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INSTABILITY IN VERTEBRAL METASTASES: APPLICABILITY, LIMITATIONS, AND PERSPECTIVES OF THE SINS

INSTABILIDADE EM METÁSTASES VERTEBRAIS: APLICABILIDADE, LIMITAÇÕES E PERSPECTIVAS DO SINS

INESTABILIDAD EN METÁSTASIS VERTEBRALES: APLICABILIDAD, LIMITACIONES Y PERSPECTIVAS DEL SINS

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ABSTRACT

Objective: To review the current literature on the applicability of the Spinal Instability Neoplastic Score (SINS) in evaluating vertebral instability caused by metastases, highlighting its advantages, limitations, and perspectives with emerging technologies. Methods: A structured narrative review was conducted using PubMed (2015–2025) with predefined search terms and inclusion criteria. After screening, 27 relevant studies addressing SINS validity, reliability, clinical impact, and integration with artificial intelligence (AI) were included. Results: Most reviewed studies were retrospective observational (56%), followed by systematic reviews (26%) and narrative reviews (19%). Three main trends were identified: prediction of vertebral fractures and survival associated with SINS; therapeutic decision-making for intermediate scores (SINS 7–12); and assessment of inter- and intraobserver reliability. The intermediate category remained clinically ambiguous, often requiring specialist judgment. While SINS demonstrated overall good reliability, some components, such as bone quality, showed lower interobserver agreement. AI integration, particularly with large language models, demonstrated potential to improve accuracy and reduce subjectivity in scoring. Conclusions: SINS has been established as a useful and reliable tool for evaluating metastatic spinal instability, significantly improving multidisciplinary communication and therapeutic decision-making. However, limitations remain related to subjectivity and its static nature. The incorporation of AI may significantly enhance diagnostic precision, enabling more dynamic and individualized analyses. Further research into integrative predictive models based on clinical, radiomic, and biological data is recommended to optimize clinical decision-making. ***Level of Evidence V; Structured Narrative Review, non-systematic.***

Keywords: Spinal Neoplasms; Neoplasm Metastasis; Spinal Cord Compression; Vertebral Fractures; Adjuvant Radiotherapy; Artificial Intelligence.

RESUMO

Objetivo: Revisar a literatura atual sobre a aplicabilidade do Spinal Instability Neoplastic Score (SINS) na avaliação da instabilidade vertebral causada por metástases, destacando suas vantagens, limitações e perspectivas com novas tecnologias. Métodos: Realizou-se uma revisão narrativa estruturada com busca na base PubMed (2015-2025), utilizando descritores e critérios de inclusão predefinidos. Após triagem, selecionaram-se 27 estudos relevantes sobre validade, confiabilidade, impacto clínico do SINS e integração com inteligência artificial (IA). Resultados: Os estudos revisados foram majoritariamente observacionais retrospectivos (56%), seguidos por revisões sistemáticas (26%) e narrativas (19%). Identificaram-se três tendências principais: predição de fraturas vertebrais e sobrevida associadas ao SINS; estratégias terapêuticas na faixa intermediária (SINS 7-12); e avaliação da confiabilidade inter e intraobservador. Observou-se que a categoria intermediária é clinicamente ambígua, exigindo julgamento especializado. Embora o SINS apresente boa confiabilidade global, alguns componentes, como a qualidade óssea, exibem baixa concordância interobservador. A integração com IA, especialmente através de grandes modelos de linguagem, demonstrou potencial para aumentar a precisão e reduzir subjetividades nas avaliações. Conclusões: O SINS consolidou-se como ferramenta útil e confiável na avaliação da instabilidade vertebral metastática, com importante impacto na comunicação multidisciplinar e na tomada de decisão terapêutica. Entretanto, apresenta limitações relacionadas à subjetividade e natureza estática da classificação. A incorporação de IA pode aprimorar significativamente sua precisão diagnóstica, oferecendo análises mais dinâmicas e individualizadas. Recomenda-se maior exploração de modelos preditivos integrativos baseados em dados clínicos, radiômicos e biológicos para otimizar a tomada de decisão clínica. ***Nível de evidência V; Revisão Narrativa Estruturada não sistemática.***

Descritores: *Neoplasias da Coluna Vertebral; Metástase Neoplásica; Compressão da Medula Espinal; Fraturas Vertebrais; Radioterapia Adjuvante; Inteligência Artificial.*

RESUMEN

Objetivo: Revisar la literatura actual sobre la aplicabilidad del Spinal Instability Neoplastic Score (SINS) en la evaluación de la inestabilidad vertebral causada por metástasis, destacando sus ventajas, limitaciones y perspectivas con nuevas tecnologías. Métodos: Se realizó una revisión narrativa estructurada utilizando PubMed (2015–2025) con términos de búsqueda y criterios de inclusión predefinidos. Tras la selección, se incluyeron 27 estudios relevantes que evaluaban la validez, la confiabilidad, el impacto clínico del SINS y su integración con

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la inteligencia artificial (IA). Resultados: La mayoría de los estudios fueron observacionales retrospectivos (56%), seguidos de revisiones sistemáticas (26%) y revisiones narrativas (19%). Se identificaron tres tendencias principales: la predicción de fracturas vertebrales y la supervivencia asociadas al SINS; las estrategias terapéuticas en la categoría intermedia (SINS 7–12); y la evaluación de la confiabilidad inter e intraobservador. La categoría intermedia mostró ambigüedad clínica, requiriendo frecuentemente juicio especializado. Aunque el SINS mostró buena confiabilidad global, algunos componentes, como la calidad ósea, tuvieron menor concordancia interobservador. La integración con IA, en particular con modelos de lenguaje de gran escala, demostró potencial para mejorar la precisión y reducir la subjetividad. Conclusiones: El SINS se ha consolidado como una herramienta útil y confiable para evaluar la inestabilidad vertebral metastásica, mejorando la comunicación multidisciplinaria y la toma de decisiones terapéuticas. Sin embargo, persisten limitaciones relacionadas con la subjetividad y su naturaleza estática. La incorporación de la IA puede mejorar significativamente la precisión diagnóstica, permitiendo análisis más dinámicos e individualizados. Se recomienda explorar modelos predictivos integradores basados en datos clínicos, radiómicos y biológicos para optimizar la toma de decisiones clínicas. ***Nivel de evidencia V; Revisión Narrativa Estructurada no sistemática.***

Descriptores: *Neoplasias de la Columna Vertebral; Metástasis Neoplásica; Compresión de la Médula Espinal; Fracturas Vertebrales; Radioterapia Adyuvante; Inteligencia Artificial.*

INTRODUCTION

Vertebral metastases represent a significant and frequent clinical challenge in oncology patients, with incidence progressively increasing due to improvements in detection methods and primary treatments that prolong life expectancy.[1–5] These lesions may constitute the initial manifestation of disease in up to 20% of cases and are the most common type of skeletal tumor, with the spine as the most frequent site of bone involvement.[6,7] The complications arising from vertebral metastases have a major impact on patients' quality of life, ranging from local and radicular pain to spinal cord compression and mechanical instability, which in many cases require surgical intervention for decompression and stabilization.[8]

Historically, the diagnosis of spinal instability in patients with metastases has been inconsistent and often subjective, depending largely on the individual surgeon's experience.[3] To standardize and improve this assessment, the Spine Oncology Study Group (SOSG) developed, in 2010, the Spinal Instability Neoplastic Score (SINS). This evidence-based and expert consensus classification system was created to enhance diagnostic quality of instability and to facilitate triage of patients in emergency units. SINS evaluates six specific parameters – location of the lesion, mechanical pain, bone lesion quality, spinal alignment, vertebral body involvement, and posterior element involvement – assigning points that classify the spine as stable (0–6 points), indeterminate (7–12 points), or unstable (13–18 points).[2]

The applicability of SINS has been shown to improve communication among medical specialties and optimize patient referral, resulting in faster and more efficient access to specialized teams. Patients with SINS scores between 7 and 18 are formally recommended for evaluation by a spine specialist.[4] Studies indicate that higher SINS categories are directly associated with more severe grades of epidural spinal cord compression (ESCC), with a greater likelihood of surgical interventions and spinal instrumentation.[8] Beyond its primary function in evaluating mechanical instability, recent evidence challenges the initial notion that SINS lacks prognostic value, suggesting that a high SINS ($\geq$13) may be associated with significantly shorter overall survival in patients with metastatic cervical spine cancer, potentially reflecting the biological aggressiveness of the tumor.[6] SINS has also proven useful as a surveillance tool for monitoring progression of instability in patients treated with radiotherapy.[8]

Despite these advantages, the practical application of SINS faces challenges. A high proportion of patients fall into the "indeterminate" stability category (approximately 69.14% in one study), which still requires subjective clinical judgment from a specialist to define management. Moreover, the SINS scale does not account for the presence of multiple metastatic lesions as a modifying factor in instability criteria, even though it is common for many patients to present with three or more lesions (62.96% in some studies). While SINS has demonstrated improved interobserver agreement in stability assessments among professionals, the reproducibility of treatment decisions among spine surgeons has remained low (between 0.248 and 0.265 Kappa), underscoring the persistent reliance on clinical judgment and practice patterns, especially in the complex intermediate zone (7–12 points).[4]

In this scenario of diagnostic and decision-making complexity, artificial intelligence (AI) and, specifically, large language models (LLMs) such as ChatGPT-4, emerge as promising tools.[6] Studies indicate that ChatGPT-4 aligns with the recommendations of most human surgeons in a significant proportion of treatment choices for vertebral metastases (73%), offering support in image analysis, diagnosis, patient stratification, and decision-making. However, AI recommendations still tend to be generalized, and the quality of results is intrinsically linked to the quality of training data, raising important ethical concerns regarding potential biases, data privacy, and the increasing influence of industry in clinical management.[9]

Against this multifaceted backdrop, the present article aims to review the current literature on instability in vertebral metastases and, in light of the most recent knowledge, identify the applicability of SINS, its advantages, limitations, and the perspectives of its integration with new technologies, such as artificial intelligence, in optimizing management and clinical decision-making.

METHODOLOGY

A structured narrative review was conducted with the aim of evaluating the current literature on vertebral instability in metastases, with emphasis on the applicability of the Spinal Instability Neoplastic Score (SINS), its advantages, limitations, and perspectives.

Search strategy

The bibliographic search was carried out exclusively in the PubMed/MEDLINE database, covering the last 10 years (2015–2025). Free-text terms and MeSH (Medical Subject Headings) descriptors were combined using Boolean operators, encompassing topics related to vertebral instability, spinal metastases, SINS, and emerging technologies. The search strategy used was:

("Spinal Instability Neoplastic Score" OR "SINS" OR ("spinal instability" AND (metastatic OR metastases)) OR "spine instability" OR "metastatic spine instability") AND ("vertebral neoplasms" OR "spinal neoplasms" OR "spinal metastases" OR "spine metastases" OR "metastatic spine disease")

Inclusion and exclusion criteria

We included original articles, systematic reviews, narrative reviews, guidelines, and expert consensus documents addressing vertebral instability related to metastases and/or the application of SINS. We excluded studies related exclusively to trauma or degenerative instability, isolated case reports without clinical application of SINS, and publications without full text available.

Study selection and data extraction

Selection was conducted in two stages: screening of titles and abstracts, followed by full-text reading of potentially eligible articles. For each included study, the following information was extracted:

authors, year of publication, study type, population analyzed, main objectives, assessment of SINS (validity, reliability, clinical impact), integration with new technologies, and main conclusions. Data were organized into a standardized spreadsheet for narrative synthesis.

Data analysis

The selected studies were analyzed descriptively, focusing on the identification of advantages and limitations of SINS, as well as the most recent evidence assessing its integration with artificial intelligence, machine learning, and radiomic tools.

RESULTS

The search yielded 342 results, of which 186 were excluded due to lack of full-text availability. Following title, abstract, and full-text screening, 27 publications met the inclusion criteria. The studies are listed in Table 1.

The analysis of 27 studies included and published over the past ten years demonstrates a growing interest in the use of the Spinal Instability Neoplastic Score (SINS) for assessing vertebral instability in patients with spinal metastases. Of the total studies, 7 (26%) were

Table.

Author/Year	Study Type	Sample	Main Objective	Outcomes Assessed
Okai et al., 2025[7]	Systematic Review and Meta-analysis	13 articles, total of 1822 patients with intermediate SINS (7–12). 834 patients from 5 studies for meta-analysis of interventions.	To evaluate demographics, tumor histology, management (surgery or radiotherapy), and outcomes of patients with intermediate SINS.	Differences in surgical vs. radiotherapy-only management, complication rates, vertebral fracture rates, need for surgery after radiotherapy. Changes in KPS and ECOG scores, and PROMs (SOSGOQ, SF-36, EQ-5D, Pain NRS).
Confavreux et al., 2021[10]	Review	Not applicable (literature review). Discusses 30 spine surgeons regarding SINS.	To discuss the standardization of vertebral lesions by SINS and its limitations, proposing numerical simulations for fracture risk assessment.	Not directly applicable to patient outcomes. Focuses on SINS reliability and fracture prediction.
Lenschow et al., 2022[11]	Retrospective, Single Center	331 patients with SINS 7–12 (140 SINS 7–9, 191 SINS 10–12).	To evaluate the clinical utility of spinal instrumentation in SINS 7–12 in terms of neurological outcome.	Neurological function (Frankel Score), surgical complications, surgical time, estimated blood loss.
Lee et al., 2025[12]	Retrospective, Single Center	286 patients with intermediate SINS (7–12). 72 patients in the cohort after propensity score matching (36 Denosumab, 36 Non-Denosumab).	To evaluate whether denosumab can improve spinal stability and reduce the conversion rate to surgery in patients with impending instability (intermediate SINS).	Conversion rate to surgery, improvement in SINS score (total, pain, bone lesion), and Hounsfield unit.
Chan et al., 2025[13]	Retrospective, Single Center	96 patients with spinal metastases (124 cases/MRI exams).	To evaluate the accuracy of SINS calculation using two large language models (LLMs: Claude 3.5 and Llama 3.1) compared to physician assessments.	Agreement (ICC and Gwet's Kappa) between LLM-derived total SINS and clinical reference standard; agreement for individual SINS components and overall accuracy of SINS category.
Bostel et al., 2021[14]	Retrospective	221 patients with osteolytic bone metastases in thoracic or lumbar spine.	To evaluate stability pre- and post-radiotherapy using SINS and Taneichi, verify concordance, and analyze predictive factors, SRE, and overall survival after radiotherapy.	Spinal stability (SINS and Taneichi) at baseline, 3 and 6 months after RT. Skeletal-related events (SRE). Pain response.
Serratrice et al., 2022[15]	Narrative Review	Literature review.	To describe changes and usefulness of SINS (including limitations for scores 7–12) in managing metastatic spine disease.	Not directly applicable to patient outcomes. Focuses on tool utility.
Kang et al., 2024[5]	Retrospective, Cohort, Single Center	106 patients undergoing surgical treatment for cervical metastatic cancer. 71 SINS 0–12, 35 SINS ≥13.	To compare patient characteristics and perioperative complications between low-to-moderate and high SINS groups.	Demographics, functional status (ECOG-PS, Frankel, KPS), cancer type, surgery type, surgical time, estimated blood loss, surgical complications.
Cavalcante et al.,[16] 2017	Prospective Cohort Analysis	105 patients with symptomatic metastatic spinal cord compression (MSCC) undergoing surgery.	To assess correlation between preoperative SINS and VAS (pain), pre- and postoperative association of VAS and AIS, and SINS and primary tumor type.	Preoperative SINS, VAS, AIS, primary tumor type.
Lee et al., 2021[17]	Systematic Review and Meta-analysis	21 studies, total of 2118 patients.	To outline accuracy and precision of total and individual SINS components for spinal instability in predicting vertebral compression fractures (VCFs).	Accuracy of SINS (total and components) in predicting VCFs. Interobserver precision/reliability of SINS (total and components).
Doyle et al., 2025[18]	Post-hoc Cohort Analysis	194 patients with 391 spinal lesions, followed for new or worsened fractures after RT.	To evaluate SINS as a predictor of vertebral compression fracture (VCF), the risk contributions of the 6 SINS factors, and other factors for fracture risk.	Occurrence of new or worsened vertebral fractures, total SINS and components, use of bone-strengthening medications.
Hussain et al., 2018[19]	Prospective Cohort, Single Center	131 patients undergoing surgical stabilization for metastatic spinal tumor.	To determine whether SINS correlates with patient-reported preoperative pain and disability, and whether surgical stabilization improves PROs.	Preoperative SINS, BPI and MDASI-SP (PROs) pre- and postoperatively, ASIA score, epidural spinal cord compression (ESCC) grade.

Author/Year	Study Type	Sample	Main Objective	Outcomes Assessed
van der Velden et al., 2017[20]	Prospective Observational Cohort	Patients with painful spinal metastases (≥2), treated with palliative radiotherapy (final sample not explicitly reported, but with response subgroups).	To investigate the relationship between the degree of spinal (in) stability (SINS) and response to palliative radiotherapy.	Complete pain response, overall pain response (complete and partial combined) after radiotherapy, spinal adverse events (SAEs).
Arana et al., 2016[21]	Independent Multicenter Reliability Study	90 patients with spinal metastases. 83 specialists from 44 hospitals (various specialties).	To evaluate intra- and interobserver agreement in using SINS by all physicians involved in management.	Intra- and interobserver agreement in SINS calculation, instability classification, and affected level localization; overall agreement with tumor board classification.
Fox et al., 2017[22]	Reliability Study	23 residents and 2 spine fellows. 30 selected cases with balanced SINS distribution.	To determine intra- and interobserver reliability of SINS among trainees (fellows and residents) and its role as an educational tool.	Intra- and interobserver reliability of total SINS and of each component.
Versteeg et al., 2023[23]	Multicenter Prospective Observational Cohort	307 patients treated for spinal metastases (174 surgery ± RT, 133 RT alone).	To investigate the association between total SINS, individual components, and patient-reported outcomes (PROs).	Total SINS and components, PROs (Pain NRS, SOSGOQ, SF-36, EQ-5D) at baseline and follow-up.
Kwan et al., 2025[24]	Systematic Review	39 articles included. Total of 1205 patients with intermediate SINS (7–12) in 8 studies, and 376 lesions in 4 studies focused on radiotherapy.	To systematically review outcomes and complications of patients with intermediate SINS undergoing radiotherapy, percutaneous interventions, minimally invasive, or open surgeries.	Pain scores, functional status, neurological outcome, ambulation, survival, and perioperative complications.
Yahanda et al., 2024[25]	Narrative Review	Not applicable (literature review).	To present a review of Artificial Intelligence (AI) in spine surgery, its use across all stages of the perioperative process, and applications for research.	Not applicable.
VERSTEEG, 2016[26]	International Retrospective Review	Patients undergoing stabilizing surgery or radiotherapy for metastases: 107 (67%) radiotherapy patients and 105 (66%) surgical patients were in the impending instability category (SINS 7–12).	To assess the impact of introducing SINS into routine clinical practice, comparing mean spinal instability scores in patients referred for surgery or radiotherapy before and after SINS implementation.	Mean spinal instability (SINS scores) in surgical versus radiotherapy cohorts, and changes in referral patterns.
Pennington, 2019[27]	Meta-analytic Review	7 studies.	To evaluate overall intra- and interobserver reliability of SINS and of each domain in patients with spinal metastases, and to perform meta-analysis across observers.	Overall intra- and interobserver reliability of SINS and of each domain.
Pennington, 2019[28]	Retrospective Cohort	51 patients with a total of 436 lesions.	To evaluate the need for stabilization within the "uncertain" (intermediate) SINS category.	Conservative or surgical treatment in patients with intermediate scores.
MIYAJI, 2023[29]	Retrospective Cohort	42 patients with castration-resistant prostate carcinoma.	To assess whether spinal instability, as determined by SINS, is a prognostic factor for survival in patients with castration-resistant prostate cancer spinal metastases.	Survival related to SINS.
Masuda, 2018[30]	Retrospective Study	44 patients who underwent decompression and stabilization for spinal metastases.	To evaluate the effectiveness of SINS in predicting surgical outcomes and survival.	Changes in Frankel score and Eastern Cooperative Oncology Group Performance Status (ECOG-PS), and patient survival assessed according to SINS, Tokuhashi, and Katagiri scores.
Bobinski et al., 2024[31]	Retrospective Cohort Study	256 patients (196 men and 60 women), mean age 70 (24–88 years).	To investigate the correlation between SINS and Epidural Spinal Cord Compression (ESCC) grades, and the association between SINS and preoperative ambulation and postoperative survival.	Correlation between SINS and ESCC grades, association between SINS and pre-surgical ambulation, and postoperative survival.
Dial et al., 2022[32]	Retrospective Cohort Study	Cohort of 211 patients.	To compare outcomes across different treatment modalities for metastatic disease with indeterminate instability (SINS 7–12).	Survival duration, need for retreatment, and other clinical variables.
Kim Y.H. et al., 2020[33]	Retrospective Observational Study	79 patients (47 in the initial conservative group and 32 in the initial surgical group).	To determine treatment strategies for "impending instability" in spinal metastases.	Treatment outcomes (surgery vs. radiotherapy) and management strategies for patients with intermediate SINS.
Dosani et al., 2018[34]	Retrospective Study	195 patients with a mean follow-up of 6.1 months.	To evaluate the impact of SINS on surgical referral patterns and outcomes.	Surgical referral patterns and SINS-related outcomes, specifically for patients with intermediate SINS.

systematic reviews or meta-analyses, addressing primarily the reliability of SINS, its accuracy in predicting fractures, and management strategies for patients with intermediate scores (7–12). Five (19%) were narrative reviews, focused on the conceptual limitations of SINS and on potential improvements, including integration with numerical models or artificial intelligence..

The 15 original observational studies (56%) included retrospective cohorts (10 studies), prospective cohorts (3 studies), and multicenter interobserver reliability studies (2 studies). Sample sizes ranged from 42 to 391 lesions, with broad representation of primary tumors such as breast, lung, and castration-resistant prostate cancer. (Figure 1)

In terms of objectives, three main trends were identified:

1. Prediction of vertebral fractures and survival (10 studies): validating SINS as a predictor of skeletal events or mortality in specific tumor subgroups.
2. Therapeutic decision-making in intermediate instability (SINS 7–12) (9 studies): exploring strategies of conservative management versus surgical intervention, the impact of adjuvant therapies such as denosumab, and the timing of conversion to surgery.
3. Reliability of SINS (5 studies): including multicenter analyses with specialists and residents, confirming good overall agreement but variability in individual components, particularly in the "bone quality" domain.

Two studies explored the application of emerging technologies, such as artificial intelligence and natural language models for automated SINS calculation, showing promising results in diagnostic accuracy.

The most frequently evaluated outcomes were:

- Neurological function (Frankel, ASIA);
- Pain and quality of life (VAS, SOSGOQ, SF-36, EQ-5D);
- Mechanical events (vertebral fracture, need for reintervention);
- Overall survival.

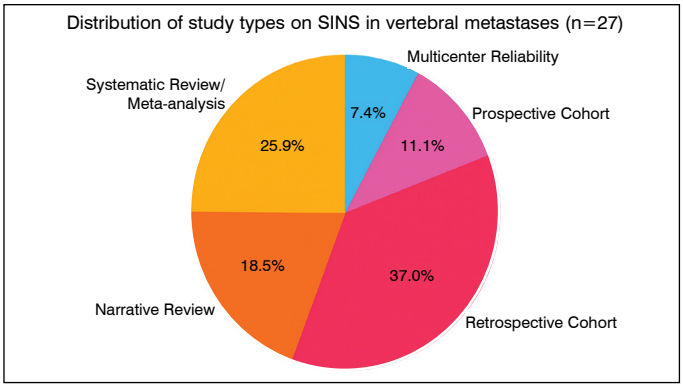

Figure 1. Distribution of the types of studies included in the review.

DISCUSSION

The Spinal Instability Neoplastic Score (SINS) was primarily designed to classify spinal instability in patients with neoplastic metastases, assisting in guiding therapeutic decisions. However, its role has expanded to include the prediction of vertebral fracture (VF) risk and survival prognosis, although results require careful interpretation.

Regarding fracture prediction, the meta-analysis by Lee et al.[17] indicated that SINS has moderate diagnostic power for predicting radiotherapy-induced VFs, with a pooled sensitivity of 0.79 and a pooled specificity of 0.54, highlighting a substantially low specificity. This study emphasizes that SINS was not originally developed to predict post-radiotherapy fractures and that, although some of its components—such as vertebral body collapse and lytic bone lesions—showed correlation with VF incidence, others (location, pain, alignment, and posterolateral involvement) demonstrated negligible associations. Complementarily, Doyle et al.[18], in a single-institution study, validated the cumulative SINS score as a significant predictor of post-radiotherapy fracture risk ($P < 0.01$). Specifically, lesion location at L2–L4, mixed or lytic morphology, and vertebral collapse of less than 50% were identified as the strongest individual predictors of fracture. This study also suggested that the inclusion of bone-strengthening medications, such as bisphosphonates, may mitigate VF risk after radiotherapy. Collectively, these findings suggest that, although SINS is a useful tool for estimating VF risk, its accuracy may be improved by considering more predictive individual components and weighting specific risk factors.

With respect to survival prediction, Miyaji et al.[29] investigated patients with castration-resistant prostate cancer and found that those with unstable spines (SINS ≥ 7) had significantly reduced survival compared to those with stable spines (SINS ≤ 6), with a hazard ratio of 2.60 (95% CI, 1.07–5.93; $p = 0.0345$). This finding suggests that a high SINS may not only indicate mechanical instability but also reflect tumor biological aggressiveness and greater predisposition to systemic dissemination. Similarly, Masuda et al.[30], in a retrospective study of patients undergoing decompression and stabilization for spinal metastases, demonstrated that median survival was significantly better in the stable SINS group (SINS ≤ 12). Although the study by Masuda et al. was limited by selection bias (including only surgically treated patients with relatively high SINS scores, limiting generalizability), it concluded that SINS is appropriate for surgical decision-making and may be used to predict survival. These results point to the dual potential of SINS as a tool that not only assesses mechanical stability but also provides insights into tumor biology and overall prognosis, which is crucial in formulating comprehensive treatment strategies for patients with spinal metastases.

Therapeutic decision-making for patients with spinal metastases in the indeterminate instability category (SINS 7–12) remains a major clinical challenge, characterized by uncertainty and the need for complex clinical judgment. This "gray zone" encompasses most patients requiring treatment, and management decisions are often based on multidisciplinary tumor board review.

Several management strategies have been explored. A systematic review by Okai et al.[7], analyzing 13 articles, revealed that although overall complication rates are similar between surgical management (with or without radiotherapy) and radiotherapy alone in the intermediate SINS category, the types of complications differ, with wound-healing problems being more common after surgery and vertebral fractures as the primary complication after radiotherapy. Dial et al.[32] compared treatment strategies for intermediate SINS, including external beam radiotherapy (EBRT) alone, surgery with EBRT (S+E), and cement augmentation with EBRT (K+E). They concluded that surgical stabilization (S+E) was independently associated with longer survival and ambulation compared with EBRT alone. The K+E group showed excellent results, with the lowest retreatment rates. Importantly, patients with radioresistant tumors and intermediate SINS should not be treated with EBRT alone, given the high retreatment rates observed. Kim et al.[33], when evaluating treatment strategies for impending instability, observed a trend toward less deterioration in Karnofsky Performance Status in the surgically treated group, although no statistically significant differences were found in outcomes or need for reoperation among the intermediate SINS subgroups.

The adoption of SINS has influenced surgical indication trends. Okai et al.[7] demonstrated that a significantly greater proportion of patients in the SINS 10–12 subgroup received surgical management (77.2% vs. 53.4% in the 7–9 group), with odds more than six times higher for surgical intervention compared with the 7–9 group. This suggests that patients with SINS scores of 10–12 and estimated survival ≥3 months may benefit from stabilization, especially considering the larger lytic area and higher probability of vertebral body fracture in this subgroup. The introduction of SINS into clinical practice has resulted in a decrease in mean SINS scores among patients referred for surgery and radiotherapy, which may indicate earlier diagnosis and referral for intervention.

In terms of outcomes, patients undergoing surgery generally demonstrate more significant improvements in patient-reported outcome measures (PROMs), such as pain and quality of life, compared with those receiving radiotherapy alone. However, not all studies support

a clear distinction in surgical management within the intermediate category. Lenschow et al.[11] found no significant differences in neurological outcomes between instrumented and non-instrumented patients in the SINS 7–9 or 10–12 subgroups, despite the increased risk of complications with instrumentation. Finally, adjuvant therapies such as denosumab have shown potential. Lee et al.[12] reported that denosumab significantly reduced the conversion rate to surgery in patients with impending instability (intermediate SINS) and led to improvements in total SINS scores, pain, bone lesion, and Hounsfield units (HU). This establishes it as a viable treatment option to enhance stability and potentially reduce surgical need in this population. The heterogeneity of findings and the inherent complexity of decision--making for intermediate SINS patients underscore the ongoing need for individualized and multidisciplinary approaches.

The reliability of SINS is a cornerstone for its clinical application, and studies have consistently validated its robustness, although with variations among its components. Meta-analyses, such as that by Pennington et al.[27], demonstrated almost perfect intraobserver reliability and substantial interobserver reliability for the total SINS score. However, agreement for SINS categories (stable, indeterminate, unstable) was slightly lower, being substantial for intraobserver and moderate for interobserver assessments. Reliability evaluation of individual SINS components revealed notable discrepancies. While lesion location and pain character showed the highest agreements (almost perfect intraobserver and substantial-to-almost perfect interobserver), bone lesion quality consistently demonstrated the lowest reliability (moderate intraobserver and poor interobserver). Arana et al.[21] observed that, in routine clinical practice conditions, interobserver agreement for total SINS score was only moderate, but "almost perfect" for identification of the most affected vertebral level. Fox et al.[22] highlighted that SINS is a reliable educational tool for spine surgery residents and fellows, with most subcomponents showing moderate-to-almost perfect agreement, except for bone quality. This variability in individual components underscores the inherent subjectivity of certain criteria and the importance of clinical judgment, even when using a standardized scale.

To overcome these limitations and improve reproducibility, integrating SINS with new technologies such as artificial intelligence (AI) and natural language models (LLMs) has emerged as a promising frontier. A recent study by Chan et al.[13] evaluated the accuracy of LLMs in computing SINS from radiology reports and electronic health records. The results were remarkable: the Claude 3.5 model demonstrated high accuracy (ICC = 0.984) in calculating total SINS, outperforming another LLM (Llama 3.1) and being comparable to clinical evaluators. Moreover, Claude 3.5 achieved almost perfect agreement across all individual SINS components, including those historically showing lower reliability, such as bone lesion quality and pain. This suggests that LLMs can significantly enhance reproducibility, reduce subjectivity, and optimize diagnostic efficiency by automating structured tasks and analyzing large data volumes consistently. Yahanda et al.[25] further support that AI can be trained to analyze vast datasets, generate models, identify associations, and make predictions at speeds unattainable without modern computational power. Applying AI to SINS may enable more dynamic analyses, moving beyond static scale evaluation to deeper insights into bone strength and fracture risk through finite element models based on quantitative CT (qCT). Although the quality of AI-generated results depends on training data curation and requires ongoing validation, the potential of AI-driven tools to enhance accuracy and consistency in spinal instability assessment represents a major advancement for clinical decision-making in patients with vertebral metastases.

Therefore, despite the consolidated role of SINS as an essential clinical tool, it is crucial to integrate more dynamic analyses and consider additional aspects such as specific tumor biology, temporal progression, and the use of emerging technologies to optimize clinical decisions, especially in cases with intermediate scores. Future research should focus on refining additional criteria and developing dynamic predictive models, strengthening the accuracy and safety of therapeutic decisions for patients with vertebral metastases.

CONCLUSION

The literature of the past ten years demonstrates that the Spinal Instability Neoplastic Score (SINS) has been consolidated as a fundamental tool for assessing vertebral instability in patients with spinal metastases, with a direct impact on supporting multidisciplinary decision-making.

Although it has shown good overall reliability, particularly among experienced specialists, important limitations remain, such as its static nature, low specificity in predicting post-radiotherapy fractures, and significant uncertainty in the intermediate range (7–12 points). The integration of SINS with emerging technologies, such as artificial intelligence and machine learning, holds promising potential to enhance diagnostic accuracy, reduce subjectivity in assessments, and provide dynamic, individualized predictive models. Future research should focus on this technological integration to improve risk stratification, decision-making efficiency, and, consequently, clinical outcomes in patients with vertebral metastases.

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