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## Assessment of risk factors for the vertebral body kyphotic deformity progression in patients with type A1 injuries of the thoracolumbar junction

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More than 60% of traumatic injuries of the spine occur in the zone of the thoracolumbar junction (TLJ), and 60–75% of these fractures are of a compression nature. Type A1 injuries are characterized by the least osteo-destructive changes compared to other injuries. Traditionally, they are treated conservatively. A number of studies conducted in the last 10 years, shows a high rate of failure of conservative treatment, as evidenced by the progression of kyphotic deformity of the compressed vertebral body. Most of these publications are devoted to osteoporotic lesions in aged patients, while this aspect has been little studied in patients of working age with normal bone density.

**Objective:** to evaluate the factors influencing the risk of kyphotic deformity progression in patients of working age with type A1 traumatic injuries of the thoracolumbar junction.

**Materials and methods.** The analysis of clinical cases of patients who visited the outpatient department of Romodanov Neurosurgery Institute of National Academy of Medical Sciences of Ukraine in the period from 2019 to 2022 with traumatic damage to the TLJ zone. Forty-seven victims who met the selection criteria were selected. Gender, age, body mass index, level of damage, location of the damaged endplate (caudal or cranial), bone tissue radiodensity, angular kyphotic deformity of the vertebral body, and pain intensity were considered as predictors. Depending on the presence or absence of deformity progression 2 months after the injury, the patients were divided into two clinical groups. The most clinically significant predictors were identified using the LASSO (Least Absolute Shrinkage and Selection Operator) regression method.

**Results.** LASSO screening identified five potential predictors. The final logistic regression model after regularization demonstrated high predictive performance: the area under the ROC curve (AUC) was 0.907, and the predictive accuracy was 85%. When assessing the risk of kyphotic deformity progression in traumatic injuries of type A1 of the TLJ zone, age, bone density, angular kyphotic deformity of the vertebral body, and pain intensity are of the greatest importance, demonstrating a directly proportional relationship. A compressed caudal endplate is also associated with a higher risk of post-traumatic progression of angular kyphosis. The nomogram developed using the mentioned factors makes it possible to quantify the degree of risk when choosing a therapy strategy.

**Conclusions.** The performed analysis made it possible to create a nomogram for predicting the increase in kyphotic deformity of the vertebral body in A1 fractures of TLJ region. The proposed model can be used for a rational assessment of the risk degree when choosing the optimal tactics for treating patients.

**Keywords:** thoracolumbar junction; wedge-shaped compression fracture; progressive deformity; risk factors; nomogram

### Introduction

According to the literature, more than 60% of traumatic spinal injuries occur in the thoracolumbar junction (TLJ). The compression or flexion-compression mechanism causes about 54% of type A injuries of

TLJ and 60–75% of osteo-traumatic changes in this zone [1,2].

All type A injuries are compression and involve elements of the anterior support complex only. Such injuries are characterized by a wide range of traumatic

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changes in the vertebral body - from minor wedge-shaped deformity to burst fractures. According to the AOSpine Thoracolumbar Spine Injury Classification System (AO TLSICS), vertebral body compression injuries are divided into wedge-shaped compression fractures proper (A1), splitting fractures (in some interpretations - comminuted, A2), burst incomplete (A3) and complete (A4) fractures [3]. This approach, despite the convenience of injury classification, creates certain difficulties when interpreting literature data, since it is not always clear whether it is about compression fractures (A1) or compression injuries in general.

Compression fractures are characterized by the least osteo-traumatic changes compared to other compression injuries of the spine. Since, according to the two-column concept of spinal stability, compression fractures are stable and rarely accompanied by neurological disorders, conservative treatment has traditionally been the mainstay method [4].

Conservative therapy involves the use of analgesics symptomatically, bed rest, fixation of the TLJ with a corset and repeated examination (usually x-ray once a month) [5]. It is assumed that such tactics in most cases allows achieving stable regression of pain and consolidation of damage within 4–6 weeks. Surgical treatment is classically considered for type A1 injuries only when conservative methods are ineffective [6]. In the publications of the last decades, the optimality of this approach is considered questionable. It has been noted that compression fractures, even with minimal damage to the endplate, lead in some cases to the progression of kyphotic deformity and persistent intense pain [7,8]. Given the fact that the main criterion for the effectiveness of therapy is often considered to be the patient's quality of life, more and more researchers recommend gentle minimally invasive surgical techniques as a promising alternative to long-term conservative treatment [9,10].

The analysis of the literature demonstrates that most publications devoted to therapeutic tactics and possible consequences of the treatment of type A1 injuries of TLJ refer to osteoporotic traumatic and non-traumatic fractures mainly in the aged population [11–13]. The issue of optimising treatment methods, in particular the feasibility of surgical interventions in the younger and working age population, has been little studied.

**Objective:** to evaluate the factors influencing the risk of kyphotic deformity progression in patients of working age with type A1 traumatic injuries of the thoracolumbar junction.

#### **Materials and methods**

**The study design** is prospective and retrospective observational.

#### **Study participants**

Analysis of clinical cases of patients who applied for consultation at the outpatient department of Romodanov Neurosurgery Institute of National Academy of Medical Sciences of Ukraine in the period from 2019 to 2022

due to traumatic injury of the TLJ zone (Th11–L2). The progression of kyphotic deformity of the injured vertebral body was assessed according to neuroimaging data (spondylograms or computed tomography performed immediately after the injury and 2–4 months later during follow-up examination).

All patients provided informed consent to the processing of treatment outcomes while maintaining confidentiality. The study was approved by the Committee on Ethics and Bioethics of the Institute of Neurosurgery named after Acad. A.P. Romodanov of the National Academy of Sciences of Ukraine (Minutes No. 4 dated September 5, 2018).

#### **Inclusion criteria:**

- Patients' age from 18 to 60 years;
- presence of the results of radiography and/or spiral computed tomography of appropriate quality, performed in the first 5 days after the injury and 2–4 months after the injury, which provide a reason to unambiguously verify the traumatic damage of type A1 of the TLJ zone according to AO TLSICS;
- wearing a semi-rigid unloading brace for at least 2 months after the injury;
- neurological status corresponding to functional class E according to the ASIA (American Spinal Injury Association) scale [14];
- patient's consent to participate in the study.

#### **Exclusion criteria:**

- verified clinically significant manifestations of osteoporosis;
- presence of chronic pain of any etiology before the injury, requiring regular medication;
- presence of ankylosing spondylitis or diffuse idiopathic skeletal hyperostosis previously diagnosed or detected during the primary examination;
- history of trauma and/or spinal surgery;
- presence of a neoplastic process of any localisation or somatic pathology in decompensation stage;
- presence of persistent mental and behavioral disorders.

#### **Methods for assessing clinical data**

Basic demographic data of the injured (gender, age, height and body weight) were studied. The nature of the injury was classified according to AO TLSICS [3]. The functional class of neurological disorders was determined using the ASIA scale. The intensity of pain sensations was assessed 2–3 weeks after the injury using the Numerical Rating Scale (NRS) [15]. Quantitative assessment of the radiodensity of bony tissue was performed by determining on native scans the Hounsfield unit (HU) of the spongy substance of the vertebral body located caudal to the damaged one. 110 HU was chosen as the threshold value that allows denying clinically significant osteoporosis [16].

Deformation of the injured vertebral body was assessed as the angle between the superior and inferior endplates (vertebral endplate angle (VAE)). An increase in deformity by  $\geq 5^\circ$  in dynamics was considered ineffective conservative method of treatment.

*This article contains some figures that are displayed in color online but in black and white in the print edition.*

### Statistical processing

Statistical data processing was performed using R (version 4.2.3) in the RStudio development environment (version 2023.03.0+386). During the analysis, the probability of statistical error of the first kind was taken as  $\alpha=0.05$ , errors of the second kind were taken as  $\beta=0.2$ . The compliance of the trait to the normal distribution law was checked using the Shapiro-Wilk test. To assess the nature of the frequency distribution of features, the Pearson's  $\chi^2$  test or Fisher's exact test was used in the case of a small number of observations. The statistical significance of differences in numerical indicators between groups was determined using the Welch t-test or the Mann-Whitney U-test, depending on the nature of the distribution of the trait. A binomial logistic regression model was used to determine the nature and degree of influence of the analyzed factors on the probability of vertebral body deformity progression. The most clinically significant predictors were determined using the LASSO (Least Absolute Shrinkage and Selection Operator) regression method.

### Results and their discussion

Based on the results of primary material processing, 47 clinical cases were selected (**Table 1**). It was found that 31 (66%) of the injured applied for a consultation immediately (within the first 5 days) after the injury, 16 (34%) - within 2–4 months. In the latter case, the intensity of pain sensations was assessed retrospectively on the basis of medical documentation and a survey of the injured. Depending on the progression of the vertebral body deformity, the patients were divided into two groups. The first group (n=33) included patients with a stable X-ray pattern, the second (n=14) included patients with negative dynamics.

### Clinical case

Patient L., 55 years old, height – 175 cm, body weight – 93 kg, body mass index (BMI) – 30.4 kg/m<sup>2</sup>, was injured in fall from a height of about 1 m. Initial examination was performed the next day after the fall (**Fig. 1**). A compression fracture of the L1 vertebral body with damage to the inferior endplate and kyphotic

**Table 1.** Characteristics of patient groups

Indicator	No deformity progression, n=33	Deformity progression, n=14	p
Gender:			0,8753*
male	19 (57,58%)	7 (50,0%)	
female	14 (42,42%)	7 (50,0%)	
Age, years	37,7 (95% CI 34,12–41,28)	48,93 (95% CI 43,35–54,51)	0,0012 <sup>‡</sup>
Body mass index, kg/m <sup>2</sup>	27,78 (95% CI 26,14–29,42)	29,7 (95% CI 27,35–32,05)	0,1673 <sup>#</sup>
Level of damage:			0,929 <sup>Δ</sup>
Th11	3 (9,09%)	1 (7,14%)	
Th12	12 (36,36%)	4 (28,57%)	
L1	12 (36,36%)	6 (42,86%)	
L2	6 (18,18%)	3 (21,43%)	
Endplate:			0,2316*
superior	22 (66,67%)	6 (42,86%)	
inferior	11 (33,33%)	8 (57,14%)	
Bone tissue radiodensity, HU	166,03 (95% CI 155,84–176,22)	138,64 (95% CI 130,17–147,12)	0,0001 <sup>#</sup>
VAE,°	5,58 (95% CI 4,62–6,54)	8,07 (95% CI 6,61–9,53)	0,02 <sup>‡</sup>
Pain intensity, score	3 (95% CI 2,11–2,98)	3 (95% CI 2,4–3,6)	0,2 <sup>‡</sup>

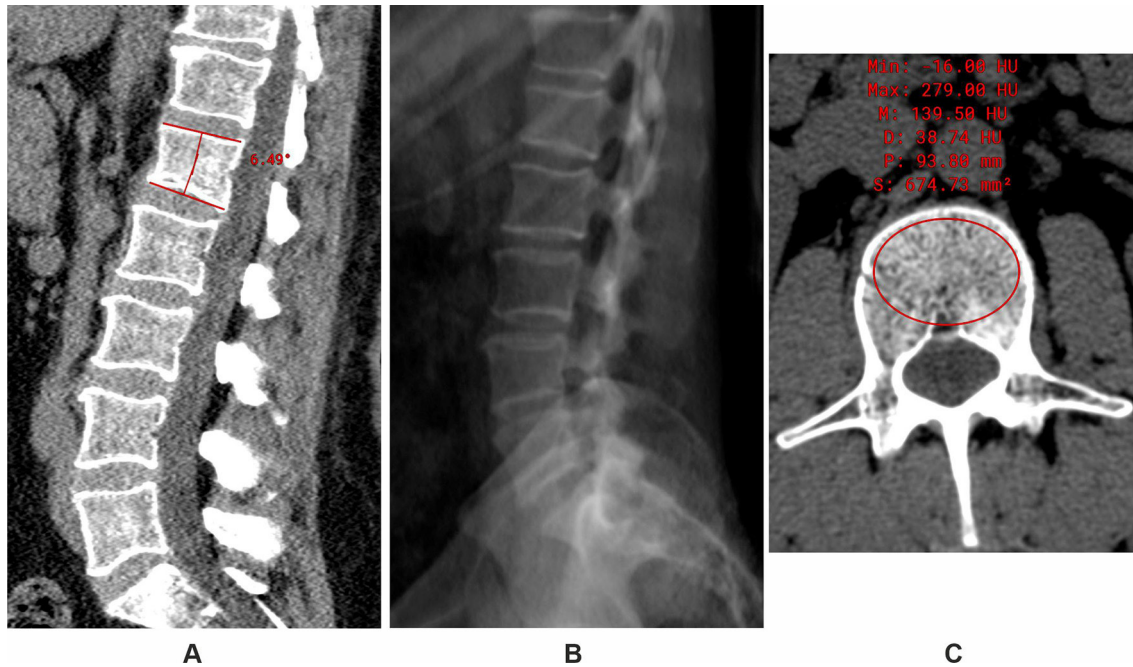
Notes: CI – confidence interval; \* – Pearson's  $\chi^2$  test; <sup>‡</sup> – Mann-Whitney U-test; <sup>#</sup> – t- Welch t-test; <sup>Δ</sup> – Fisher's exact test.

deformity of 6.5° is determined. The density of the bone tissue of the L2 vertebral body is 139.5 HU.

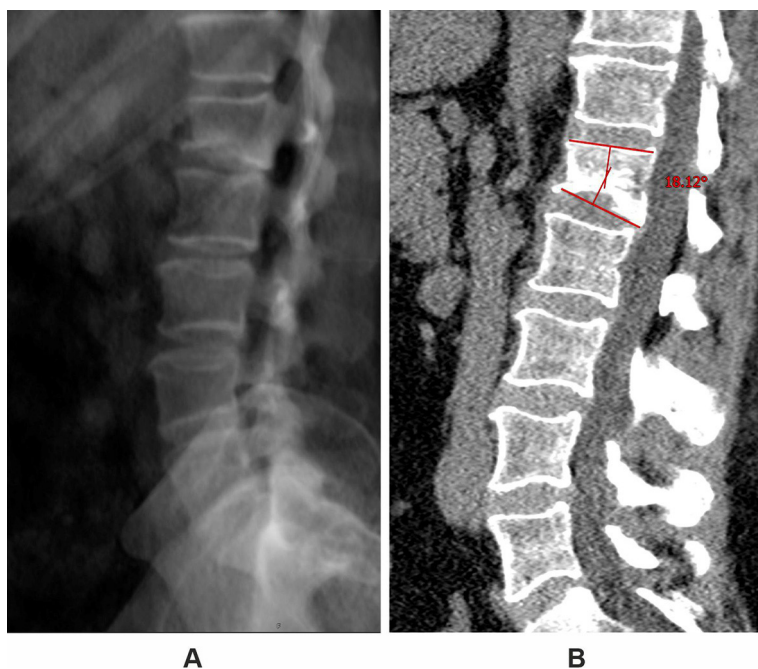
The patient was recommended a regimen of minimal motion activity for 2 weeks, wearing a semi-rigid unloading brace for 2 months, and X-ray control. She denies violation of the regime. Within 1 month after the injury, she noted persistent pain (5 points), which then decreased to 3-4 points, but required regular administration of painkillers. In 2 months after the injury, control X-ray was performed and, considering

the negative dynamics of computed tomography (**Fig. 2**). The findings showed an increase in the degree of kyphotic deformity of the compressed vertebra up to 18°.

During statistical processing of the results of the patients examination of the analyzed sample using a polynomial logistic regression model taking into account all factors, the data on the strength of association of predictors with the results of treatment were obtained (**Fig. 3**).

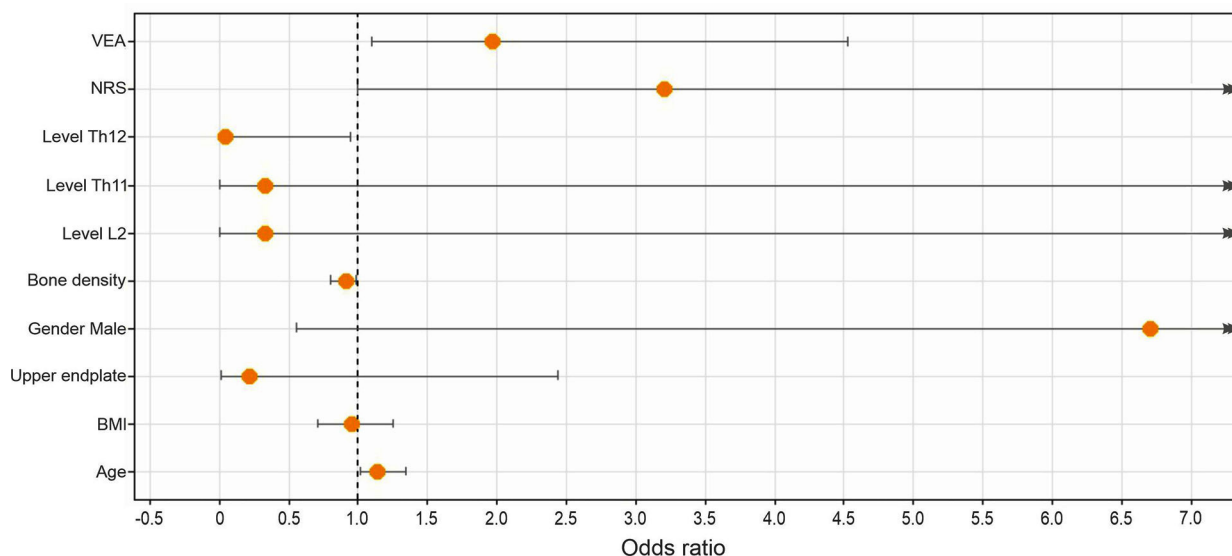


**Fig. 1.** Patient L. The next day after the injury: A - computed tomography, sagittal reconstruction; B - spondylography, lateral projection; C - computed tomography, native section, axial projection at the level of the L2 vertebral body



**Fig. 2.** Patient L. 2 months after the injury: A - spondylography, lateral projection; B - computed tomography, sagittal reconstruction





**Fig. 3.** The strength of association between the analysed predictors and treatment outcomes

Given the wide confidence intervals of the odds ratio of the analysed predictors, the model was regularised using the LASSO regression method to identify the most clinically significant factors. Iterative analysis was performed using the 10-fold cross-validation technique (**Fig. 4A**). The obtained indicator  $\lambda$  was 0.0438 ( $\text{Log}\lambda = -3.128$ ). It was found that age, X-ray density of bone tissue, compressed end plate, angular kyphotic deformity of the vertebral body and pain intensity are most important in predicting the probability of the growth of vertebral body deformity in patients with traumatic injuries of type A1 of the TLJ zone (**Table 2**).

Analysis of the predictive performance of the model showed high indicators (**Fig. 4B**): the area under the ROC curve (AUC) was 0.907, the prediction accuracy was 85%. To visually represent the dependence of kyphotic deformity progression on the predictors analysed, as well as to simplify risk determination, a nomogram was constructed based on a logistic model (**Fig. 5**). For the presented clinical case, the calculation was as follows: 55 years old on the "age" scale corresponds to 61 points ("points" scale), bone tissue density 140 HU corresponds 83 points, damage to the inferior endplate corresponds to 12 points, initial kyphotic deformity  $6.5^\circ$  corresponds to 37 points, pain intensity 5 points according to NRS corresponds to 46 points. The total amount is 239 points, which according to the "total score" scale corresponds to a probability of kyphotic deformity progression  $>90\%$  ("predictive indicator" scale).

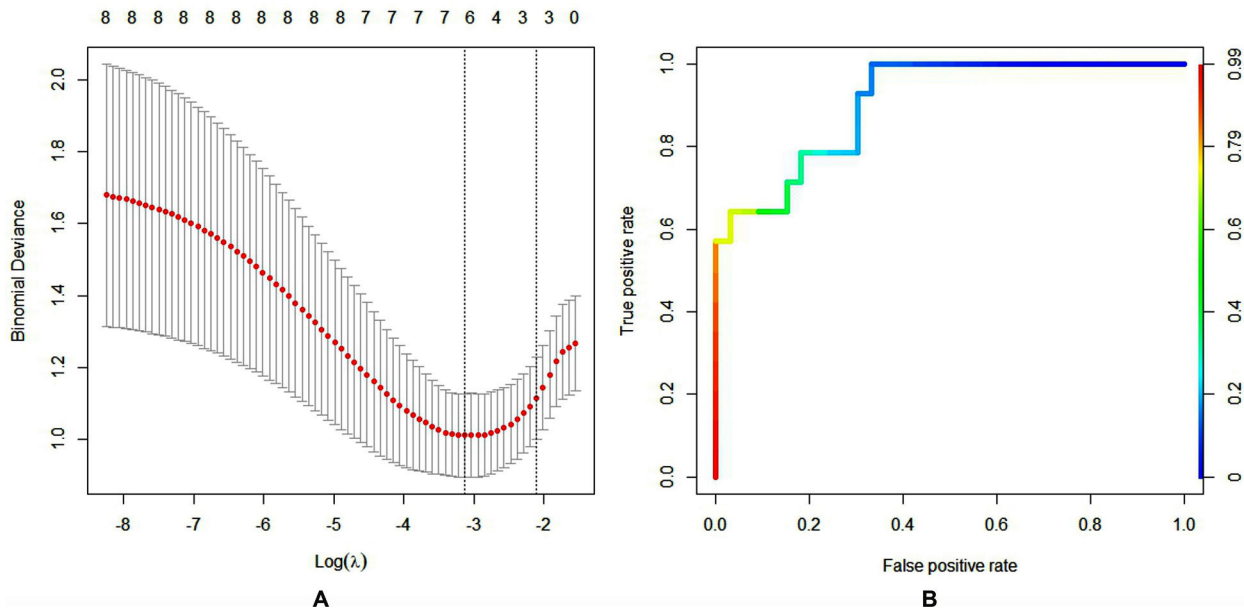
When analyzing the results obtained, it is useful to consider the significance of each of the predictors used.

The age of the injured person is one of the most obvious factors affecting the rate and ability of bone consolidation. Traditionally, the age aspect has been associated with the density of bone tissue, which is supported by a significant number of both instrumental and clinical observations. According to J.J. Schreiber et al. [11], the maximum values of bone tissue density (253.5–256.7 HU) in the healthy adult population were registered in the age group of 18–19 years, and the

minimum values are registered in the age group of 80–89 years (67.3–90.0 HU). Analysis of the epidemiology of osteoporotic spinal fractures revealed that of the 1.4 million fractures reported annually worldwide, the majority occur in patients over 50 years of age [17]. In addition, several studies show that all compression osteoporotic lesions of the TLJ zone inevitably progress when conservative therapy alone is used [12]. Regression model analysis did not reveal convincing multicollinearity between age and bone density. This may be due to several reasons. First, the study did not include patients with confirmed manifestations of osteoporosis, which to some extent limits the linearity of the relationship between the specified parameters. Secondly, the quality of bone tissue determined by age is characterized not only by mineral density. Other factors (collagen structure, porosity, and microarchitecture) are important both for determining the ability to resist physical influences and for the consolidation of traumatic injuries [18, 19]. The given data suggest that when determining deformity risk, indicators of age and mineral density (as measured by spiral computed tomography) should be evaluated independently. Our data are supported by a number of studies [12,20].

The issue of the influence of the damaged endplate localisation (cranial or caudal) on the risk of deformity progression of the injured vertebra has been little studied. Analysis of the available literature did not reveal any studies that unambiguously confirm or refute the dependence we have established. The only publications considering the localisation of the injury zone as a predictor are devoted to osteoporotic injuries, so the possibility of extrapolating the results to the population in general is questionable [12].

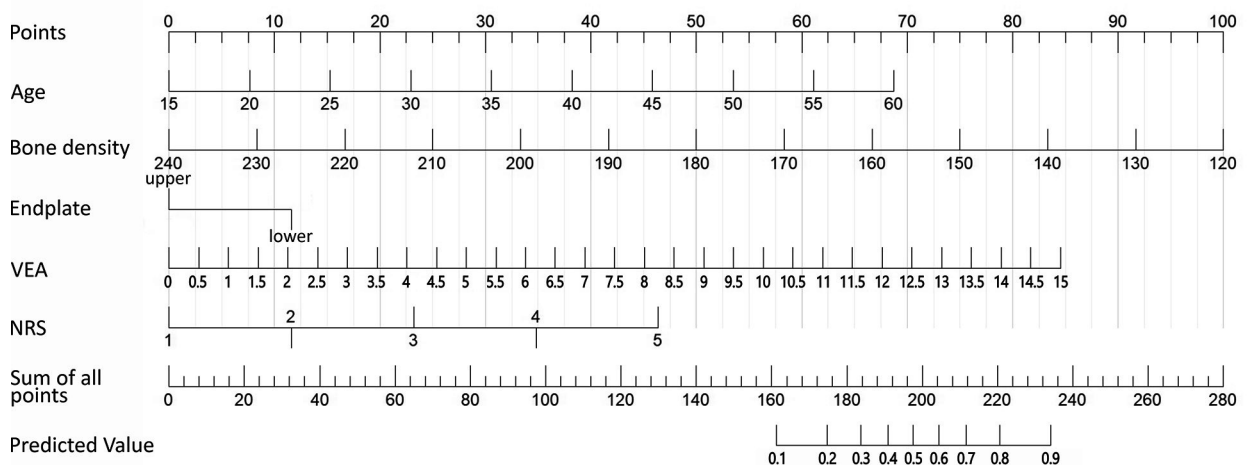
The degree of initial kyphotic deformity of the vertebral body, resulting directly from mechanical impact, plays a significant role in determining treatment outcomes and long-term consequences. In fact, it is the angular deformity that is the only objective criterion characterising the degree of damage in type A1



**Fig. 4.** Determination of the optimal value of  $\lambda$  in the LASSO model with 10-fold cross-validation (A) and the ROC curve characterizing the predictive performance of the optimised model (B)

**Table 2.** Characteristics of the polynomial logistic regression model for assessing the level of risk progression of kyphotic deformity of the damaged vertebral body

Predictor	B	SE	Z	p	Odds ratio (95% confidence interval)
Age	0,0924	0,0543	1,70	0,0886	1,10 (0,994-1,24)
X-ray density of bone tissue	-0,0504	0,0271	-1,86	0,0634	0,951 (0,896-0,999)
Compressed endplate	-0,7023	0,926	-0,758	0,448	0,495 (0,072-3,04)
Angular kyphotic deformity of the vertebral body	0,3407	0,210	1,62	0,105	1,41 (0,974-2,27)
Pain intensity	0,7014	0,466	1,5	0,133	2,02 (0,865-5,73)



**Fig. 5.** Nomogram for calculating the risk of progression of vertebral body kyphotic deformity in patients with type A1 fractures of the TLJ zone

fractures. The more pronounced the deformity, the more damaged both the endplate and the microstructure of the spongy tissue of the vertebral body and, accordingly, the greater the impairment of the supporting function. In 1977, A.A. White et al. convincingly demonstrated that the more pronounced the deformity of the vertebral body, the more load it experiences due to the change in the arm of force and the higher the probability of further deformity progression [21]. Accordingly, the directly proportional relationship established by our statistical analysis seems to be sufficiently pathogenetically argued.

Analysis of the intensity of pain sensations registered in patients of the studied clinical groups revealed certain differences that did not reach the level of statistical significance. However, the nomogram shows a significant correlation between pain intensity and the risk of post-traumatic deformity. The nature of this phenomenon and its causal relationships have been practically unexplored. On the one hand, a number of studies demonstrate that the presence of kyphotic deformity of the vertebral body causes 20% of patients to have persistent moderate or severe pain [22], which, cannot be attributed to minimal instability due to the presence of consolidation in the long-term period of injury. It has been shown that performing vertebroplasty, even without correction of kyphotic angulation, significantly reduces pain intensity [23]. On the other hand, it has been noted that pain sensations significantly affect muscle tone, leading to an increase in the load on the compressed area of the spine [24]. In this regard, pain should be considered not only as a result of deformity progression, but also as one of the factors leading to its development.

In our study, parameters with no convincing prognostic value are the patient's gender and BMI. Since, at first glance, such data are debatable, possible pathogenetic mechanisms of their influence on the phenomenon under study should be considered. The frequency of type A1 injuries of the TLJ zone, in contrast to other types of injuries, is higher in women, which is explained by the significant influence of osteoporotic injuries on the overall statistics of the indicator. Given that osteoporotic fractures are prone to progression, the incidence of progressive kyphotic deformity is also higher in females. Due to the age criterion and densitometric indicators, this fact is completely eliminated in our study. In addition, it is known that in the age range of 20–59 years, the average HU value, determined in the bodies of the lumbar vertebrae, is statistically significantly higher in women, which, taking into account metabolic peculiarities, creates better prerequisites for consolidation than in men of the same age category [25, 26].

The body mass index is a popular method for assessing whether a person's body weight corresponds to his height. According to WHO recommendations, the indicator  $>25 \text{ kg/m}^2$  corresponds to preobesity,  $>30 \text{ kg/m}^2$  to obesity [27]. A large number of studies analysing both the frequency of spinal fractures of different genesis and the dynamics of consolidation use BMI as a basic criterion [20,28]. However, according to some authors, the informativeness of this indicator for assessing constitutional features and as a predictor of bone consolidation is low [29]. In patients with a higher

BMI, better bone tissue density values are registered, which is due to an adaptive response to increased axial load [13,30]. Given that BMI does not take into account gender and age, its real relationship with the frequency of the analyzed parameter cannot be determined by linear methods of statistical analysis and requires a more detailed study. This is confirmed by literature data [28].

### Conclusions

Age, bone density, angular kyphotic deformity of the vertebral body, and pain intensity were found to have the greatest influence on the risk of kyphotic deformity progression of type A1 traumatic injuries of the TLJ zone, demonstrating a directly proportional relationship. A compressed caudal endplate is also associated with a higher risk of post-traumatic progression of angular kyphosis. The nomogram developed using the specified factors makes it possible to quantitatively assess the degree of risk when choosing a therapy strategy for the injured. The results obtained indicate that conservative methods of treatment cannot be considered optimal when a high risk of kyphotic deformity progression is determined, whereas the feasibility of vertebroplasty and kyphoplasty is reasonable. Further research on the use of minimally invasive surgical treatment methods for minimal degrees of vertebral body compression damage of the TLJ area is a promising direction in the complex of measures aimed at improving the quality of life of the injured and maximally restoring working capacity.

### Disclosure

#### *Conflict of interest*

The authors declare no conflict of interest.

#### *Informed consent*

Informed consent was obtained from each of the patients.

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