632-200109150-00012.
5. **Cammisa FP Jr, Eismont FJ, Green BA.** Dural laceration occurring with burst fractures and associated laminar fractures. J Bone Joint Surg Am. 1989;7:1044–1052. DOI: 10.2106/00004623-198971070-00011.
6. **Xu JX, Zhou CW, Wang CG, Tang Q, Li JW, Zhang LL, Xu HZ, Tian NF.** Risk factors for dural tears in thoracic and lumbar burst fractures associated with vertical laminar fractures. Spine. 2018;43:774–779. DOI: 10.1097/BRS.0000000000002425.
7. **Ozturk C, Ersozlu S, Aydinli U.** Importance of greenstick lamina fractures in low lumbar burst fractures. Int Orthop. 2006;30:295–298. DOI: 10.1007/s00264 005 0052 0.
8. **Park JK, Park JW, Cho DC, Sung JK.** Predictable factors for dural tears in lumbar burst fractures with vertical laminar fractures. J Korean Neurosurg Soc. 2011;50:11–16. DOI: 10.3340/jkns.2011.50.1.11.
9. **Skiak E, Karakasli A, Harb A, Satoglu IS, Basci O, Havitcioglu H.** The effect of laminae lesion on thoracolumbar fracture reduction. Orthop Traumatol Surg Res. 2015;101:489–494. DOI: 10.1016/j.otsr.2015.02.011.
10. **Kahamba JF, Rath SA, Antoniadis G, Schneider O, Neff U, Richter HP.** Laminar and arch fractures with dural tear and nerve root entrapment in patients operated upon for thoracic and lumbar spine injuries. Acta Neurochir (Wien). 1998;140:114–119. DOI: 10.1007/s007010050071.

11. **Keenen TL, Antony J, Benson DR.** Dural tears associated with lumbar burst fractures. J Orthop Trauma 1990;4:243–245. DOI: 10.1097/00005131-199004030-00001.
12. **An KC, Park DH, Kwon YW.** Relationship between lamina fractures and dural tear in low lumbar burst fractures. J Korean Fract Soc. 2011;24:256–261. DOI: 10.12671/jkfs.2011.24.3.256.
13. **Luszczyk MJ, Blaisdell GY, Wiater BP, Bellabarba C, Chapman JR, Agel JA, Bransford RJ.** Traumatic dural tears: what do we know and are they a problem? Spine J. 2014;14:49–56. DOI: 10.1016/j.spinee.2013.03.049.
14. **Pau A, Silvestro C, Carta F.** Can lacerations of the thoraco-lumbar dura be predicted on the basis of radiological patterns of the spinal fractures? Acta Neurochir (Wien). 1994;129:186–187. DOI: 10.1007/BF01406502.
15. **Pickett J, Blumenkopf B.** Dural lacerations and thoracolumbar fractures. J Spinal Disord. 1989;2:99–103. DOI: 10.1097/00002517-198906000-00006.
16. **Sharma M, Sharma AK, Gill M, Kumar G.** Dural tears associated with burst fractures of lumbar vertebrae: A series of three cases. Indian J Neurosurg. 2017;6:10–14. DOI: 10.1055/s-0036-1584599.
17. **Jensen MC, Kelly AP, Brant-Zawadzki MN.** MRI of degenerative disease of the lumbar spine. Magn Reson Q. 1994;10:173–190.
18. **Marciello MA, Flanders AE, Herbison GJ, Schaefer DM, Friedman DP, Lane JI.** Magnetic resonance imaging related to neurologic outcome in cervical spinal cord injury. Arch Phys Med Rehabil. 1993;74:940–946. DOI: 10.5555/uri:pii:000399939390271B.
19. **Lee IS, Kim HJ, Lee JS, Kim SJ, Jeong YJ, Kim DK, Moon TY.** Dural tears in spinal burst fractures: predictable MR imaging findings. AJNR Am J Neuroradiol. 2009;30:142–146. DOI: 10.3174/ajnr.A1273.
20. **Miller CA, Dewey RC, Hunt WE.** Impaction fracture of the lumbar vertebrae with dural tear. J Neurosurg. 1980;53:765–771. DOI: 10.3171/jns.1980.53.6.0765.
21. **Yoshiiwa T, Miyazaki M, Kodera R, Kawano M, Tsumura H.** Predictable imaging signs of cauda equina entrapment in thoracolumbar and lumbar burst fractures with greenstick lamina fractures. Asian Spine J. 2014;8:339–345. DOI: 10.4184/asj.2014.8.3.339.
22. **Denis F, Burkus JK.** Diagnosis and treatment of cauda equina entrapment in the vertical lamina fracture of lumbar burst fractures. Spine. 1991;16(8 Suppl):S433–S439. DOI: 10.1097/00007632-199108001-00025.
23. **Silvestro C, Francaviglia N, Bragazzi R, Piatelli S, Viale GL.** On the predictive value of radiological signs for the presence of dural lacerations related to fractures of the lower thoracic or lumbar spine. J Spinal Disord. 1991;4:49–53.
24. **Vaccaro AR, Oner C, Kepler CK, Dvorak M, Schnake K, Bellabarba C, Reinhold M, Aarabi B, Kandziora F, Chapman J, Shanmuganathan R, Fehlings M, Vialle L.** AOSpine thoracolumbar spine injury classification system: fracture description, neurological status and key modifiers. Spine. 2013;38:2028–2037. DOI: 10.1097 BRS.0b013e3182a8a381.
25. **Maynard FM Jr, Bracken MB, Creasey G, Ditunno JF Jr, Donovan WH, Ducker TB, Garber SL, Marino RJ, Stover SL, Tator CH, Waters RL, Wilberger JE, Young W.** International Standards for Neurological and Functional Classifcation of Spinal Cord Injury. American Spinal Injury Association. Spinal Cord. 1997;35:266–274. DOI: 10.1038/sj.sc.3100432.
26. **Haher TR, Felmly WT, O'Brien M.** Thoracic and lumbar fractures: diagnosis and management. In: Bridwell K.H., DeWald R.L., eds. The Textbook of Spinal Surgery. 2nd edition. Philadelphia, 1997:1763–1837.
27. **Denis F.** The three-column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine. 1983;8:817–831. DOI: 10.1097/00007632-198311000-00003.

Address correspondence to:
Martikyan Avetik Gurgenovich
N.V. Sklifosovsky Research Institute of Emergency Medicine,
3 Bolshaya Sukharevskaya Sq., Moscow, 129090, Russia,
amartikyan@mail.ru

Received 03.03.2021
Review completed 09.12.2021
Passed for printing 12.12.2021

Avetik Gurgenovich Martikyan, neurosurgeon of the Department of neurosurgery, N.V. Sklifosovsky Research Institute of Emergency Medicine, 3 Bolshaya Sukharevskaya Sq., Moscow, 129090, Russia; Hospital for War Veterans No. 2, 168 Volgogradskiy prospect, Moscow, 109472, Russia, ORCID: 0000-0002-4831-4055, amartikyan@mail.ru;
Andrey Anatolyevich Grin, DMSc, head of the Department of emergency neurosurgery, N.V. Sklifosovsky Research Institute of Emergency Medicine, 3 Bolshaya Sukharevskaya Sq., Moscow, 129090, Russia; Professor of the Department of Neurosurgery and Neuroreanimation, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, 1a, build. 4 Kuskovskaya str., Moscow, 111398, Russia, ORCID: 0000-0003-3515-8329, aagreen@yandex.ru;
Aleksandr Ernestovich Talypov, DMSc, leading researcher of the Department of emergency neurosurgery, N.V. Sklifosovsky Research Institute of Emergency Medicine, 3 Bolshaya Sukharevskaya Sq., Moscow, 129090, Russia, ORCID: 0000-0002-6789-8164, dr.talypov@mail.ru;
Sevak Levonovich Arakelyan, neurosurgeon of the Department of neurosurgery, City Clinical Hospital No. 13, 1/1 Velozavodskaya Str., Moscow, 115280, Russia, ORCID: 0000-0003-1381-2350, dr.sevaks@yandex.ru.