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MECHANISM-SPECIFIC TIMING OF UNPLANNED REOPERATIONS WITHIN 30 DAYS AFTER SPINAL METASTASIS SURGERY

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ABSTRACT

Objective: This study evaluated the 30-day incidence, mechanisms, and timing of unplanned reoperation after surgery for spinal metastases.

Materials and Methods: This retrospective cohort study included adults who underwent surgery for spinal metastases between June 2020 and September 2025. Patients who died within 30 postoperative days were excluded because complete ascertainment of observed 30-day reoperations was not possible. Intradural metastases were also excluded. Thirty-day returns to the operating room were adjudicated as planned staged procedures or unplanned reoperations. Unplanned reoperations were further classified as technical, tumor-related, mechanical, or wound-related after a review of clinical notes and imaging. Continuous variables were compared using the Wilcoxon rank-sum test, and categorical variables were compared using Fisher's exact test.

Results: A total of 127 patients met the eligibility criteria. Six procedures that occurred within 30 days were adjudicated as planned, staged operations, leaving 121 patients in the analytic cohort. Eighteen patients (14.9%) underwent an unplanned reoperation within 30 days. The median time to unplanned reoperation was 14.5 days (Q1-Q3, 2.5-26.5). Technical events occurred earliest [n=4; median postoperative day (POD) 2], followed by tumor-related events (n=4; median POD 6), mechanical events (n=5; median POD 22), and wound-related events (n=5; median POD 25). Timing differed across mechanisms (p=0.023). Metastatic spinal tumor frailty index >1 was more frequent in the reoperation group (83.3% vs. 42.7%, p=0.0018).

Conclusion: Unplanned early reoperation after spinal metastasis surgery showed distinct mechanism-specific timing patterns. Technical failures clustered earliest, whereas mechanical and wound-related failures occurred later. A mechanism-based description may provide a more precise framework for reporting very early postoperative returns to the operating room.

Keywords: Spinal metastasis, reoperation, complications, timing, surgical outcomes

INTRODUCTION

Surgery for spinal metastases aims to preserve or restore neurological function, relieve pain, and maintain spinal stability in a medically fragile population[1-3]. In this setting, an unplanned return to the operating room (OR) is one of the most consequential postoperative events because it can prolong hospitalization, delay rehabilitation, and postpone systemic therapy or postoperative radiotherapy[4,5].

Most published series in metastatic spine surgery report reoperation as a pooled outcome[4,6,7]. Although useful for overall benchmarking, that approach does not distinguish between clinically different early return to OR scenarios. Revision for an implant malposition, repeat decompression for persistant or recurrent tumor-related compression, surgery for instability progression, and operative treatment of wound complications do not reflect the same mechanism or timing patterns.

A further challenge is that not all secondary operations within the early postoperative period represent postoperative failure in the same way. In metastatic spine surgery, some procedures are intentionally staged as part of a planned treatment strategy and should not be interpreted as unplanned postoperative events. Separating planned staged procedures from true unplanned reoperations may therefore improve interpretability when evaluating very early operative returns.

The present study was designed as a descriptive analysis of unplanned reoperation within 30 days after the index surgery for spinal metastases. The aims were to determine the 30-day incidence of these events, describe their timing according to the dominant clinical mechanism, and compare baseline characteristics between patients with and without unplanned early reoperation. We hypothesized that unplanned reoperations within the first postoperative month would show mechanism-specific temporal clustering rather than a uniform distribution across the 30-day period.

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MATERIALS AND METHODS

Study Design and Patient Selection

This retrospective cohort study was conducted at a single tertiary referral center after University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital Institutional Ethics Committee approval (approval no: KAEK/15.10.2025.370, date: 21.10.2025). The requirement for informed consent was waived due to anonymized use of data and the retrospective nature of the study. Adult patients who underwent surgery for spinal metastases between June 2020 and September 2025 were screened. Patients with intradural metastases were excluded.

The study endpoint was observed unplanned reoperation within 30 days of the index procedure. Because this endpoint required a patient to remain alive and under postoperative observation long enough for complete ascertainment of an early return to the OR, patients who died before completing the 30-day postoperative window were excluded from the primary incidence analysis. This design was chosen to study very early observed operative returns rather than all postoperative adverse events in a competing risk framework. These exclusions are shown in the patient flow diagram (Figure 1), and the potential for survivorship bias is addressed in the discussion.

Endpoint Definition and Reoperation Adjudication

The primary outcome was unplanned reoperation within 30 days of the index procedure. All returns to the OR within this period were reviewed independently by 2 neurosurgeons using operative reports, inpatient progress notes, discharge summaries and all available spinal imaging. Each case was first adjudicated as either a planned staged procedure or an unplanned reoperation. Planned staged procedures were defined as secondary operations intentionally anticipated as part of the treatment strategy and were recorded separately rather than counted as outcome events.

For unplanned reoperations, each event was then assigned to the dominant subtype for descriptive analysis: technical, tumor-related, mechanical, or wound-related. Technical events included revision for implant or screw malposition. Tumor-related events included repeat surgery for persistent or recurrent neural compression primarily attributable to epidural or osseous tumor burden. Mechanical events included progressive deformity, early instability progression, or delayed implant/cage migration not primarily attributable to tumor

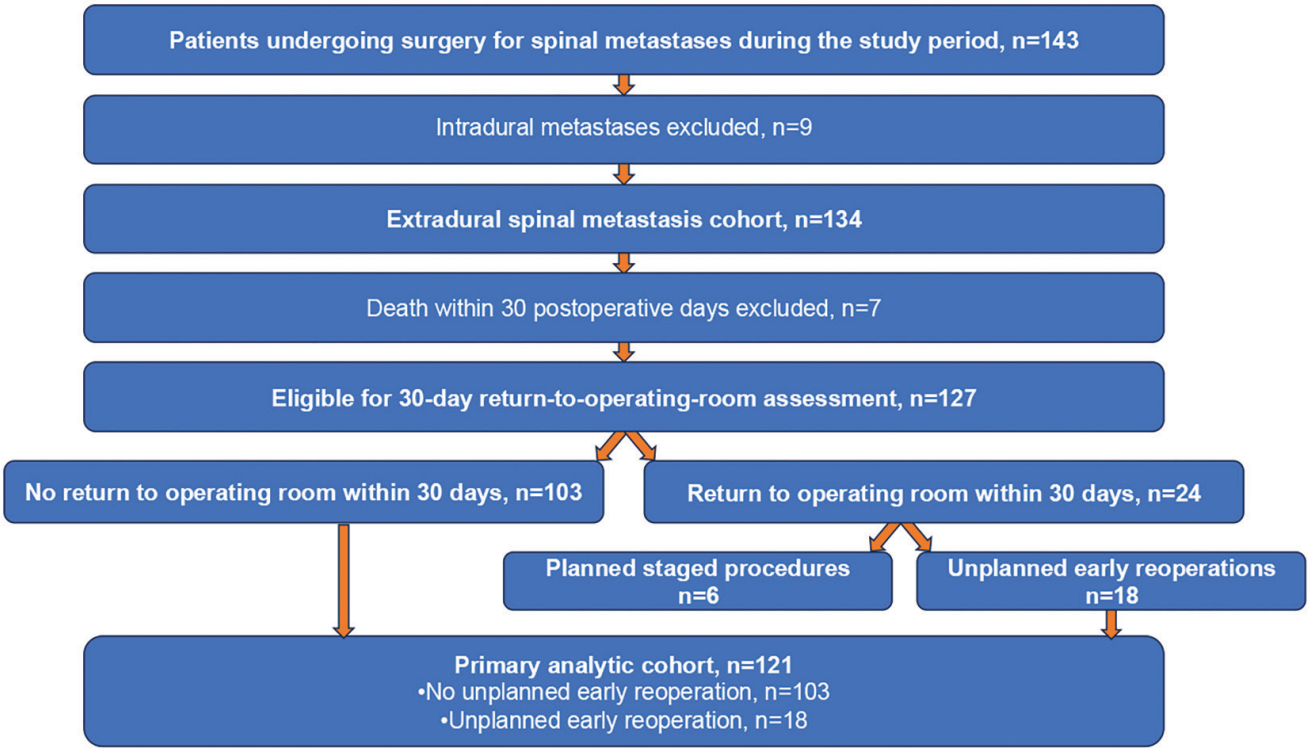

Figure 1. Patient flow diagram. Flow diagram of cohort assembly and endpoint adjudication. Of 143 patients who underwent surgery for spinal metastases during the study period, 9 with intradural metastases and 7 who died within 30 postoperative days were excluded, leaving 127 eligible for 30-day return to operating room assessment. Among these, 24 patients returned to the operating room within 30 days: 6 planned staged procedures and 18 unplanned early reoperations. The primary analytic cohort therefore comprised 121 patients, including 103 patients without unplanned early reoperation and 18 with unplanned early reoperation

progression. Wound-related events included infection, wound breakdown, epidural abscess, cerebrospinal fluid fistula, or other wound problems requiring operative treatment. Discrepancies between adjudicators were resolved by consensus.

Recorded Variables

Recorded variables included age, sex, body mass index, operative duration, perioperative transfusion, Bilsky grade-epidural spinal cord compression, Eastern Cooperative Oncology Group (ECOG) status, metastatic spinal tumor frailty index (MSTFI), spinal instability neoplastic score (SINS) category, extent of involved segments, index surgery type, tumor level grouped as cervical, thoracic, lumbar or sacral and tumor growth categories as slow, moderate-, rapid-growth according to Tomita et al.[8]. Bilsky grade was classified according to the epidural spinal cord compression scale described by Bilsky et al.[9]. SINS was categorized as stable (0-6), potentially unstable (7-12), or unstable (13-18) according to the original description by Fisher et al.[3]. MSTFI was defined according to De la Garza Ramos et al.[10] as a metastatic spine-specific frailty index incorporating anemia, chronic lung disease, coagulopathy, electrolyte abnormality, pulmonary circulation disorder, renal failure, malnutrition, non-elective admission, and surgical approach; for this study, scores >1 were analyzed as elevated frailty burden. Tumor growth category was assigned from the primary pathology using a Tomita-style classification as slow-, moderate-, or rapid-growth[8]. Primary tumors explicitly categorized in the original Tomita framework were classified accordingly; histologies not specifically listed were pragmatically mapped to the nearest biologically comparable growth group for descriptive analysis. Index surgeries were grouped into 4 categories: decompression-only, short-segment posterior stabilization with tumor separation, long-segment posterior stabilization with tumor separation and corpectomy-involving procedures.

Statistical Analysis

Continuous variables are presented as median (Q1-Q3) and categorical variables as number (percentage). Continuous variables were compared with the Wilcoxon rank-sum test and categorical variables with Fisher's exact test. Differences in time to reoperation across mechanism-specific subtypes were assessed with the Kruskal-Wallis test, followed by Bonferroni-adjusted pairwise Wilcoxon testing. Analyses were performed in R version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria) using the base stats package. Because only 18 primary events were observed, multivariable modeling was not pursued.

RESULTS

A total of 127 patients met final eligibility criteria. Six procedures within 30 days were adjudicated as planned staged operations and excluded from the primary endpoint analysis. The final analytic cohort therefore consisted of 121 patients, of whom 18 (14.9%) underwent unplanned reoperation within 30 days (Figure 1).

Baseline demographic, disease-related, and operative characteristics of the analytic cohort stratified by unplanned early reoperation status are summarized in Table 1. Age showed a non-significant trend toward younger patients in the reoperation group (median 55.5 vs. 63.0 years, p=0.085). Sex, body mass index, Bilsky grade 3, ECOG 3-4 status, perioperative transfusion, operative duration, tumor level, extent of vertebral involvement, Tomita-style tumor growth category, index surgery group, and SINS category did not differ significantly between groups (all p>0.05). MSTFI >1 was more frequent among patients with unplanned early reoperation than among those without reoperation (83.3% vs. 42.7%, p=0.0018).

Thoracic lesions predominated in both groups, accounting for 59.2% of patients without early reoperation and 72.2% of those with early reoperation. The extent of vertebral involvement was most commonly >4 vertebrae in the no-reoperation group (37.9%) and 2 vertebrae in the reoperation group (38.9%), without a statistically significant between-group difference. Tomita-style tumor growth category also did not differ significantly between groups (p=0.527), with rapid-growth primaries accounting for 46.6% of patients without early reoperation and 61.1% of those with unplanned early reoperation. Index surgery was distributed across all 4 predefined operative categories, with no meaningful difference between groups: decompression-only in 32.0% vs. 27.8%, short-segment posterior stabilization in 25.2% vs. 27.8%, long-segment posterior stabilization in 30.1% vs. 33.3%, and corpectomy-involving procedures in 12.6% vs. 11.1% in patients without versus with unplanned early reoperation, respectively (Table 1).

A case-level summary of all 18 unplanned early reoperations is presented in Table 2. These consisted of 4 technical, 4 tumor-related, 5 mechanical, and 5 wound-related reoperations. Median time to unplanned reoperation was 14.5 days (Q1-Q3, 2.5-26.5; range, 1-29). A clear temporal gradient was observed across mechanisms: technical events occurred earliest (n=4, median POD 2, range 1-4), followed by tumor-related events (n=4, median POD 6, range 2-28), mechanical events (n=5, median POD 22, range 15-29), and wound-related events (n=5, median POD 25, range 13-28) as illustrated in Figure 2. Overall timing differed across subtypes (Kruskal-Wallis p=0.023), although Bonferroni-adjusted pairwise comparisons were not significant.

The second procedures performed after unplanned early reoperation also differed across subtypes (Table 2). All 4 technical reoperations were treated with screw revision. Among tumor-related events, 4 patients underwent separation surgery alone for recurrent radicular symptoms associated with persistent tumor-related compression. Mechanical reoperations were managed with implant revision in the case of cage migration and with additional stabilization in the remaining 4 cases, including long-segment stabilization in 3 and short-

Table 1. Baseline demographic, disease-related, and operative characteristics of the analytic cohort stratified by unplanned early reoperation status

Variable	No unplanned early reoperation (n=103)	Unplanned early reoperation (n=18)	p-value
Age, years	63.0 (54.0-69.5)	55.5 (48.2-62.0)	0.085
Female sex	30 (29.1%)	5 (27.8%)	1.000
BMI, kg/m^2	25.4 (23.1-28.4)	24.3 (23.5-25.2)	0.527
Bilsky grade 3	47 (45.6%)	8 (44.4%)	1.000
ECOG 3-4	33 (32.0%)	6 (33.3%)	1.000
MSTFI >1	44 (42.7%)	15 (83.3%)	**0.0018**
Perioperative transfusion	57 (55.3%)	11 (61.1%)	0.798
Operative duration, min	235.0 (150.0-315.0)	300.0 (185.0-340.0)	0.451
Tumor level			0.769
Cervical	9 (8.7%)	1 (5.6%)	
Thoracic	61 (59.2%)	13 (72.2%)	
Lumbar	32 (31.1%)	4 (22.2%)	
Sacral	1 (1.0%)	0 (0.0%)	
Tumor growth category (Tomita-style)			0.527
Slow	48 (46.6%)	6 (33.3%)	
Moderate	7 (6.8%)	1 (5.6%)	
Rapid	48 (46.6%)	11 (61.1%)	
Extent of vertebral involvement			0.202
1 vertebra	25 (24.3%)	5 (27.8%)	
2 vertebrae	23 (22.3%)	7 (38.9%)	
3 vertebrae	16 (15.5%)	0 (0.0%)	
>4 vertebrae	39 (37.9%)	6 (33.3%)	
Index surgery group			0.968
Decompression-only	33 (32.0%)	5 (27.8%)	
Short-segment posterior stabilization	26 (25.2%)	5 (27.8%)	
Long-segment posterior stabilization	31 (30.1%)	6 (33.3%)	
Corpectomy-involving procedures	13 (12.6%)	2 (11.1%)	
SINS category			0.926
Stable (0-6)	11 (10.7%)	2 (11.1%)	
Potentially unstable (7-12)	63 (61.2%)	12 (66.7%)	
Unstable (13-18)	28 (27.2%)	4 (22.2%)	

Values are presented as median (Q1-Q3) or n (%), unless otherwise indicated. Continuous variables were compared using the Wilcoxon rank-sum test and categorical variables using Fisher's exact test. Tumor growth category was assigned from the primary pathology using a Tomita-style classification as slow-, moderate-, or rapid-growth. Histologies not explicitly listed in the original Tomita framework were pragmatically assigned to the most biologically comparable growth group for descriptive purposes. BMI: Body mass index, ECOG: Eastern Cooperative Oncology Group, MSTFI: Metastatic spinal tumor frailty index, SINS: Spinal instability neoplastic score

segment stabilization in 1. Wound-related reoperations consisted of dural and wound repair for the 2 cerebrospinal fluid fistulas, wound washout and repair for 2 wound infections, and abscess drainage with wound repair for 1 epidural abscess/wound infection case.

When subtype was examined in relation to index surgery, technical events followed 3 long-segment posterior stabilization procedures and 1 short-segment posterior stabilization procedure. Tumor-related reoperations followed 2 long-segment and 2 short-segment posterior stabilization procedures. Mechanical reoperations followed 4 decompression-only procedures and 1 corpectomy-involving procedure. Wound-related reoperations followed 1 decompression-only procedure, 2 short-segment posterior stabilization procedures, 1 long-segment posterior stabilization procedure, and 1 corpectomy-involving procedure. Thus, the relationship between complication subtype and index surgery was not limited to the mechanical subgroup alone.

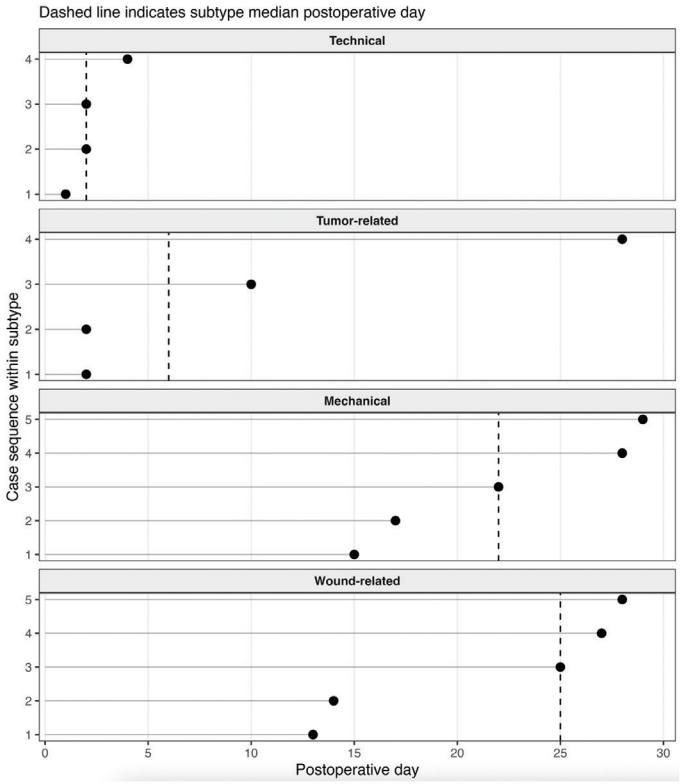

Figure 2. Timing of unplanned early reoperations by mechanism-specific subtype. Each dot represents 1 unplanned early reoperation plotted according to postoperative day on the x-axis. Panels are stratified by mechanism-specific subtype, and dashed vertical lines indicate the median postoperative day within each subtype. The y-axis denotes case sequence within subtype. Technical events occurred earliest, followed by tumor-related events, whereas mechanical and wound-related events clustered later within the 30-day postoperative period

Table 2. Case-level summary of unplanned early reoperations within 30 days

Case	POD	Subtype	Indication	Second surgery
1	1	Technical	Screw malposition with aortic proximity	Screw revision
2	2	Technical	Symptomatic screw malposition	Screw revision
3	2	Technical	Symptomatic screw malposition	Screw revision
4	2	Tumor-related	Persistent epidural tumor compression	Separation
5	2	Tumor-related	Persistent epidural tumor compression	Separation
6	4	Technical	Symptomatic screw malposition	Screw revision
7	10	Tumor-related	Persistent epidural tumor compression	Separation
8	13	Wound-related	Cerebrospinal fluid fistula	Dural+wound repair
9	14	Wound-related	Cerebrospinal fluid fistula	Dural+wound repair
10	15	Mechanical	Cage malposition/migration	Implant revision
11	17	Mechanical	Progressive kyphosis/instability	Long-segment stabilization
12	22	Mechanical	Progressive kyphosis/instability	Short-segment stabilization
13	25	Wound-related	Wound infection	Wound washout and repair
14	27	Wound-related	Wound infection	Wound washout and repair
15	28	Mechanical	Progressive kyphosis/instability	Long-segment stabilization
16	28	Tumor-related	Residual/progressive tumor with recurrent radicular symptoms	Separation
17	28	Wound-related	Epidural abscess/wound infection	Abscess drainage+wound repair
18	29	Mechanical	Progressive kyphosis/instability	Long-segment stabilization

Planned staged procedures were excluded from this table and from the primary endpoint analysis. Each unplanned reoperation was classified according to the dominant clinical mechanism. POD: Postoperative day

DISCUSSION

Unplanned early reoperation after surgery for spinal metastases is a clinically important outcome in a medically fragile population undergoing surgery to preserve neurological function, relieve pain, restore stability, and maintain access to further oncologic treatment[1,2,11]. A second operation within the first postoperative month may prolong hospitalization, interrupt rehabilitation, and complicate the sequencing of radiotherapy or systemic therapy. Contemporary metastatic spine series have also linked early postoperative setbacks such as unplanned readmission to worse postoperative performance and, in some cohorts, shorter survival, supporting the clinical relevance of studying early return to the OR in greater detail[5,12,13]. In this retrospective single-center cohort, unplanned reoperation within 30 days after surgery for spinal metastases occurred in 14.9% of the analytic cohort after planned staged procedures were considered separately. The median time to reoperation was 14.5 days, and the observed events demonstrated a heterogeneous mechanism-based distribution across the early postoperative period. Technical reoperations clustered in the immediate postoperative phase, whereas tumor-related events tended to occur earlier within the 30-day window and mechanical and wound-related reoperations were more often encountered later.

Most published metastatic spine series report reoperation as a pooled endpoint[6,7,14]. While that approach is useful for broad benchmarking, it does not distinguish between clinically different early return-to-OR scenarios. The present study was intentionally restricted to unplanned reoperation within 30 days, with planned staged procedures adjudicated separately, and with additional subdivision of unplanned events according to dominant clinical mechanism. This approach does not attempt to provide a comprehensive account of all postoperative failures after metastatic spine surgery. Rather, it focuses on the very early postoperative interval and asks whether operative returns within that period show recognizably different timing patterns.

The overall 30-day incidence in this study lies within the broad range reported previously, although direct comparison across studies remains limited by differences in case mix, follow-up duration, and endpoint definitions. Tarawneh et al.[4] reported a pooled reoperation rate of 8.3% in a systematic review, Quraishi et al.[15] reported 10.7%, and Paulino Pereira et al.[6] observed reoperation in 18% of 647 surgically treated patients over a longer follow-up period. Patel et al.[7] further showed that 30-day unplanned readmission and reoperation after surgery for vertebral column metastases are strongly influenced by medical complexity. Against this background, the present series is best interpreted as a descriptive cohort that clarifies how a meaningful proportion of clinically important revision events occur very early and arise from mechanistically distinct processes.

Technical reoperations occurred earliest, which is consistent with the way implant malposition, inadequate decompression, or procedure-related neurological deterioration usually declare themselves through early imaging or early clinical worsening. Tumor-related reoperations followed shortly thereafter. In the current era of NOMS-based decision-making and separation surgery, the surgical objective is frequently decompression and stabilization rather than radical oncologic resection[2,11]. Within that framework, earlier tumor-related return to surgery may reflect persistent ventral compression or residual disease not adequately controlled by the index procedure, whereas later events within the same subgroup may reflect rapidly progressive epidural disease. This distinction also matters from a treatment-sequencing standpoint. In external cohorts, earlier initiation of postoperative radiotherapy has been associated with improved 1-year survival, while wound-focused studies have not demonstrated a clear wound-healing penalty from reasonably timed early postoperative radiotherapy[16,17]. Although our data cannot address causality in this pathway, they support the practical importance of avoiding preventable reoperation when postoperative oncologic treatment is time-sensitive. At the same time, the small number of tumor-related events and the retrospective nature of adjudication require cautious interpretation.

The pattern of second operations also supports the clinical coherence of the mechanism-based classification used in this study. Technical cases uniformly required screw revision, tumor-related cases underwent repeat decompression-oriented procedures with or without added short-segment stabilization, mechanical cases generally required implant revision or additional stabilization, and wound-related cases underwent dural repair, washout, or abscess drainage according to the underlying problem. Although these observations remain descriptive, the correspondence between indication and second procedure suggests that the adjudicated subtypes reflected clinically recognizable early return-to-OR scenarios rather than a purely semantic classification.

The mechanical subgroup is the most hypothesis-generating component of the present study. All five mechanical reoperations occurred in patients with SINS scores in the potentially unstable range (7-12), and four of the five followed decompression-only procedures. It should not be taken to imply that decompression without stabilization was inappropriate in any individual patient, nor that a specific operative choice directly caused the subsequent event. Surgical decision-making in metastatic spine disease is individualized and influenced by neurologic status, tumor burden, prognosis, construct feasibility, systemic condition, and goals of care[2,3,11]. However, it is compatible with the possibility that some lesions in the intermediate mechanical-risk range may destabilize soon after posterior decompression when additional load-sharing support is not provided. This interpretation is consistent with the original purpose of SINS as a framework for identifying lesions at risk of instability and guiding consideration of stabilization[3]. It is

also directionally consistent with prior reports showing that symptomatic construct failure and early mechanical revision remain relevant causes of treatment failure in metastatic spine surgery, including more recent work suggesting that early construct failure may represent a distinct clinical subgroup rather than simply a late extension of the same process[18,19]. Importantly, the mechanical subgroup in the present study was clinically heterogeneous, incorporating both progressive kyphosis/instability after non-instrumented decompression and delayed cage migration after reconstruction. Accordingly, the present data support only a limited descriptive observation: in this small cohort, early mechanical deterioration was encountered in a subset of patients with intermediate mechanical-risk lesions, and this pattern may warrant further study in larger series.

Wound-related reoperations formed the latest cluster in this cohort, occurring predominantly during the second to fourth postoperative weeks. This distribution is consistent with prior metastatic spine studies in which wound complications are among the most frequent reasons for revision[4,15,20,21]. Recent studies have linked wound complications in this population to factors such as nutritional status, extent of surgery, preoperative radiotherapy, systemic therapy exposure, and frailty[22-24]. The higher prevalence of MSTFI >1 in the reoperation group in our series is compatible with that broader literature. At the same time, the limited number of events and the absence of multivariable modeling mean that this finding should be interpreted cautiously. In the present study, MSTFI is better viewed as a marker associated with early reoperation burden rather than as an independently established predictor.

An important strength of the present study is that it did not treat all early secondary operations equivalently. Planned staged procedures were adjudicated separately and excluded from the primary endpoint, thereby allowing the reported incidence to reflect unplanned early operative returns rather than all 30-day reoperations. This distinction is particularly relevant in metastatic spine surgery, where intentionally staged treatment strategies may occur in selected cases. The study also moves beyond a purely pooled reoperation rate by providing case-level characterization of indication, timing, and secondary procedure.

Study Limitations

Several limitations should be acknowledged. First, this was a retrospective single-center study with a limited number of events, and the study was not powered for robust adjusted analyses or mechanism-specific modeling. Second, although reoperation adjudication was performed independently by 2 neurosurgeons with consensus resolution, some degree of classification uncertainty is unavoidable in retrospective chart-based event assignment. Third, the study was intentionally restricted to the 30-day postoperative interval and therefore does not capture later local progression, delayed wound complications, or late construct failure. The findings should therefore not be interpreted as a comprehensive analysis of failure after metastatic spine surgery. Fourth, patients who died before completing the 30-day observation window were excluded from the primary incidence analysis because the endpoint required complete ascertainment of an observed return to the OR. Although this approach was methodologically aligned with the chosen endpoint, it may have introduced survivorship bias by excluding patients with limited postoperative observation time and potentially high early complication burden. Finally, as with other retrospective institutional series, reoperations performed outside the index center may not have been fully captured.

CONCLUSION

Unplanned early reoperation after surgery for spinal metastases occurred in 14.9% of the primary analytic cohort and followed distinct mechanism-specific timing patterns. Technical events tended to occur earliest, whereas mechanical and wound-related events were generally observed later in the first postoperative month. In this cohort, mechanical reoperations were encountered in patients with SINS scores in the potentially unstable range, but this observation should be regarded as descriptive and hypothesis-generating, not causal. A mechanism-based description of very early unplanned operative returns may offer a more precise framework for reporting postoperative events after metastatic spine surgery, but the clinical implications of this approach require validation in larger studies.

Ethics

Ethics Committee Approval: This retrospective cohort study was conducted at a single tertiary referral center after University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital Institutional Ethics Committee approval (approval no: KAEK/15.10.2025.370, date: 21.10.2025).

Informed Consent: The requirement for informed consent was waived due to anonymized use of data and the retrospective nature of the study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: A.T.B., B.T., Concept: A.T.B., Design: A.T.B., Data Collection or Processing: A.T.B., B.T., Analysis or Interpretation: A.T.B., B.T., Literature Search: A.T.B., B.T., Writing: A.T.B., B.T.

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of academic phrasing. All outputs generated by the AI tool were carefully reviewed, revised, and verified by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the final manuscript. The use of AI was limited to writing support and did not influence the study data, statistical analyses, results, or conclusions.

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