Global Spine Journal
2026, Vol. 0(0) 1-9

DOI: 10.1177/21925682261426936
journals.sagepub.com/home/gsj
Sage

AO Spine Clinical Practice Recommendations: An Overview of the Current State of Fusion Surgery for Patients With Spinal Metastasis: Is Fusion Necessary?

Federico Landriel, MD[1], Fabio Cofano, MD[2], Santiago Matías Hem, MD, PhD[3], Syed Muhammed Karim, MD[4], Ankit I. Mehta, MD[5], Ori Barzilai, MD[6], Nicolas Dea, MD, MSc, FRCSC[7], Alessandro Gasbarrini, MD[8,9], C. Rory Goodwin, MD, PhD[10], Ilya Laufer, MD[11], Jeremy Reynolds, MBChB[12], Jorrit-Jan Verlaan, MD, PhD[13], Charles G. Fisher, MD, MHSc, FRCSC[7], and Cordula Netzer, MD, MBA[14]

Abstract

Study Design: Literature review with clinical recommendations.

Objective: Providing a clear and concise overview based on the of key literature and consensus expert opinion on spinal fusion following stabilization for spine metastases and offer actionable recommendations on when to fuse and not fuse in this patient population.

Methods: Key articles from the published literature on spinal metastases treated with stabilization followed by fusion were reviewed, and clinical recommendations were formulated. The recommendations are categorized as either strong or conditional based on an assessment of methodological quality and expert opinion. This assessment considers factors such as experience, risks, burdens, costs, patient values, and circumstances.

Results: Four articles were selected by practicing spinal oncology surgeons and each was evaluated for its methodological strength and its scientific evidence.

[1] Neurosurgical Department, Spine Unit, Hospital Italiano de Buenos Aires, Buenos Aires, Argentina
[2] Department of Neurosurgery, Neurosciences, University of Torino, Torino, Italy
[3] Neurosurgery Department, Hospital Italiano de Buenos Aires, Buenos Aires, Argentina
[4] Department of Orthopaedic Surgery, MedStar Georgetown Cancer Institute at MedStar Franklin Square Medical Center, Baltimore, MD, USA
[5] Department of Neurosurgery, University of Illinois at Chicago, Chicago, IL, USA
[6] Department of Neurosurgery, Memorial Sloan Kettering Cancer Center, New York, NY, USA
[7] Combined Neurosurgical and Orthopedic Spine Program, Department of Orthopedics Surgery, University of British Columbia, Vancouver, BC, Canada
[8] Department of Spine Surgery, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy
[9] Department of Biomedical and Neuromotor Sciences, University of Bologna, Bologna, Italy
[10] Department of Neurosurgery, Spine Division, Duke University, Durham, NC, USA
[11] Department of Neurosurgery, New York University Langone Health, New York, NY, USA
[12] Department of Spinal Surgery, Oxford University Hospitals NHS Foundation Trust, Oxford, UK
[13] Department of Orthopaedic Surgery, University Medical Center Utrecht, Utrecht, Netherlands
[14] Department of Spine Surgery, University Hospital of Basel, Basel, Switzerland

Corresponding Authors:
Federico Landriel, Neurosurgical Department, Spine Unit, Hospital Italiano de Buenos Aires, Tte. Gral. Juan D. Peron 4190, Buenos Aires C1199ABB, Argentina.
Email: federico.landriel@hospitalitaliano.org.ar

Cordula Netzer, Department of Spine Surgery, University Hospital of Basel, Spitalstrasse 21, Basel 4031, Switzerland.
Email: cordula.netzer@usb.ch

Conclusion: Fusion rarely influences clinical outcomes in metastatic spine surgery. Treatment should prioritize mechanical stability, pain control, functional preservation, and timely continuation of oncologic therapy rather than pursuing bony arthrodesis. Fusion should be considered exclusively in select long-surviving patients, however routine attempts to enhance fusion or delay adjuvant therapy are not justified.

Keywords

spinal metastases, fusion rate, literature review, bone grafts, hardware failure, pseudarthrosis, surgical site infection, wound healing complications, outcome

Introduction

Spinal metastases occur in up to 40% of patients with advanced cancer and represent the most frequent malignant lesions of the axial skeleton.[1–3] Advances in systemic oncology, radiotherapy, and minimally invasive stabilization have improved outcomes and extended survival for many patients. As a result, the long-term integrity of spinal constructs and the relevance of achieving bone fusion have become increasingly important considerations in reducing loosening and reoperations of oncologic spine surgery.[4,5]

Historically, spinal fusion was pursued to enhance mechanical stability and prevent hardware failure, mirroring principles from degenerative and traumatic pathologies.[4] However, the biological environment in metastatic disease differs substantially. Factors such as malnutrition, systemic therapies, poor bone quality, tumor-related osteolysis and radiation-induced osteonecrosis may impair osteogenesis and hinder the likelihood of arthrodesis.[6,7] Moreover, the limited life expectancy of many patients introduces a competing risk that often precludes the biological timeline required for fusion to occur.[4]

Recent literature demonstrates wide variability in reported fusion rates following stabilization for metastatic disease, ranging from as low as 6% to nearly 60%, depending on criteria for fusion assessment, imaging modality, follow-up duration, and survival.[3–5,8] Despite low rates of radiographic fusion, the incidence of hardware failure remains modest—typically under 10%—suggesting that achieving solid bony fusion may not be essential for clinical success.[4,7,9] Instead, the focus of modern oncologic spine surgery has shifted toward achieving immediate stability, durable pain relief, and maintenance of neurological function rather than long-term arthrodesis.[5,7,9] The surgical technique to achieve spinal fusion typically involves the placement of bone graft or substitute across adjacent vertebral segments, combined with internal fixation (e.g., pedicle screws and rods). Posterior instrumentation alone, without anterior reconstruction or formal fusion, has been shown to be safe and effective for palliation in most cases of metastatic spinal disease, particularly given the high competing risk of death.[7,9] Fusion may still be considered in carefully selected patients with longer expected survival and favorable bone quality, but this is not the standard approach.[5,10]

Accordingly, the AO Spine Knowledge Forum Tumor (AOSKFT)- a multidisciplinary, international group of experts in spinal oncology - undertook this review to provide a structured synthesis of the available knowledge on fusion following surgical stabilization for spinal metastases.

Methods

The AOSKFT comprises 8 steering board members, 7 advisory board members and 58 associate members. Key words for literature research included: spinal metastases, fusion rate, pseudarthrosis, radiotherapy, surgical site infection, outcome, wound healing complication. 12 articles meeting the inclusion criteria have been identified. Within a consensus meeting in the presence of the AOSKFT steering board 4 out of these 12 key articles were selected based on series size, data included, recency, and topic diversity. All 4 were selected because they address the necessity, feasibility, and clinical impact of spinal fusion in metastatic disease from complementary perspectives: survival-limited populations, long-term survivors, biological constraints, and comparisons of surgical approaches. Moreover, the selected studies reported explicitly radiographic or CT-confirmed fusion outcomes after surgery for spinal metastases.

The focus was on primary source publications rather than systematic reviews. Each article was summarized by 2 AOSKF associate members. The summaries were incorporated into a single document by the first and last authors, and all 8 members of the steering committee from the knowledge forum reviewed the final manuscript. Consensus was reached on the final clinical recommendations following a virtual meeting to review the summaries. Systematic reviews were referenced in the discussion to support the conclusions and recommendations developed based on the best quality evidence from the selected primary sources.

Studies were included if they met the following criteria:

Population: Adults with metastatic spinal disease undergoing instrumented stabilization followed by fusion with or without decompression.

Intervention: Spinal surgery with attempted fusion using autograft, allograft, or synthetic substitutes, with perioperative systemic or radiation therapy (RT) permitted.

Comparator: Alternative surgical approaches or materials, and presence or absence of radiotherapy.

Outcomes: Fusion rates (complete or partial) confirmed by imaging, hardware failure, reoperation rates, and relationship to survival.

Data Extraction: Patient demographics, primary tumor histology, surgical approach, graft type, radiotherapy regimen, imaging modality, and duration of follow-up were extracted. Particular attention was paid to definitions of fusion and methods of radiographic assessment, as heterogeneity was expected.

Synthesis: Due to variability in reporting and definitions, meta-analysis was not possible. Instead, each article was summarized according to rationale, main findings, methodological strengths and limitations, and practical recommendations. The synthesis aimed to highlight both consistent trends and uncertainties across studies.

Quality Assessment and Recommendation Framework: The certainty of evidence was assessed using the GRADE framework. Recommendations were categorized as strong or conditional based on methodological quality and expert consensus. In addition to study results, clinical judgment was informed by surgeon experience and practical considerations such as risks, burdens, costs, patient values, and individual circumstances.

Results

Study 1

Evaluation of fusion status in patients with a minimum 1-year survival post-oncologic spinal fusion. Wilson et al. Spine J. 2025 Apr 10: S1529-9430(25)00182-2. doi: 10.1016/j.spinee.2025.04.002.[5]

Clinical Rationale. Oncologic patients present an unfavorable environment for fusion (comorbidity, RT/chemotherapy). As survival for some patients with metastatic disease continues to improve, fusion may be an increasingly important goal to decrease the likelihood of spinal hardware failure and the need for revision surgeries. This study examines fusion rates in patients undergoing surgery for metastatic spine tumors who survive for at least 1 year, aiming to contribute data on factors that may influence fusion rates.

Clinical Summary. This retrospective, single-center study included 74 patients who underwent open posterior metastatic spine tumor separation surgery with instrumented fusion using morselized allograft or synthetic graft, survived for at least 1 year, and had a CT at 1 year to assess fusion status. Fusion status is assessed on CT at the facet joints cranial and caudal to the level of tumor decompression, with Hounsfield units (HU) of the fusion mass also measured. The rate of complete fusion was 10.8% while the rate of partial fusion was 59.5%. The incomplete bridging bone had no clinical impact. Neither post op chemotherapy nor radiotherapy was associated with a lower rate of fusion. The HU of the fusion mass was higher in patients who had undergone fusion.

There were 5 cases (6.8%) of mechanical complications: 4 cases of asymptomatic hardware loosening, managed conservatively, and 1 case of a superior endplate fracture, managed surgically. Construct failure was not associated with any subgroup.

Methodological Review. The fusion definition focused on adjacent facets to the level of tumor separation, but was not assessed on the resected tumor segment, where it is arguably far more critical for ensuring the construct's durability. Details regarding the posterior fusion technique (intertransverse or facet), extent of instrumentation, anterior column reconstruction, and degree of vertebral destruction by tumor are unavailable. Selection bias: only 43% of eligible patients who survived for 1 year after surgery were included in the study, as the majority did not undergo CT at 1 year. This limits the certainty of the reported main result, the fusion rate, even if one accepts the fusion assessment methodology provided in this study. While spine CT HU has been extensively reported as a method for determining bone mineral density and has demonstrated reliability in predicting instrumentation failure and pseudarthrosis, its role in assessing fusion quality remains unclear. Given the study design and the limitations above, this study provides very low-quality evidence (GRADE).

Recommendation for Integration into Clinical Practice. According to the GRADE methodology, a conditional recommendation is made for clinical/radiographic CT fusion assessment in patients with clinical suspicion of hardware failure. The assessment should not be done on a routine basis as the incomplete bridging bone appears to have no clinical impact.

Study 2

Survival, fusion, and hardware failure after surgery for spinal metastatic disease. Yee et al. J Neurosurg Spine. 2021 Jan 29; 34(4): 665-672. doi: 10.3171/2020.8. SPINE 201166.[4]

Clinical Rationale. The palliative aim of surgical treatment in metastatic spine disease–along with poor overall survival in this patient population–has resulted in limited data regarding fusion outcomes in metastatic spine surgery. With improving survival in patients with metastatic spine disease, fusion may be an important clinical endpoint to decrease the risk of symptomatic hardware failure and revision surgeries, but fusion remains challenging to achieve due to factors including adjuvant treatments and poor nutritional status. This study aims to evaluate the outcomes of patients who undergo surgery for metastatic spine tumors, focusing on fusion rates and hardware failure while accounting for death as a competing risk.

Clinical Summary. This study includes 164 adult patients between 1999 and 2018, who underwent decompression and instrumented fusion for spinal metastatic disease with different approaches. Complete fusion was defined as bony growth across at least one facet joint and/or intervertebral disc at all instrumented levels on CT, while partial fusion was defined as bony growth across at least one instrumented level. Though only 50.6% of patients had CTs available to assess fusion status, 82.6% of patients with missing CTs survived <6 months from surgery. The vast majority of patients received only allograft bone and some form of adjuvant radiotherapy. Median survival was 11 months in this cohort, with 23.2% achieving partial fusion and 6.1% achieving full fusion. When accounting for the competing risk of death, partial fusion occurred in 28.8% with complete fusion in 8.2%. The incidence of hardware failure was 4.2%

Methodological Review. This is a retrospective, single-center study evaluating fusion rate on CT for patients who have undergone metastatic spine tumor surgery using death as a competing risk. The heterogeneity of surgical techniques, the retrospective nature of the study, the ~50% of patients without CT data to assess fusion rates, and the low hardware failure rate, which limits multivariate analysis, represent the major limitations. The rigorous definition of "complete fusion" in particular is a strength. The analysis was properly conducted with time-dependent and risk-adjusted data. Using death as a competing risk is novel and important in the study design. This study provides very low-quality evidence (GRADE).

Recommendation for Integration into Clinical Practice. Based on the GRADE methodology there is a conditional recommendation that surgeons should work alongside medical oncologists to consider expected patient survival when deciding whether to attempt fusion along with spinal instrumentation in this patient population. The primary objective of surgery is to achieve immediate mechanical stability. The pursuit of additional bone fusion should not be driven by considerations of invasiveness, or the extent of surgery.

Study 3

The Effect of Perioperative Radiation Therapy on Spinal Bone Fusion Following Spine Tumor Surgery. Kim et al. J Korean Neurosurg Soc. 2016 Nov;59(6):597-603. doi: 10.3340/jkns.2016.59.6.597.[6]

Clinical Rationale. In most cases, several radiotherapy protocols are combined with surgery to treat spinal metastatic disease, aiming to better preserve the spine's stability and the integrity of the spinal cord or nerve roots. Nevertheless, fusion processes could be impaired by the detrimental effects of radiation on tissue healing. This paper aims to analyze fusion rate and factors affecting fusion in patients with spinal metastases after surgery and perioperative radiation treatment.

Clinical Summary. The study includes patients treated with surgery involving instrumentation and bone graft reconstruction combined with perioperative RT, both pre- or post-operatively. CT scans at follow-up were used to assess radiological outcomes in terms of bone fusion, as graded by the Bridwell system. A total of 33 patients were investigated with a mean follow-up of 30.4 months. The use of autograft appeared to be the only factor affecting bone fusion (75% in autograft vs 41% in allograft, $P = 0.049$). Fusion was performed using locally harvested autograft obtained during posterior decompression, supplemented with morselized allograft when needed. Iliac crest autograft was not used, as the surgical technique intentionally avoided donor-site morbidity in this oncologic population. Timing, type, and dose of radiotherapy did not impact fusion, nor did the location of the graft and surgical approach.

Methodological Review. This single-center retrospective analysis presents several limitations. The materials and methods paragraph describes a considerable part of the results, but no inclusion and exclusion criteria are presented, nor is the study protocol for follow-up. The mean follow-up of 30.4 months does not reflect survival of all patients with metastatic disease; it reflects a survivorship bias inherent to the study's inclusion criteria. The study does not specify the type of bone graft or biologic used, nor any technical details related to fusion, limiting interpretation of their fusion rates. The heterogeneity of the group, considering factors potentially impacting fusion, is only partially addressed, with no robust adjustment for confounders. Also considering the retrospective nature of the study, the quality of evidence is very low-quality (GRADE).

Recommendation for Integration into Clinical Practice. According to the GRADE methodology, a conditional recommendation is made for the consideration of the effects of radiation and grafts on bone graft fusion. Although radiotherapy protocols may exert a comparable effect on fusion rates, the selection of bone graft or biomaterial could be a salient factor. A local autograft could be considered to enhance the probability of fusion. When readily available and without added morbidity, the primary concern should be to minimize surgical intervention, as fusion generally exerts a negligible impact on clinical outcome in metastatic spine. The impact of radiation on fusion appears to be considerably less substantial than previously presumed in this patient population. It is imperative to refrain from postponing essential oncological treatments solely based on a conjectured negative effect of RT on fusion.

Study 4

Comparison of Outcomes in Patients with Cervical Spine Metastasis After Different Surgical Approaches: A Single-Center Experience. Chanbour et al. *World Neurosurgery.* 2024;181: e789–e800. doi: 10.1016/j.wneu.2023.10.127.[11]

Clinical Rationale. Spinal fusion after surgery for cervical spine metastases is poorly documented. This study provides valuable insights into fusion outcomes across three distinct surgical approaches and various anterior vertebral body reconstruction techniques.

Clinical Summary. This retrospective single-center cohort study included 61 patients with cervical spine metastases undergoing separation surgery and stabilization between 2010 and 2021. The primary comparison was the operative approach: anterior (18%), posterior (45.9%), or combined (36.1%). The secondary comparison was specific to patients who underwent anterior corpectomy only among (1) cortical allograft, (2) static cage filled with auto/allograft, and (3) expandable cage with auto/allograft. Postoperative neurological deficit was higher in the anterior group (18.2% vs 0% in the posterior group; P = 0.038). Dysphagia was most frequent in the combined group (54.5%; P = 0.010). The Karnofsky Performance Score (KPS) improved across all groups, reaching statistical significance only in the anterior group (59.1 to 82.2; P = 0.006). No significant differences among groups in overall survival (P = 0.655) or local recurrence (P > 0.999). Among the 51 patients alive at 3 months postoperatively (10 died in the first 3 months), only 19 (37.2%) had adequate follow-up imaging to assess fusion; 57.8% achieved radiographic fusion at a median of 8.3 months. Allograft was the most frequently used material for vertebral body replacement, followed by static cages and expandable cages. No significant differences in fusion rates were reported among graft types. The study did not report statistically significant differences in fusion rates between anterior, posterior, and combined approaches, though the small numbers and high loss to follow-up limit meaningful comparison.

Methodological Review. Single-center, retrospective cohort, moderate sample size, no randomization or robust multivariate adjustment. Fusion was evaluated by almost half of the patients using static radiographs, which limited its validity. Significant missing data, specifically for fusion assessment: substantial loss to radiographic follow-up (62.8% without imaging >3 months), introducing major risk of attrition bias. Fusion was determined by lack of interspinous motion >1 mm on flexion-extension x-ray (n = 6, 31.5%), intragraft/extragraft bridging bone on CT scan (n = 4.21%), or static AP x-ray (n = 9, 47.3%). Lack of blinded radiologic review or standardized time points undermines internal validity. High risk of bias with 62% lacking follow-up imaging. Among the 51 patients alive at 3 months, only 19 (37.2%) underwent follow-up imaging; fusion occurred in 11 (57.9%) with a median duration of 8.3 months (interquartile range, 4.6-13.7 months). It means, on the one hand, that 32 (62.8%) did not have adequate follow-up imaging to determine if a fusion had occurred, and on the other hand, that nearly half of the 19 evaluated patients (47.3%) had their fusion assessed with a suboptimal method, as static radiography is. Therefore, the number of evaluable patients for fusion, which is only 19, considerably limits the statistical power to detect differences by approach or graft type. Added to this, as previously mentioned, almost half were evaluated using a suboptimal method (it often overestimates rates of solid fusion). Limitations: Retrospective design, small sample, heterogeneity in tumor types, non-standardized fusion assessment, and potential surgical selection bias. Very little confidence in the estimate; the true fusion rates may be markedly different from those reported. The quality of evidence appeared to be of very low-quality (GRADE).

Recommendation for Integration into Clinical Practice. According to the GRADE methodology, a conditional recommendation is made for an individualized surgical approach. The decision should be informed by the extent of anatomical involvement, the degree of instability, and the surgeon's individual preferences. The extant body of research does not support the hypothesis that a specific surgical technique is superior to another. The selection of graft type, whether allograft, cage, or expandable device, is determined by patient anatomy, surgeon experience, and expected survival. However, there is an absence of evidence supporting the superiority of one graft over another.

Discussion

The surgical management of metastatic spinal disease presents a complex challenge, balancing palliative goals with the increasing need for long-term spinal stability due to improved patient survival. Achieving bony fusion in theory is probably important in maintaining spinal stability and preventing hardware failure, especially in patients with extended life expectancies.[1,10] However, the unique biological environment in metastatic spinal disease, characterized by factors such as malnutrition, poor bone quality, tumor-related osteolysis, significantly impairs osteogenesis and the likelihood of successful fusion.[6,7,12,13]

The literature on spinal fusion following stabilization for metastatic disease remains very limited and heterogeneous, reflecting variability in study design, population survival, imaging methods, and definitions of fusion. It is however a very challenging patient population to study and will likely remain so.

Fusion, Mechanical Stability and Biological Considerations

Presently, there is an absence of high-quality data that report on the relative prevalence or frequency of fusion vs non-fusion surgery in patients with spinal metastases. Most extant studies are retrospective and heterogeneous, and they do not systematically distinguish intentional fusion from instrumentation alone. Furthermore, the presence of limited survival, the competing risk of death, and inconsistent definitions of fusion result in substantial underreporting and survivorship bias. Earlier series focusing on cervical metastatic disease reported higher fusion rates, often based on less stringent radiographic criteria and with substantial loss to follow-up. Heidecke et al observed a 96.8% fusion rate in 62 patients following anterior cervical decompression and fusion, while Chuang et al and Omeis et al each reported 100% fusion in cohorts of 9 and 4 patients, respectively, after anterior or circumferential reconstruction.[2,13,14] Although these results appear excellent, they should be interpreted with caution; fusion assessment often relies on plain radiographs rather than CT, which cannot accurately distinguish true bony bridging from stable fibrous tissue or immobilized motion segments, leading to overestimation of fusion rates. Moreover, it is widely acknowledged that in cervical anterior surgery, higher fusion rates are observed.[2,13] Some of these older cohorts were small, highly selected, and enriched with longer-term survivors, which introduces a selection bias. Patients who lived long enough to allow fusion maturation were disproportionately represented, inflating reported success.[2,12]

Modern CT-based studies with survival-adjusted analyses offer a more realistic and clinically relevant picture of fusion outcomes in metastatic spine surgery, with fusion rates following stabilization for metastatic disease, ranging from as low as 6% to nearly 60%.[4,5] Study 1 reported a complete fusion rate of 10.8% and a partial fusion rate of 59.5% in patients surviving at least 1-year post-surgery.[5] Similarly, Study 2 found 6.1% full fusion and 23.2% partial fusion, with these rates dropping to 8.2% and 28.8% respectively, when accounting for the competing risk of death, emphasizing that incomplete or absent fusion is rarely correlated with clinical instability and the reality that many patients succumb before fusion can occur.[4] Study 4 observed radiographic fusion in 57.8% of patients at a median of. 8.3 months, though this was based on a subset of patients with adequate follow-up imaging and varied assessment methods.[11] These consistently low rates of complete fusion, coupled with a low incidence of construct failure (typically under 10%; 6.8% in Study 1; 4.2% in Study 2, and the experience of key opinion leaders in spine oncology suggest that achieving solid bony fusion is probably not essential for clinical success in most cases.

In recent series of patients treated with spinal instrumentation without any intentional attempt to achieve fusion, fixation alone provided sufficient mechanical stability to relieve pain, preserve neurological function, and support the timely initiation of adjuvant therapy. Importantly, hardware failure rates remained low and mostly without clinical repercussion despite the absence of biological fusion, underscoring that stabilization, rather than arthrodesis, is a primary goal in most patients with metastatic spine disease.[15,16]

In terms of **construct design** study Chanbour et al reported no statistically significant differences in fusion rates across anterior, posterior, or combined surgical instrumentations, although these findings were limited by small numbers and high loss to follow-up.[11] Altaf et al in a systematic review and consensus expert opinion of reconstruction in MSD recommend to ensure optimal mechanical stability the use of a prefabricated prosthesis and/or polymethylmethacrylate (PMMA) for anterior column reconstruction alone; bilateral posterior pedicle screw fixation above and below the anterior construct when anterior and posterior columns require resection and, in patients requiring posterolateral decompression without the need for anterior column reconstruction, bilateral posterior pedicle screw fixation at least one level above and one level below the involved segment.[10]

Circumferential reconstructions and structural autografts favor biological fusion but could require extensive soft tissue exposures, which may but also carry higher morbidity, longer recovery times, and delayed initiation of adjuvant radiotherapy compared to modern minimally invasive approaches.[1,2,17,18] Thus, 360° surgery should be reserved for cases of multicolumn instability or high risk of construct failure, rather than pursued routinely to improve fusion rates in these fragile patients.

The emphasis in metastatic spine surgery has shifted from achieving fusion to ensuring immediate mechanical stability. Granberg et al underscored that robust construct design and screw purchase are the primary determinants of long-term durability, with fusion playing a minimal role in preventing failure.[1] In the large cohort analyzed by Yee et al, mechanical failure occurred in only 4% of cases, despite low fusion rates, suggesting that solid arthrodesis is not a prerequisite for construct longevity. These findings support a paradigm shift toward "functional fusion," where stability, pain relief, and tumor control are prioritized over radiographic bony continuity.[4]

Adjuvant Therapies and Fusion

The interaction between **radiotherapy** and bone fusion remains controversial. Study 1 found no significant association between postoperative radiotherapy and decreased fusion rates, noting that fusion success correlated more closely with bone mineral density, measured in Hounsfield units, than with the type or timing of radiation.[5] Study 3 further supported this, indicating that the timing, type, and dose of radiotherapy did not significantly influence fusion outcomes.[6] These findings challenge the conventional assumption that adjuvant radiation invariably compromises bone healing. Conversely, Wong et al observed that high cumulative radiation doses may impair osteogenesis, particularly when combined with corticosteroid or bisphosphonate therapy, both of which further suppress bone remodeling.[3] Elder et al also noted that patients receiving radiotherapy experienced delayed fusion, with an average time to union of 6.1 months vs 4.3 months in non-irradiated cases.[12] Emerging data suggest, however, that stereotactic body radiotherapy (SBRT) at lower doses, administered more than 1 month postoperatively, may enhance fusion for autograft and allograft.[1] Some studies indicate that SBRT patients have higher fusion rates compared to conventional external beam radiation therapy (EBRT),[19] while others found no impact of RT timing, type, or dose on fusion rates for autograft/allograft.[6] Even so, it is important to recognize that the dose-dependent effects of radiation vary across tissues within the treated region: while higher doses may impair graft incorporation and fusion, appropriately dosed radiotherapy (Donaubauer et al), particularly in lytic metastases, can reduce or stop osteolytic agents and consequently promote bone formation and healing, thereby potentially enhancing construct stability. Some evidence suggests **chemotherapy** may have a direct inhibitory effect on bone healing.[20] The anti-angiogenic, antiproliferative, and cytotoxic properties of these agents disrupt neovascularization, inhibit callus formation, and interfere with host–graft incorporation, ultimately leading to reduced bone apposition and delayed consolidation.[21,22] Earlier experimental studies in animal models consistently reports that exposure to cyclophosphamide, doxorubicin, and methotrexate was associated with decreased osteogenesis and impaired bone remodeling.[23,24] Notably, in a rabbit posterolateral fusion model, administration of a single intravenous dose of doxorubicin at the time of surgery resulted in a marked reduction in autograft fusion rates compared with untreated controls.[25] More recently, systematic reviews and clinical series have provided higher-level evidence that chemotherapy can delay the time to fusion without necessarily reducing the overall likelihood of achieving union. Elder et al report that patients receiving perioperative chemotherapy demonstrated a significantly longer mean fusion time (6.0 vs 4.3 months) compared with those not exposed to systemic therapy,[12] yet no statistically significant difference in final fusion rates was observed.[1,5] This suggests that while chemotherapy may impede the graft interface osteogenesis, it would not have clinical impact.

While **immunotherapy** shows promise for improving overall survival and controlling metastatic spine disease growth no studies have directly assessed its impact on fusion in metastatic spine disease. Recent advances in oncology, particularly the use of immune checkpoint inhibitors (ICIs), have transformed cancer treatment and improved survival for many patients.[26] ICIs such as cytotoxic lymphocyte antigen-4 (CTLA-4), programmed cell death protein 1 (PD-1) or programmed death ligand 1 (PD-L1) inhibitors restore antitumor immune activity by reactivating cytotoxic T cells.[1] While their clinical benefit in oncological fusion remains limited, emerging preclinical and clinical data suggest these agents may exert protective effects on bone by reducing tumor-induced osteolysis and indirectly promoting osteogenesis.[12,27,28] Further clinical studies are needed to clarify how immunotherapy influences bone graft biology and fusion outcomes in this patient population.

Graft Selection

Selecting grafts in MSD must balance biologic fusion potential with mechanical stability and the realities of adjuvant therapy scheduling. Contemporary series emphasize that construct stability and patient biology often outweigh graft choice in determining success.[1,4,5]

Autograft is osteogenic, osteoinductive, and osteoconductive; thus, it retains the greatest fusion biologic potential. In tumor cohorts receiving perioperative RT, autograft showed higher fusion rates than allograft (75% vs 41%),[6] but its use is limited in oncology due donor-site morbidity, poor host bone quality, potential risk of microscopic tumor cell contamination, limited life expectancy, and may delay adjuvant therapy if it adds a harvest complication.[1,3,10,12]

Allografts, although less osteoinductive, maintain allograft properties and avoid donor-site morbidity. Akinduro et al report a significantly lower fusion rate at 12 months in the allograft-only cohort compared to the autograft cohort (37.5% vs 66.7%, respectively).[19] Even lower fusion rates between 16 and 18% at 12 months of the surgical stabilization were observed when morselized allograft alone was used to augment fusion efforts,4,8, with hardware failure rates of 2.6%.4 The cost and potential risks of disease transmission have prompted interest in synthetic materials.[29]

There are many beneficial alternatives to autografts and allografts with promising fusion results. **Synthetic substitutes**, such as hydroxyapatite and calcium phosphate cements, and **biologics** as demineralized bone matrix and bone morphogenetic proteins despite lacking one or more properties of autograft, may enhance fusion, though oncologic safety concerns persist.[30] Advantages of these materials include fewer complications, lower costs, and some of the osteoinduction, osteoconduction, and osteogenesis properties. Disadvantages encompass a lack of these properties altogether, as well as growth factor-induced carcinogenicity and complications.[12,31]

Across studies, autograft remains the gold standard for osteogenesis, consistently outperforming allografts and synthetic substitutes in fusion rates.[1,6] When easily obtainable and without added morbidity, local autograft may be used to support fusion. Nonetheless, surgical decision-making should focus on limiting operative burden, as achieving fusion rarely alters clinical outcomes in the metastatic spine setting. Newer osteobiologic materials have shown variable results in small series and warrant further study in metastatic cohorts. The ongoing transition toward biomaterials that combine osteoconductive and osteoinductive properties may offer a balance between safety and efficacy.[1]

Limitations

A critical limitation across all reviewed studies is the methodological quality, consistently rated as very low-quality evidence (GRADE). Common issues include retrospective designs, small sample sizes, heterogeneity in patient populations and surgical techniques, and significant variability in the definition and assessment of fusion. A major challenge was the substantial loss to follow-up, particularly for radiographic imaging, which severely limits the certainty of reported fusion rates and the ability to draw robust conclusions. The lack of standardized assessment methods, including the use of static radiographs which can overestimate fusion, further complicates interpretation. Publication bias, where studies with suboptimal fusion rates may be less likely to be published, also contributes to the challenge of drawing definitive conclusions.

Despite these challenges, we identified some recommendations grounded in consensus expert opinion and best available evidence.

Conclusions

Conditional Recommendations

- Surgeons should avoid investing additional operative time, resources, or morbidity in attempts to achieve fusion in most patients with metastatic spine disease, as current evidence does not demonstrate a consistent clinical benefit.
- Consider non-fusion fixation techniques, such as percutaneous or other minimally invasive instrumentation, to achieve the necessary mechanical stability in patients with metastatic spine disease. These approaches can provide rapid, reliable stabilization while avoiding the morbidity, added operative time, and limited biological benefit associated with attempting fusion.
- Adjuvant oncologic therapies should not be delayed out of concern for their potential impact on fusion; timely continuation of systemic treatment remains a priority.
- In carefully selected patients with favorable prognosis and longer anticipated survival, biological fusion may be considered, although its incremental clinical value remains uncertain and should be weighed against overall treatment goals.
- Consider using locally available autograft when feasible to modestly increase the likelihood of fusion, provided it does not add morbidity or require additional invasive harvest. However, graft selection should prioritize minimizing surgical burden or invasiveness.
- Given the inherent difficulty in accurately predicting survival, a pragmatic approach is to follow all instrumented patients with standard clinical and radiographic surveillance; this may vary by surgeon and or institution. Routine surveillance assessing for fusion should not be done unless symptoms suggestive of hardware failure arise. Patients should be educated around these symptoms.

A comprehensive review of the extant literature on the subject, which has not yielded consistent evidence of the long-term benefits of achieving fusion, coupled with the insights of our panel of experts, leads us to conclude that, in most cases of patients undergoing surgery for spinal metastases, the achievement of fusion is of negligible clinical significance. The primary objective continues to be durable "functional stability," in which mechanical stability, pain relief, tumor control, and early resumption of oncologic treatment are prioritized over radiographic bony continuity.

From a research perspective, to enhance comprehension of the function of radiotherapy, chemotherapy, and immunotherapy, or their combination in terms of fusion, it is recommended that future studies utilize standardized fusion assessment criteria, robust follow-up protocols, and detailed reporting on the timing and dosing of adjuvant therapies. From a clinical perspective, there are three factors to consider. Firstly, the consistently low fusion rates are indicative of a limited biological potential for arthrodesis in metastatic spine disease. Secondly, there is a growing body of evidence demonstrating that durable clinical and mechanical outcomes can be achieved without fusion. Consequently, further research centered on fusion may offer minimal additional value.

Acknowledgements

This work was organized by AO Spine through the AO Spine Knowledge Forum Tumor, a focused group of international spine tumor experts. AO Spine is a clinical division of the AO Foundation, which is an independent medically guided not-for-profit organization. Support was provided directly through AO Network Clinical Research.

ORCID iDs

Ankit I. Mehta https://orcid.org/0000-0001-6931-6095
C. Rory Goodwin https://orcid.org/0000-0002-6540-2751
Cordula Netzer https://orcid.org/0000-0001-7381-373X

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. Granberg HA, de Paulo Martins Coelho V, Palmer JD, et al. The effect of radiotherapy, chemotherapy, and immunotherapy on fusion rate in spinal surgery using osteobiologics for patients with metastatic spinal disease: a systematic review. *Neurosurg Rev*. 2024;47(1):796. doi:10.1007/s10143-024-02769-3.
2. Heidecke V, Rainov NG, Burkert W. Results and outcome of neurosurgical treatment for extradural metastases in the cervical spine. *Acta Neurochir (Wien)*. 2003;145(10):873-880. doi:10.1007/s00701-003-0107-1.
3. Wong YC, Chau WWJ, Kwok KO, Law SW. Incidence and risk factors for implant failure in spinal metastasis surgery. *Asian Spine J*. 2020;14(6):878-885. doi:10.31616/asj.2020.0034.
4. Yee TJ, Saadeh YS, Strong MJ, et al. Survival, fusion, and hardware failure after surgery for spinal metastatic disease.

J Neurosurg Spine. 2021;34(4):665-672. doi:10.3171/2020.8.SPINE201166.
5. Wilson S, Ward J, Bardeesi A, et al. Evaluation of fusion status in patients with minimum 1-year survival post-oncologic spinal fusion. *Spine J*. 2025;25(11):S1529-S9430. doi:10.1016/j.spinee.2025.04.002.
6. Kim TK, Cho W, Youn SM, Chang UK. The effect of perioperative radiation therapy on spinal bone fusion following spine tumor surgery. *J Korean Neurosurg Soc*. 2016;59(6):597-603. doi:10.3340/jkns.2016.59.6.597.
7. Suvithayasiri S, Santipas B, Wilartratsami S, Ruangchainikom M, Luksanapruksa P. Non-fusion palliative spine surgery without reconstruction is safe and effective in spinal metastasis patients: retrospective study. *Sci Rep*. 2021;11(1):17486. doi:10.1038/s41598-021-97056-2.
8. Alamanda VK, Robinson MM, Thompson JC, Kneisl JS, Patt JC. Necessity of bony fusion after surgical treatment of metastatic spine tumors. *J Am Acad Orthop Surg*. 2020;28(19):e853-e859. doi:10.5435/JAAOS-D-19-00244.
9. Drakhshandeh D, Miller JA, Fabiano AJ. Instrumented spinal stabilization without fusion for spinal metastatic disease. *World Neurosurg*. 2018;111:e403-e409. doi:10.1016/j.wneu.2017.12.081.
10. Altaf F, Weber M, Dea N, et al. Evidence-based review and survey of expert opinion of reconstruction of metastatic spine tumors. *Spine (Phila Pa 1976)*. 2016;41(Suppl 20):S254-S261. doi:10.1097/BRS.0000000000001819.
11. Chanbour H, Bendfeldt GA, Chen JW, et al. Comparison of outcomes in patients with cervical spine metastasis after different surgical approaches: a single-center experience. *World Neurosurg*. 2024;181:e789-e800. doi:10.1016/j.wneu.2023.10.127.
12. Elder BD, Ishida W, Goodwin CR, et al. Bone graft options for spinal fusion following resection of spinal column tumors: systematic review and meta-analysis. *Neurosurg Focus*. 2017;42(1):E16. doi:10.3171/2016.8.FOCUS16112.
13. Chuang HC, Wei ST, Lee HC, Chen CC, Lee WY, Cho DY. Preliminary experience of titanium mesh cages for pathological fracture of middle and lower cervical vertebrae. *J Clin Neurosci*. 2008;15(11):1210-1215. doi:10.1016/j.jocn.2007.11.011.
14. Omeis I, Bekelis K, Gregory A, et al. The use of expandable cages in patients undergoing multilevel corpectomies for metastatic tumors in the cervical spine. *Orthopedics*. 2010;33(2):87-92. doi:10.3928/01477447-20100104-12.
15. Park S, Lee K, Lee C, Jung JY, Park JH, Kim G, Kim K. Instrumented surgical treatment for metastatic spinal tumors: is fusion necessary? *J Neurosurg Spine* 2020;32(3):456-464. doi:10.3171/2019.8.SPINE19583. 31756698.
16. Silva A, Yurac R, Guiroy A, Bravo O, Morales Ciancio A, Landriel F, Hem S. Low Implant Failure Rate of Percutaneous Fixation for Spinal Metastases: A Multicenter Retrospective Study. *World Neurosurg* 2021;148:e627-e634. doi:10.1016/j.wneu.2021.01.047. 33484887.
17. Barzilai O, Bilsky MH, Laufer I. The role of minimal access surgery in the treatment of spinal metastatic tumors. *Glob Spine J*. 2020;10(2 Suppl):79S-87S. doi:10.1177/2192568219895265.
18. Conti A, Acker G, Kluge A, et al. Decision making in patients with metastatic spine. The role of minimally invasive treatment modalities. *Front Oncol*. 2019;9:915. doi:10.3389/fonc.2019.00915.
19. Akinduro OO, De Biase G, Goyal A, et al. Focused versus conventional radiotherapy in spinal oncology: is there any difference in fusion rates and pseudoarthrosis? *J Neuro Oncol*. 2022;156(2):329-339. doi:10.1007/s11060-021-03915-3.
20. Pountos I, Georgouli T, Blokhuis TJ, Pape HC, Giannoudis PV. Pharmacological agents and impairment of fracture healing: what is the evidence? *Injury*. 2008;39(4):384-394. doi:10.1016/j.injury.2007.10.035.
21. Hazan EJ, Hornicek FJ, Tomford W, Gebhardt MC, Mankin HJ. The effect of adjuvant chemotherapy on osteoarticular allografts. *Clin Orthop Relat Res*. 2001;385:176-181. doi:10.1097/00003086-200104000-00027.
22. Høgevold HE, Grøgaard B, Reikerås O. Effects of short-term treatment with corticosteroids and indomethacin on bone healing. A mechanical study of osteotomies in rats. *Acta Orthop Scand*. 1992;63(6):607-611. doi:10.1080/17453679209169718.
23. Burchardt H, Glowczewskie FP, Enneking WF. The effect of adriamycin and methotrexate on the repair of segmental cortical autografts in dogs. *J Bone Joint Surg Am*. 1983;65(1):103-108.
24. Friedlaender GE, Tross RB, Doganis AC, Kirkwood JM, Baron R. Effects of chemotherapeutic agents on bone. I. Short-term methotrexate and doxorubicin (Adriamycin) treatment in a rat model. *J Bone Joint Surg Am*. 1984;66(4):602-607.
25. Tortolani PJ, Park AE, Louis-Ugbo J, et al. The effects of doxorubicin (Adriamycin) on spinal fusion: an experimental model of posterolateral lumbar spinal arthrodesis. *Spine J*. 2004;4(6):669-674. doi:10.1016/j.spinee.2004.05.254.
26. Groszman L, Hubermann JA, Kooner P, Alamiri N, Bozzo A, Aoude A. The impact of adjunct medical therapy on survival after spine metastasis: a systematic review and pooled data analysis. *Cancers (Basel)*. 2024;16(7):1425. doi:10.3390/cancers16071425.
27. Morgen SS, Lund-Andersen C, Larsen CF, Engelholm SA, Dahl B. Prognosis in patients with symptomatic metastatic spinal cord compression: survival in different cancer diagnosis in a cohort of 2321 patients. *Spine (Phila Pa 1976)*. 2013;38(16):1362-1367. doi:10.1097/BRS.0b013e318294835b.
28. Lee SC, Shin MK, Jang BY, Lee SH, Kim M, Sung JS. Immunomodulatory effect and bone homeostasis regulation in osteoblasts differentiated from hADMSCs via the PD-1/PD-L1 axis. *Cells*. 2022;11(19):3152. doi:10.3390/cells11193152.
29. Antonacci CL, Davey AP, Kia C, Zhou H. Use of ceramic synthetic allografts in spine surgery: a narrative review with early basic science and clinic data of novel nanosynthetic bone graft. *J Spine Surg*. 2024;10(4):715-723. doi:10.21037/jss-24-55.
30. Inglis JE, Goodwin AM, Divi SN, Hsu WK. Advances in synthetic grafts in spinal fusion surgery. *Int J Spine Surg*. 2023;17(S3):S18-S27. doi:10.14444/8557.
31. Vaccaro AR, Chiba K, Heller JG, et al. North American spine society for contemporary concepts in spine care. Bone grafting alternatives in spinal surgery. *Spine J*. 2002;2(3):206-215. doi:10.1016/s1529-9430(02)00180-8.