RESULTS OF SURGICAL TREATMENT OF THE THORACIC SPINAL NERVE TUMORS: A RETROSPECTIVE ANALYSIS

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Objective. To analyze clinical and morphological features of neurogenic hourglass tumors in the thoracic spine and their impact on outcomes of treatment through posterior surgical approaches.
Material and Methods. The results of surgical treatment of 295 patients with tumors growing from the nerve roots of the thoracic spinal cord were studied. In 63 (21 %) of them, tumors of the spinal nerves were diagnosed. The vast majority of neoplasms were represented by Grade 1 neuromas – in 57 (90 %) patients, Grade 1 neurofibromas were found in 3 (5 %) patients, and High-grade malignant tumors – in 3 (5 %). Intracanal neoplasms were found in 42 (66.7 %) cases and intraextravertebral (hourglass) – in 21 (33.3 %).
Results. Microsurgical removal of tumor was performed using two types of low-traumatic surgical approaches: 1) posterior median approach – in 56 (89.0 %) cases, of which hemilaminectomy was performed in 36 (64.4%) cases, interlaminectomy – in 15 (26.8 %) cases, and laminectomy – in 5 (8.1 %) cases; 2) paravertebral approach – in 7 (11.0 %) out of 63 cases with partial facetotomy or facetectomy and resection of part of the head and upper or lower edge of the rib at the same level. Tumors were removed totally in 56 (88.9 %) patients and subtotally – in 7 (11.1%). Intracanal tumors were removed totally in 40 (95.2 %) patients. A similar totality was achieved in removal of 16 (76.2 %) of hourglass neurinomas. Surgical interventions performed in the early postoperative period improved the functional state of patients: the Karnofsky Performance Scale (KPS) index increased from 70–80 to 90 %, the VAS pain score decreased from 5–6 to 2 points. Good clinical outcomes were achieved in 42 (66.7 %) patients, satisfactory – in 17 (27.0 %), and unsatisfactory – in 6 (6.3 %). Twenty nine patients had symptoms of myelopathy, complete regression of which occurred in 3 (10.3 %) cases, partial – in 9 (34.6 %), in 13 (50.0 %) cases they remained at the preoperative level, and in 4 (15.4 %) – worsened.
Conclusion. The use of modern neurointroscopy, microsurgical techniques and low-traumatic posterior surgical approaches for resection of tumors of the spinal nerve roots in the thoracic spine provides good clinical outcomes of treatment in the early postoperative period. The existing hourglass tumor in the thoracic spine reduces the likelihood of its total removal when performing a low-traumatic posterior approach.
Key Words: neurinoma, schwannoma, extramedullary tumors, spinal cord tumors, hourglass tumors.
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According to the third edition of the International Classification of Diseases for Oncology (ICD-O), adopted by the World Health Organization in 2017, neoplasms of spinal nerves are represented by the following types of tumors: neurinoma (schwannoma), neurofibroma, perineurioma, and also malignant peripheral nerve sheath tumors (MPNST). Neurinoma is the most common histotype of neoplasm of spinal nerves; neurofibromas are less common (their ratio to schwannomas is 9 : 1); perineuriomas make up only 1 % of tumors from the peripheral nerve sheath [1]. MPNST comprise tumors that were previously called malignant schwannoma, neurogenic sarcoma, and neurofibrosarcoma. This group of neoplasms is rare and accounts for only 3–10 % of all malignant tumors [2].

In 1910, Verokay was the first to introduce the term "neurinoma". Considering the invasion pattern of the neoplasm of Schwann cells forming the myelin sheath, the second term "schwannoma" is also broadly used [3]. In most cases, it is a benign indolent tumor that has a clear border with the surrounding anatomical sites and a well-marked capsule. It is common in the group of peripheral nerve tumors. Neurinomas are the most widespread primary tumors of the spine. Their annual incidence is 0.3–0.5 per 100,000 people, corresponding to approximately 25–30 % of primary spinal tumors with intraextradural and paravertebral expansion and, in rare cases, intramedullary localization [4-6]. The prevailing number of schwannomas are diagnosed in the thoracic spine [6]. There is not much of a considerable difference in the prevalence of tumors in men and women; they are most often diagnosed in the age range of 40–60 [7].

A special consideration should be given to tumors of the thoracic spine, which often have an intraextracanal invasion pattern, running along the spinal root into the extravertebral space through the intervertebral foramen, forming its isthmus. These tumors are referred as hourglass ones (dumbbell), first described by Heuer in 1929 as tumors penetrating through a narrow intervertebral foramen with further paravertebral expansion [8, 9]. Tumors in the form of dumbbells or hourglasses account for 6 to 15 % of all spinal tumors. 90 % of these cases are schwannomas; 35 % of them are localized in the thoracic spine [6, 9]. The problems of gross total resection of these type of tumors, especially the hourglass type invading the pleural cavity, and the maximum reduction in cases of their recurrence, are far from final resolution and remain topical. Despite the apparently total resection of these neoplasms, the overall frequency of their recurrence is quite high and amounts to an average of 4 to 6 % for schwannomas [7].

The objective is to analyze clinical and morphological features of neurogenic hourglass tumors in the thoracic spine and their impact on outcomes of treatment through posterior surgical approaches.

Material and Methods

Design: an open observational parallel non-controlled non-randomized retrospective cross-sectional single-centered study.

Conditions and participants: the subject of the study was the medical documentation (case reports) of patients operated between February 2008 and December 2020.

Inclusion criteria: 1) the presence of tumors growing from the spinal cord roots, confirmed histologically; 2) performing surgical treatment in accordance with the standard protocol; 3) the period of postoperative follow-up to 23 days from the time of surgery.

Exclusion criteria: 1) fatal case in the early postoperative period; 2) lack of medical documentation in the postoperative period (up to 23 days from the time of surgery) and loss of remote contact with the person who have been operated; 3) concomitant diseases triggering additional neurologic impairment.

Course of the procedure

The study included data from patients operated on for tumors growing from the spinal cord roots. At the preoperative stage, all patients underwent clinical neurological examination and contrast MRI of the spinal cord at the lesion level (Toshiba Excelart Vantage MRI machines, Japan). The magnetic field intensity was 1.5 T and the thickness of the slices was 4 mm in T1, T2, FLAIR, and DWI modes. The MRI data helped to visualize and localize the tumor. It promoted determining the degree of compression of the spinal cord, the presence of not only intracanal but also paravertebral components in hourglass tumors, as well as evaluating the ratio of the paravertebral lymph node with the thoracic aorta, inferior vena cava, and lung parenchyma.

After detecting clinical signs that could be accompanied by structural changes in the spine, patients additionally underwent multi-layer spiral CT on the Toshiba Aquilion 64-slice CT scanner (Japan). The thickness of the slices was 1 mm. CT images helped to visualize the enlarged intervertebral foramen, and also to judge the degree and nature of changes in the bone formations of the spine.

To determine the volume of neoplasms, the formula for calculating the volume of ellipsoidal bodies was used since this shape most closely follows the shape of tumors: $4/3\pi \times$ (craniocaudal length/2) × (transverse diameter/2)^2 [10].

In all cases, tumor resection was performed in a single step with the maximum radicality. If this was not possible, tumors were resected to the maximum possible rate. Sets of domestic and foreign microsurgical instruments were used in all procedures. At the stage of tumor resection, Sonaca ultrasonic aspirators (Soring and CUSA) and bipolar coagulation were used. The procedures were performed under a Carl Zeiss OPMI Vario 33 microscope (Germany), magnification *10.0–12.0. The duroplasty was carried out with synthetic dissolvable suture ETISORB (Johnson & Johnson, registration certificate FS No. 2005/1663) or similar materials replacing DM and alloplants approved for use in medical practice on the territory of the Russian Federation. All procedures were performed under the control of Inomed ISIS Xpert neurophysiological monitoring (Germany). In the early postoperative period (up to 22 days after surgery), MRI control was performed.

Techniques

Clinical and neurological assessment of the condition of patients before surgery and the outcomes of surgical treatment was conducted according to the classification of the functional status of the operated patients [11]. Based on that, the outcomes of surgical interventions were assessed depending on the severity of preoperative and postoperative neurological symptoms. The outcome of surgical treatment was assessed as follows: 1) good (transition of the operated patients to a higher level of the functional class); 2) satisfactory (improvements within one functional class); 3) unsatisfactory (deterioration or absence of positive dynamics).

The Eden classification (1941) was applied to hourglass tumors in the thoracic spine. This classification distinguishes four growth types of intraparavertebral neoplasms [9].

In dynamics, the functional status of the operated patients was evaluated according to the International Karnofsky Performance Scale (KPS), while the pain syndrome was assessed according to VAS [12, 13].

The presence and severity of myelopathy in pre- and postoperative periods were estimated according to the Japanese Orthopedic Association (JOA) scale for thoracic myelopathy, which was developed from the JOA scale for cervical myelopathy by excluding motor and sensory scores for the upper extremities. The regression degree of myelopathy after surgery was estimated as the ratio of the actual increase in JOA scores (postoperative JOA scores – preoperative JOA scores) to the theoretically maximum possible recovery in this patient (11 points is the maximum possible score indicating the absence of myelopathy symptoms). The resulting proportion is represented in percentages. The formula in general form: [postoperative score – preoperative score] / [11 – postoperative assessment] × 100 % [14].

The surgical treatment outcomes of neurogenic tumors growing from the spinal cord roots at the thoracic level, the histological structure of neoplasms, their volume, and localization relative to DM, the spinal cord, and the vertebral column were analyzed.

The studies carried out comply with ethical standards developed under the WMA Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Subjects", as amended in 2000, and the "Rules of Clinical Practice in the Russian Federation", approved by the Order of the Ministry of Health of the Russian Federation No. 200n as of April 1, 2016. The study was approved by the Biomedical Ethics Committee of the institution. All data is depersonalized.

Statistical analysis

The normality of the distribution for clinical characteristics measured in quantitative scales with more than three observations was evaluated formally using the Shapiro – Wilk test. Normally distributed characteristics were described by the values of the mean and standard deviation in the form: M ± SD. For variables with an abnormal distribution, the median, the 1st and the 3rd quartiles were used in the following format: Me |1stQ; 3rdQ|. Categorical data is presented in the form of the number of observations and fractions. A two-sample Student's t-test was used to evaluate the significance of differences in the mean normally distributed values of two independent groups. The Fisher's exact test was used to determine the significance of differences in cross tables of type r on c. Also, the difference of 95 % confidence intervals for means, medians, or proportions was estimated by the Wilson Method. The Mann – Whiney U-test was used to evaluate the significance of the differences in the event of deviation from the normality of distribution of the characteristic in at least one of the groups. In multiple comparisons, the obtained values of the achieved significance level (p-level) were corrected using the Benjamini – Hochberg Procedure. One-way analysis of variance (ANOVA) was used to assess the significance of the differences between three or more independent groups, provided that the intra-group normality of the distribution was observed. In the event of deviation from the normality of distribution or other basic assumptions of the analysis of variance, the Kruskal – Wallis test was applied. To evaluate the effect of predictors on the volume of tumor resection, the odds ratio was calculated with 95% confidence intervals. In all cases, the differences were considered as statistically significant at the obtained significance level of $p < 0.05$. Statistical analysis was performed on RStudio software, Inc., Boston, MA, version 1.2.1335.

Results

Between 2008 and 2020, a total of 295 patients with tumors in the thoracic spine underwent surgery at the Neurosurgical Unit No. 1 of the Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan. Out of them, 63 (21 %) had tumors in the sheaths of the spinal nerves. The average age of patients was 50.7 ± 13.6, which is statistically significantly lower than the age of patients with other histological types of tumors ($p = 0.032$ |95 % CI: 0.37; 8.16|). The study population included 47 (75 %) women and 16 (25 %) men. Hourglass tumors were 50 % |95 % CI: 14; 59| more frequent in women ($p = 0.096$). The distribution of tumors of various histostructures over the years of the study is shown in **Fig. 1**.

The overwhelming number of tumors is represented by neurinomas (Grade 1, ICD-O 9560/0) – 56 (89 %), while in two cases they are associated with the presence of neurofibromatosis type 1. Neurofibromas (Grade 1, ICD-O 9540/0) were found in three people, and MPNST were identified in three more patients (High-grade, ICD-O 9540/3). The detailed distribution of tumors around the vertebral column, spinal cord, DM and their volume is presented in **Table 1**.

Out of 63 neurogenic neoplasms, 42 (66.7 %) were intracanal, and 21 (33.3 %) were intraextravertebral (hourglass). More than half of the neurogenic tumors were found intradural – 35 (56 %), less frequently extradural – 22 (35 %), and 6 (9 %) intraextradural. According to the Eden classification, tumors of type III – 11 (52 %), type II – 5 (24 %), and type IV – 4 (19 %) dominated; type I was found only in 1 (5 %) case. The median tumor volume of type I is 1.33 cm^3, type II – 7.8 (2.17; 14.07) cm^3, type III – 13.57 (2.80; 17.98) cm^3, and type IV – 9.72 (8.60; 11.50) cm^3. The majority of tumors were localized in the lower thoracic spine (T9–T12) – 34 (54 %). In the upper (T1–T4) and middle (T5–T8) segments of the thoracic spine, 16 (25 %) and 13 (21 %) tumors were diagnosed, respectively. Localization of hourglass tumors **(Fig. 2a)** was statistically significantly different: the latter prevailed in the upper thoracic spine – 69 % |95 % CI: 44; 86|; tumors in the lower thoracic spine were significantly less common – 18 % |95 % CI: 8; 34|; $p = 0.004$.

The median tumor volume was 7.67 cm^3 |95 % CI: 1.4; 10.6| larger in hourglass neoplasms ($p = 0.003$). They also significantly differed from each other in relation to volume ($p = 0.023$). The average size in the largest dimension corresponded to 3.90 ± 1.21 cm; the minimum size was 2.1 cm; the maximum size was 6.4 cm. The smallest quantity was comprised by tumors of less than 2 cm^3 **(Fig. 2b)** – 12% (95 % CI: 4; 31).

In 38% |95 % CI: 28; 90| cases, hourglass tumors invaded the thoracic cavity ($p < 0.001$) and 24 % less often |95 % CI: 8; 87| than intravertebral tumors invaded the vertebral bodies ($p = 0.018$). Meanwhile, the disruption of the vertebral bodies has always been observed in malignant tumors ($p = 0.004$).

An MRI examination revealed a picture of round-shaped neoplasms with a clear border that had the surrounding tissue. Neurogenic tumors in 87 % of cases were hyperintensive in T2-weighted images (T2WI). The pattern of contrast differed depending on the tumor structure: in the presence of only a solid component, the neoplasms contrasted homogeneously in 78 % of cases. In 21 % of cases, tumors had a cystic component, which was manifested by a peripheral or mixed type of contrast. In 1 % of cases, the tumor did not accumulate contrast agents.

The primary endpoint of this study was the functional status of the patient according to the McCormick et al. (2000), KPS and VAS scales till 22 days from the time of the surgery.

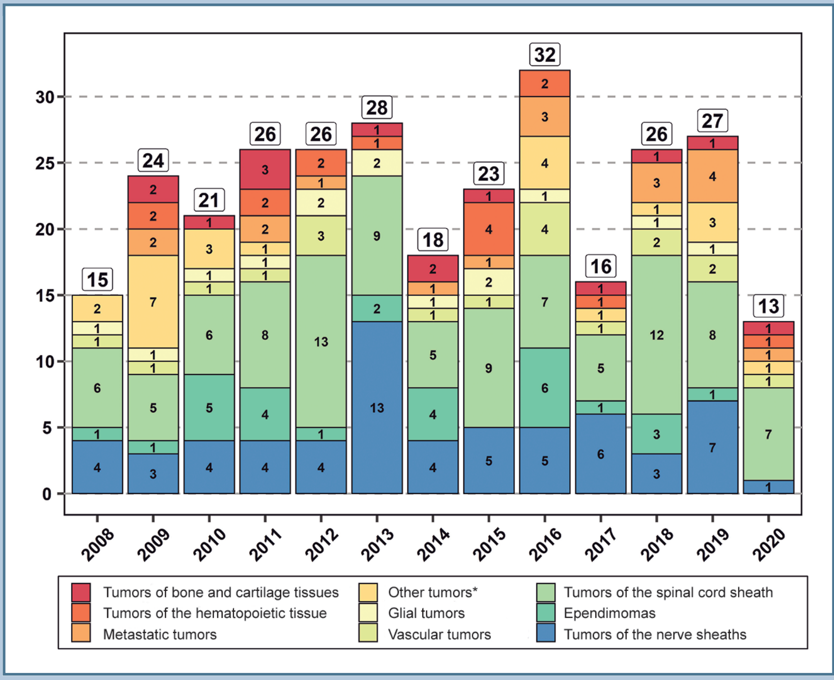

Fig. 1
Histological characteristics of tumors and their distribution by years of study; * lipomas, angiolipomas, histiocytomas, melanoblastomas, rhabdomyosarcomas, cholesteatomas, juvenile xanthogranulomas and unspecified formations

The main clinical symptoms of the disease and data on the functional status of patients throughout the observation series before surgery are shown in **Table 2**. Before the procedure, all patients corresponded to the 2nd functional class according to the McCormick scale.

The most common symptom before surgery in patients of the study group was a pain in the lumbar spine (49 % of cases). Pain syndrome in the chest was marked in 44 % of cases, in the lower extremities (in 21 %). Sensory (46 %) and motor (46 %) disorders in the lower extremities were less common. The pelvic organs dysfunction of the central type supplemented the clinical picture in 19 % of cases. The average time of onset of symptoms, regardless of the anatomical localization of tumors, was 6 |5; 8| months. In 6 (9.5 %) patients, the neoplasms were an accidental finding, and they were asymptomatic.

In almost half of the cases (46 %), by the time of admission to the unit, patients had clinical manifestations of thoracic myelopathy, an increase in the frequency of which was considerably associated with the presence of an intradural tumor component ($p = 0.004$). It did not, however, differ between anatomical types of neurogenic tumors ($p = 0.846$). In 29 patients with myelopathy, the median values of its severity according to JOA-T at admission corresponded to 8 points |6; 10|.

The characteristics of procedures and clinical indicators in the early postoperative period are given in **Table 3**.

All patients underwent a one-stage procedure. Posterior median approaches were mainly used for removal – 56 (89.0 %) cases, with interlaminectomy in 15 (26.8 %) of them, hemilaminectomy in 36 (64.4 %), and laminectomy at 1–2 levels in 5 (8.9%). In 7 (11.0 %) of these patients, paravertebral approaches were used for the resection of tumors. Seven (33.3 %) out of 21 patients with intraextravertebral neoplasms were operated on through paravertebral approach with partial facetotomy or facetectomy, resection of a part of the head and the upper or lower edge of the rib at the same level. Fourteen patients (66.7 %) underwent procedures through posterior approach with hemilaminectomy on the neoplasm side. Partial facetectomy ($p < 0.001$) and resection of the head ($p < 0.001$) and edges of the rib were more often performed in tumors of Eden types III ($n = 3$; 43 %) and IV ($n = 4$; 57 %) with a volume of more than 4 cm^3 – 45 % (95 % CI: 22; 80) and 33 % of cases, respectively. Facetectomy and facetotomy, and resection of a part of the rib head were more often performed when tumors invaded the vertebral bodies and arches.

Surgical interventions aimed at resection of the tumor and elimination of spinal cord compression resulted in an improvement in the functional status of patients **(Table 3)**. After surgery, a statistically significant clinical improvement was observed in comparison with the preoperative KPS level ($p < 0.001$). In the early postoperative period, the evaluation of the functional status increased from 70–80 to 90 %. The intensity of pain has also decreased according to VAS: from 5–6 to 2 points ($p < 0.001$). Out of 63 operated patients who had the 2nd class on the McCormic scale before the surgery, 42 (66.7 %) moved to the 1st functional class due to the regression of neurology ($p = 0.005$); 17 (27 %) remained in the 2nd class with improved neurologic indicators. There was a deterioration of focal symptoms in 4 (6.3 %) patients with the preserved 2nd class).

The procedure had no effect on the median values of the severity of myelopathy according to JOA-T, which were 8 |6; 10| and 8 |7; 9| points at the time of admission and discharge from the hospital in all 29 patients, respectively. Complete regression occurred in 3 (10.3 %) of the operated patients with symptoms of myelopathy. Nine (34.6 %) of the remaining 26 (89.7 %) patients had a partial regression of myelopathy symptoms; in 13 (50.0 %) patients, symptoms persisted at the preoperative level; in 4 (15.4 %)

Table 1

Distribution of patients according to the anatomical characteristics of tumors of the spinal nerves, n (%)

Clinical characteristics	Patients with hourglass tumor (n = 21)	Patients with other tumor types (n = 42)	p-value [95% CI]†	All observations (n = 63)
Relation to the spinal cord[1]				
Ventral	–	24 (56)	–	24 (56)
Dorsal		18 (44)		18 (44)
Lateralization				
Left-handed	12 (57)	25 (60)	>0.99 [-31; 26]	37 (59)
Right-handed	9 (43)	17 (40)		26 (41)
Relation to the dura mater				
Intraextradural	6 (29)	0 (0)	<0.001*	6 (9)
Intradural	0 (0)	35 (83)		35 (56)
Extradural	15 (71)	7 (17)		22 (35)
Spine level				
Upper thoracic (T1–T4)	11 (52)	5 (12)	0.004**	16 (25)
Middle thoracic (T5–T8)	4 (19)	9 (21)		13 (21)
Lower thoracic (T9–T12)	6 (29)	28 (67)		34 (54)
Tumor volume, cm^3	9.72 [2.18; 14.99]	2.05 [0.57; 6.17]	0.003** [1.40; 10.60]	3.08 [1.33; 9.90]
A (less than 2 cm^3)	3 (14)	21 (50)	0.023**	24 (38)
B (2–4 cm^3)	6 (29)	6 (14)		12 (19)
C (greater than 4 cm^3)	12 (57)	15 (36)		27 (43)
Chest invasion	9 (43)	2 (5)	<0.001* [28; 90]	11 (17)
Vertebral body invasion	6 (29)	2 (5)	0.018** [8; 87]	8 (13)

For normally distributed indicators, the mean and standard deviation are indicated; for abnormally distributed indicators, the median, the 1st and 3rd quartiles are indicated. † p-values of Student's t-test (Mann – Whitney U-test) / Fisher's exact test [difference 95 % CI for mean (median) / proportion], adjusted by Benjamini – Hochberg method; * p-value < 0.05; ** p-value < 0.1; [1] only for intracanal located tumors.

patients, worsening of symptoms was observed in the form of an increase in lower paraparesis and pelvic organ dysfunction of the central type.

Therefore, in our series, 42 (66.7 %) patients obtained good clinical outcomes after surgery, 17 (27.0 %) patients had satisfactory outcomes, and 4 (6.3 %) patients had unsatisfactory outcomes.

The removal of neoplasms from various anatomical locations did not result in significant blood loss; its volume did not differ significantly (p = 0.086). Meanwhile, the surgery duration for resection of hourglass tumors was the longest (compared to intracanal neoplasms) – 192.6 ± 60.6 min and 158.5 ± 51.4 min, respectively (p = 0.041).

The average postoperative length of hospital stay was 10.6 days, the minimum was 4.0 days, and the maximum was 23.0 days. There was no postoperative mortality. The number of postoperative complications did not rely on the anatomical

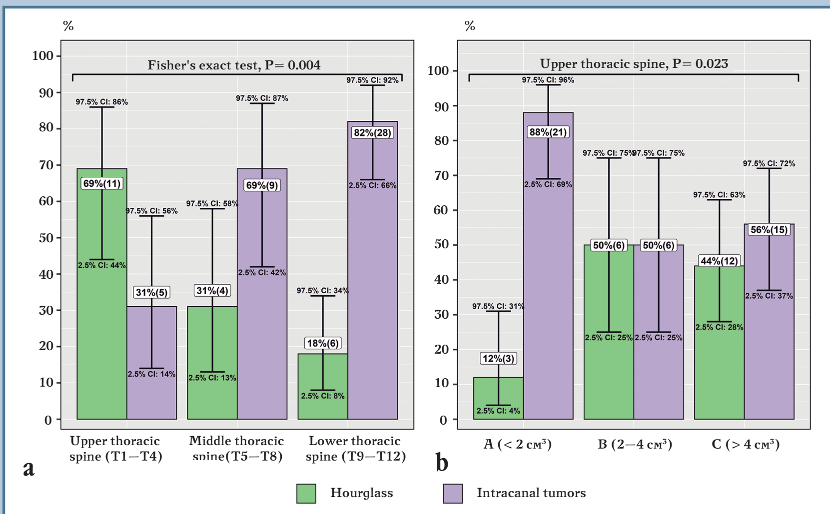

Fig. 2
Distribution of tumors by levels of the thoracic spine **(a)** and by volume **(b)**: the value of Fisher's exact test is indicated, the width of 95 % confidence intervals

Table 2

The main clinical indicators of patients before surgery

Clinical characteristics	Patients with hourglass tumor (n = 21)	Patients with other tumor types (n = 42)	p-value |95% CI|†	All observations (n = 63)
Age, years	50.0 ± 11.3	51.1 ± 14.7	0.793 |-7.8; 5.6|	50.7 ± 13.6
Female, n (%)	20 (95)	27 (64)	0.108 |14; 59|	47 (75)
Postoperative hospital stay	10.6 ± 3.6	12.2 ± 3.8	0.644 |-3.6; 0.4|	11.6 ± 3.8
Duration of symptoms, months	5.5 |4.25; 7.00|	6 |5.5; 8.5|	0.644 |-3; 1|	6|5; 8|
Symptoms for over a year, n (%)	6 (38)	22 (55)	0.644 |-34; 11|	28 (50)
Chest pain, n (%)	12 (57)	16 (38)	0.644 |-9; 44|	28 (44)
Pain in the lumbar spine, n (%)	5 (24)	26 (62)	0.108 |-59; -9|	31 (49)
Pain in the lower extremities, n (%)	3 (14)	10 (24)	0.714 |-44; 18|	13 (21)
Lower extremities numbness, n (%)	9 (43)	20 (48)	0.793 |-31; 22|	29 (46)
Weakness in the lower extremities, n (%)	8 (38)	21 (50)	0.644 |-37; 16|	29 (46)
Pelvic organ dysfunction, n (%)	3 (14)	9 (21)	0.793 |-43; 23|	12 (19)
Strengthening of leg reflexes, n (%)	4 (19)	11 (26)	0.793 |-39; 22|	15 (24)
Presence of clonuses, n (%)	3 (14)	3 (7)	0.644 |-33; 69|	6 (10)
Thoracic myelopathy, n (%)	9 (43)	20 (48)	0.793 |-31; 22|	29 (46)
JOA-T before surgery, points	7 |6; 9|	8.5 |6.75; 10.00|	0.644 |-3; 1|	8|6; 10|
Karnofsky Perfomance scale, %	80 |60; 90|	70 |60; 80|	0.644 |-10; 10|	80|60; 90|
McCormick scale, functional class	2 |1; 2|	2 |2.00; 2.75|	0.644 |-1; 0|	2 |1; 2.5|
VAS, points	5 |4; 6|	6 |4; 7|	0.644 |-1; 1|	5 |4; 7|

For normally distributed indicators, the mean and standard deviation are indicated; for abnormally distributed indicators, the median, the 1st and 3rd quartiles are indicated. † p-values of Student's t-test (Mann — Whitney U-test) / Fisher's exact test |difference 95 % CI for mean (median) / proportion|, adjusted by Benjamini — Hochberg method; JOA-T — modified scale for assessment of the severity of thoracic myelopathy by Japan Orthopedic Association (JOA).

localization of neoplasms (p = 0.208) and was equal to 4 (6.3 %). Two of the operated patients had a superficial infection at the surgical site, one had an epidural hematoma, and the other had a pneumothorax. The last 2 cases required reoperation.

Total resection of the tumor was performed in 56 (88.9 %) patients, and 7 (11.1 %) patients underwent subtotal resection. Meanwhile, tumors in the spinal canal were removed in 40 (95.2 %) of 42 operated patients. A similar volume of surgery was achieved with hourglass neurinomas in 16 (76.2 %) of 21 operated patients, which is 22 % |95% CI: 0; 44| significantly less (p = 0.013) than with intracanal types of tumors.

Together with the analysis of the obtained outcomes, we investigated a number of clinical factors affecting the volume of the resected tumor. The presence of hourglass neurinomas significantly reduces the likelihood of total resection (OR = 12.26 |95 % CI: 1.24–617.99|). The other potential predictors studied had no effect on the resection volume (Fig. 3).

Discussion

Based on the retrospective non-controlled non-randomized cross-sectional single-centered study, we summarized the clinical outcomes of the treatment of 63 patients with tumors of spinal nerve roots in the thoracic spine, obtained in the early postoperative period.

An asymptomatic course of the disease was marked by the clinical peculiarities of hourglass tumors at the thoracic spine in 9.5 % of cases, which is revealed only by neuroimaging studies. During the study of the anatomical and topographic picture of this type of tumor, the peculiarities of their localization along the length of the thoracic spine, not previously mentioned in literary sources, were established. Hourglass tumors are most often (69 % of cases) diagnosed in the upper thoracic spine, and intravertebral neoplasms (54 %) – in the lower thoracic spine.

The McCormick et al. (2000) scale was used in the early postoperative period to assess the functional status and quality of life of the operated patients. It provided an opportunity to estimate the surgical outcomes depending on the degree of severity of pre- and postoperative neurological symptoms.

The most frequent syndrome in the clinical picture of the disease was pain caused by radiculopathy of the root, from which the neoplasm grew. Pain in the thoracic and lumbar spine prevailed in patients. Sensory and motor disorders in the lower extremities and pelvic organ dysfunction were present, but to a lesser extent.

Resection remains the most effective treatment technique for spinal cord

Table 3

The main clinical indicators of operated patients in the early postoperative period

Indicators	Patients with hourglass tumor (n = 21)	Patients with other tumor types (n = 42)	p-value |95 % CI| †	All observations (n = 63)
Surgical interventions				
Surgery duration, min	192.6 ± 60.6	158.5 ± 51.4	0.200 |2.9; 65.5|	169.8 ± 56.5
Blood loss, ml	250 |200; 300|	200 |150; 300|	0.350 |0; 100|	200 |150; 300|
Facetectomy, n (%)	12 (57)	5 (12)	<0.001* |22; 80|	17 (27)
Rib resection, n (%)	7 (33)	0 (0)	<0.001* |9; 57|	7 (11)
Postoperative period				
Chest pain, n (%)	2 (10)	6 (14)	0.948 |-49; 30|	8 (13)
Pain in the lumbar spine, n (%)	6 (29)	19 (45)	0.712 |-42; 11|	25 (40)
Pain in the lower extremities, n (%)	1 (5)	1 (2)	>0.99 |-70; 100|	2 (3)
Lower extremities numbness, n (%)	6 (29)	17 (40)	0.83 |-38; 15|	23 (37)
Weakness in the lower extremities, n (%)	7 (33)	20 (48)	0.83 |-39; 13|	27 (43)
Pelvic organ dysfunction, n (%)	2 (10)	5 (12)	>0.99 |-46; 36|	7 (11)
Strengthening of leg reflexes, n (%)	4 (19)	10 (24)	0.948 |-38; 26|	14 (22)
Presence of clonuses, n (%)	2 (10)	2 (5)	0.892 |-46; 82|	4 (6)
Thoracic myelopathy, n (%)	9 (43)	18 (43)	0.948 |-31; 22|	27 (43)
JOA-T after surgery, points	8 |6; 9|	8 |7.00; 9.25|	>0.99 |-2; 2|	8 |7; 9|
Karnofsky Perfomance scale, %	90 |60; 100|	90 |60.00; 97.5|	0.867 |-10; 10|	90 |60; 100|
McCormick scale, functional class	1 |1; 2|	2 |1.00; 2.75|	0.712 |-1; 0|	2 |1; 2|
VAS, points	2 |1; 3|	2 |1; 4|	0.83 |-1; 0|	2 |1; 4|
Postoperative complications, n (%)	4 (19)	3 (7)	0.712 |-20; 73|	7 (11)

For normally distributed indicators, the mean and standard deviation are indicated; for abnormally distributed indicators, the median, the 1st and 3rd quartiles are indicated. † p-values of Student's t-test (Mann — Whitney U-test) / Fisher's exact test |difference 95 % CI for mean (median) / proportion| , adjusted by Benjamini — Hochberg method; JOA-T — modified scale for assessment of the severity of thoracic myelopathy by Japan Orthopedic Association (JOA).

neurinoma. The technique and tactics for treatment of this pathology were developed at the end of the twentieth century [15, 16]. Modern techniques of neuroendoscopy in diagnostics, surgical equipment, as well as mini-invasive surgical techniques contribute to the total resection of tumors [17, 18]. Nevertheless, the choosing the surgical technique and operative approach for neoplasms with complex anatomical relationships with the dura mater, spinal cord, spine, and thoracic organs still remains a disputable issue.

A large number of articles have been devoted to the use of minimally invasive approaches for the resection of spinal cord tumors. The use of a minimum volume of bone resection in approaches to extramedullary tumors (hemilaminectomy) has a number of advantages. They are the following: maximum preservation of orthopedic stability; a decrease in intraoperative blood loss; a decrease in muscle dissection; a decrease in the surgery duration; and, as a result, a decrease in postoperative pain syndrome and a faster physical rehabilitation [19–21].

Currently, thoracoscopic techniques have been successfully used for the resection of tumors in the thoracic spine. The possibility of using thoracoscopic approaches for the resection of spinal nerve tumors such as neurofibromas and hourglass schwannomas has been clinically verified. This technique is able to provide a full direct approach to the anterior surface of the thoracic spine. Its application improves the quality of life, reduces the patient's rehabilitation time, and provides a good cosmetic effect [22–25].

The most difficult to resect are intracanal tumors with an anterior localization. To resect them, some surgeons offer anterior approaches [26]; others – endoscopic approach or endoscopic assistance [27–29]; others – microsurgical resection from the posterior approaches with a section of the odontoid ligaments. This technique promotes mobilization of the spinal cord and less traumatic eradication of the tumor in 94.4 % [18, 30] of cases.

Nevertheless, the use of minimally invasive approaches for the resection of extramedullary tumors due to the limited resection of the bone structures of the spine and the limited field of vision of the surgeon can result in additional trauma to soft tissues, neural structures, and worsening of neurological symptoms [31]. Thus, surgical approaches should be, first of all, less traumatic for the spinal cord and not for the bone formations of the spine. The resection degree of the bone structures of the spine and ribs should be commensurate with the possibility of non-traumatic eradication of neurinomas.

We used the microsurgical tumor resection technique with two types of surgical approaches: posterior median and paravertebral. The choice of techniques for microsurgery and types of approaches is driven by anatomical features of the localization of tumors, most of which (n = 42; 66.7 %) were found only in the spinal canal; and 21 (33.3 %) neoplasms had an hourglass growth. The latter were mostly large (51 %) and belonged to types III and IV according to the Eden classification. In 56 (89 %) cases, a posterior median surgical approach was used to reach the tumor. This approach is recommended to be performed by laminectomy at two levels. Most intradural tumors are treated with hemilaminectomy or laminoplasty to preserve the spine's bone formations. For this purpose, hemilaminectomy was performed in 64 % of cases of intracanal tumors. In 15 % of cases, interlaminectomy was done. In cases of anterior localization of the tumor, laminectomy with dissection of the odontoid ligaments at the tumor level was performed in 5 (8.9 %) cases. Posterior median approaches with hemilaminectomy were used to resect 21 hourglass tumors in 14 (66.7 %) patients. Seven (33.3 %) patients underwent procedures via paravertebral approaches with partial facetotomy or facetectomy, resection of a part of the head and the upper or lower edge of the rib at the same level. In tumors of type III (n = 3; 43 %) and type IV (n = 4; 57 %) according to Eden, having a volume of more than 4 cm^3, partial facetectomy, facetotomy, and resection of the head and edges of the rib were performed more often — in 45 and 33 % of cases, respectively ($p < 0.001$). We agree with the conclusions of Chung [32] that hemilaminectomy in combination with partial facetectomy has a great advantage in resection of this anatomical variant of neurinoma. This is due to the fact that most tumors are localized on one side of the spinal canal and paravertebral space. Thus, they could easily be dissected through this approach using hemilaminectomy and facetectomy. In cases of tumor invasion into the vertebral bodies and arches, facetectomy and facetotomy, and resection of a part of the rib head were performed more often.

It is known that the gross total resection of tumors of difficult localization, such as hourglass tumors, often presents great technical difficulties. Sometimes procedures end with subtotal resection, and it is required to perform several procedures for their total resection.

Based on the analysis of a number of clinical factors affecting the volume of resected tumors, an essential relationship between the presence of an hourglass tumor and the degree of its total resection was found. It was testified that this type of tumor in the thoracic spine significantly decreased the probability of its total resection.

The obtained data can be regarded as a cumulative risk factor affecting the volume of tumor resection and treatment outcomes with a less traumatic posterior surgical approach. The other reviewed clinical indicators did not have a statistically significant effect on the volume of neurinomas resected, which promotes the use of this factor as a predictor.

Therefore, the obtained clinical data of surgical treatment of tumors growing from the roots of the spinal cord at the thoracic level and their statistical processing with the inclusion of logistic regression demonstrated that the application of modern diagnostic techniques (MRI and 3D Image Reconstruction for CT scans), microsurgical techniques, and less traumatic posterior surgical approaches promotes the achievement of good clinical outcomes in the early postoperative period.

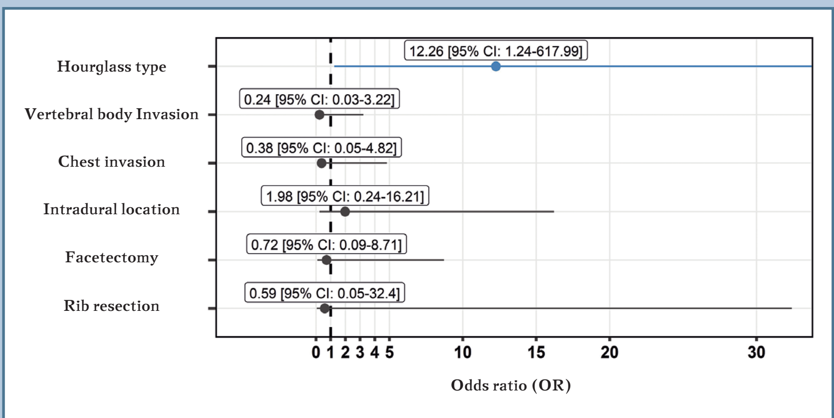

Fig. 3
Evaluation of the influence of predictors on the volume of tumor resection: odds ratio (OR) values are indicated, the width of 95 % confidence intervals

Conclusions

1. The use of posterior approaches for the resection of neurogenic tumors of the thoracic spine gives the opportunity to perform gross total resection of schwannomas in 88.9 % of cases without thoracotomy.
2. In the studied cohort of patients, hourglass tumors required facetectomy and rib resection significantly more often in case of application of posterior approaches. This should be considered when planning a surgical intervention. These tumors also have large median sizes in the study population and are more often detected in the upper thoracic spine in comparison with intracanal tumors.
3. Hourglass tumors can be regarded as a cumulative risk factor affecting the volume of tumor resection and treatment outcomes.

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