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Prediction of repeated osteoporotic fractures of the thoracic and lumbar vertebrae (experimental study)

A. I. Popov, M. V. Moloduk

Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv

Objective. To analyze the patterns of occurrence of postoperative recurrent vertebral compression fractures (RVCF) depending on the location of the primary fracture after puncture vertebroplasty. Methods. 520 case histories of patients with osteoporotic fractures of the thoracic and lumbar spine of various locations were analyzed. The total number of treated vertebral bodies was 1,458 (thoracic 596 — 40.88 %, lumbar 862 — 59.12 %). Most often, compression fractures of the spine occurred in the thoracolumbar junction (784 — 53.77 %). RVCF was diagnosed in 64 (12.31 %) people (95 % CI: 9.94–14.68 %) during follow-up examinations, after 1, 3, 6 or 12 months. since the operation. The study was carried out by 3 methods of forecasting: assessment of conditional probabilities, study of the significance of a primary fracture as a predictor of repeated fracture in a specific vertebra, analysis of associative rules and relationships Results. According to the 1st method, all conditional probabilities do not exceed 0.4 and the highest of them are the probabilities L_I and L_{IV} RVCF (0.39) with a primary Th_{VI} fracture, and the probability of Th_{VIII} RVCF (0.38) with a Th_V primary fracture. Method II found only two regularities that allow an interpretation that corresponds to the purpose of our research. The third method revealed the associative rules and connections of the primary fracture of Th_V with RVCF L_I, Th_{XII}; according to Th_{VI} with RVCF L_I, L_{II}; in the case of Th_{VIII} with RVCF L_I, Th_{XII}; Th_X fracture with Th_X, Th_{XI}, Th_{XII}, L_{II} RVCF; under Th_{XI} conditions with Th_V, Th_{VII}, Th_{VIII}, Th_{IX}, Th_X, Th_{XII} RVCF; for Th_X with RVCF Th_{IX}, Th_{XI}, Th_{XII}, L_{II}; Th_X fracture with Th_X, Th_{XI}, Th_{XII}, L_{II} RVCF. Conclusions. Prediction of repeated osteoporotic fractures is an important and topical problem of today's vertebrology. Our study shows the most vivid patterns that are characteristic of the general sample of patients, namely: with a primary fracture of Th_{XI} — a new deformation of Th_{VIII} is possible; in the case of ThVII — new fractures of Th_{IX}, Th_{XII}, L_I; for Th_{XII} — injuries of Th_{XI}; primary L_I — new Th_{XII}, L_{IV}, L_V.

Мета. Проаналізувати закономірності виникнення післяопераційних повторних компресійних переломів хребців (ПКПХ) залежно від розташування первинного перелому після пункційної вертебропластики. Методи. Проаналізовано 520 історій хвороб пацієнтів із остеопоротичними переломами грудного і поперекового відділів хребта різної локалізації. Загальна кількість пролікованих тіл хребців склала 1 458 (грудний відділ 596 — 40,88 %, поперековий 862 — 59,12 %). Найчастіше компресійні переломи хребта виникали у грудо-поперековому переході (784 — 53,77 %). ПКПХ діагностовано в 64 (12,31 %) осіб (95 % ДІ: 9,94–14,68 %), під час контрольних оглядів, після 1, 3, 6 або 12 міс. з моменту операції. Дослідження проводилося 3 способами прогнозування: оцінювання умовних імовірностей, вивчення значущості первинного перелому як предиктора повторного перелому в конкретному хребці, аналіз асоціативних правил і зв'язків. Результати. Відповідно до I способу, усі умовні ймовірності не перевищують 0,4 і найвищими з них є ймовірності ПКПХ L_I і L_{IV} (0,39) за умови первинного перелому Th_{VI}, та ймовірність ПКПХ Th_{VIII} (0,38) за первинного перелому Th_V. Способом II знайдено лише дві закономірності, що дозволяють інтерпретацію, яка відповідає меті нашого дослідження. Третій спосіб виявив асоціативні правила та зв'язки первинного перелому Th_V з ПКПХ L_I, Th_{XII}; за Th_{VI} з ПКПХ L_I, L_{II}; у разі Th_{VIII} з ПКПХ L_I, Th_{XII}; перелому Th_X з ПКПХ Th_{IX}, Th_{XI}, Th_{XII}, L_{II}; за умов Th_{XI} з ПКПХ Th_V, Th_{VII}, Th_{VIII}, Th_{IX}, Th_X, Th_{XII}; за Th_X з ПКПХ Th_{IX}, Th_{XI}, Th_{XII}, L_{II}; перелому Th_X з ПКПХ Th_{IX}, Th_{XI}, Th_{XII}, L_{II}. Висновки. Прогнозування повторних остеопоротичних переломів — важлива й актуальна проблематика сьогодення вертебрології. Наше дослідження показує найбільш яскраві закономірності, які характерні для загальної вибірки пацієнтів, а саме: за первинного перелому Th_{XI} — можлива нова деформація Th_{VIII}; у разі Th_{VII} — нові переломи Th_{IX}, Th_{XII}, L_I; за Th_{XII} — травми Th_{XI}; первинного L_I — нові Th_{XII}, L_{IV}, L_V. Ключові слова. Переломи хребців, повторний компресійний перелом, предиктори, прогнозування, профілактика, остеопороз, закономірності.

Key words. Vertebral fractures, repeated compression fracture, predictors, prognosis, prevention, osteoporosis, patterns

Introduction

The risk of postoperative recurrent vertebral compression fractures (RVCFs) in patients undergoing puncture vertebroplasty (PVP) is now widely recognized among vertebrologists. Independent risk factors associated with them have been published in previous studies [1, 2]. RVCF probability of in patients with osteoporosis after PVP was shown to reach 34.8 %. [3, 4] According to the literature, independent risk factors for RVCF include fracture site, cement leakage, advanced age, sagittal biomechanical imbalance, and low bone density. In recent years, an increasing number of vertebrologists have focused their attention on the more detailed development and validation of prognostic models for RVCF after PVP. In the model proposed by Y. Qian et al., predictors included bone mineral density (BMD), leakage, and cement morphology with corresponding AUCs of 0.848 and 0.867 for the training and test sets [5]. In the study of Y. Ma et al. female sex, cerebrovascular diseases, previous fractures, and intervertebral cement leakage were named as risk factors for RVCF [6]. C. Dai et al. identified cement leakage, Cobb's angle, assessment of pain syndrome according to the VAS scale, and treatment of osteoporosis as independent predictors in their model in the postmenopausal population [7]. However, only a few experiments used visual mathematical models for a clearer and more intuitive presentation of data. An increasing number of scientists conduct relevant studies and create different nomograms for prognosing RVCF [8, 9] and direct them to study the risk of vertebral fractures after vertebroplasty. We made an attempt to find the regularities of RVCF to determine the specific location of the future injury, depending on the location of the primary one, in order to prevent the possibility of RVCF after PVP.

Purpose: to analyze the patterns of postoperative repeated compression fractures of the vertebrae depending on the location of the primary fracture after puncture vertebroplasty.

Materials and methods

The materials of the study were reviewed at the meeting of the bioethics committee at the State Establishment Professor M. I. Sytenko Institute of Joint and Spine Pathology of the National Academy of Sciences of Ukraine dated 13.06.2022, No. 224.

A retrospective study was carried out based on the analysis of medical histories of 520 patients with osteoporotic fractures of the thoracic and lumbar spine with fractures of the vertebral bodies of various localizations, who were treated in the department of vertebrology of Professor M. I. Sytenko Institute of Joint and Spine Pathology of the National Academy of Sciences of Ukraine. The age of patients ranged from 54 to 89 years (average — 64 years). The gender distribution in the studied sample is heterogeneous with a predominance of women (82.50 % (95 % CI: 79.76–85.24 %) vs. 17.50 % (95 % CI: 14.76–20.24 %): $Z = 21.0$; $p < 0.000001$).

The total number of treated vertebral bodies was 1,458 (thoracic 596 — 40.88 %, lumbar 862 — 59.12 %). Most often, compression fractures of the spine occurred in the thoracolumbar junction (784 — 53.77 %). RVCF was diagnosed in 64 (12.31 %) subjects (95 % CI: 9.94–14.68 %) during follow-up examinations, 1, 3, 6 or 12 months after the operation. The observation period was 10 years.

Data on the site (vertebra) of the primary fracture, the degree of compression, and the number of damaged vertebrae in the thoracic and lumbar regions were considered as potential predictors of RVCF; as well as information about the patient's presence/absence of such concomitant conditions as degenerative scoliosis, hyperkyphosis, cardiovascular or endocrine system diseases.

A description of the data on the frequency of fractures of certain vertebrae is provided in the form of absolute and relative frequencies with 95 % confidence intervals. The statistical significance of the differences between the relative frequencies of fracture of each vertebra in the primary and RVCF was tested using the Z test for two proportions at a confidence level of 95 %.

The presented results allow us to imagine the general picture regarding the frequency of fractures of certain vertebrae in cases of both primary osteoporotic fracture and RVCF. However, they do not answer the question of how the primary fractures in a single vertebra are related to the fracture of a specific vertebra in a recurrent case. We sought an answer to this question using 3 prognostic methods.

I — estimation of conditional probabilities

One of the ways to determine the relationship between primary and secondary fractures is to analyze the probability of a fracture of a certain vertebra in the event of recurrent osteoporotic spine fracture. Indicators of these conditional probabilities are shown in Fig. 1 a, b.

II — study of significance of the primary fracture as a predictor of recurrent fracture in a specific vertebra

Assessment of the significance of the presence/absence of damage to each of the vertebrae in primary osteoporotic fracture for predicting the presence/

absence of a fracture in a specific vertebra in RVCF was carried out on the basis of the χ^2 criterion implemented in the Feature selection and variable screening module of the STATISTICA package. The data of patients with RVCF (64 cases) were selected for analysis. Binary indicators stating the presence/absence of injury were consistently chosen as dependent variables; binary variables indicating the presence/absence of a fracture of a certain vertebra in the primary fracture as potential predictors.

III — analysis of associative rules and connections

This analysis was performed using the Link analysis module of the STATISTICA package. The data of patients with RVCF (64 cases) were selected for evaluation. When removing these values from the total set, a minimum support of 1 % was set (to examine even those associations that hardly occur) with confidence greater than 50 %. The search for regularities is limited to studying only cases when all dichotomous variables took the value 1 (corresponds to the presence of a fracture in one or another vertebra). In general, under the specified settings, 1,038 associative rules were included in the study, of which we considered only those that contained information about vertebral damage in the primary fracture and the recurrent one.

This directly corresponded to the purpose of the study and allowed us to avoid consideration of unnecessary side connections. Thus, 106 associative rules that meet the given conditions remained (Table 3).

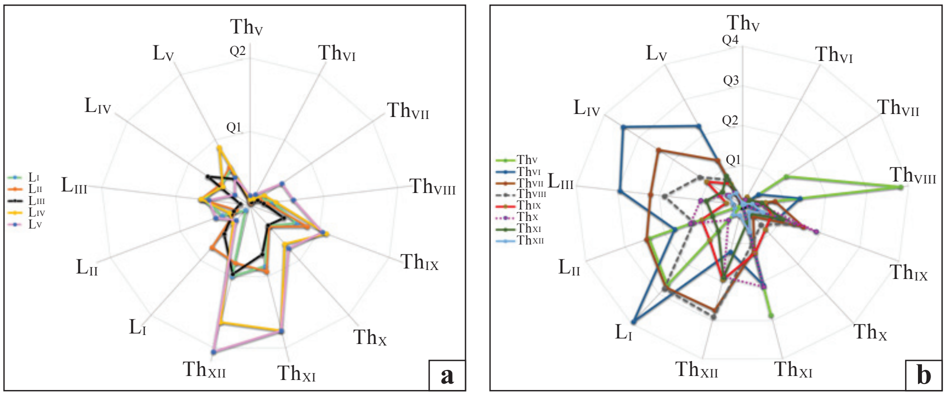

Fig. 1. Conditional probabilities of RVCF of the following divisions of the spine: a) lumbar (the vertebrae of the lumbar department in the primary fracture are marked with different lines, RVCF is the axis of the graph); b) thoracic (the vertebrae of the thoracic department in the primary fracture are marked with different lines, RVCF is the axis of the graph)

Table 1

Comparative analysis of the frequency of damage to individual vertebrae of the lumbar and thoracic divisions of the spine in primary and RVCF

Vertebra	Frequency of fractures				Significance of differences	
	primary (n=520)		recurrent (n=64)			
	abs.	%; (CI—95%)	abs.	%; (CI—95%)	Z	p
Th$_{III}$	1	0.19; (–0.12–0.51)	0	0.00; (0.00–0.00)	0.4	0.360
Th$_{IV}$	6	1.15; (0.38–1.92)	0	0.00; (0.00–0.00)	0.9	0.190
Th$_{V}$	8	1.54; (0.65–2.43)	4	6.25; (1.27–11.23)	2.5	0.006
Th$_{VI}$	22	4.23; (2.78–5.68)	5	7.81; (2.29–13.33)	1.3	0.090
Th$_{VII}$	39	7.50; (5.60–9.40)	8	12.50; (5.70–19.30)	1.4	0.080
Th$_{VIII}$	46	8.85; (6.80–10.89)	12	18.75; (10.72–26.78)	2.5	0.006
Th$_{IX}$	55	10.58; (8.36–12.80)	16	25.00; (16.10–33.90)	3.3	0.001
Th$_{X}$	43	8.27; (6.28–10.26)	12	18.75; (10.72–26.78)	2.7	0.003
Th$_{XI}$	99	19.04; (16.21–21.87)	18	28.13; (18.88–37.37)	1.7	0.040
Th$_{XII}$	194	37.31; (33.82–40.80)	21	32.81; (23.16–42.47)	0.7	0.240
L$_{I}$	241	46.35; (42.75–49.94)	17	26.56; (17.48–35.64)	3.0	0.001
L$_{II}$	197	37.88; (34.39–41.38)	15	23.44; (14.73–32.15)	2.3	0.010
L$_{III}$	166	31.92; (28.56–35.29)	17	26.56; (17.48–35.64)	0.9	0.190
L$_{IV}$	130	25.00; (21.88–28.12)	15	23.44; (14.73–32.15)	0.3	0.390
L$_{V}$	78	15.00; (12.42–17.58)	13	20.31; (12.04–28.58)	1.1	0.130

Results

According to the data obtained by method I, all conditional probabilities do not exceed 0.4, and the highest of them is the possibility of RVCF L_I and L_{IV} (0.39) in primary fracture of Th_{VI}, and Th_{VIII} (0.38) in primary fracture of Th_V. There are also high probabilities in primary Th_{VI} fracture followed by RVCF L_{III} and L_V; (0.29; 0.22); in primary fracture of Th_{VII} — RVCF Th_{XII}, L_I, L_{II}, L_{III} and L_{IV} (0.27; 0.27; 0.24; 0.22; 0.24); in primary fracture of Th_V — RVCF Th_{XI}, L_I and L_{II} (0.28; 0.26; 0.23); in primary fracture of Th_{VIII} — RVCF Th_{XII} and L_I (0.28, 0.28). Thus, primary fracture of Th_{VI} is associated with the highest probability of RVCF L_I, L_{IV} (0.39). In method II, firstly, the screening did not indicate significant predictors of damage to the Th_V, Th_{VI} and Th_X vertebrae in a recurrent fracture among the indicators of injury of individual vertebrae in the primary fracture. Secondly, Th_V deformity is a significant predictor of the presence/absence of RVCF Th_{VIII}, and Th_{VI} of RVCF L_{IV}, in case of Th_{VII} deformation — RVCF L_{II} and L_{IV}, Th_{VIII} fracture — RVCF L_I, Th_X injury — RVCF Th_{IX}, Th_{XI} and L_{II}, and L_{IV} — RVCF Th_{XI}, L_I and L_V, deformation of L_V — RVCF Th_{VII}.

The study showed only two regularities allowing an interpretation that corresponded to the purpose of our study. Both refer to damage in the primary vertebral fracture Th_X, identified as significant predictors of the presence/absence of RVCF Th_{IX} and Th_{XI} (Table 2) in the recurrent osteoporotic fracture.

Indeed, in the absence of a primary fracture of the Th_X, there were 47 cases in which the Th_{IX} was not broken in the event of a re-fracture, and 12 cases in which the Th_{IX} was damaged. Comparing the respective relative frequencies (79.66 % CI: 71.04–88.28 % vs. 20.34 % CI: 11.72–28.96 %), there was a statistically significant difference between them ($Z = 6.4$; $p < 0.0001$), allowing us to draw conclusions that in the absence of Th_X injuries in the primary fracture, they should be expected in the case of Th_{IX} injuries in a recurrent fracture. Moreover, the reverse is also true, because in the presence of Th_X damage in the primary fracture, there is a statistically significant preponderance of Th_{IX} damage in the recurrent fracture (80.0 % CI: 50.58–100.09 % vs. 20.0 % CI: 9.42– 49.42 %: $Z = 1.9$; $p = 0.0289 < 0.05$).

Similarly, in the presence of injuries to the Th_X vertebra in the primary fracture, the proportion of cases in which Th_{XI} is injured in the case of re-fracture is greater than in the absence of fractures of this vertebra (80.0 % CI: 50.58–100.09 % vs. 20.0 % CI: 9.42–49.42 %: $Z = 1.9$; $p = 0.0289 < 0.05$). And at the same time, in the absence of trauma to the Th_X vertebra in the primary fracture, the proportion of cases in which Th_{XI} is damaged in the event of a repeated fracture is statistically significantly less than in the absence of fractures of this location (23.73 % CI: 14.62–32.84 % vs. 76.27 % CI: 67.16–85.38 %: $Z = 5.7$; $p < 0.0001$). Therefore, among the significant

Таблиця 2

Results of screening for the importance and significance of variables in RVCF Th_{IX} та Th_{XI}

A significant predictor of the presence/absence of RVCF (v1 = "recurrent")					
primary fracture (vertebra)	$Th_{IX}(Th_X)$		primary fracture (vertebra)	$Th_{IX}(Th_X)$	
	chi-square	p-value		chi-square	p-value
Th_{IX}			Th_{XI}		
Th_X	8.750	0.003	Th_X	7.220	0.007
L_{IV}	1.550	0.210	L_{IV}	6.880	0.008
Th_{XI}	1.090	0.290	L_V	3.490	0.060
L_{II}	1.070	0.300	Th_{XI}	1.690	0.190
Th_V	0.680	0.400	Th_V	0.480	0.480
L_V	0.540	0.450	Th_{IX}	0.390	0.520
Th_{VI}	0.480	0.480	L_I	0.390	0.520
Th_{VIII}	0.380	0.530	Th_{VII}	0.380	0.530
L_I	0.330	0.560	L_{II}	0.300	0.580
Th_{VII}	0.150	0.690	Th_{VIII}	0.180	0.670
L_{III}	0.100	0.740	Th_{XII}	0.150	0.680
Th_{XII}	0.020	0.870	L_{III}	0.001	0.960
—	—	—	Th_{VI}	0.001	0.970

relationships between the vertebrae in primary and RVCF, only two were informative for the purpose of our study. They were concerned with the association of Th_X lesions in the primary fracture with the presence of Th_{IX} and Th_{XI} vertebral injuries in the case of RVCF. Such a situation made it necessary to search for methods of evaluating the dependencies between primary and recurrent fractures of certain vertebrae with a focus on the cases of fractures, as well as taking into account the possible existence of patterns more complex than paired connections, which was done using the analysis of associative rules (method III). Below, we reviewed the extracted rules separately for each and together with several vertebrae in the primary fracture, based on the goal of characterizing their possible connections with RVCF (Table 3).

Discussion

This study aimed to evaluate relationships using three methods/methods of data analysis, which allowed us to examine both the effect of the primary fracture of each vertebra separately and in combination with fractures of other locations.

Some authors created nomograms using independent predictors to determine the risk of RVCF after PVP. J. Zheng et al. constructed a nomogram based on 3 independent predictors:

Table 3

Associative rules that link injuries of certain thoracic and lumbar vertebrae in primary osteoporotic fracture in RVCF

Primary fracture	Independent PKKPH	RVCF in a combination of several primary fractures	Comment
1	2	3	4
Th_V	Th_{VIII}	$Th_V + Th_{XI} = Th_{VII}, Th_{VIII}$; $Th_V + Th_{VI}=Th_{VIII}$; $Th_V + Th_{VII} = Th_{VIII}, Th_{XI}, L_I, L_{II}$	Th_V damage in the primary osteoporotic fracture was associated in our study with new vertebral deformations of Th_{VII}, Th_{VIII}, Th_{XI}, L_I i L_{II}
Th_{VI}	L_I, L_{II}	$Th_{VI} + Th_V = Th_{VIII}$; $Th_{VI} + Th_{VII} = L_I, L_{IV}, L_V$; $Th_{VI} + Th_{VIII} = L_I, L_{III}$; $Th_{VI} + Th_{IX} = L_I, L_{IV}, L_V$; $Th_{VI} + Th_{XII} = L_{IV}$; $Th_{VI} + L_I = L_I, L_{III}, L_{IV}, L_V$	Independent fractures of Th_{VI} were associated only with secondary fractures of L_I and L_{IV}. Secondary fractures in the Th_{VIII} vertebra — with a primary fracture of Th_{VI} i Th_V
Th_{VII}	Independent primary fractures of Th_{VII} did not generate any associative rules	$Th_{VII} + Th_V = Th_{VIII}, Th_{XI}, L_I, L_{II}$; $Th_{VII} + Th_{VI} = L_I, L_{IV}, L_V$; $Th_{VII} + Th_{VIII} = Th_{XII}, L_I$; $Th_{VII} + Th_{IX} = L_{II}, L_{IV}$; $Th_{VII} + Th_X = Th_{IX}, L_{II}, L_{IV}$; $Th_{VII} + Th_{XI} = Th_{XII}, L_I, L_{III}$; $Th_{VII} + Th_{XII} = L_I–L_{IV}$; $Th_{VII} + L_{II} = L_I, L_{III}, L_{IV}, L_V$; $Th_{VII} + L_{III} = Th_{XII}, L_{II}$	All excluded rules involved cases when the primary fracture in Th_{VII} was combined with fractures of one of the thoracic vertebrae (Th_V–Th_{XII}), or with a fracture of L_{II} or L_{III}
Th_{VIII}	L_I, Th_{XII}	$Th_{VIII} + Th_{VI} = L_I, L_{III}, L_{IV}, L_V$; $Th_{VIII} + Th_{VII} = Th_{XII}, L_I$; $Th_{VIII} + Th_X =Th_{IX}, L_{II}, L_{IV}$; $Th_{VIII} + Th_{XI} = Th_{XII}, L_I, L_{III}$; $Th_{VIII} + L_{II} = L_I, L_{III}$; $Th_{VIII} + L_{III} = Th_{XII}, L_{II}$	The largest number of associative rules contained patterns leading to injury after recurrent fracture of L_I vertebra. These are both independent primary fractures of Th_{VIII}, and combinations of fractures of this vertebra with fractures of Th_{VII}, Th_{XI}, Th_{VI} and L_{II}
Th_{IX}	Independent primary fractures of Th_{IX} did not generate any associative rules	$Th_{IX} + Th_{VI} = L_{IV}, L_V$; $Th_{IX} + Th_{VII} = L_{II}, L_{IV}$; $Th_{IX} + Th_X = Th_{IX}$; $Th_{IX} + Th_{XI} = L_{II}, L_{IV}$; $Th_{IX} + L_{II} = L_{III}, L_{IV}, L_V$; $Th_{IX} + L_{III} = Th_{XII}, L_{II}$	All excluded rules involved cases where the primary fracture in Th_{IX} was combined with fractures of one of the thoracic vertebrae (Th_{IV}–Th_{XII}), or with a fracture of L_{II}, L_{III}, or L_{IV}
Th_X	Th_{IX}, Th_{XI}, Th_{XII}, L_{II}	$Th_X + Th_{VII} = L_{II}, L_{IV}$; $Th_X + Th_{VIII} = L_{II}, L_{IV}$; $Th_X + Th_{IX} = Th_{IX}$; $Th_X + Th_{XI} = Th_{IX}, L_{II}$; $Th_X + L_I = Th_{XI}, Th_{XII}, L_{III}, L_V$; $Th_X + L_{II} = Th_{XI}, Th_{XII}, L_{III}, L_V$; $Th_X + L_{IV} = Th_{XI}, Th_{XII}$	Excluded associative rules link independent primary Th_X fractures with recurrent, predominantly thoracic, fractures. These are separate injuries due to repeated osteoporotic fractures of Th_{IX}, Th_{XI}, Th_{XII} and L_{II} vertebrae, as well as combined repeated fractures of Th_{XI} and Th_{XII}, Th_{XI} and Th_{IX}, Th_{IX} and L_{II}

Continuation of Table 3

1	2	3	4
Th_{XI}	Th_V, Th_{VII}, Th_{VIII}, Th_{IX}, Th_X, Th_{XII}	$Th_{XI} + Th_V = Th_{VII}, Th_{VIII}$; $Th_{XI} + Th_{VII} = Th_{XII}, L_I, L_{III}$; $Th_{XI} + Th_{VIII} = Th_{XII}, L_I, L_{III}$; $Th_{XI} + Th_{IX} = L_{II}, L_{IV}$; $Th_{XI} + Th_X = Th_{IX}, L_{II}$; $Th_{XI} + Th_{XII} = L_V$; $Th_{XI} + L_I = L_V$; $Th_{XI} + L_{II} = L_V$; $Th_{XI} + L_{III} = L_V$; $Th_{XI} + L_{IV} = L_V$; $Th_{XI} + L_V = Th_{VIII}, Th_{IX}, Th_X, Th_{XII}, L_V$;	Associative rules from method I involving damage to the Th_{XI} vertebra in the primary osteoporotic fracture include a wide range of associations with new vertebral fractures, starting with Th_{VII} and ending with L_V
Th_{XII}	Independent primary fractures of Th_{XII} did not generate any associative rules	$Th_{XII} + Th_{VI} = L_{IV}$; $Th_{XII} + Th_{VII} = L_{IV}$ $Th_{XII} + Th_{XI} = L_V$; $Th_{XII} + L_V = Th_{XI}$	Combinations with primary Th_{VI}, Th_{VII}, Th_{XI}, and L_{II} fractures were associated with new Th_{XI}, L_{IV}, or L_V vertebral deformities. In most cases, the primary Th_{XII} fracture was combined with a new Th_{XI} fracture
L_I	Independent primary fractures of L_I did not generate any associative rules	$L_I + Th_{VI} = L_I, L_{III}, L_{IV}, L_V$; $L_I + Th_X = Th_{XI}, Th_{XII}, L_{III}, L_V$; $L_I + Th_{XI} = L_V$; $L_I + L_{IV} = Th_{XI}$; $L_I + L_V = Th_{IX}, Th_{XI}$	Combinations of L_I fracture with L_{IV}, Th_{XII} and L_V fractures were the most frequent, and relatively rare — with Th_X and Th_{VI} fractures
L_{II}	Independent primary fractures of L_{II} did not generate any associative rules	$L_{II} + Th_{VI} = L_I, L_{II}$; $L_{II} + Th_{VII} = L_I, L_{III}, L_{IV}, L_V$; $L_{II} + Th_{VIII} = L_I, L_{II}$; $L_{II} + Th_{IX} = L_I, L_{III}, L_{IV}, L_V$; $L_{II} + Th_X = Th_{XI}, Th_{XII}, L_{III}, L_V$; $L_{II} + Th_{XI} = L_V$; $L_{II} + L_{IV} = Th_{XI}$;	Combination of L_{II} and L_{IV} injuries in primary osteoporotic vertebral fracture is associated with new Th_{XI} deformity
L_{III}	Independent primary fractures of L_{III} did not generate any associative rules	$L_{III} + Th_{VII} = Th_{XII}, L_{II}$; $L_{III} + Th_{VIII} = Th_{XII}, L_{II}$; $L_{III} + Th_{IX} = Th_{XII}, L_{II}$; $L_{III} + L_{II} = Th_{XII}, L_V$;	L_{II} refracture has more frequent associations with Th_{VII} than L_{III} primary fracture, and L_V refracture with Th_{XI} primary fracture than L_{III}. Fracture of vertebra L_{III} is not the main cause of secondary fractures of these vertebrae, but only accompanies fractures of Th_{VII} and Th_{XI}.
L_{IV}	Independent primary fractures of L_{IV} did not generate any associative rules	$L_{IV} + Th_{IX} = Th_V, Th_{VIII}, Th_{XI}, Th_{XII}$; $L_{IV} + Th_X = Th_{XI}, Th_{XII}$; $L_{IV} + Th_{XI} = L_V$; $L_{IV} + L_I = Th_{XI}$; $L_{IV} + L_{II} = Th_{XI}$	Primary L_{IV} fracture in combination with Th_{XI} fracture is associated with L_V fracture in recurrent osteoporotic vertebral fracture. The L_V is the only vertebra of the lumbar region, the injury of which in the case of a recurrent osteoporotic fracture is accompanied by the injury of the L_{IV} in the primary fracture
L_V	Independent primary fractures of L_V did not generate any associative rules	$L_V + Th_{XI} = Th_{VIII}, Th_{IX}, Th_X, Th_{XI}, Th_{XII}, L_V$; $L_V + Th_{XII} = Th_{XI}, Th_{XII}$; $L_V + L_I = L_V$;	Most often, L_V recurs together with a Th_{XI} fracture, which is associated with injuries to the Th_{VIII}, Th_X, Th_{XI}, Th_{XII} and L_V vertebrae in recurrent osteoporotic fractures

leakage of bone cement and its poor dispersion, fractures of the locking plate [10]. Q. Li et al. created a model based on 6 variables: age, dose of bone cement, its leakage and dispersion, contact between bone cement and locking plate, and treatment of osteoporosis [11].

W. Li et al. included 4 predictors: female gender, positive history of fractures, diagnosis of cerebrovascular disease, and leakage of bone cement into the intervertebral space [12]. A. Zhang et al. used the following parameters for the nomogram: age, body mass index, BMD, bone cement leakage, vertebral height, osteoporosis treatment, vertebral height restoration coefficient [13].

These works, without exaggeration, are of great importance in the prognosis of RVCF, but they are all created to determine the probability of repeated vertebral fracture after PVP. They do not make it possible to assess and plan the possibility of introducing bone cement into an adjacent or distant

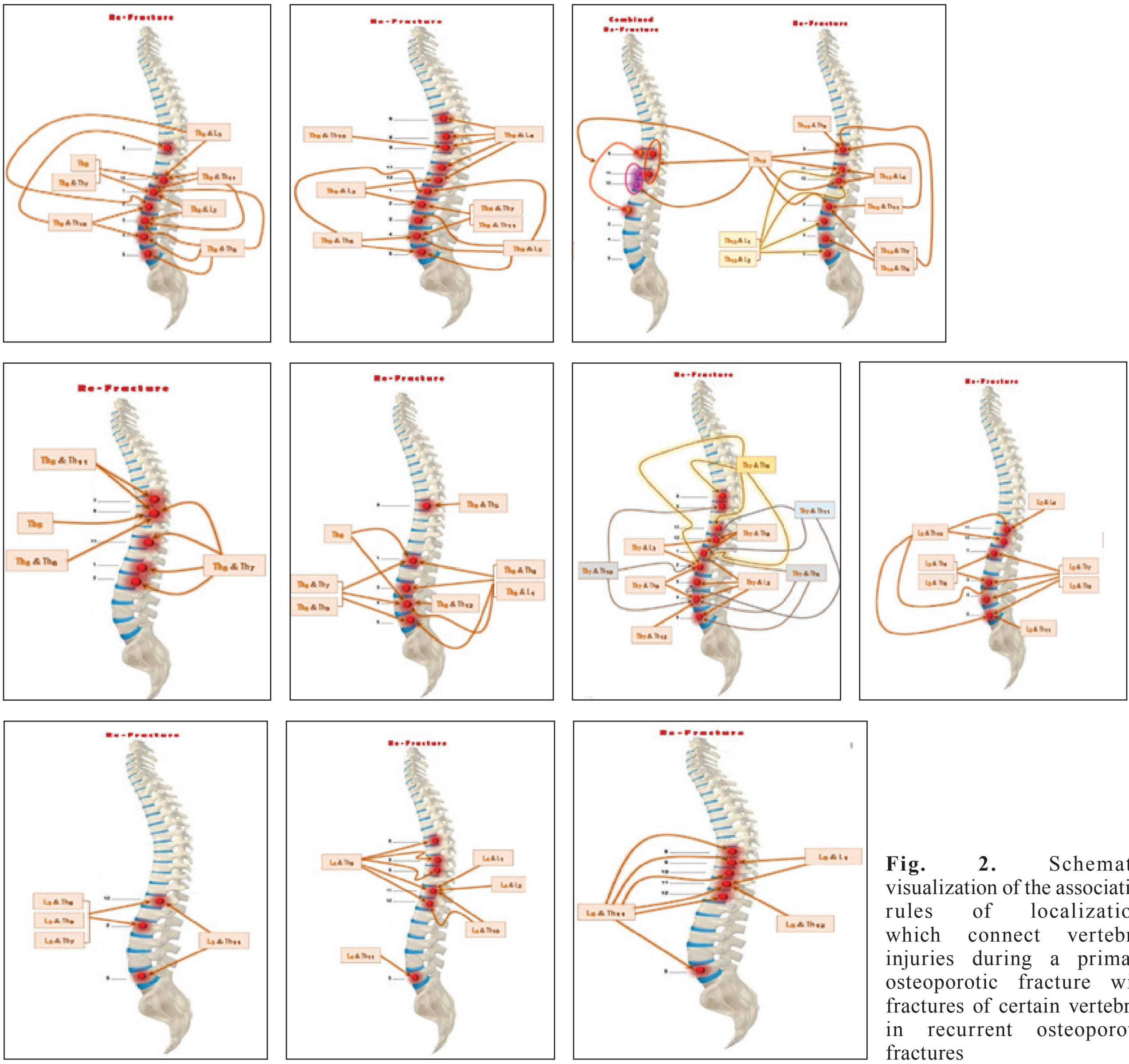

Fig. 2. Schematic visualization of the associative rules of localization, which connect vertebral injuries during a primary osteoporotic fracture with fractures of certain vertebrae in recurrent osteoporotic fractures

vertebra for the purpose of preventing RVCF, because they do not give an answer in which vertebra will re-fracture.

This experimental work has several limitations. First, all cases were recorded in orthopedic surgery patients of our hospital, without comparing data from other medical centers. External validation involving a larger and more diverse patient population from different countries and regions is needed to refine the findings. Second, because it is a retrospective analysis, the study is subject to selection bias. Future prospective studies with larger sample sizes and collaboration with other treatment facilities are needed to confirm accuracy. Note that some data were lost in the retrospective study, and we did not consider bone mineral density in the analysis.

Conclusions

Prognosis of repeated osteoporotic fractures is an important and topical problem of today's vertebrology. We emphasize that there are quite a few publications devoted to this issue. Our study shows the most vivid patterns that are characteristic of the general sample of patients, namely: a primary fracture of Th_{XI} is associated with a possibility of new deformation of Th_{VIII}; that of Th_{VII} with new fractures of Th_{IX}, Th_{XII}, L_I; Th_{XII} with injuries of Th_{XI}; primary L_I with new Th_{XII}, L_{IV}, L_V;

The prospect of further research is the development of a system for detecting patterns of new deformations of the vertebral bodies, which is possible after biomechanical research, practical testing and critical evaluation of the results.

Conflict of interest. The authors declare no conflict ofinterest.

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PREDICTION OF REPEATED OSTEOPOROTIC FRACTURES OF THE THORACIC AND LUMBAR VERTEBRAE (EXPERIMENTAL STUDY)

A. I. Popov, M. V. Moloduk

Sytenko Institute of Spine and Joint Pathology National Academy of Medical Sciences of Ukraine, Kharkiv

✉ Andrii Popov, MD, DSci in Orthopaedics and Traumatology: aipopovdoc@gmail.com

✉ Mykyta Moloduk, MD: NikitaMoloduk@gmail.com