Original Research

SPINE RESEARCH

OPEN

# Single-stage percutaneous biopsy and stabilization accelerate oncologic care and improve patient-reported outcomes in spinal neoplastic lesions

Nikita Zaborovskii[a,b,*], Sergei Masevnin[a], Vladislav Murakhovsky[a], Dmitrii Ptashnikov[c], Rashid Tikhilov[a]

**Abstract**

**Background:** Spinal neoplastic lesions are traditionally managed through staged procedures, potentially introducing delays in oncologic care. Single-stage percutaneous approaches may optimize treatment timelines while maintaining diagnostic accuracy and structural stability.

**Objective:** This study aimed to evaluate whether single-stage percutaneous biopsy and stabilization reduce time to definitive oncologic therapy and improve patient-reported outcomes compared with staged procedures in adults with mechanically unstable spinal neoplastic lesions of uncertain histology.

**Methods:** A retrospective cohort study analyzed 65 consecutive patients with spinal neoplastic lesions managed between November 2020 and May 2025. Patients were categorized into single-stage ($n$ = 21) and staged ($n$ = 44) groups based on whether percutaneous biopsy and stabilization were performed during the same operative session or as separate procedures. Primary outcome was the time from biopsy to initiation of definitive oncologic therapy. Secondary outcomes included changes in health-related quality of life assessed using visual analogue scale and Spine Oncology Study Group Outcomes Questionnaire, measured at baseline and at histopathological diagnosis availability.

**Results:** Baseline characteristics were comparable between groups. Mean time from biopsy to definitive therapy was significantly shorter in the single-stage cohort (30.2 days, 95% confidence interval: 24.5–35.9) versus staged cohort (40.1 days, 95% confidence interval: 36.7–43.5), representing a 9.9-day reduction ($p$ = 0.008). At histopathological diagnosis, single-stage patients reported significantly lower pain scores (visual analogue pain assessment scale 4.3 vs 6.9, $p < 0.001$), superior physical function (77.7 vs 65.5, $p$ = 0.002), and higher overall quality of life (SOSGOQ2.0 total 63.2 vs 57.0, $p$ = 0.015). Adverse event rates were comparable between groups, with no significant difference in complications or repeat procedures.

**Conclusions:** Single-stage percutaneous biopsy and stabilization accelerate oncologic care initiation and improve early patient-reported outcomes without compromising safety, representing a preferred pathway for managing mechanically unstable spinal neoplastic lesions.

**Abbreviations:** CI = confidence interval, HRQoL = health-related quality of life, SINS = Spinal Instability Neoplastic Score, VAS = visual analogue pain assessment scale.

**Keywords:** minimally invasive spine surgery, oncologic therapy, patient-reported outcomes, percutaneous stabilization, single-stage surgery, spinal neoplasm

## 1. Introduction

Spinal neoplastic lesions represent a complex clinical challenge that requires careful coordination between diagnostic, surgical, and oncologic interventions.[1–4] These lesions, whether primary bone tumors or metastatic deposits, frequently present with mechanical instability that necessitates urgent stabilization to prevent neurological deterioration and alleviate debilitating pain.[5] The traditional

Supplemental Digital Content is available for this article.

[a] Vreden National Medical Research Center of Traumatology and Orthopedics, Saint-Petersburg, Russia, [b] Spine Surgery and Bone Oncology Scientific Department, Saint-Petersburg State University - Medical Institute, Saint-Petersburg, Russia, [c] Saint-Petersburg Clinical Hospital of the Russian Academy of Sciences, Saint-Petersburg, Russia.

* Correspondence: Nikita Zaborovskii, Spine Surgery and Bone Oncology Scientific Department, R.R.Vreden National Medical Research Center of Traumatology and Orthopedics, st. A.Baykova, 8, Saint-Petersburg 195427, Russia (e-mail: n.zaborovskii@yandex.ru).



Spine Research (2025) 1:3;187–195

Received: 17 September 2025 / Accepted: 16 October 2025

http://dx.doi.org/10.1097/br9.0000000000000023

approach has involved a staged strategy: initial diagnostic biopsy followed by subsequent stabilization procedures, with definitive oncologic therapy initiated only after histopathologic confirmation and mechanical stabilization are complete.[6] However, this conventional staged approach may inadvertently introduce delays in the oncologic care pathway.[7] These delays are particularly concerning given the progressive nature of many spinal neoplasms and their associated complications, including pathological fractures, spinal cord compression, and intractable pain that significantly impair quality of life.[8]

Recent advances in minimally invasive spinal surgery techniques, including percutaneous biopsy and stabilization methods, have created new opportunities to optimize the management paradigm for these patients.[9] The integration of diagnostic and stabilization procedures within a single operative session represents a potentially transformative approach that could eliminate procedural delays while maintaining diagnostic accuracy and structural stability. This single-stage strategy may particularly benefit patients with mechanically unstable lesions, who face the dual challenges of progressive structural compromise and delayed access to definitive oncologic therapy.

The objective of this study was to evaluate whether a single-stage surgical strategy, combining percutaneous biopsy and spinal stabilization within one operative session, could reduce delays to initiation of definitive oncologic therapy and improve patient-reported outcomes compared with a staged approach in adults with spinal neoplastic lesions of uncertain histology and mechanical instability.

## 2. Materials and methods

This retrospective study was performed at a single tertiary care center with a dedicated spine surgery and bone oncology service, encompassing all eligible patients managed from November 2020 to May 2025. From 1,565 assessed cases, 65 patients met the analytical criteria (Fig. 1). All consecutive adult patients (≥ 18 years) presenting with a spinal lesion of unknown histology and clinical and/or radiographic features suggestive of mechanical instability were screened. The analytical cohort comprised patients with subsequent histopathologic confirmation of a neoplastic spinal lesion based on the index biopsy. Additional inclusion criteria were the availability of complete preoperative clinical and imaging data and completion of health-related quality of life (HRQoL) assessments. For primary spinal tumors, sequencing of stabilization and definitive resection was determined by a multidisciplinary tumor board. Cases directed after biopsy to definitive oncologic resection rather than a stabilization-focused pathway were excluded. Additional exclusion criteria were high-grade epidural spinal cord compression or neurological deficit requiring decompression, cervical spine involvement, incomplete clinical records, or loss to follow-up before outcome collection.

### 2.1. Clinical and demographic data

Age, sex, American Society of Anesthesiologists grade, Eastern Cooperative Oncology Group performance status, primary tumor type, descriptive Spinal Instability Neoplastic Score (SINS) components, and extent of vertebral involvement were extracted from electronic medical records and preoperative imaging. Time intervals from biopsy to fixation and from biopsy to initiation of definitive oncologic therapy were systematically recorded. Pain intensity was documented using the visual analogue pain assessment scale (VAS). HRQoL was assessed using the Spine Oncology Study Group Outcomes Questionnaire (SOSGOQ2.0)[10] at baseline (before biopsy) and reevaluated at the time when definitive histopathological diagnosis became available for clinical decision-making.[11]

The final analytic cohort, subsequently categorized into single-stage ($n$ = 21) and staged ($n$ = 44) groups. Single-stage surgery was defined as percutaneous biopsy and stabilization performed during the same operative session under a single anesthetic. Staged intervention was defined as biopsy followed by delayed stabilization in a separate procedure. Percutaneous core biopsy of the affected vertebra was performed using a Jamshidi needle under fluoroscopic guidance. Stabilization employed image-guided percutaneous pedicle screw–rod constructs, with construct extent individualized to lesion location, vertebral involvement, and alignment.

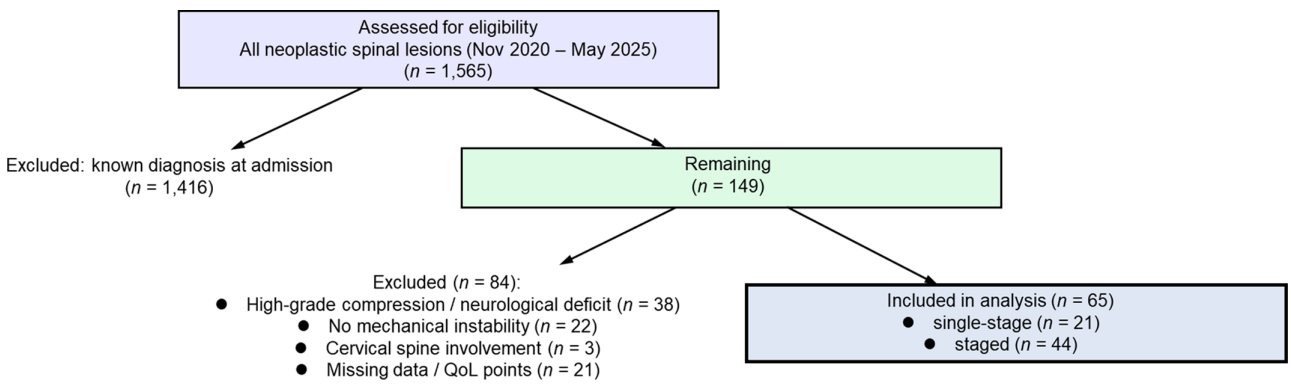


**Figure 1.** Flowchart of this study.

All procedures were performed by 2 surgeons operating simultaneously from bilateral sides. Procedures could be performed under local anesthesia in selected medically fragile patients.[12] Patients were mobilized on the operative day under physiotherapy supervision following a standardized enhanced recovery after surgery protocol. Postoperative analgesia followed a standardized multimodal approach aligned with evidence-based guidelines for spine surgery pain management.[13] Hospital discharge occurred on postoperative day 2 or 3, with no external immobilization required given the immediate mechanical stability achieved through percutaneous fixation. Following definitive histologic diagnosis, the initial oncologic management strategy was selected by a multidisciplinary tumor board and implemented in accordance with institutional and guideline-concordant protocols.

Primary outcome was the interval from index biopsy to initiation of definitive therapy (surgery, systemic anticancer treatment, radiotherapy, or combination approaches), expressed in days. Secondary outcomes included (1) change in HRQoL (VAS, SOSGOQ2.0 total and subdomain scores: pain, physical function, mental health, social function), measured before biopsy and reassessed at the time of definitive histopathological diagnosis; and (2) perioperative adverse events, including reoperation at the index level, repeat biopsy due to insufficient or inconclusive sampling, unplanned urgent fixation, and acute pain-related readmission.

The study protocol was reviewed and approved by the institutional review board. Informed consent requirements were waived in view of the retrospective design and anonymized data analysis. The study was conducted in accordance with the Declaration of Helsinki and relevant local regulations. No external funding was obtained for this work.

### 2.2. Data analysis

Statistical analyses were conducted in R (version 4.4.1) using the gtsummary package for descriptive summaries and comparisons. Continuous variables are reported as means with 95% confidence intervals (CIs), and categorical variables as counts and percentages. Between groups, means were compared using Welch's 2-sample $t$ test to accommodate potential heterogeneity of variances; where distributional assumptions were questionable, results were corroborated with the Wilcoxon rank-sum test. For patients managed with the staged approach, the prespecified component intervals "biopsy to stabilization" and "stabilization to therapy" were summarized descriptively and compared using a paired Wilcoxon signed-rank test. Two-sided $p$-values $< 0.05$ were considered statistically significant.

## 3. Results

Baseline characteristics were comparable between the single-stage ($n = 21$) and staged ($n = 44$) cohorts (Table 1). Sex distribution, age, American Society of Anesthesiologists class, and Eastern Cooperative Oncology Group performance status showed no statistically significant differences. The prevalence of metastatic disease outside the index spinal lesion was similar across groups. Extent of vertebral involvement and SINS total scores were likewise balanced.

Fixation length, including the index level, most frequently comprised 3 levels in 28 of 65 cases (43%) (Fig. 2). Five-level constructs were used in 25 cases (38%), six-level constructs in 6 cases (9.2%), four-level constructs in 4 cases (6.2%), and seven-level constructs in 2 cases (3.1%).

For the 65 included patients, the mean time from index biopsy to initiation of definitive therapy was 30.2 days (95% CI: 24.5–35.9) in the single-stage cohort and 40.1 days (95% CI: 36.7–43.5) in the staged cohort, yielding a

**Table 1**

***Baseline clinical and disease characteristics by treatment strategy.***

| *Characteristic* | *Single-stage n = 21* | *Staged n = 44* | *p-value* |
|---|---|---|---|
| Sex, | | | |
| Female | 16 (76%) | 26 (59%) | 0.2 |
| Male | 5 (24%) | 18 (41%) | |
| Age, years (95% CI) | 55.3 (51; 60) | 57.1 (52.0, 65.0) | 0.5 |
| ASA, *n* (%) | | | |
| 1 | 8 (38%) | 8 (18%) | 0.2 |
| 2 | 10 (48%) | 25 (57%) | |
| 3 | 3 (14%) | 11 (25%) | |
| ECOG | | | |
| 0–2 | 9 (43%) | 26 (59%) | 0.2 |
| 3–4 | 12 (57%) | 18 (41%) | |
| Metastatic disease outside the index spinal lesion (visceral or osseous) | 9 (43%) | 18 (41%) | 0.9 |
| Vertebral involvement, *n* (%) | | | |
| 1 | 17 (81%) | 37 (84%) | 0.8 |
| 2–3 | 4 (19%) | 7 (16%) | |
| SINS total, score | 12.7 (11.0, 15.0) | 11.8 (10.0, 13.5) | 0.14 |

ASA, American Society of Anesthesiologist; CI, confidence interval; ECOG, Eastern Cooperative Oncology Group; SINS, Spinal Instability Neoplastic Score.

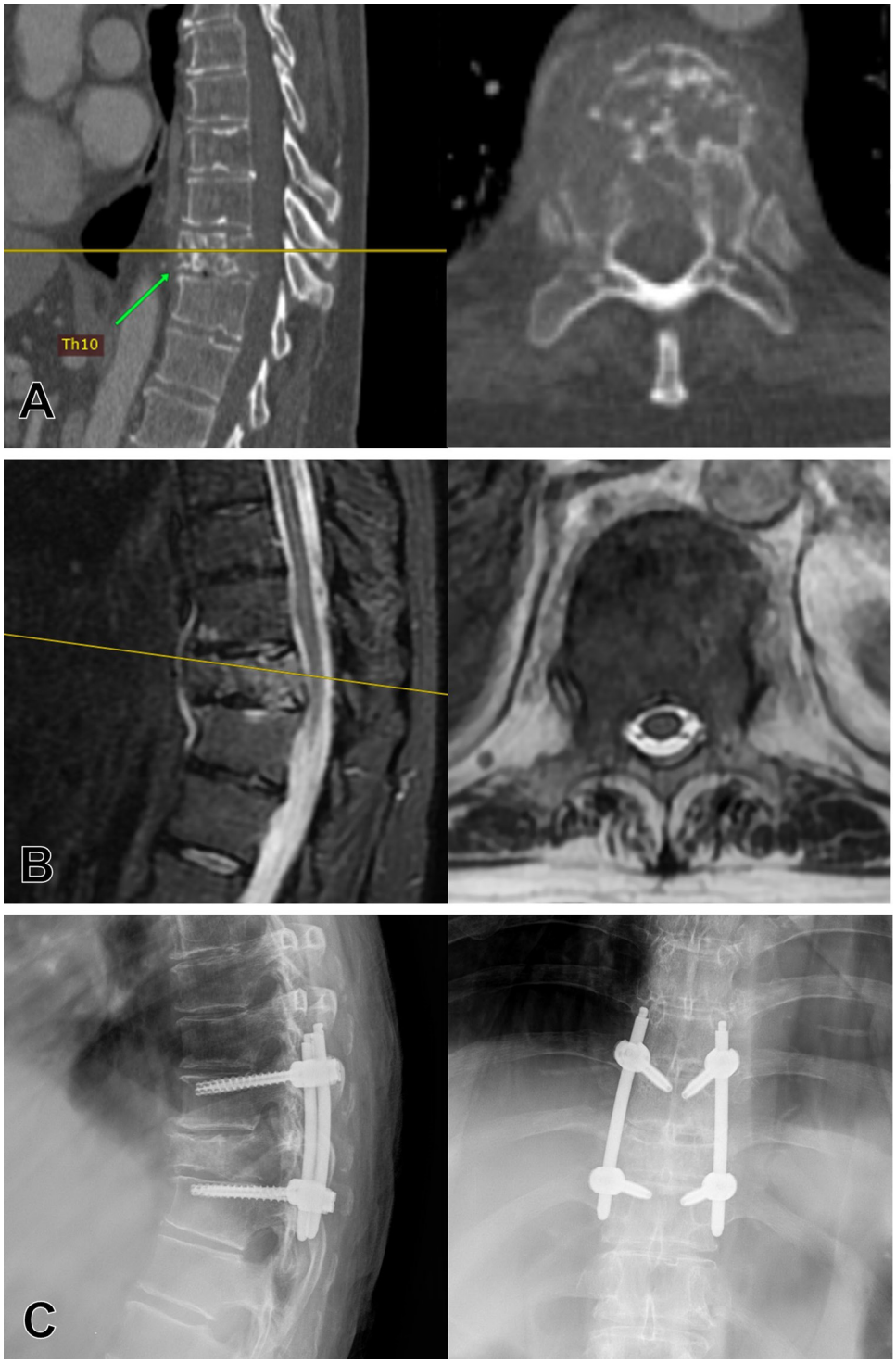


**Figure 2.** Single-stage percutaneous biopsy and stabilization in a 56-year-old female patient with Th10 vertebral neoplasm presenting with mechanical back pain. (A) Computed tomography demonstrates pathological fracture of the Th10 vertebral body. (B) T2-weighted magnetic resonance imaging reveals the vertebral lesion without evidence of spinal cord compression. (C) Postoperative anteroposterior X-ray following single-stage percutaneous core needle biopsy and pedicle screw–rod stabilization (T9–T11). The procedure was performed under local anesthesia with an operative time of 40 minutes and an estimated blood loss of 10 mL. The patient experienced immediate pain relief and early mobilization, with histopathological diagnosis confirming metastatic non–small cell lung cancer, enabling prompt initiation of systemic therapy.

mean difference of −9.9 days (single-stage minus staged). The difference was statistically significant by Welch's $t$ test ($t = -2.82$, $p = 0.008$) and confirmed by the Wilcoxon rank-sum test ($p = 0.009$). Within the staged pathway, the intervals "biopsy to stabilization" and "stabilization to therapy" differed significantly (paired Wilcoxon test $p < 0.001$), indicating an uneven distribution of process-related delay across stages (Fig. 3).

Clinically meaningful differences between groups were evident at the time of histopathological diagnosis (Fig. 4).

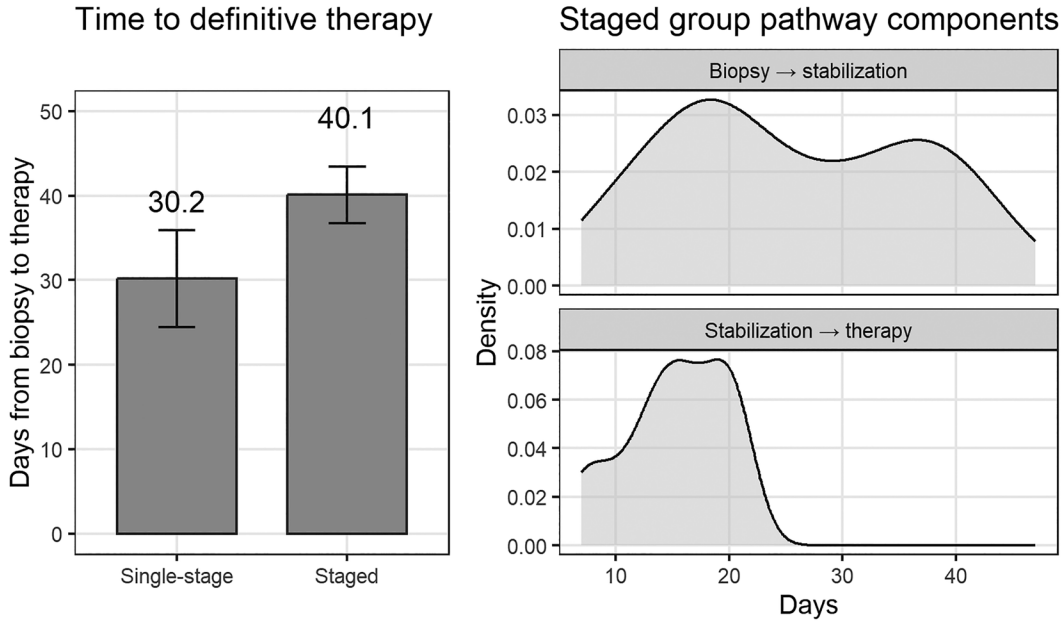


**Figure 3.** Time to definitive therapy and delay components in the staged pathway. Left, mean time from index biopsy to initiation of definitive therapy for single-stage and staged groups. Right, kernel density estimates of interval durations within the staged pathway.

Patients who underwent single-stage surgery reported substantially lower pain (VAS 4.3 vs 6.9; $p < 0.001$) and superior physical function (77.7 vs 65.5; $p = 0.002$). Overall health-related quality of life was also higher in the single-stage cohort (SOSGOQ2.0 total score 63.2 vs 57.0; $p = 0.015$). The SOSGOQ2.0 pain subdomain showed a marked advantage for single-stage intervention (51.2 vs 37.5; $p < 0.001$), while no group differences were observed in mental health or social function.

In the single-stage cohort, adverse events included repeat biopsy in 2 patients and one revision for pedicle screw malposition. In the staged cohort, acute pain-related readmission occurred in 3 patients, repeat biopsy was required in 3 cases, and 2 patients underwent unplanned urgent fixation due to instability progression while still in the diagnostic phase, before planned stabilization.

Regarding primary tumor distribution, metastatic tumors from common solid primaries (breast, kidney, lung, prostate, and thyroid) accounted for the majority of cases ($n = 43$, 66%). Hematologic malignancies, including multiple myeloma and lymphoma, were observed in 7 patients (11%). Primary bone tumors ($n = 6$, 9.2%) comprised chordoma, chondrosarcoma, osteosarcoma, osteoblastoma, and giant cell tumor. The remaining 9 cases (14%) represented less frequent gastrointestinal, gynecologic, urological, and cutaneous malignancies (Table S1, Supplemental Digital Content, https://links.lww.com/SPRES/A4).

Postoperative oncologic management most frequently involved combined-modality treatment, with systemic therapy plus radiotherapy constituting the dominant approach in more than half of the cohort (58%). Systemic therapy alone was applied in one-fifth of patients, whereas radiotherapy as a single modality was less common (9.2%). Surgical strategies were used selectively, including resection performed after neoadjuvant therapy (4.5%), standalone resection (4.6%), and separation surgery followed by radiotherapy (3.1%).

## 4. Discussion

Modern approaches to spinal tumor evaluation emphasize multifactorial analysis incorporating mechanical instability, neurologic deficit, and oncologic prognosis.[14,15] In cases of neoplastic spinal lesions without confirmed diagnosis, rapid and safe tissue verification is crucial for initiating specialized treatment.[16] However, current guidelines lack consensus on surgical stabilization criteria during the diagnostic phase for neurologically intact patients with uncertain oncologic status.[17,18] The proposed single-stage approach addresses this gap by providing provisional percutaneous stabilization as an "internal brace" until diagnostic confirmation and treatment strategy selection.

The primary finding of this retrospective cohort study demonstrates that single-stage percutaneous biopsy and stabilization of spinal neoplastic lesions significantly expedites the initiation of definitive oncologic therapy while improving HRQoL compared to a staged approach. The observed 10-day reduction in time to definitive treatment represents a clinically meaningful advancement that extends beyond the mechanical considerations of spinal stabilization to encompass the holistic oncologic care pathway.

The selection of percutaneous pedicle screw fixation over cement augmentation techniques in our institutional approach warrants discussion. While percutaneous cement augmentation (vertebroplasty or kyphoplasty) can effectively treat painful vertebrae with osteolysis or compression fractures secondary to tumor infiltration,[19] several limitations restrict its application in our patient

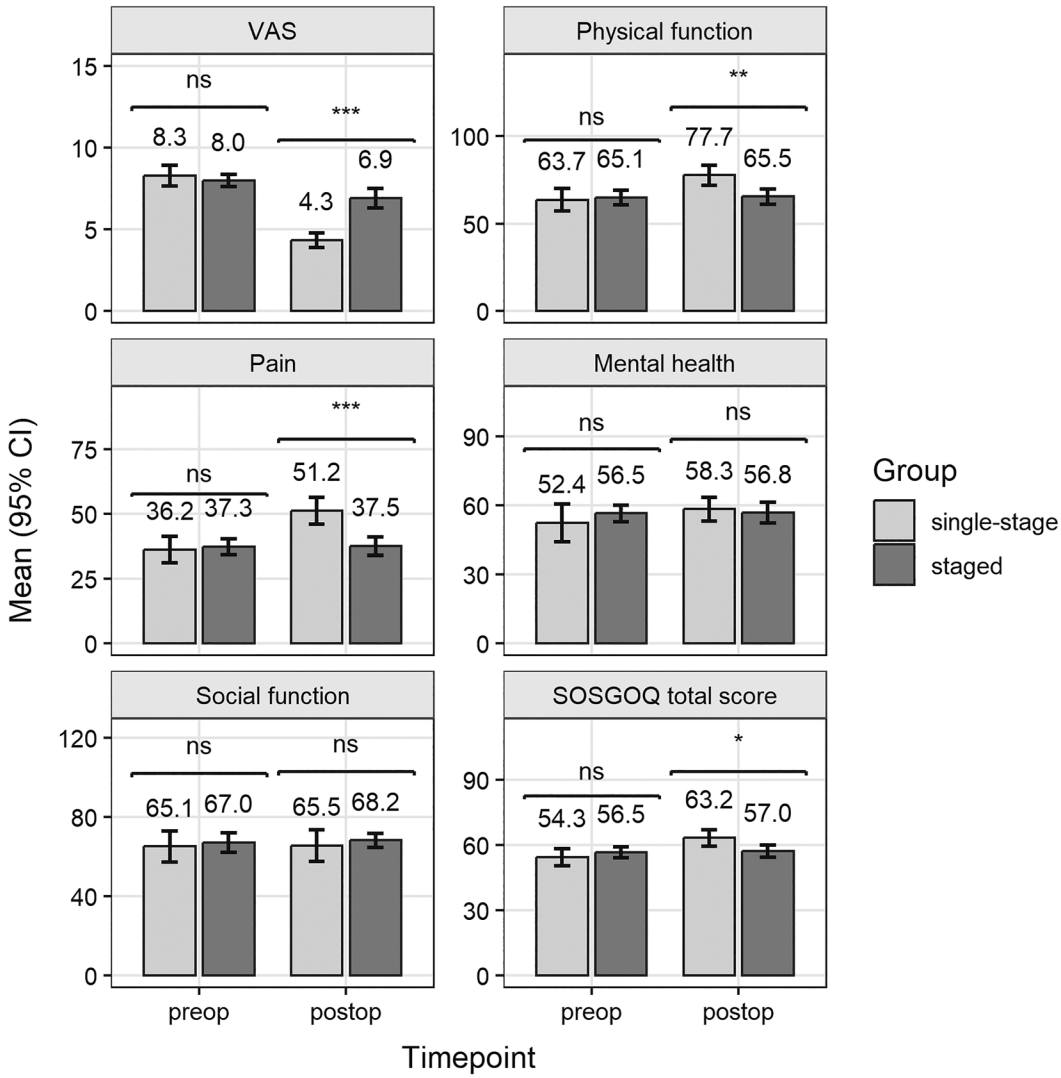


**Figure 4.** Patient-reported outcomes preoperatively and postoperatively at the time of histopathologic diagnosis: comparison of single-stage versus staged surgery (VAS pain, physical function, SOSGOQ2.0 subdomains, and total score). VAS, visual analogue pain assessment scale.

population. First, cement augmentation presents safety concerns in cases where no posterior vertebral body wall exists, creating risks of extravasation and neural compromise.[20] Second, in cases with extensive osteolysis where little to no trabecular bone remains for cement interdigitation, augmentation becomes less mechanically effective.[21] Third, cement augmentation can create challenges if a repeat biopsy is required, as the hardened cement may impede subsequent tissue sampling.[22] In contrast, percutaneous extralesional pedicle screw fixation allows preservation of the pathological area for potential future interventions while providing superior biomechanical stability, particularly when middle column and pedicle involvement is present.[23] Furthermore, pedicle screw constructs can effectively reduce pain during neoadjuvant chemotherapy and minimize the risk of vertebral body collapse during radiation therapy.[24] The current effectiveness of bone-modifying agents has also reduced our reliance on vertebroplasty for pain management in many cases.[25]

While our study cohort predominantly consisted of patients with metastatic spinal disease (90.8%), the application of simultaneous biopsy and stabilization to primary spinal tumors warrants careful consideration. Our approach should be applied with particular caution in cases where en bloc resection is planned, as the placement of instrumentation may potentially compromise optimal surgical margins or interfere with the formulation of neoadjuvant chemotherapy protocols, such as the "chemotherapy-surgery-chemotherapy" regimen commonly employed for Ewing's sarcoma.[26] In our cohort, primary bone tumors comprised only 6 patients (9.2%) and presented primarily as solitary spinal lesions of unknown histology with severe mechanical pain and radiographic evidence of spinal instability. These patients were considered for single-stage treatment because they presented with significant mechanical symptoms requiring urgent stabilization, while histological diagnosis remained uncertain. The clinical priority in these cases was to address mechanical instability and obtain tissue

diagnosis simultaneously, particularly when the clinical presentation suggested an urgent need for systemic therapy initiation. We emphasize that all treatment decisions for primary spinal tumors require careful multidisciplinary consultation and should be individualized based on tumor histology, extent of disease, patient performance status, and treatment goals.[27] The placement of percutaneous instrumentation should not preclude subsequent definitive surgical management when indicated.

As demonstrated by Tol et al.,[28] patients with symptomatic spinal neoplastic lesions experience considerable delays throughout their referral chain, with median total delays of 99 days from symptom onset to surgical treatment. Our findings suggest that organizational inefficiencies can be mitigated through procedural integration, as single-stage procedures eliminate the inherent delay between diagnostic confirmation and stabilization that characterizes the staged approach. Previous studies have consistently demonstrated that surgical stabilization of mechanically unstable spinal lesions provides substantial pain reduction and improved quality of life.[24,29] Our results extend this understanding by showing that the timing and integration of stabilization within the diagnostic workflow can further enhance these benefits. The staged approach, while diagnostically sound, exposes patients to a vulnerable interval during which progressive collapse, neural compression, or escalating pain may occur, as evidenced by the 3 acute pain-related readmissions and 2 unplanned urgent fixations observed in our staged cohort.

From an oncological perspective, the expedited initiation of definitive therapy in the single-stage cohort has implications beyond operational efficiency. Current evidence suggests that treatment delays in spinal metastases are associated with unfavorable surgical outcomes, increased complications, and impaired quality of life.[8] While our study did not aim to evaluate survival differences, the reduced time to therapy initiation may be particularly relevant for aggressive histologies. The integration of diagnostic and stabilization procedures also facilitates more seamless multidisciplinary care coordination, as demonstrated by the more frequent utilization of combined-modality treatments in our single-stage cohort. The safety profile observed in both cohorts was comparable, with no significant difference in adverse event rates. This finding contradicts potential concerns about increased procedural complexity or decision-making under diagnostic uncertainty. The fact that procedures could be performed under local anesthesia in medically fragile patients further supports the feasibility and safety of this approach across diverse patient populations.

A key implication of these findings is that a percutaneous stabilization at the diagnostic stage is not only feasible and safe but also provides tangible benefits in accelerating access to oncologic therapy and improving early HRQoL in adults with mechanically unstable or potentially unstable neoplastic spinal lesions of uncertain histology. This integrative approach can thus be regarded as a pragmatic, patient-centered enhancement to the standard care pathway for this population. Based on our experience, the ideal candidates for single-stage biopsy and stabilization are patients with: short-segment, nonmultiple thoracolumbar spinal lesions, mechanical instability as assessed by SINS score (typically 9–15),[30] absence of high-grade epidural spinal cord compression or neurological deficits, suspected or confirmed metastatic disease or hematological malignancies, no requirement for immediate tumor resection or decompressive surgery, anatomical suitability for percutaneous instrumentation. This approach is particularly valuable for patients where expediting diagnosis is critical, including those with multiple spinal lesions, concurrent visceral organ involvement, or suspected aggressive histologies requiring prompt systemic therapy initiation.

This study has several limitations. First, the retrospective design inherently introduces risks of selection bias and unmeasured confounding variables. Patient selection for single-stage versus staged approaches may have been influenced by surgeon preference or patient factors not fully captured in our analysis, though both groups demonstrated comparable baseline characteristics. Second, our single-center design may limit generalizability to other healthcare settings with different organizational structures, multidisciplinary team dynamics, or treatment protocols. The healthcare system-specific delays observed in our study may vary significantly across different environments. Third, our approach has specific selection criteria that limit its broad applicability. Patients with high-grade epidural spinal cord compression, cervical spine involvement, or multisegment disease were excluded, meaning that eligible patients represent only a small proportion of spinal tumor cases. This selective application underscores the importance of appropriate patient selection and multidisciplinary decision-making. Fourth, there was inherent variability in the timing of definitive histopathological diagnosis availability. While we measured time from index biopsy to initiation of definitive therapy, the interval between biopsy and definitive histopathological diagnosis could vary significantly between patients, particularly in cases requiring repeat biopsy due to insufficient or inconclusive initial sampling. This occurred in 2 patients in the single-stage group and 3 patients in the staged group, potentially introducing bias in our primary time-to-treatment endpoint. Finally, the lack of long-term follow-up represents a significant limitation of our study design. We cannot assess whether the single-stage approach leads to higher rates of unplanned reoperations, hardware failure, or other late complications. This limitation is particularly relevant given that some patients may require additional surgical procedures due to disease progression or mechanical failure over time. While our study was designed to focus on the acute impact of treatment strategy on care acceleration and early quality of life outcomes, this approach precluded assessment of longer term clinical outcomes such as local tumor control, progression-free survival, or overall survival. Future studies with extended follow-up periods are warranted to

comprehensively evaluate the long-term safety and efficacy of this approach.

## 5. Conclusion

Single-stage percutaneous biopsy and stabilization in adults with mechanically unstable spinal neoplastic lesions significantly accelerate initiation of definitive oncologic therapy and improve early patient-reported outcomes compared to a staged approach, without compromising safety. This integrative strategy streamlines care and should be considered as a preferred pathway in the multidisciplinary management of these patients.

## Acknowledgments

Not applicable.

## Ethics approval

The study was approved by the Hospital Institutional Review Board and complied with International Ethical Guidelines for Biomedical Research, Declaration of Helsinki, and local laws. Approval was granted by the Institutional Review Board of Vreden National Medical Research Center of Traumatology and Orthopedics, Saint-Petersburg, Russia. (IRB No. 003/24-1, 06/24/2025).

## Conflicts of interest

The authors have no conflicts of interest to disclose.

## Funding source

Not applicable.

## Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## Author contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Nikita Zaborovskii, Sergei Masevnin, and Vladislav Murakhovsky. The first draft of the manuscript was written by Nikita Zaborovskii, and all authors commented on previous versions of the manuscript. Dmitrii Ptashnikov and Rashid Tikhilov provided supervision and critical revision of the manuscript. All authors read and approved the final manuscript.

## Consent to participate

Informed consent requirements were waived in view of the retrospective design and anonymized data analysis.

## Consent for publication

Patients signed informed consent regarding publishing their data and photographs.

## References

[1] Aizenberg MR, Fox BD, Suki D, McCutcheon IE, Rao G, Rhines LD. Surgical management of unknown primary tumors metastatic to the spine. J Neurosurg Spine. 2012;16:86–92.
[2] Charest-Morin R, Fisher CG, Sahgal A, et al. Primary bone tumor of the spine—an evolving field: what a general spine surgeon should know. Global spine journal. 2019;9(1_suppl):108S–16S.
[3] Nowak H, Szwacka DM, Pater M, et al. Holistic approach to the diagnosis and treatment of patients with tumor metastases to the spine. Cancers. 2022;14:3480.
[4] Gao C, Yao T, Zhang T, et al. Empowering the future of spinal surgery through digital and intelligent technologies. Spine Research. 2025;1:23–30.
[5] Kumar N, Hui SJ, Lee R, Athia S, Rothenfluh DA, Tan JH. Implant and construct decision-making in metastatic spine tumour surgery: a review of current concepts with a decision-making algorithm. Eur Spine J. 2024;33:1899–910.
[6] Missenard G, Bouthors C, Fadel E, Court C. Surgical strategies for primary malignant tumors of the thoracic and lumbar spine. Orthop Traumatol Surg Res. 2020;106(1, Supplement):S53–62.
[7] van Tol FR, Choi D, Verkooijen HM, Oner FC, Verlaan JJ. Delayed presentation to a spine surgeon is the strongest predictor of poor postoperative outcome in patients surgically treated for symptomatic spinal metastases. Spine J. 2019;19:1540–7.
[8] Meyer HS, Wagner A, Raufer A, Joerger AK, Gempt J, Meyer B. Surgery in acute metastatic spinal cord compression: timing and functional outcome. Cancers. 2022;14:2249.
[9] Barzilai O, Robin AM, O'Toole JE, Laufer I. Minimally invasive surgery strategies changing the treatment of spine tumors. Neurosurg Clin N Am. 2020;31:201–9.
[10] Zaborovskii N, Denisov A, Shapton J, et al. Cross-cultural adaptation, reliability, and validity of the Russian version of the Spine Oncology Study Group Outcomes Questionnaire (SOSGOQ2.0). J Neurosurg Spine. 2023;39:568–75.
[11] Kamath J, Cruess DG, Claffey K, Wilson L, Phoenix N, Tannenbaum S. Symptom distress associated with biopsy in women with suspect breast lesions. ISRN Oncol. 2012;2012:1–9.
[12] Sebaaly A, Rizkallah M, Riouallon G, et al. Percutaneous fixation of thoracolumbar vertebral fractures. EFORT Open Rev. 2018;3:604–13.
[13] Chakravarthy VB, Laufer I, Amin AG, et al. Patient outcomes following implementation of an enhanced recovery after surgery pathway for patients with metastatic spine tumors. Cancer. 2022;128:4109–18.
[14] Laufer I, Rubin DG, Lis E, et al. The NOMS framework: approach to the treatment of spinal metastatic tumors. Oncologist. 2013;18:744–51.
[15] Paton GR, Frangou E, Fourney DR. Contemporary treatment strategy for spinal metastasis: the "LMNOP" system. Can J Neurol Sci. 2011;38:396–403.
[16] Traina F, Errani C, Toscano A, et al. Current concepts in the biopsy of musculoskeletal tumors: AAOS exhibit selection. J Bone Joint Surg Am. 2015;97:e7.
[17] Rispoli R, Reverberi C, Targato G, et al. Multidisciplinary approach to patients with metastatic spinal cord compression: a diagnostic therapeutic algorithm to improve the neurological outcome. Front Oncol. 2022;12:902928.
[18] Spratt DE, Beeler WH, de Moraes FY, et al. An integrated multidisciplinary algorithm for the management of spinal metastases: an international spine oncology consortium report. Lancet Oncol. 2017;18:e720–30.
[19] Sadeghi-Naini M, Aarabi S, Shokraneh F, Janani L, Vaccaro AR, Rahimi-Movaghar V. Vertebroplasty and kyphoplasty for

metastatic spinal lesions: a systematic review. Clin Spine Surg. 2018;31:203–10.
[20] Sciubba DM, Pennington Z, Colman MW, et al. Spinal metastases 2021: a review of the current state of the art and future directions. Spine J. 2021;21:1414–29.
[21] Leone A, Cianfoni A, Zecchi V, Cortese MC, Rumi N, Colosimo C. Instability and impending instability in patients with vertebral metastatic disease. Skeletal Radiol. 2019;48:195–207.
[22] Sozzi C, Trentadue M, Nicolì L, Tavani F, Piovan E. Utility of vertebral biopsy before vertebroplasty in patients with diagnosis of vertebral compression fracture. Radiol Med. 2021;126:956–62.
[23] Lu J, Chen Y, Hu M, Sun C. Systematic review and meta-analysis of the effect of using percutaneous pedicle screw internal fixation for thoracolumbar fractures. Ann Palliat Med. 2022;11:250–9.
[24] Schwab JH, Gasbarrini A, Cappuccio M, et al. Minimally invasive posterior stabilization improved ambulation and pain scores in patients with plasmacytomas and/or metastases of the spine. Int J Surg Oncol. 2011;2011:239230.
[25] Ng TL, Tu MM, Ibrahim MFK, et al. Long-term impact of bone-modifying agents for the treatment of bone metastases: a systematic review. Support Care Cancer. 2021;29:925–43.
[26] Gerrand C, Amary F, Anwar HA, et al. UK guidelines for the management of bone sarcomas. Br J Cancer. 2025;132:32–48.
[27] Tan JJH, Stirling E, Kaiser R, et al. Oxford spinal sarcoma service: excellent oncological outcomes with a centralised multidisciplinary approach to primary spinal tumour care. Eur Spine J. 2025;34:3592–600.
[28] Tol FR van, Versteeg AL, Verkooijen HM, Öner FC, Verlaan JJ. Time to surgical treatment for metastatic spinal disease: identification of delay intervals. Glob Spine J. 2021;13:316.
[29] Hussain I, Barzilai O, Reiner AS, et al. Patient-reported outcomes after surgical stabilization of spinal tumors: symptom-based validation of the Spinal Instability Neoplastic Score (SINS) and surgery. Spine J. 2018;18:261–7.
[30] Mahakul DJ, Visen A, Agarwal J. The truly intermediate subgroup within the SINS "Potentially Unstable" category: the matryoshka doll phenomenon. World Neurosurg. 2024;189:e745–52.