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Research Article

Management of Minimally Invasive Spine Surgery in Spinal Metastases: A Comprehensive Systematic Review and Meta-Analysis on Strategies, Treatments, and Outcomes

Daniel Encarnacion-Santos[1,*], Gennady Chmutin[2], Egor Chmutin[3], Stepan A Kudryakov[4], Petr Baygushev[4], Renat Nurmukhametov[5], Medet Donasov[6], Dilerbek Nuriddinov[1], Arstanbekov Beksultan[1], Nazmin Ahmed[7], Sultan Mujib Dabiry[8], Peter Magembe Mrimba[9], Bipin Chaurasia[10]

[1] Resident, Department of Neurosurgery, Russian People's Friendship University, Moscow, Russia
[2] Professor, Department of Neurosurgery, Russian People's Friendship University, Moscow, Russia
[3] Associate Professor, Department of Neurosurgery, Russian People's Friendship University, Moscow, Russia
[4] Division of Vertebrology, Petrovskovo Academy, Moscow, Russia
[5] Associate Professor; Division of Vertebrology, Petrovskovo Academy, Moscow, Russia
[6] Department of Neurosurgery, Petrovskovo Academy, Moscow, Russia
[7] Neurosurgeon, Department of Neurosurgery, Ibrahim Cardiac Hospital and Research Institute, Shahbag, Dhaka, Bangladesh
[8] Department of Emergency Medicine, Medical Park Ankara Hospital, Ankara, Turkey
[9] Orthopedic Surgeon, Kilimanjaro Christian Medical University College, Moshi, Tanzania
[10] Department of Neurosurgery, Neurosurgery Clinic, Birgunj, Nepal

[*]Corresponding author: Daniel Encarnacion-Santos; Department of Neurosurgery, Russian People's Friendship University, Moscow, Russia. Tel: +79-253847196
Email: danielencarnacion2280@gmail.com

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Abstract

Background: Minimally invasive spine surgery (MISS) represents an effective and increasingly adopted treatment strategy for spinal metastases. Over one million Americans are diagnosed with spinal metastases each year, and just 1.5 million are reported to be diagnosed; only 40-70 percent are spinal metastases. More advanced current percutaneous treatments such as kyphoplasty and vertebroplasty have improved the status of patients previously ruled out for surgery. Osteoblastic and osteolytic spinal metastases can be assessed and treated with percutaneous microwave ablation.
Methods: A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The comprehensive search involved several databases, including ScienceDirect and PubMed/MEDLINE, and was performed using the PRISMA guidelines, R software, and Excel. Search terms included “minimally invasive approach in metastatic lesions of the spine and spinal cord” combined with terms specifying surgical techniques, rehabilitation methods, and associated pathologies. Only studies published in English from January 2012 to February 2025 were included.
Results: Our study was based on a comprehensive systematic review and meta-analysis of 2380 patients with spinal metastases who were treated with minimally invasive and traditional open approaches, specifically vertebroplasty and kyphoplasty. We found 1090 patients (46%) with spinal metastases, where 509 cases (21%) were treated with the minimally invasive approach (MISS), while the traditional open approach [traditional open surgery (TOS)] was used for 432 patients (18%). 1611 patients (67%) were intervened by the leves of the fractures. Affected levels, whose cement breaches were 752 patients (31%) with metastases and CSF leaking.
Conclusion: New concepts were also employed in the minimally invasive, open approach which began with minimally invasive procedures such as vertebroplasty and kyphoplasty, and proceeded to treatments like percutaneous microwave ablation. Simple radiation therapy and chemotherapy, including the use of second-generation bisphosphonates such as pamidronate, are recommended, as well as steroids such as dexamethasone and methylprednisolone.

Keywords: Minimally Invasive Surgery; Metastases; Kyphoplasty; Vertebroplasty

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Background

Minimally invasive spine surgery (MISS) for spinal metastasis is a complete and safe procedure, which is to execute a completely optimal and effective treatment for spinal metastases. Generally, around 70% of patients with spinal metastases will have spinal cord compression, and only 10% will produce an overflow of neurological symptoms, mostly pain, which will compromise the dynamic functionality of the spine and life. Over one million Americans are diagnosed with spinal metastases each year and just 1.5 million are reported to be diagnosed; only 40-70 percent are spinal metastases (1). The cause of these spinal lesions is the spread of cancer through the lymphatic system via the blood vessels, particularly the Batson venous plexus (2). Neurological problems of the spinal cord are commonly addressed by surgical decompression with laminectomy. While minimally invasive surgery in patients with spinal tumors may be at risk for future complications, more advanced current percutaneous treatments such as kyphoplasty and vertebroplasty have improved the status of patients previously ruled out for surgery (3). Osteoblastic and osteolytic spinal metastases can be assessed and treated with percutaneous microwave ablation. Bone cement filling provides a complete treatment for spinal stability, construction, and rehabilitation (4). Spinal metastases can be treated with corticosteroids, bisphosphonates, and chemotherapy. Almost all of the metastases have osteolytic uptake (71%), over 21% are mixed up, and only 8% have osteoblastic origin. Patients with chemotherapy, radiation, and surgical management are addressed by less invasive percutaneous methods. The vertebrae are afflicted in 45-86 percent in the vertebral body and about 40% posteriorly (5).

This study aims to assess the effectiveness of surgical intervention in patients with spinal metastases and the various postoperative pain management strategies involving spinal decompression and stabilization.

Methods

A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review focused on surgical outcomes and treatment modalities related to the minimally invasive approach to treating spinal lesions caused by spinal metastases. The comprehensive search involved several databases, including ScienceDirect and PubMed/MEDLINE, and was performed using the PRISMA guidelines. Statistical analyses were performed using SPSS software (version 26.0, IBM Corporation, Armonk, NY, USA), R 5.4 software, and Microsoft Excel. Search terms included “minimally invasive approach in metastatic lesions of the spine and spinal cord” combined with terms specifying surgical techniques, rehabilitation methods, and associated pathologies [International Prospective Register of Systematic Reviews (PROSPERO) ID: 1278340].

Based on the visual analog scale (VAS) score, Modified Tokuhashi score, and Bauer score, only studies published in English from January 2012 to February 2025 were included.

The population, intervention, comparison, and outcome (PICO) framework was used to define the study population, focusing on patients aged 18 to 85 years with spinal cord metastasis and possible spinal cord injuries (Figure 1).

Search Strategy and Medical Subject Headings (MeSH) Terms: The search strategy incorporated MeSH terms related to spinal cord metastases:

- "Spine metastasis/cerebrospinal fluid" (MeSH)
- "Spine metastasis/complications" (MeSH)
- "Spine metastasis/diagnosis" (MeSH)
- "Spine metastasis/diagnostic imaging" (MeSH)
- "Spine metastasis/diet therapy" (MeSH)
- "Spine metastasis/drug therapy" (MeSH)
- "Spine metastasis/epidemiology" (MeSH)
- "Spine metastasis/etiology" (MeSH)
- "Spine metastasis/mortality" (MeSH)
- "Spine metastasis/pathology" (MeSH)
- "Spine metastasis/physiopathology" (MeSH)
- "Spine metastasis/prevention and control" (MeSH)
- "Spine metastasis/psychology" (MeSH)
- "Spine metastasis/radiotherapy" (MeSH)
- "Spine metastasis/rehabilitation" (MeSH)
- "Spine metastasis/surgery" (MeSH)
- "Spine metastasis/therapy" (MeSH)

["spine" (MeSH Terms) OR "spine" (All Fields)] AND ["neoplasm metastasis" (MeSH Terms) OR "neoplasm" (All Fields)] AND ["metastasis" (All Fields) OR "neoplasm metastasis" (All Fields) OR "metastasis" (All Fields)].

Keywords: Additional keywords included “spine or spinal cord metastasis”, “MISS”, “surgery”, “tetraplegia”, “spinal cord and spinal column injuries and compression from metastases”, “instability”, “surgical approaches”, and “postoperative restoration and rehabilitation”.

Inclusion Criteria

- Age range: 18 to 85 years
- Biomechanical correction of spinal instability and pain caused by metastatic spread
- Management of spinal metastatic sites through stereotactic surgery and conventional radiotherapy
- Postoperative neurological outcomes or postoperative outcomes after spinal intervention in metastatic foci

Exclusion Criteria

- Patients with lower limb paralysis who do not meet surgical criteria established by the metastatic spine scales.
- Patients with tumor foci cannot meet the inclusion criteria for metastasis but rather originate in the same vertebra or anatomical point.
- Patients in pediatric ages, as they are not the focus of this research.

Data Collection: The collection of various studies may cover some collected data regarding the dissemination, invasion, or metastasis by spinal cord compression in terms of its management, diagnosis, and development through treatment, also examining the frequency of pain, numbness, tingling, and radiculopathy of the affected thoracic or lumbar root, details on the most commonly used or conservative surgical techniques, such as minimally invasive surgery, such as stabilization techniques including laminectomy or decompression that exert this type of vertebral invasion.

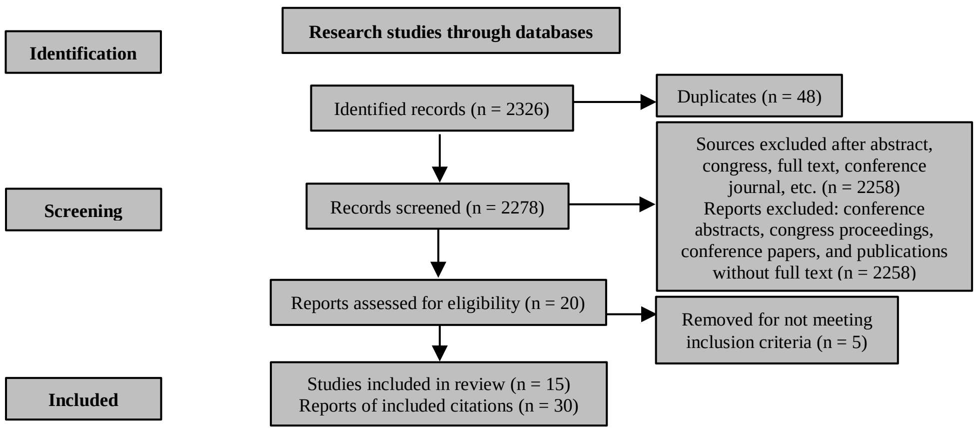

Figure 1. PRISMA on spinal metastasis flowchart

Data Extraction and Analysis: Data extraction was carried out through standard systems and a rigorous evaluation of the most relevant research articles. We collected all the important studies available. Detailed information about the studies was collected based on the literature, including demographic characteristics, interventions, control parameters in comparative studies, authorship, year of publication, and study design.

Risk of Bias Assessment: Based on the quality of the methodology of systematic and meta-analysis studies, the following data in the figures and tables were chosen, where it is demonstrated how the operating systems revealed a low risk of bias in the measurement of the intervention and the blinding of the outcome assessment and a high risk of bias in the selection of study participants.

The ROBINS-I and RevMan 5.3 software for bias were used to assess the risk of bias for non-randomized studies, which was able to assess, using its methodology, that it adhered to the PRISMA criteria to determine the degree of bias.

Adherence to Guidelines: This systematic review and meta-analysis followed the PRISMA guidelines on reporting preferred items for systematic reviews and meta-analyses, ensuring that the review was methodologically sound, transparent, and consistent. The PRISMA framework provided a structured approach to reviewing the scientific literature, ensuring minimal bias and improving reproducibility.

Quality Assessment: The quality and reliability of the included studies were assessed by critical analysis of six clinical trials on patients with spinal metastases. This critical analysis, described in table 1, of patients treated surgically with MISS or traditional open surgery (TOS), considered aspects related to the design and methodology, the adequacy of the sample size, possible biases and limiting factors, internal validity, and the reliability of the evidence of the effectiveness of minimally invasive approaches.

Statistical Analysis: Data analysis was performed using SPSS software, RevMan software, and Excel (shown in tables 1-5 and figures 1-9). The results were presented as mean ± standard deviation (SD) values. A P-value less than 0.05 was considered significant. Summary statistics such as mean differences and odds ratios (ORs) were used to characterize the outcomes of interest. To estimate outcome measures based on individual data from the included studies, a random effects model was applied. Statistical analyses were performed at the meaningful level of $P < 0.05$.

Results

The present research was founded on a thorough systematic review and meta-analysis involving 2380 patients with spinal metastases who underwent treatment using minimally invasive and traditional open techniques, specifically vertebroplasty and kyphoplasty (Table 1).

The study discovered 1090 patients with spinal metastases (46%) where the minimally invasive technique (MISS) was used for 509 patients (21%), while the conventional open technique (TOS) included 432 interventions (18%). From 1290 individuals with spinal metastases (54%), 1611 (67%) were intervened (Table 2). Moreover, there were 752 patients with metastases and CSF leaking (31%).

The results of the assessment of data heterogeneity can be seen in tables 1-4 and figures 1-8.

A review carried out in mid-2021 showed that the use of surgical metastasectomy is considered a modern systemic treatment. Since spinal metastases greatly compromise the health status of patients, introducing total en bloc spondylectomy (TES) as a method of spinal metastasis with a lower risk of tumor recurrence and complications. Therefore, the intralesional transpedicular osteotomy has a fine-wire saw for the procedure; adequate spinal metastasectomy, which does not come from spinal cord or nerve root injuries, even in primary patients with no evidence of disseminated extraspinal metastasis, with a widely or completely resectable solitary lesion in the spine and with a cardiac response or resistance to the development of surgery has also good outcomes. Excellent response has also been reported in kidney and thyroid metastases for spinal metastasectomy. (6).

Table 1. Minimally invasive spine surgery (MISS) and traditional open surgery (TOS)

Authors	Study design	Year	Sample size	MISS	TOS	Levels	Blood loss	Postoperative pain	P-value
Zhu et al. (7)	Retrospective-observational	2021	154	49	105	Thoracolumbar spine metastasis	Mean ± SD: 805 ± 138 ml vs. 1732 ± 359 ml	N/A	0.019
Saadeh et al. (8)	Retrospective	2019	40	20	20	Thoracic spine	748.57 vs. 950.48 ml	Mean ± SD: -1.71 ± 0.50 vs. 0.33 ± 0.70	0.018
Morgen et al. (9)	Non-blinded randomized controlled	2020	49	27	23	T5-L3	0.175 l vs. 0.500 l	N/A	0.002
Hansen-Algenstaedt et al. (10)	Prospective-observational	2017	60	30	30	N/A	Mean ± SD: 1156.0 ± 572.3 ml vs. 2062.1 ± 1148.0 ml	N/A	N/A
Hikata et al. (11)	Retrospective-observational	2017	50	25	25	Thoracolumbar	340.1 ml vs. 714.3 ml	44%	0.001
Kumar et al. (12)	Prospective cohort study	2017	45	18	27	Thoracolumbar	621 ml	N/A	< 0.001
Fang et al. (13)	Retrospective-observational	2012	41	24	17	Thoracolumbar spine	Mean ± SD: TOS: 1721 ± 293 ml; mini-open corpectomy: 1058 ± 263 ml	N/A	< 0.050
Miscusi et al. (14)	Prospective	2015	42	23	19	Thoracic	N/A	N/A	N/A
Lau and Chou (15)	Retrospective-observational	2015	49	21	28	Thoracic	917.7 ml vs. 1697.3 ml	N/A	0.019
Huang et al. (16)	Retrospective-observational	2006	46	29	17	Thoracic spine metastasis	1110 vs. 1162 ml	N/A	0.630
Quraishi et al. (17)	Retrospective	2013	153	45	53	Thoracolumbar spine	N/A	N/A	0.048
Lo and Yang (18)	Retrospective	2017	52	37	18	Thoracolumbar spine	N/A	N/A	0.003
Fan et al. (19)	Retrospective	2016	37	15	18	Spinal	N/A	N/A	< 0.001
Meyer et al. (20)	Retrospective	2022	140	46	N/A	Thoracolumbar	N/A	N/A	0.024
Younsi et al. (21)	Retrospective	2020	101	79	15	Thoracolumbar	N/A	49%	0.134
Tateiwa et al. (22)	Retrospective	2019	31	21	17	Thoracolumbar	N/A	N/A	< 0.001

MISS: Minimally invasive spine surgery; TOS: Traditional open surgery; SD: Standard deviation; N/A: Not available

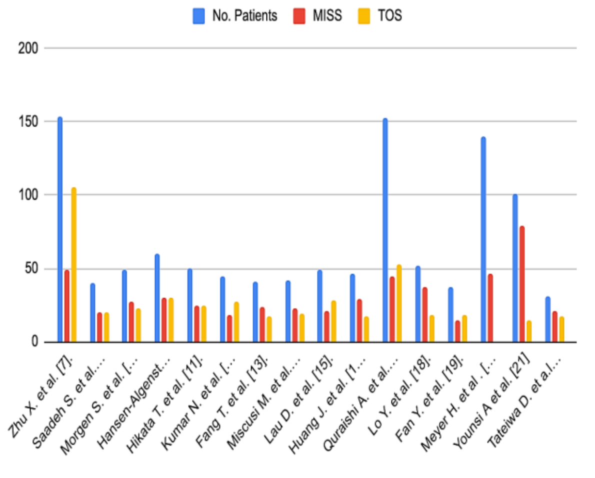

Figure 2. Representative graph of various studies of patients undergoing minimally invasive spine surgery (MISS) and traditional open surgery (TOS)

In addition, another relevant study was conducted in mid-2020 at the Rizzoli Orthopedic Institute in Bologna, Italy, and at the Cisanello Hospital in Pisa, Italy in 52 patients with spinal metastases, who summarized this pathology from 2001 to 2018, treated with the minimally invasive technique with percutaneous pedicle screw fixations, which later studies mention are more effective in degenerative diseases and trauma, with mini-decompressions in cases of spinal cord compression. The Frankel classification was employed both preoperatively and postoperatively, as well as the VAS score (23).

Table 3. The results of regression analysis of the patients with minimally invasive spine surgery (MISS) and metastasis

Parameter	Posterior			95% CI	
	Mode	Mean	Variance	Lower bound	Upper bound
TOS = 105	154.000	154.000	105.497	135.128	172.872
TOS = 15	101.000	101.000	65.435	86.137	115.863
TOS = 17	40.122	40.122	69.856	24.765	55.478
TOS = 18	47.673	47.673	99.411	29.353	65.993
TOS = 19	42.000	42.000	224.754	14.454	69.546
TOS = 20	40.000	40.000	258.467	10.460	69.540
TOS = 23	49.000	49.000	191.457	23.576	74.424
TOS = 25	50.000	50.000	206.774	23.579	76.421
TOS = 27	45.000	45.000	287.186	13.863	76.137
TOS = 28	49.000	49.000	246.159	20.172	77.828
TOS = 30	60.000	60.000	172.312	35.881	84.119
TOS = 53	153.000	153.000	114.874	133.307	172.693
TOS = N/A	140.000	140.000	112.377	120.522	159.478

Dependent Variable: Sample size; Model: TOS, Regression Weight Variable: MISS; d. Assume standard reference priors.

A recent retrospective study conducted in 2023, and based on the period between 2017 and 2020, sought to compare the treatment of extensive spinal metastasis in patients with minimally invasive spines with ultra-long construct navigation by surgery and radiotherapy with that of patients receiving radiotherapy alone. Knowing that spinal metastasis requires many interventions, whether surgery, radiotherapy, or chemotherapy, MISS spine surgery has been superior to open surgery, showing fewer complications and, therefore, a better postoperative response, remembering that radiotherapy is the most suitable alternative for those who do not qualify for surgery. There was no comparable baseline response or any difference between the two groups, albeit the longest anatomical construct in the series involved the T1 to the iliac. There was improvement in pain in both groups (P = 0.01); however, the minimally invasive ultra-long construct showed a lower VAS score following treatment (P = 0.003), indicating pain reduction. There was also no difference in survival. MISS is advised for improving multilayer participation; however, radiation therapy alone is recommended for pain alleviation (24-26).

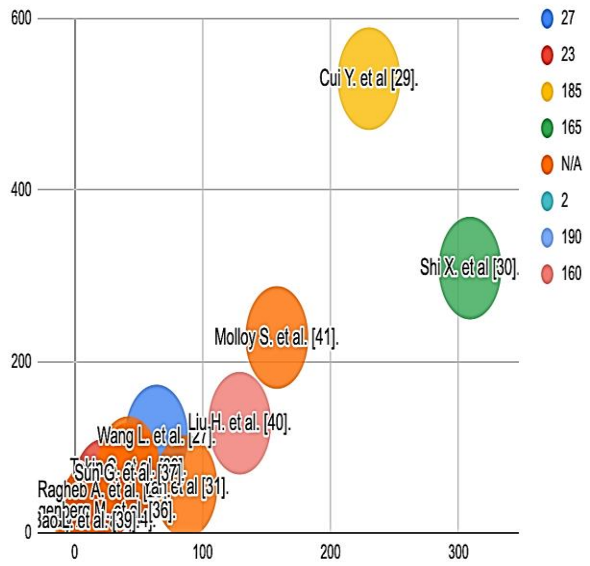

Figure 3. Patients with spinal metastases undergoing vertebroplasty and kyphoplasty for affected fractured vertebral levels

Table 2. Patients with spinal metastasis, treated with vertebroplasty and kyphoplasty

Authors	Year	Study design	Patients No.	Management	Levels vertebral fractures	Metastasis/ leaking	Follow-up	P-value
Wang et al. (27)	2022	Retrospective	64	PVP	113	27	N/A	0.001
Ragheb et al. (28)	2022	Retrospective	23	Vertebroplasty or kyphoplasty alone	50	23	39 months	< 0.050
Cui et al. (29)	2022	Retrospective	230	Vertebroplasty	530	185	N/A	0.024
Shi et al. (30)	2021	Retrospective	309	PVP	309	165	N/A	0.020
Yan et al. (31)	2022	Prospective	87	PVP	54	N/A	6-12 months	< 0.001
Xia et al. (32)	2021	Prospective	11	Kyphoplasty	N/A	2	6 months	< 0.001
Tekin et al. (33)	2020	Retrospective	42	Vertebroplasty and kyphoplasty	76	N/A	N/A	0.001
Sebaaly et al. (34)	2018	Retrospective case series	11	Kyphoplasty	15	N/A	6.1 months	< 0.050
He et al. (35)	2020	Retrospective	147	Kyphoplasty	N/A	190	1 year	0.010
Stangenberg et al. (36)	2017	Case series	14	Vertebroplasty	25	N/A	9 months	N/A
Sun et al. (37)	2014	Retrospective	43	Vertebroplasty	69	N/A	1 year	0.050
Zhang et al. (38)	2017	Retrospective	13	Vertebroplasty	N/A	N/A	3 months	0.001
Bao et al. (39)	2017	Retrospective	9	Vertebroplasty	14	N/A	6 months	< 0.050
Liu et al. (40)	2017	Retrospective	129	Kyphoplasty	128	160	12 months	> 0.050
Molloy et al. (41)	2016	Retrospective	158	Kyphoplasty	228	N/A	3 months	< 0.001

PVP: Percutaneous vertebroplasty; N/A: Not available

Radiosurgery has shown several complications, including vertebral fractures, whose pathophysiology is due to compression, and radiation myelopathy. Stereotactic radiosurgery and stereotactic body radiotherapy showed that vertebral fractures had an incidence of 0.7% and 40.5%, respectively. There may be variations depending on the type of treatment; radiation myelopathy is almost unreported due to poor initial compression. However, the spinal cord has shown tolerance of 14-16 Gy (42-44).

Global Spine Tumor Study Group

Adopting a Classification for Surgical Strategies:

1. It emphasized radical, complete, extralesional, and intralesional excision of the tumor-affected vertebra, emphasizing palliative decompression, tumor cytoreduction, or total vertebrectomy.

2. Approaches may include piecemeal excision and/or total vertebrectomy.

3. Besides, a blocking or piecemeal approach may be used; this type of excision will be a margin for resection of the tumor, whether intralesional or extralesional (45, 46) (Figure 4).

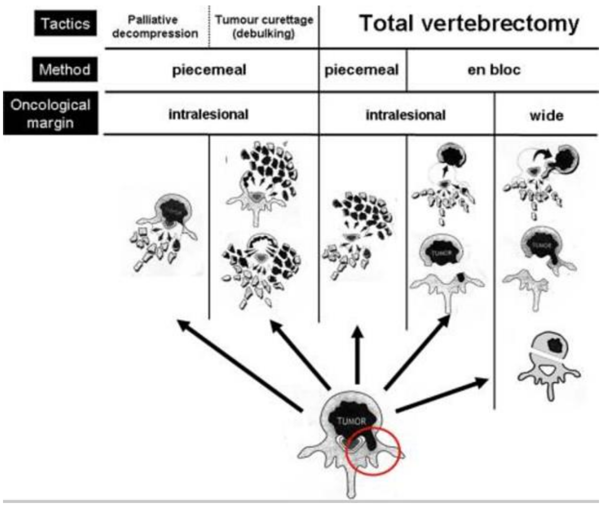

Figure 4. Classification for surgical strategies, according to Global Spine Tumor Study Group

Tokuhashi Score: This system was described by Tokuhashi in 1989 as a benchmark for preoperative evaluation based on a patient's prognosis for a metastatic spinal tumor. New references were also published between 2005 and 2009. The scoring system has six elements, considered to influence the overall prognosis; these include bone metastases other than spinal metastases, the number of spinal metastases, primary lesions, the presence or absence of metastases to major neighboring organs, and paralysis (47-49). According to survival periods, the scores are as≤3 months with a total score of 0-5, 12 months with a total score of 8, and more than 12 months with a total score of 9. The primary lesion was graded from 3 (0-2) to 6 (0-5), 0-8, 9-11, and ≥ 12 when it was ≤ 3 months, 6 months, 12 months, and more than 12 months (50-52).

Modified Tokuhashi Score

Bauer Score: Bauer and Wedin (53) developed a model system for survival following spinal surgery and extremity metastases that included five variables based on prognosis in non-primary lung cancer, solitary skeletal metastases, primary breast and kidney tumors, lymphomas, and myeloma, as well as in the absence of visceral metastases and pathological fractures.

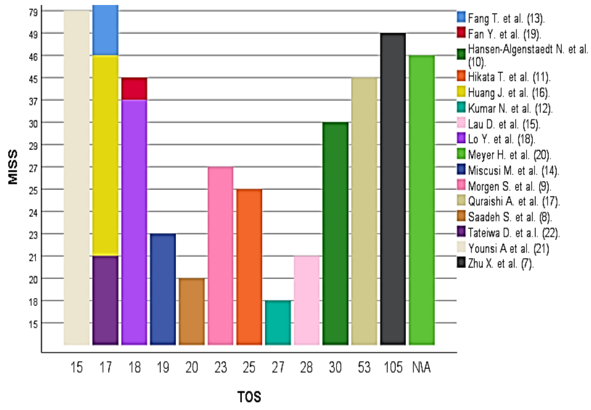

Figure 5. Comparison of procedures for patients with spinal metastases, minimally invasive spine surgery (MISS) vs. traditional open surgery (TOS)

A version of the Bauer score, which linked pathological fracture as a predictive indicator, was developed by Leithner et al. (54), and is still used to gradually transition from non-surgical treatment to extensive excisions (55).

Table 4. Modified Tokuhashi score for spinal metastases

Points	Predictive factors
0-2	General; poor, medium, good
0-2	Amount of metastases external of the vertebra, about three or more, one or two, none
0-2	Number of metastases in the vertebra, three or more, one or two, none
0-2	Visceral metastases, not removable, removable, none
0-5	Primary cancer: liver/gallbladder/unknown, others: kidney, uterus, rectum, thyroid/breast, prostate/carcinoid
0-2	Neurologic status-Frankel (E/C-D/A-B)
Score	**Treatment objective**
12-15	Excisional surgery

Modified Bauer Score

High-Grade Radioresistant Metastatic Spinal Tumors: Surgery + Spine Stereotactic Radiosurgery: This surgery is only for patients with high-grade radioresistant tumors compressing the spinal cord. The main objective is to restore neurological status, comparing conventional external beam radiotherapy alone. The positive results observed according to statistics are in terms of recovery of ambulation, maintenance of bowel and bladder continence, narcotic use, and survival. Positive neurological outcomes were obviously present in myelopathic patients with radioresistant tumors. Tumors that did not meet the criteria were radiosensitive tumors such as lymphoma and myeloma. Radiotherapy-resistant tumors and malignant solid tumors that did not respond to treatment were also included. Instability was not considered a contraindication to radiotherapy as a primary treatment. According to Cybulski's criteria, 30% of surgeries are considered unstable, following the bias of a surgical group. Understanding that irradiation was greater in the irradiated group elevated the better results of surgery.

Table 5. Modified Bauer score for spinal metastases

Points	Positive predictive factors	
1	No visceral metastases	
1	No lung cancer	
1	Primary tumor: breast, kidney, lymphoma, multiple myeloma	
1	Solitary metastasis	
Score	**Treatment objective**	**Surgical strategy**
0-1	Supportive care	No surgery
2	Short palliation	Posterior surgery
3-4	Local control	Anterior-posterior

Maintaining walking and two-step ambulation was significant in this group. Neurological recovery with conventional external beam surgery at one-year follow-up remains a complication in 70%. Radioresistant tumor recurrence was significantly higher. Radiotherapy alone was better compared to adjuvant therapy in the postoperative period, reducing the need for aggressive surgical approaches, such as en bloc spondylectomy (56-59).

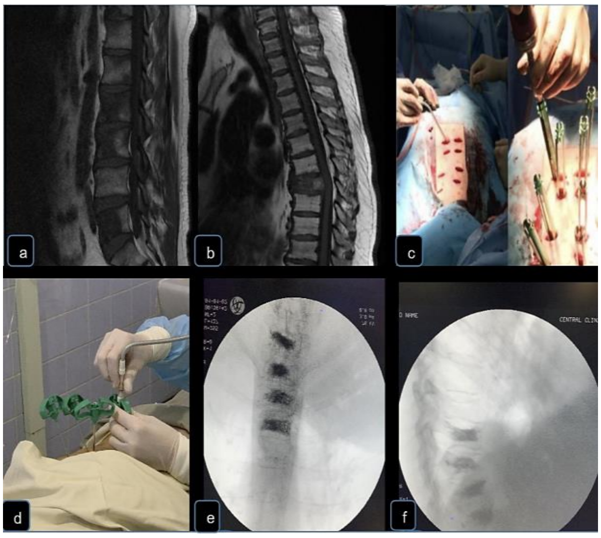

Figure 6. a) Multilevel lumbar metastasis; b) Magnetic resonance imaging (MRI) of thoracolumbar metastasis; c) Placement of percutaneous pedicle screws; d) Placement of cement over the guide after 3-5 minutes of drying; e and f) Multilevel axial and lateral vertebral correction for stabilization and pain control in the spine (With permission from the Petrovsky National Research Center of Spinal Surgery and Neurosurgery, Moscow, Russia)

Spine Metastasis

The spine is the most common site of metastasis. Depending on the location, metastases to the thoracic spine occur in up to 70% of cases, lumbosacral metastases occur in 25% of cases, and cervical metastases occur in up to 15% (60-62). Multiple metastases occur in up to 30%. The most common metastases are osteolytic, at 8%, and osteoblastic, at 21%; some are both osteolytic and osteoblastic. The most common primary cancers responsible for osteolytic lesions include breast and lung cancers, as well as melanoma, renal cancer, and thyroid cancer. The most common osteoblastic primary cancers include carcinoid, medulloblastoma, nasopharyngeal, prostate, and urothelial cancers (63-65). Mixed osteolytic and osteoblastic cancers occur in the breast, cervix, lung, and ovaries cancers. Regarding the detection of early spinal metastases, they are difficult to detect by radiography, as they must have at least 50% mineral loss and be at least 1 cm in diameter (66-68). Bone scintigraphy also helps detect spinal metastases due to its high sensitivity of up to 60-100 percent and specificity of 70-100 percent. In some cases of avascular osteolytic lesions, scintigraphy cannot detect some effects or misses some, and with degenerative changes, the uptake of the tracer may be increased (69, 70). Fluorine-18 fluorodeoxyglucose (18F-FDG) positron emission tomography (PET)/computed tomography (CT) has a higher sensitivity (80-100 percent) and specificity (99%) than bone scintigraphy (71, 72).

Contralateral Pedicle Osteotomy

This is known as a contralateral pedicle and posterolateral root resection (COPPER) procedure.

This procedure involves performing a laminectomy above and below the tumor to expose the dura mater, similar to the contralateral hemilaminectomy, which connects them. The ipsilateral pars interarticularis is removed, adding the articular facets superiorly and inferiorly to the formation. The pedicles and nerve roots are exposed on the tumor side when the osteotomy is performed through the contralateral approach (73, 74).

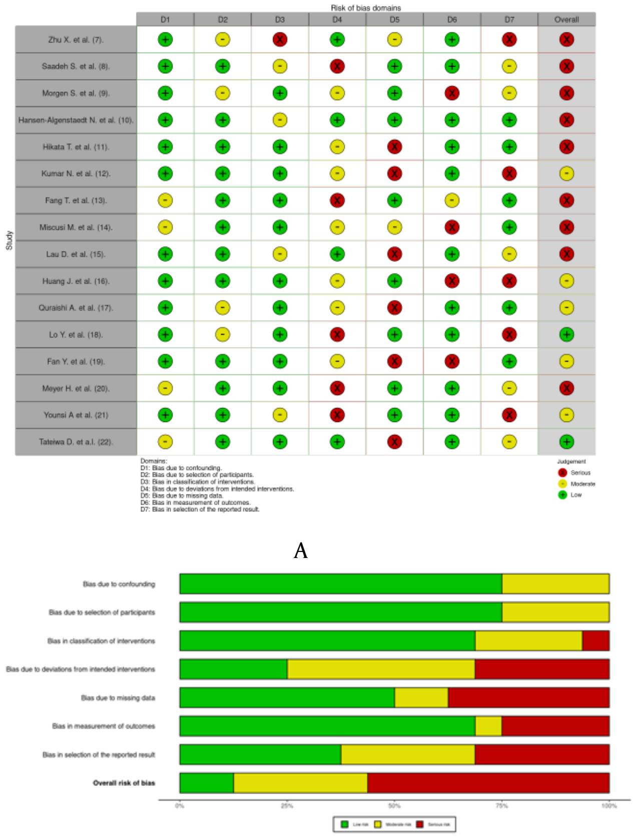

Figure 7. Representation of the risk of bias for patients diagnosed with minimally invasive spinal surgery for spinal metastases. The quality of the meta-analysis was assessed using the ROBIN-I tool: A) Traffic light charts were evaluated at the corresponding domain level for each study. B) Weighted bar charts showing the distribution of the risk of bias assessment in each study according to the bias domain.

Vertebroplasty

Vertebroplasty is a procedure using a type of cement, percutaneous polymethylmethacrylate (PMMA), used when the spine is injured or affected. It consists of a percutaneous injection of cement into the vertebra. It is used for benign fractures, metastasis, and compression of the vertebral body (43, 75). This method effectively improves the anatomical integrity of weight-bearing vertebral injuries and axial or appendicular spine injuries, stabilizing and minimizing the risk of pathological fractures (76). After the percutaneous PMMA cement is injected, an exothermic heat reaction occurs, solidifying the structures and providing pain relief for the patient by eliminating or destroying the nociceptive endings that cause pain (27, 77, 78). Percutaneous PMMA cement has a short polymeric cytotoxic reaction; therefore, its curative use is limited. It must be followed by an ablative treatment or procedure. Consequently, vertebroplasty can be performed immediately after radiofrequency or microwave ablation. The surgeon must wait for the ice to melt so as not to affect the polymerization of the percutaneous PMMA treatment (38, 79, 80).

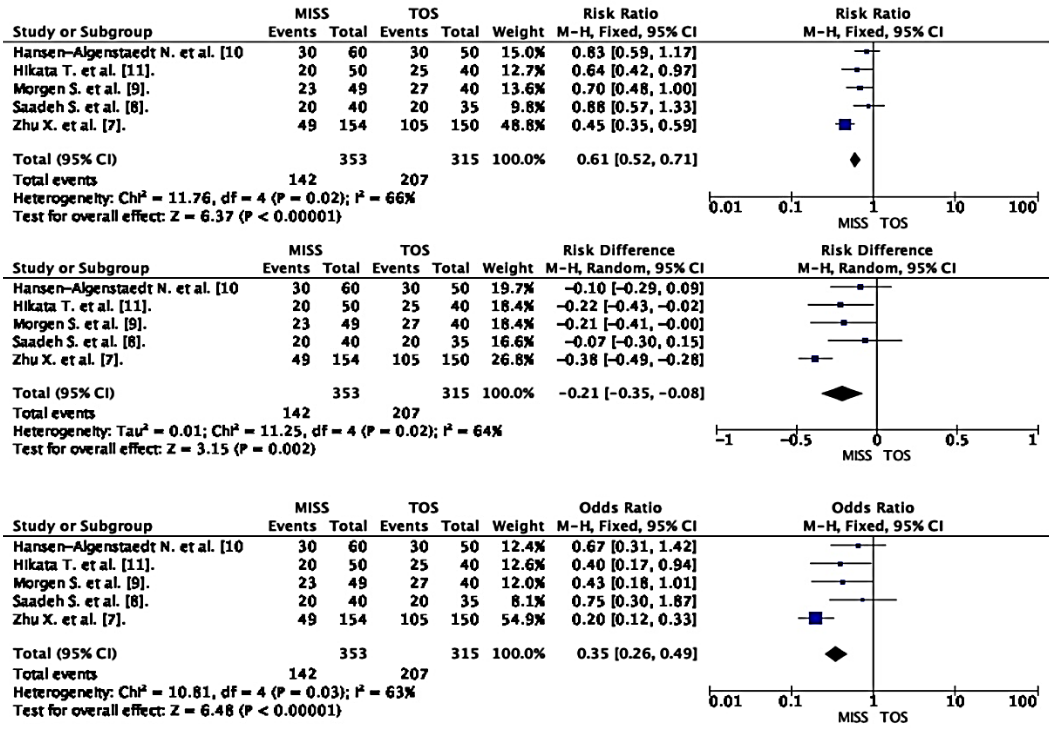

Figure 8. Minimal spine metastases comparison [minimally invasive spine surgery (MISS) vs. traditional open surgery (TOS)]

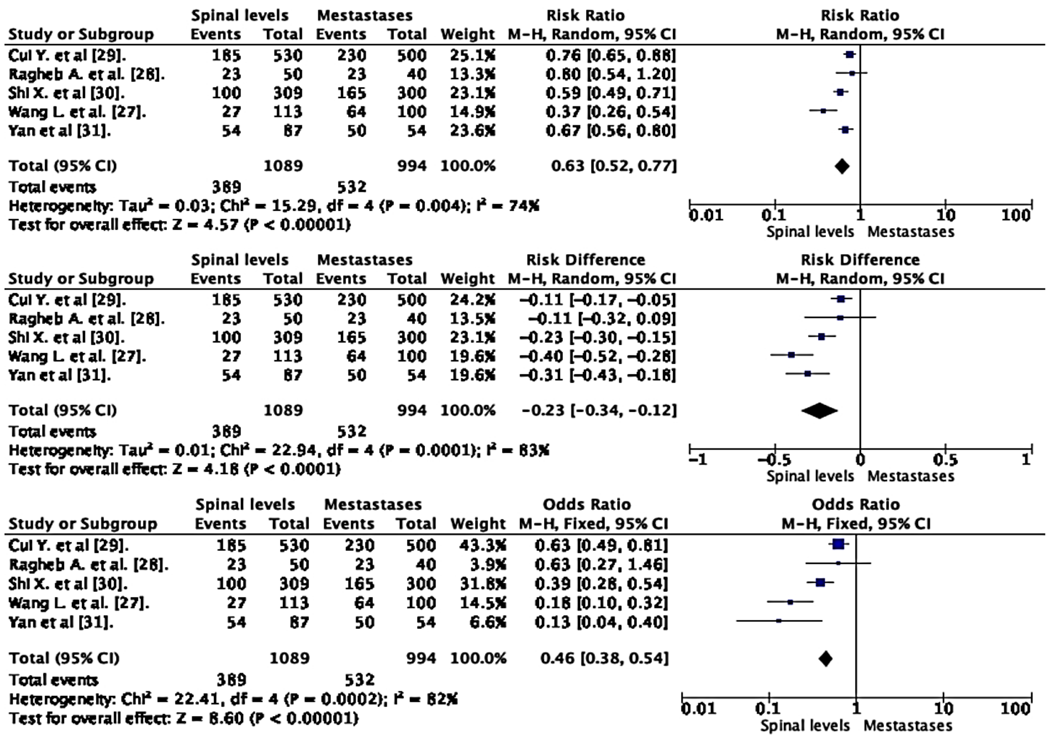

Figure 9. Surgical management of spinal metastases, by level and metastases region

The procedures are carried out in axially loaded areas of the spine and in the acetabular regions, which are affected by the exerted compression. However, the injected cement may be sufficient to consolidate the bone (81-83). Therefore, torsional force can be generated in the appendicular bone, specifically in the diaphysis of long bones, which will lead us to perform different strategies to consolidate the bone, such as intramedullary nailing, as well as external fixation in conjunction with cement vertebroplasty. There is a risk of potential fractures due to bone metastases, which can be measured in the extremities by Mirels score (3, 84, 85).

Discussion

In this recent study based on the National Institutes of Health (NIH) database, we included 2326 publications on the management of MISS in spinal metastases. Of these, 48 were duplicates, and 2278 were screened. Of these, 2258 were excluded, and 20 met the eligibility criteria. After removing 5, 15 publications were selected for this research.

In our review, a total of 2380 patients with spinal metastases were treated with minimally invasive and traditional open methods, including vertebroplasty and kyphoplasty (Table 1). We discovered 1090 patients with spinal metastases (46%), where the minimally invasive technique (MISS) included 509 interventions (21%), while the conventional open technique (TOS) included 432 interventions (18%). In table 2, we have 1290 individuals (54%) with spinal metastases that 1611 (67%) were intervened by the leves of the fractures whose cement breaches were 752 patients (31%) with metastases and CSF leaking (31%).

Zhu et al. based their findings on current studies without any significant references. The only difference in blood volume was that it was smaller in the MISS group than in the TOS group (748.57 vs. 950.48 ml, P = 0.039), with the exception of sex (P = 0.04). Therefore, MISS is recommended for patients with spinal metastases and myelopathy, as well as for patients with spinal or thoracolumbar metastases (7).

In a recent randomized controlled trial (RCT) by Morgen et al., surgical treatment in patients with spinal cord metastases, intended as palliative care, aims to restore neurological function. While treatments such as radiotherapy and chemotherapy carry a risk of infection, leading to revision surgery, these risks can also delay adjuvant treatment in patients with metastatic compression. Injuries due to metastatic compression are observed in approximately 10% of these patients; these injuries sometimes bleed postoperatively (9).

According to several authors, survival rates are higher in preoperative outpatients, while the opposite is true for postoperative patients. Preoperative ambulation capacity is generally considered a positive factor in postoperative outpatient prognosis. However, functional outcomes did not influence patient survival. One study focused on the thoracic spine, which included multiple surgical techniques, leading to varying ambulation and postoperative survival rates. The authors suggest that in palliative decompression, postoperative outpatients will have a better quality of life (18).

Spinal metastases are a condition affecting more than 1.6 million people with cancer in the United States (US). Therefore, in mid-2015, between 1% and 10% of new cases of spinal metastases were diagnosed. It should be noted that in these patients, osteolytic metastatic lesions are very painful and debilitating, which reduces daily mobility. This is one of the causes of mobility in traditional open surgery, which has led us to minimally invasive therapy, from vertebroplasty to vertebral augmentation and new coblation, ablation, and radiofrequency systems, external beam radiation therapy, and intraoperative radiation therapy (90).

The most common cancers that metastasize to the spine, based on histology, are breast, prostate, and lung cancers. It is estimated that more than 40% of patients with cancer will develop spinal metastases during the course of the disease. Almost all spinal metastases are discovered after a diagnosis of primary cancer, 10% are believed to be of unknown origin. While 20% will involve the spinal cord and present epidural metastases, which generally affect the vertebral body and pedicle regions, only 5% will have intradural metastases, and less than 1% will have intramedullary metastases (59, 87, 88).

Neurological Status Assessment on T2-Weighted Magnetic Resonance Imaging (MRI)

The degree of spinal cord compression can be assessed based on the 6-grade system: Neurological, Oncological, Mechanical, and Systemic (NOMS) (89, 90).

Epidural Spinal Cord Compression: The system classifies injuries as:

0: Injury to the vertebral body that does not invade the epidural space.

1: Invasion into the epidural space:

a) There is no deformation of the dural sac; b) Deformation of the dural sac is present; c) There is contact with the spinal cord, but no compression.

2: There is spinal cord compression with cerebrospinal fluid (CSF) observed or present.

3: There is spinal cord compression without CSF observed.

Conservative Treatment

While a comparative relationship between dexamethasone, the most commonly used steroid, and methylprednisolone is not considered, chemotherapy and bisphosphonates for some specific tumor types are considered; hormonal therapy, such as in breast, prostate, and thyroid cancers, is considered as a general medication (91, 92). Dosing can be in two regimens: dexamethasone at a high dose with an initial bolus of up to 100 mg and a subsequent dose of 96 mg/day. It should be considered for administration in patients with progressive neurological problems (93, 94). Dexamethasone can also be administered at a moderate dose as an intravenous (IV) bolus of 10 mg, continuing with 16 mg/day up to approximately 4 times a day. This dose is well tolerated but is not recommended for non-paretic outpatients (95, 96). An essential and effective medication is pamidronate, a second-generation bisphosphonate. This drug is used for bone metastases, both in breast cancer and osteolysis of multiple myeloma (97). Zoledronic acid is a very recent drug with the characteristics of an imidazole ring. The bisphosphonate will depend on the type of reduction, as well as the expected risk of skeletal complications such as pathological fractures and spinal cord compression, as well as the radiation therapy and surgery used for stabilization (98-100).

Zhu et al. advocate the use of MISS as an optimal technique for spinal metastases and myelopathy (7), while Saadeh et al. (8) and Morgen et al. (9) reported a decrease in bleeding and postoperative pain with the same technique. They noted the use of pedicle screws with MISS fixation, muscle-sparing, and thoracolumbar fixation. However, Morgen et al. reported a longer duration of open surgery. Hansen-Algenstaedt et al. showed a slight contradiction, mentioning that MISS and open surgery had comparable results in patients with spinal metastases (10). The advantage of their technique is the same decrease in blood, hence fewer transfusions and a shorter hospital stay. Hikata et al. emphasized this advantage compared to the other authors but indicated and recommended its use in patients with a shorter life span (11).

Limitations and Future Directions: In spinal metastases, the use of radiosurgery is common but limited, as it causes fractures in 0.7% to 40% of cases. Radiosurgery does have results when used alone. Very aggressive en bloc spondylectomy has also been considered, yielding poor results, but has not been ruled out. Open surgery is increasingly declining in demand, as the minimally invasive approach offers advantages in terms of recovery and rehabilitation. Targeting spinal metastases using MRI and CT remains more relevant than ever, as does monitoring of primary cancers through tumor markers and noninvasive procedures to confirm histology, such as biopsy. Thousands of cases of spinal metastatic cancers derived from primary breast, prostate, and lung cancers continue to be reported each year. These cases can have a prognosis before metastatic spread if treated early.

Conclusion

Several approaches for managing pain or the extent of spinal cord compression brought on by spinal metastases were developed by Tokuhashi, Bauer, Tomita, etc. Additionally, new ideas were used in the open minimally invasive method, which began with minimally invasive surgeries like vertebroplasty and kyphoplasty and proceeded to therapies like percutaneous microwave ablation for spinal metastases. Simple chemotherapy and radiotherapy are advised, along with the use of second-generation bisphosphonates like pamidronate and steroids like methylprednisolone and dexamethasone. This systematic review and meta-analysis demonstrates that minimally invasive surgical approaches both the tubular and the minimally invasive systems were better, even for the treatment of spinal metastases following the detection of the initial cancer. After the spine was stabilized, the surgeon used vertebroplasty, open laminectomy, and posterior osteotomy to restore the negative nociceptive system to pain. Following the decompression of spinal metastases or tumors, this generated a feeling of pain reduction. In more than 85%, the physician received great results. This study clearly demonstrates the importance of a minimally invasive approach, even for older or higher-risk patients, in order to ensure good hospital management and a quicker recovery. It also shows that this approach is superior to TOS for patients with spinal metastases whose spinal dynamics are already compromised.

Conflict of Interest

The authors declare no conflict of interest in this study.

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