

Primary, Metastatic, and Locally Aggressive Tumors of the Vertebral Column in Adults: An 11-Year Single-Center Analysis

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Abstract

Introduction: Tumors of the vertebral column are a heterogeneous group of primary and metastatic lesions requiring specialized surgical care. Epidemiological and histopathological data from Central Asia remain limited.

Objective: To evaluate the demographic, histopathological, anatomical, and early neurological characteristics of adult patients surgically treated for tumors of the vertebral column in Kazakhstan.

Methods: This retrospective single-center observational study included adult patients aged ≥ 18 years who underwent surgery for vertebral column tumors at a tertiary neurosurgical center in Astana, Kazakhstan, between January 2015 and December 2025. Demographic data, tumor origin, histopathology, anatomical localization, and early postoperative neurological outcomes were analyzed.

Results: The final cohort included 148 patients. Mean age was 57.2 years, median age was 59 years, and the range was 22–81 years. There were 75 males (50.7%) and 73 females (49.3%). Primary tumors were identified in 51 patients (34.5%), while metastatic tumors were present in 97 patients (65.5%). Primary tumors were mainly represented by plasmacytoma/plasma-cell neoplasms and giant cell tumors. Among metastatic lesions, undifferentiated carcinoma was the most frequent subgroup, followed by renal cell, breast, and lung carcinoma. Pain regression occurred in 125 of 144 patients (86.8%). Among 92 patients with preoperative motor deficit, motor function improved or remained stable in 90 patients (97.8%).

Conclusion: Surgically treated vertebral column tumors represent a relevant spinal oncology burden in Kazakhstan, with metastatic lesions predominating. These findings provide baseline surgical clinicopathological data and support the need for a national spinal oncology registry.

Keywords: vertebral column tumors; spinal metastases; primary spinal tumors; histopathology; neurological outcomes.

Introduction

Tumors of the vertebral column represent a heterogeneous group of primary, metastatic, malignant, and locally aggressive lesions that differ substantially in

biological behavior, histopathological profile, anatomical extent, and surgical complexity [1,2]. Unlike intradural spinal cord tumors, vertebral column tumors primarily involve the osseous structures of the spine and may result in mechanical pain, vertebral body destruction,

pathological fracture, spinal instability, epidural compression, and progressive neurological deficit [3,4]. Primary vertebral tumors are relatively rare, whereas metastatic lesions represent the dominant form of malignant involvement of the spinal column in adults. Recent epidemiological and consensus-based publications emphasize that primary vertebral tumors require histology-based classification, whereas metastatic disease should be evaluated according to neurological status, oncological prognosis, mechanical instability, and systemic tumor burden [4–7].

The clinical burden of spinal metastases is substantial. A systematic review reported a clinical incidence of spinal metastases of 15.67% among patients with solid tumors, while metastatic epidural spinal cord compression and pathological vertebral compression fractures occurred in 9.6% and 12.6% of patients with spinal metastases, respectively [4]. Mechanical instability is a separate and clinically important dimension of metastatic spinal disease, and the Spine Instability Neoplastic Score was developed to standardize assessment of neoplastic spinal instability.

Surgical treatment of malignant and locally aggressive tumors of the vertebral column has several aims. In primary tumors, surgery may be directed toward local tumor control, decompression of neural structures, and reconstruction of spinal stability [8]. In metastatic disease, the surgical goal is often palliative but clinically important: pain relief, preservation or restoration of neurological function, decompression of the spinal cord or cauda equina, stabilization of the spinal column, and acquisition of tissue for histopathological verification [9]. Contemporary reviews on metastatic spinal disease emphasize that treatment should be individualized and performed within a multidisciplinary framework, integrating spine surgery, oncology, radiotherapy, radiology, and pathology [10,11].

Histopathological stratification is particularly important in spinal oncology because treatment strategy and prognosis differ markedly between primary malignant tumors, plasma-cell neoplasms, locally aggressive bone tumors, and metastases from systemic cancer [12]. In adults, plasma-cell neoplasms, chordoma, chondrosarcoma, osteosarcoma, lymphoma, and giant cell tumor are among the clinically relevant primary vertebral column lesions reported in epidemiological and institutional series [13,14]. Metastatic lesions commonly arise from renal, breast, lung, prostate, thyroid, gastrointestinal, and other visceral malignancies, although their distribution varies across populations, referral systems, and surgical cohorts [4,11,15]. International surgical series have also shown that patterns of surgically treated metastatic spine tumors vary across regions and time periods, supporting the value of country-specific and institution-specific epidemiological studies [15].

A clinically important subgroup consists of patients in whom spinal metastasis is diagnosed before the primary tumor is clearly established. In such cases, the vertebral lesion may be the first clinically significant manifestation of systemic malignancy. This is especially relevant for metastases reported as undifferentiated carcinoma or carcinoma of unknown primary origin, where histopathological and immunohistochemical evaluation of surgical tissue may guide subsequent oncological staging and systemic treatment. Immunohistochemistry remains essential for classifying undifferentiated metastatic carcinomas and for identifying the probable tissue of origin [16]. Spinal metastases from an unknown primary site have been reported as a distinct clinical scenario in which patients may initially present with pain or acute neurological symptoms before the systemic malignancy is fully characterized [17,18].

Despite the growing literature on spinal oncology, data from Kazakhstan and Central Asia remain limited. Most available

epidemiological studies are derived from large international registries or high-volume centers outside the region. Therefore, local institutional analyses are important for understanding the real surgical burden, demographic structure, tumor origin, histopathological distribution, and early postoperative outcomes in patients treated for vertebral column tumors. Surgical epidemiology studies of metastatic spine tumors have shown that treatment trends and case profiles may differ across continents and healthcare systems, which further supports the need for regional data [15].

The present study was designed as an 11-year retrospective single-center analysis of adult patients undergoing surgical treatment for tumors of the vertebral column at a tertiary neurosurgical center in Astana, Kazakhstan. Based on the available institutional dataset, the study evaluates demographic characteristics, primary versus metastatic tumor distribution, histopathological patterns, sources of metastatic disease, hospital outcomes, and early postoperative neurological changes. Special attention is given to the frequency of metastases from undifferentiated carcinoma, as this subgroup may reflect cases in which spinal involvement represents the first manifestation of an underlying systemic malignancy.

Methods

This was a retrospective single-center observational cohort study conducted at a tertiary neurosurgical center in Astana, Kazakhstan. The study was conducted in accordance with the Declaration of Helsinki and was approved by the institutional bioethics committee. The requirement for individual informed consent was waived due to the retrospective design and the use of anonymized clinical data.

The study covered an 11-year period from January 2015 to December 2025. The source material consisted of institutional surgical records, annual hospitalization lists, and archival administrative-clinical data of patients who underwent surgery for tumors involving the vertebral column. Adult patients aged ≥ 18 years were eligible for inclusion if they underwent surgical treatment for primary, metastatic, malignant, or locally aggressive tumors of the vertebral column. Tumors involving the cervical, thoracic, lumbar, lumbosacral, or sacral regions were considered eligible if the lesion primarily affected the osseous structures of the spine and required neurosurgical intervention.

Patients younger than 18 years were excluded. One pediatric patient identified in the dataset was removed from the final adult cohort. Patients with isolated intramedullary or intradural extramedullary tumors without vertebral column involvement were not included in the present analysis. Non-tumorous spinal lesions, infectious diseases, traumatic lesions, and patients managed without surgery were also excluded.

The following variables were extracted from the available records: year of surgery, sex, age at admission, tumor origin, histopathological diagnosis, metastatic primary source when available, spinal region, length of hospital stay, discharge status, and early postoperative neurological outcome.

Data were analyzed descriptively. Categorical variables are presented as absolute numbers and percentages. Continuous variables are presented as mean $\pm$ standard deviation (SD), median with interquartile range (IQR), and minimum–maximum range. The primary unit of analysis was hospitalization. A secondary count of unique patients was performed by identifying repeated admissions. No inferential hypothesis testing was performed because the study was designed as a descriptive epidemiological analysis. Early neurological outcomes were assessed from postoperative and discharge records. Motor

function was classified as improved, unchanged, or worsened based on documented changes in limb strength and neurological examination. ASIA and Frankel grades were not consistently available and were not assigned retrospectively.

Results

Overall cohort characteristics

The study cohort consisted of 148 unique adult patients treated surgically for tumors of the vertebral column during the 2015–2025 period. The population was balanced by sex, without a clear male or female predominance. Patients were predominantly middle-aged and older adults, with a mean age of 57.2 years and a median age of 59 years. Metastatic lesions formed the largest subgroup, accounting for nearly two-thirds of the cohort, whereas primary tumors represented approximately one-third of cases.

Table 1 Overall cohort characteristics

Variable	Value
Unique patients	148
Male sex	75 (50.7%)
Female sex	73 (49.3%)
Mean age $\pm$ SD	57.2 $\pm$ 12.7 years
Median age (IQR)	59 (51–66) years
Age range	22–81 years
Mean length of stay $\pm$ SD	15.4 $\pm$ 7.4 days
Median length of stay (IQR)	14 (11–18) days
Length of stay range	6–56 days
In-hospital mortality	1 (0.7%)
Primary tumors	51 (34.5%)
Metastatic tumors	97 (65.5%)

Most patients were middle-aged or elderly. The largest age group was 60–69 years, followed by 50–59 years. Patients younger than 40 years accounted for a minority of the cohort.

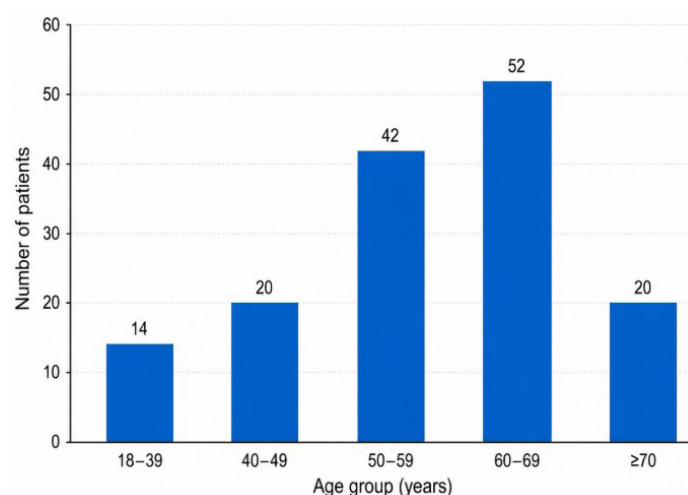


Figure 1 – Age group distribution of surgically treated patients

Annual distribution

Annual surgical volume varied over the 11-year study period, ranging from 6 to 21 cases per year. The highest number of surgically treated patients was recorded in 2023, whereas the lowest annual volume was observed in 2019. Metastatic tumors

predominated in most years, although several periods showed a relatively higher contribution of primary vertebral column tumors, particularly in 2017 and 2021. Overall, the annual distribution demonstrates a persistent spinal oncology workload with year-to-year variability in patient volume and tumor origin.

Table 2 Annual distribution and selected indicators

Year	Cases, n	% of cohort	Male/Female, n	Mean age $\pm$ SD, years	Primary tumors, n	Metastatic tumors, n
2015	9	6.1	7/2	57.3 $\pm$ 10.6	1	8
2016	12	8.1	3/9	53.9 $\pm$ 14.0	7	5
2017	17	11.5	11/6	55.9 $\pm$ 20.0	8	9
2018	20	13.5	13/7	59.0 $\pm$ 7.7	6	14
2019	6	4.1	1/5	60.0 $\pm$ 17.7	2	4
2020	10	6.8	4/6	53.0 $\pm$ 6.3	2	8
2021	14	9.5	7/7	50.9 $\pm$ 16.9	8	6
2022	9	6.1	3/6	58.8 $\pm$ 10.5	3	6
2023	21	14.2	10/11	60.9 $\pm$ 9.9	5	16
2024	16	10.8	8/8	60.9 $\pm$ 9.2	7	9
2025	14	9.5	8/6	56.6 $\pm$ 11.7	2	12
Total	148	100.0	75/73	57.2 $\pm$ 12.7	51	97

Tumor origin

Primary tumors were dominated by plasmacytoma / plasma-cell neoplasms, which accounted for more than half of all primary lesions. Giant cell tumor was the second most frequent diagnosis. The remaining primary tumor types were relatively uncommon and were represented by small numbers of cases, reflecting the histopathological heterogeneity of primary vertebral column tumors.

Table 3 Histopathological profile of primary tumors

Histopathological diagnosis	N	%
Plasmacytoma / plasma-cell neoplasm	27	52.9
Giant cell tumor	8	15.7
B-cell lymphoma	3	5.9
Osteoblastoma	3	5.9
Osteosarcoma	2	3.9
Chondrosarcoma	2	3.9
Eosinophilic granuloma / Ich	2	3.9
Undifferentiated sarcoma	2	3.9
Chordoma	1	2.0
Unspecified histology	1	2.0
Total	51	100

Among metastatic tumors, undifferentiated carcinoma became the most frequent subgroup, followed closely by renal cell carcinoma and breast carcinoma. This is important clinically: metastases of undifferentiated carcinoma should not be treated as “unspecified origin” at the tumor-origin level. They are metastatic tumors, but the exact primary site may remain unclear or require further oncological and immunohistochemical verification. This subgroup may therefore reflect patients in whom vertebral column involvement was the first clinically significant manifestation of systemic malignancy. After surgery, patients were referred to regional oncology centers for further diagnostic evaluation and treatment. Subsequent immunohistochemical findings and definitive primary-site

diagnoses were not consistently available in our institutional records. Therefore, the frequency of undifferentiated carcinoma should be interpreted with caution.

Table 4 Metastatic tumor profile

Primary source / histology of metastasis	N	%
Undifferentiated carcinoma	22	22.7
Renal cell carcinoma	21	21.6
Breast carcinoma	18	18.6
Lung carcinoma	10	10.3
Hepatocellular / liver carcinoma	5	5.2
Prostate carcinoma	4	4.1
Thyroid carcinoma	3	3.1
Gastric carcinoma	2	2.1
Adenocarcinoma, unspecified origin	2	2.1
Other rare or unclear sources	10	10.3
Total	97	100

The anatomical distribution was analyzed using mutually exclusive regional categories to avoid double counting of patients with multilevel or multiregional involvement. Thoracic-only lesions were the most frequent pattern, accounting for more than half of the cohort. Lumbar-only tumors represented the second largest group. Combined regional involvement was less common and was mainly observed as cervicothoracic or thoracolumbar disease. Isolated cervical and sacral lesions were rare, each accounting for only a small proportion of surgically treated patients.

Surgical strategy

All 148 patients underwent en bloc tumor resection by Tomita technique, with decompression of the neural elements and stabilization of the resulting vertebral defect. Reconstruction was performed using a titanium mesh cage or an expandable V-LIFT cage in 143 patients (96.6%); five patients (3.4%) received a patient-specific 3D-printed vertebral implant.

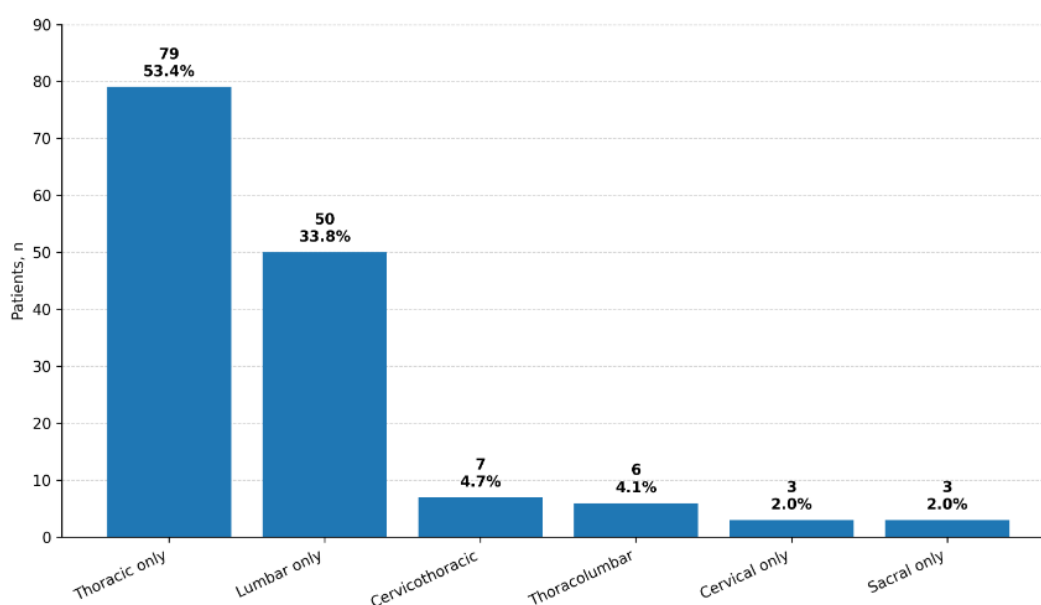


Figure 2 – Anatomical distribution of surgically treated patients by mutually exclusive regional categories

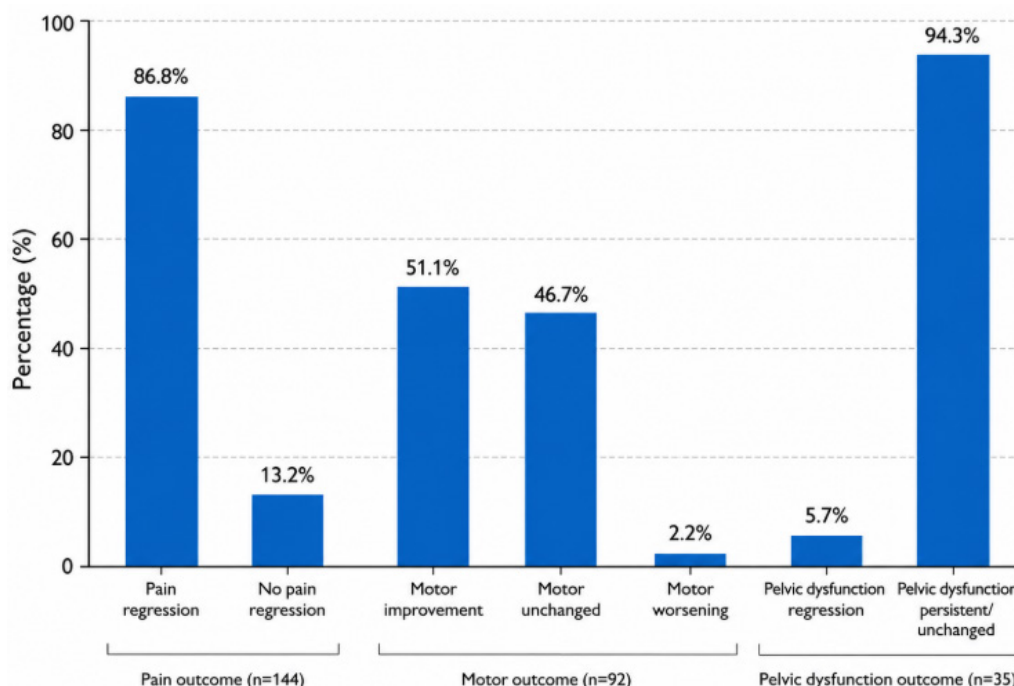


Figure 3 – Early postoperative neurological outcomes after surgical treatment of vertebral column tumors

Early postoperative neurological outcomes

Preoperative pain was documented in 144 patients, and early postoperative pain regression was recorded in 125 cases (86.8%). A preoperative motor deficit was identified in 92 patients. Early postoperative motor improvement was observed in 47 patients (51.1%), while motor status remained unchanged in 43 patients (46.7%). Postoperative motor worsening was documented in 2 patients (2.2%). Overall, motor function either improved or remained stable in 90 of 92 patients (97.8%) with preoperative motor deficit. Pelvic organ dysfunction was documented preoperatively in 35 patients. Clear early regression of pelvic dysfunction was observed in 2 cases (5.7%), whereas pelvic dysfunction persisted or showed no documented early improvement in 33 cases (94.3%).

Discussion

This retrospective single-center study summarizes an 11-year institutional experience with adult patients undergoing surgical treatment for tumors of the vertebral column in Kazakhstan. After exclusion of one pediatric case and one repeated record, the final cohort included 148 unique adult patients. The updated analysis provides data on annual surgical distribution, demographic characteristics, tumor origin, histopathological profile, anatomical localization, and early postoperative neurological outcomes.

The cohort predominantly consisted of middle-aged and older adults, with a mean age of 57.2 years and a median age of 59 years. Patients aged 50–69 years formed the largest proportion of cases, which is consistent with the expected age profile of metastatic vertebral disease and plasma-cell neoplasms [4,12]. At the same time, the broad age range of 22–81 years demonstrates that surgically relevant vertebral column tumors remain clinically important across the adult population.

Sex distribution was almost equal, with 75 male and 73 female patients. This likely reflects the heterogeneous structure of the cohort, which included both primary and metastatic tumors with different biological and epidemiological patterns. Therefore, the absence of clear sex predominance should be interpreted as a feature of the mixed surgical population rather than of a specific tumor subtype [12].

A key finding was the predominance of metastatic tumors, which accounted for 97 of 148 cases. Primary tumors were identified in 51 patients. Among primary tumors, plasmacytoma / plasma-cell neoplasms represented the largest subgroup, followed by giant cell tumor. Other primary lesions were relatively uncommon, confirming the marked histopathological heterogeneity of primary vertebral column tumors [1,12,19].

Among metastatic tumors, undifferentiated carcinoma was the most frequent subgroup, followed by renal cell carcinoma, breast carcinoma, and lung carcinoma. This finding is clinically important because metastases of undifferentiated carcinoma may represent cases in which vertebral column involvement was the first clinically significant manifestation of systemic malignancy. In such patients, surgery has not only a decompressive and stabilizing role but also an important diagnostic function by providing tissue for histopathological and immunohistochemical verification [16,20]. In our country, patients receive treatment in stages at specialized centers. Surgery is performed at a neurosurgical center, after which patients are referred to regional oncology centers for further diagnosis, radiotherapy, systemic treatment, and follow-up. Therefore, subsequent immunohistochemical results and final identification of the primary tumor were not always available in our records. This

may partly explain the high proportion of undifferentiated carcinoma in our cohort.

Anatomically, thoracic-only lesions were the most common pattern, followed by lumbar-only tumors. Combined cervicothoracic and thoracolumbar involvement was less frequent, while isolated cervical and sacral lesions were rare. This distribution is clinically relevant because thoracic lesions are more often associated with spinal cord compression, whereas lumbar and sacral lesions may present with radicular pain, cauda equina symptoms, or pelvic organ dysfunction [4,9].

Early postoperative outcomes showed frequent pain regression, documented in 125 of 144 patients with preoperative pain. Among 92 patients with preoperative motor deficit, motor function improved in 47 patients and remained unchanged in 43 patients, while deterioration was observed in only 2 cases. Thus, motor function improved or remained stable in 97.8% of patients with preoperative motor deficit. This suggests that surgery was effective mainly in achieving early pain relief and neurological stabilization.

In contrast, recovery of pelvic organ dysfunction was uncommon during the early postoperative period. Only 2 of 35 patients demonstrated clear early regression. This may be explained by severe or prolonged neural compression, involvement of the conus, cauda equina, or sacral roots, and the limited potential for rapid recovery of autonomic dysfunction.

The main value of this study is that it reflects the real-world surgical workload of a national tertiary neurosurgical center over more than a decade. These data may serve as a baseline for future spinal oncology studies in Kazakhstan and support the need for a structured national registry including histology, tumor origin, anatomical localization, neurological status, surgical strategy, complications, recurrence, adjuvant treatment, and long-term outcomes. Future prospective studies should use standardized ASIA or Frankel grading and include surgical and oncological treatment data.

All patients underwent en bloc resection with neural decompression and vertebral reconstruction. Titanium mesh or expandable V-LIFT cages were used in 143 patients, while five patients received patient-specific 3D-printed implants.

In selected patients requiring vertebral body resection and anterior column reconstruction, patient-specific three-dimensional planning and customized vertebral implants may represent a promising direction for complex spinal oncology surgery. Recent studies have shown that 3D-printed artificial vertebral bodies and personalized vertebral implants can provide feasible reconstruction after total en bloc spondylectomy, with encouraging clinical, radiological, and biomechanical outcomes [21,22]. At the same time, complication and revision patterns after 3D-printed vertebral body replacement remain important concerns, and long-term implant-related outcomes require further systematic evaluation [23]. Therefore, the present study was not designed to assess reconstruction techniques, implant integration, mechanical complications, or revision surgery.

Limitations

The present study has several limitations. First, it was a retrospective single-center analysis based on available institutional surgical records; therefore, the findings may not fully represent the national epidemiology of vertebral column tumors in Kazakhstan. Second, not all operative and perioperative variables were available for analysis, including operative time, blood loss, extent of resection, reconstruction technique, neuromonitoring, stabilization strategy, and postoperative

complications. Third, early neurological outcomes were assessed using available clinical descriptions rather than standardized prospective scales. When only pain regression was documented postoperatively, motor and pelvic functions were conservatively considered unchanged. Fourth, long-term outcomes were not assessed. Therefore, recurrence, survival, delayed neurological recovery, implant-related complications, and long-term functional status could not be evaluated. Data on radiotherapy and systemic anticancer treatment were also unavailable because patients continued their oncological treatment at regional oncology centers after surgery. Finally, cases of metastases from undifferentiated carcinoma require cautious interpretation, as the exact primary tumor site may not have been fully verified in the neurosurgical records. Thus, this study should be interpreted as an epidemiological and clinicopathological baseline analysis rather than a comprehensive evaluation of long-term surgical effectiveness.

Conclusion

This 11-year single-center study included 148 adult patients who underwent surgery for vertebral column tumors at a tertiary neurosurgical center in Astana, Kazakhstan. Metastatic tumors accounted for nearly two-thirds of the cohort. Plasmacytoma/plasma-cell neoplasms and giant cell tumors were the most common diagnoses among primary tumors, while undifferentiated carcinoma, renal cell carcinoma, breast carcinoma, and lung carcinoma were the most frequent metastatic subgroups. Documented early postoperative outcomes included frequent pain relief and motor stabilization or improvement, whereas recovery of pelvic organ dysfunction was uncommon. These findings describe the clinicopathological and surgical case mix of our institution and provide baseline data for future spinal oncology research. Prospective registries should include standardized ASIA or Frankel assessments, detailed surgical and reconstruction data, subsequent oncological treatment, and long-term neurological, oncological, and implant-related outcomes.

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Informed Consent Statement: Patient consent was waived due to the retrospective nature of the study and anonymization of all collected data.

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