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MINI-REVIEW

The evolving role of surgery in brain metastatic disease

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Abstract

Advancements in diagnostic imaging have improved the detection of brain metastases, which are now recognized as the most common intracranial malignancies. While surgical intervention may be indicated for various reasons – including histopathological confirmation, relief of mass effect, neurological improvement, and survival benefits – evidence suggests that gross total resection is particularly important for enhancing both progression-free and overall survival. However, the management of brain metastases remains largely subjective and controversial. This review aims to critically evaluate existing evidence regarding the role of surgical intervention in the treatment of brain metastases.

Keywords: Brain metastases; Surgical resection; Microsurgical resection; Stereotactic radiosurgery; Whole-brain radiotherapy

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1. Introduction

Advancements in diagnostic imaging have improved detection and recognition of brain metastases, which are now considered the most prevalent intracranial malignant tumors.[1] In such cases, gross total resection (GTR) is pivotal for improving both progression free and overall survival.[2] Since World War I, neurosurgical techniques have advanced rapidly, particularly in trauma management, including surgical debridement, cranioplasty, watertight dural closure, external drainage, and decompressive laminectomy. In addition, growing emphasis has been placed on understanding secondary brain injury and its pathophysiology.[3] The rapid development of artificial intelligence (AI) has further accelerated progress in neurosurgical practice. AI applications now support imaging analysis, clinical data aggregation, diagnostic interpretation, and treatment planning with unprecedented efficiency. For instance, Apple Intelligence – a novel AI framework developed by Apple Inc. – exemplifies this trend through its integration of innovative features across devices. Such technological advancements hold promise for enhancing patient care, revolutionizing neurosurgical training, and optimizing surgical workflow efficiency.[4] Tumor diagnosis has evolved into a multimodal paradigm. Concurrently, advances in neurosurgical techniques have enabled more precise investigation of central nervous system (CNS) tumors, significantly improving diagnostic accuracy, therapeutic interventions, survival rates, and quality of life for brain tumor patients. These advancements are particularly impactful for patients with advanced-stage disease, especially those with brain metastases. The management of brain metastases is highly

individualized, depending on factors such as patient performance status, systemic disease burden, and lesion characteristics. While some patients may benefit from whole-brain radiotherapy (WBRT), others may require surgical resection followed by adjuvant WBRT or localized radiation therapy. Neurosurgical intervention plays a critical role in selected cases by enabling histopathological diagnosis, relieving mass effect, providing symptomatic relief, achieving seizure control, and potentially improving survival.[5] Early diagnosis and optimal treatment selection are paramount for prolonging survival and maintaining quality of life in these patients.[6] However, overall prognosis remains poor, with untreated patients having a median survival of ~1 month, WBRT alone extending survival to 4 – 6 months,[7] and multimodal therapy (surgery combined with adjuvant chemo-/radiotherapy) extending survival to 10 – 15 months.[8-10] This review critically evaluates the evolving role of neurosurgery in the multidisciplinary management of brain metastases.

2. Epidemiology, diagnosis, and treatment of brain metastases

2.1. Epidemiology of brain metastases and leptomeningeal disease

Brain metastases represent a prevalent and clinically significant manifestation of advanced systemic malignancies, occurring as a frequent neurological complication in patients with metastatic solid tumors. Epidemiological data from the United States indicate an annual incidence ranging from approximately 70,000 to 400,000 newly diagnosed cases, reflecting considerable variability based on primary tumor type and detection methods. Current oncological observations demonstrate that 10 – 40% of patients with solid tumor malignancies will eventually develop intracranial metastatic involvement during the natural progression of their disease. This variable incidence is attributable to several factors, including variations in primary tumor biology, improvements in diagnostic sensitivity through advanced neuroimaging modalities, and prolonged patient survival resulting from enhanced systemic treatment options. The development of brain metastases typically signifies an advanced disease state, with significant implications for both neurological function and overall prognosis across various cancer subtypes.[11-13]

Epidemiological comparisons demonstrate that the occurrence of brain metastases exceeds the incidence of primary malignant brain tumors by approximately an order of magnitude. This tenfold differential in incidence rates has been consistently observed across multiple population-based studies and cancer registry analyses. The substantial disparity in frequency between these two categories of intracranial neoplasms reflects fundamental differences in their biological origins and pathogenesis, with metastatic lesions representing the neurological manifestations of systemic cancer progression rather than primary CNS malignancies. This marked prevalence difference has significant implications for neuro-oncological practice, resource allocation, and research priorities within the field of neuro-oncology.[14]

The evolution of systemic anticancer therapies has yielded significant improvements in controlling extracranial tumor burden and extending patient survival across multiple malignancies. However, these therapeutic advances have been accompanied by a paradoxical challenge in neuro-oncology – the majority of currently available systemic agents exhibit restricted CNS penetration due to the blood–brain barrier's selective permeability. This pharmacological limitation results in subtherapeutic intracranial drug concentrations, creating a pharmacologically privileged sanctuary for metastatic tumor cells within the CNS. As a direct consequence of improved extracranial disease control, coupled with inadequate intracranial therapeutic coverage, epidemiological data demonstrate a persistent temporal increase in the cumulative incidence of brain metastases among cancer patients. This phenomenon reflects the CNS's increasing representation as a dominant site of treatment failure in the era of modern systemic oncology.[15]

Epidemiological studies demonstrate that small cell lung cancer, adenocarcinoma, and melanoma carry the highest propensity for intracranial involvement, with 23 – 28% of patients developing brain metastases. In addition, renal cell carcinoma, human epidermal growth factor receptor 2 (HER2)-positive breast cancer, and triple-negative breast cancer exhibit significant brain metastasis rates (8 – 11%). Among metastatic gastrointestinal primaries, esophageal cancer shows the greatest risk (~5%), comparable to that of head and neck malignancies (including thyroid carcinoma). Prostate cancer rarely metastasizes directly to the brain but may secondarily involve it through calvarial/dural infiltration.[16,17]

Neurological symptoms manifest in 60 – 75% of patients with brain metastases.[18] The most common presentations include seizures (10 – 20% of cases), focal neurological deficits (20 – 75%), altered mental status (5 – 60%), and headache (25 – 57%).[19] Additional symptoms include gait disturbances/ataxia (15 – 20%), speech alterations (5 – 20%), visual changes (5 – 8%), nausea/vomiting (5%), and lethargy (5%).[20] Notably, 10 – 12% of treatment-naïve patients develop diarrhea during the initial evaluation. Radiologically, solitary lesions predominate at the time

of diagnosis, although 20 – 40% of patients eventually develop >4 metastatic foci. Brainstem involvement occurs in <10% of cases.

Leptomeningeal metastasis (also known as neoplastic meningitis or carcinomatous meningitis) develops when tumor cells infiltrate the leptomeninges and cerebrospinal fluid (CSF).[21] Although only 2 – 12% of cases present with leptomeningeal involvement at initial diagnosis, prospective studies indicate that 1 – 37% of patients may develop this complication during disease progression.[22,23]

2.2. Diagnosis and neuroimaging features of brain metastases

The contemporary diagnostic paradigm for brain metastases is fundamentally based on two principal modalities: advanced neuroimaging techniques and histopathological verification. Neuroimaging, particularly high-resolution magnetic resonance imaging (MRI) with gadolinium enhancement, serves as the primary screening tool, while tissue confirmation remains essential for definitive diagnosis, especially in cases of unknown primary malignancies. A well-documented history of extracranial malignant disease constitutes a pivotal diagnostic criterion, significantly increasing the pretest probability of metastatic intracranial lesions. Recent technological developments in AI have revolutionized detection capabilities, with AI-assisted image analysis demonstrating superior sensitivity compared to conventional human interpretation in identifying subtle metastatic foci. This enhanced detection capacity has led to a measurable reduction in diagnostic oversights while improving workflow efficiency in both radiology and neurosurgery departments. The integration of machine learning algorithms into diagnostic protocols has enabled accurate identification of most intracranial metastatic lesions, achieving performance metrics that approach expert-level interpretation. Special diagnostic challenges emerge in patients with prior exposure to cranial radiotherapy, where differentiation between new metastatic deposits and radiation-induced necrosis becomes paramount. In these complex cases, advanced imaging modalities, including magnetic resonance spectroscopy (MRS) and perfusion-weighted imaging (PWI), provide valuable adjunctive information for the preliminary characterization of suspicious lesions. MRS facilitates the detection of metabolic alterations characteristic of neoplastic tissue, while PWI evaluates microvascular changes associated with tumor angiogenesis. However, despite these technological advances, histopathological examination through biopsy or surgical resection remains the definitive diagnostic standard, particularly in clinically ambiguous scenarios or when treatment decisions require absolute diagnostic certainty. The current diagnostic approach therefore emphasizes a multimodal strategy combining: (i) AI-enhanced neuroimaging for sensitive detection, (ii) advanced functional MRI techniques for preliminary characterization, and (iii) histopathological confirmation in diagnostically challenging cases. This tiered diagnostic algorithm optimizes both detection sensitivity and diagnostic specificity while ensuring that invasive procedures are utilized only when necessary.

Brain metastases typically demonstrate characteristic imaging findings on computed tomography (CT) and MRI. On non-contrast CT, they often appear as multiple (70%) or solitary (30%) intra-axial lesions with variable density (hypo- to hyperdense) and disproportionate vasogenic edema extending along white matter tracts. Post-contrast CT shows nodular or ring-like enhancement in 90% of cases, classically exhibiting a "small lesion with big edema" pattern. Hemorrhagic metastases (e.g., from melanoma or renal cell carcinoma) appear hyperdense, sometimes with fluid-fluid levels. On MRI, metastases are typically T1 hypo-to-isointense and T2/fluid attenuated inversion recovery (FLAIR) hyperintense with surrounding edema, demonstrating strong gadolinium enhancement (ring-enhancing in necrotic lesions). Diffusion-weighted imaging may show restricted diffusion in cellular tumors (e.g., small cell carcinoma), while susceptibility-weighted imaging reveals hemorrhage in melanotic metastases. Perfusion MRI often shows elevated relative cerebral blood volume in metastases compared to surrounding edema. The "dural tail" sign may be seen with dural-based lesions, and multifocal involvement at the gray-white matter junctions is highly suggestive of metastases. Advanced techniques like MRS typically demonstrate elevated choline peaks with absent or reduced N-acetylaspartate. For surgical resection, imaging is used not only to select appropriate patients but also to assist intraoperatively through neuronavigation, fluorescence-guided surgery, and intraoperative ultrasound (Figure 1).[24]

Leptomeningeal metastasis typically demonstrates characteristic MRI findings, including smooth or nodular leptomeningeal enhancement along the cortical surfaces, brainstem, or spinal cord, best visualized on post-contrast T1-weighted images with fat suppression. The enhancement often follows the pial contours of the gyri and extends into the sulci, with possible involvement of the cranial nerves (particularly CN VII/VIII in the cerebellopontine angle) and ventricular ependyma. FLAIR sequences show hyperintense signal abnormalities in the subarachnoid spaces, independent of CSF flow artifacts, while diffusion-weighted imaging may reveal restricted diffusion in cellular tumor deposits. Advanced techniques like 3D constructive

interference in steady-state sequences improve detection of small nodules in the basal cisterns, and post-contrast fast imaging employing steady-state acquisition images can highlight cranial nerve root involvement. Associated findings include hydrocephalus (30 – 40% of cases) due to CSF pathway obstruction and superficial parenchymal metastases at the gray-white matter junction. The "sugar-coating" appearance of tumor spread along the pial surface and "drop metastases" in the spinal subarachnoid space are pathognomonic features. Contrast-enhanced MRI remains 70 – 80% sensitive when combined with clinical and CSF cytological findings (Figure 2).[25,26]

Pathological diagnosis plays a critical role in the management of brain metastases, particularly when the primary tumor is unknown or when imaging findings are equivocal. Histopathological examination (via biopsy or surgical resection) provides definitive confirmation of metastatic disease and allows for tumor subtyping, which is essential for guiding targeted therapies, especially in cancers with specific molecular profiles (e.g., epidermal growth factor receptor [EGFR]-mutant lung adenocarcinoma, HER2-positive breast cancer). Immunohistochemistry helps identify the tissue of origin (e.g., thyroid transcription factor-1 for lung, GATA binding protein 3 for breast), while molecular profiling (e.g., next-generation sequencing) can reveal actionable mutations (e.g., BRAF V600E in melanoma). Pathological analysis also distinguishes metastases from mimics such as gliomas, lymphomas, or radiation necrosis, with features such as sharp tumor-brain interfaces, epithelial morphology, and absent isocitrate dehydrogenase mutations favoring metastasis. In cases where systemic cancer is undiagnosed, pathological confirmation of brain lesions may represent the first opportunity for comprehensive biomarker testing, significantly impacting therapeutic decisions and prognosis.[27]

2.3. Multidisciplinary treatment approaches for brain metastases

The management of brain metastases requires a multidisciplinary approach tailored to patient-specific factors, including the number/size of lesions, primary tumor biology, systemic disease status, and performance status. For limited metastases (1 – 4 lesions), first-line treatment typically involves stereotactic radiosurgery (SRS), while surgical resection is preferred for symptomatic, large (>3 cm), or strategically located lesions requiring immediate decompression. WBRT remains an option for multifocal disease (>15 lesions) or as adjuvant therapy post-resection; however, hippocampal-avoidance techniques

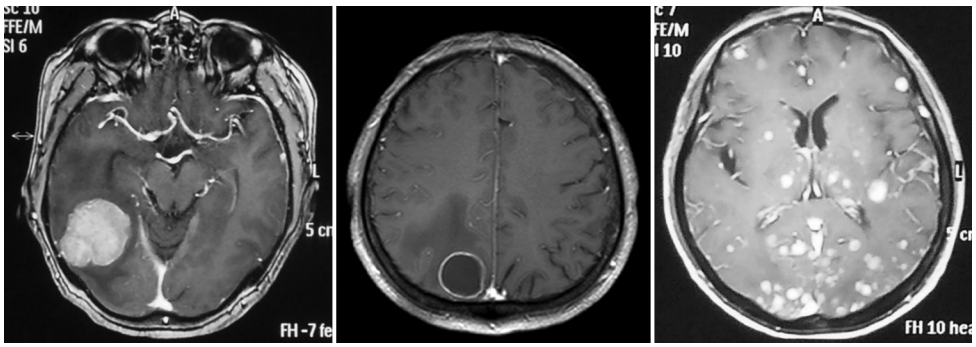

Figure 1. Multimodal imaging characteristics of common brain metastatic lesions

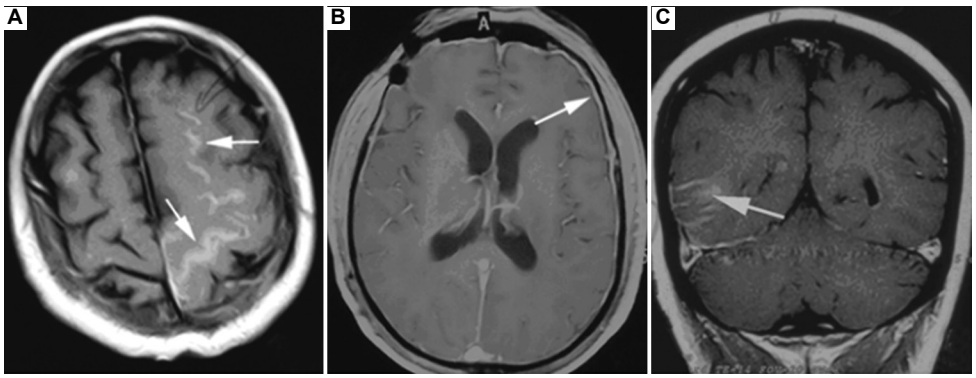

Figure 2. (A-C) Radiological manifestations of leptomeningeal carcinomatosis

and the use of memantine are now standard to mitigate neurocognitive decline. Systemic therapies with high CNS penetration (e.g., osimertinib for EGFR-mutant non-small cell lung cancer, tucatinib for HER2-positive breast cancer) are increasingly used as primary or adjunct treatments, particularly for tumors with actionable molecular subtypes. Notably, tyrosine kinase inhibitors (TKIs) demonstrate therapeutic utility not only in EGFR-mutated lung cancer–their most established indication–but also show emerging efficacy in glioblastoma management. Frumento *et al.*[28] proposed that, guided by patient stratification based on specific kinase overexpression profiles, the combination of immunotherapy with selected TKIs could unlock the full therapeutic potential of these agents, thereby reshaping the treatment landscape for glioblastoma. Emerging strategies include laser interstitial thermal therapy for radiation necrosis-prone areas, immune checkpoint inhibitors for immunogenic primaries (e.g., melanoma/non-small cell lung cancer), and blood-brain barrier disruption techniques for chemotherapy delivery. Supportive care with corticosteroids (for vasogenic edema) and anti-epileptics (for seizure prophylaxis in high-risk cases) remains integral, along with regular neuroimaging surveillance to assess treatment response and detect new metastases.

3. Neurosurgical resection in brain metastases: Therapeutic indications and outcomes

3.1. Timing of surgical intervention and preoperative evaluation

Precision radiotherapy has revolutionized the management of brain metastases, with SRS establishing itself as a cornerstone treatment modality, particularly in cases where surgical intervention is contraindicated or in patients with multiple metastases. Current neurosurgical practice guidelines strongly advocate for surgical resection as the primary therapeutic approach for patients with a solitary brain metastasis or up to three intracranial lesions, supported by level I clinical evidence.[29] The superiority of surgical decompression over SRS in achieving rapid alleviation of peritumoral edema and mass effect has been well-documented in prospective comparative studies, making it the intervention of choice for patients presenting with significant neurological deficits or life-threatening cerebral herniation.[30] Comprehensive prognostic modeling through multivariate analyses has consistently identified six key independent predictors of overall survival in this patient population: (i) chronological age, (ii) Karnofsky Performance Status (KPS) score, (iii) degree of systemic disease control, (iv) primary tumor histology, (v) absolute number of intracranial metastases, and (vi) cumulative tumor volume.[31] These variables necessitate incorporation into all pretreatment evaluation protocols, as they critically inform therapeutic decision-making algorithms. The neuro-oncological workup should include a rigorous multidisciplinary assessment encompassing neurological, oncological, and functional status evaluations before treatment stratification. Contemporary consensus guidelines from leading professional societies uniformly stress that surgical candidates must demonstrate adequate systemic disease control to achieve meaningful and durable CNS disease stabilization, as uncontrolled extracranial malignancy invariably portends poor outcomes regardless of intracranial intervention.[32] Among appropriately selected surgical candidates, the achievement of GTR has been unequivocally established as the most robust predictor of both overall survival and neurological outcomes across multiple prospective registries. The survival advantage conferred by GTR persists even after controlling for known prognostic variables, underscoring the critical importance of complete microscopic resection when technically feasible.[33] This survival benefit appears particularly pronounced in patients with favorable prognostic profiles (KPS ≥70, controlled primary disease, and age <65 years), in whom GTR has been associated with median survival durations exceeding 15 months in contemporary series.

3.2. Survival benefits of surgical intervention

The therapeutic utility of surgical intervention for brain metastases continues to be a subject of rigorous academic discourse, though multiple pivotal studies have objectively documented its clinical merits in well-defined patient populations. MacGee,[34] in a seminal investigation, quantitatively established that complete resection of solitary or limited (single-lesion) pulmonary metastatic deposits resulted in measurable improvements in patient-reported quality-of-life parameters, along with statistically significant survival prolongation. This paradigm was further validated in the CNS by Patchell *et al.*'s[35] landmark randomized controlled trial, which revealed that patients with single brain metastases who underwent complete surgical resection followed by adjuvant WBRT achieved nearly triple the median survival duration (40 weeks) compared to those who received radiotherapy alone (15 weeks). The survival advantage identified by Patchell *et al.*[35] was independently confirmed by Sause *et al.*'s[36] comprehensive retrospective analysis, which similarly reported identical survival durations of 40 weeks versus 15 weeks in the surgical resection plus radiotherapy cohort relative to non-surgical management groups. Importantly, this therapeutic benefit was consistently observed across multiple study populations. Further reinforcing the role of neurosurgical intervention, Bindal *et al.*[37] systematically

compared microsurgical resection with SRS in carefully selected cases, concluding through rigorous statistical analysis that operative management conferred superior local tumor control rates and extended survival durations when directly contrasted with SRS outcomes. Collectively, these studies underscore surgery's dual role in metastatic neuro-oncology: As a cytoreductive modality enabling immediate symptom relief through mass effect reduction, and as a foundational therapeutic intervention that enhances the efficacy of adjuvant treatments.

3.3. Controversies surrounding the efficacy of surgical intervention

The therapeutic role of surgical intervention in the management of brain metastases presents a complex clinical paradigm, with outcomes demonstrating significant variability contingent upon specific tumor biological characteristics and the integration of multimodal treatment approaches. This nuanced relationship is exemplified by the findings of Muacevic *et al*.,[38] whose comprehensive retrospective analysis of solitary metastatic lesions measuring <3.5 cm in maximum diameter revealed equivalent local tumor control efficacy when comparing surgical resection followed by WBRT with SRS as a standalone treatment modality. Their data demonstrated no statistically significant difference in local control rates between these two therapeutic strategies, suggesting that, for this specific patient population with smaller solitary metastases, surgical resection may not confer additional local control benefits beyond what can be achieved with radiosurgical approaches alone. This equipoise in local tumor control outcomes between surgical and radiosurgical management for appropriately selected smaller lesions underscores the importance of meticulous patient selection and individualized treatment planning in neuro-oncological care. The comparable efficacy observed in this clinical scenario highlights the need for careful consideration of multiple factors, including, but not limited to, lesion size, anatomical location, and patient performance status, when determining optimal therapeutic strategies for brain metastasis management. These findings contribute to an evolving understanding of the relative roles and potential limitations of surgical intervention within the broader context of multidisciplinary neuro-oncological care.[38] This finding was particularly robust in tumors <2 cm, where the local control difference was <1% between modalities. Conversely, Zacest *et al.*'s[39] 20-year longitudinal analysis of 412 melanoma brain metastasis cases established that surgical resection followed by WBRT conferred both a survival advantage and significantly better preserved quality-of-life metrics. The current evidence base regarding surgical management of brain metastases demonstrates important inconsistencies, as illustrated by the findings of O'Neill *et al.*[40] Their multicenter investigation revealed no statistically significant survival advantage when comparing combined surgical resection with low-dose WBRT versus SRS as monotherapy. The study's results challenge conventional therapeutic paradigms by suggesting that, for this specific patient population, the addition of surgical resection to low-dose WBRT may not confer measurable survival benefits beyond what can be achieved with precise radiosurgical targeting alone. These findings contribute to an ongoing clinical debate regarding optimal treatment selection, particularly in cases where minimally invasive approaches might achieve comparable oncological outcomes with potentially reduced procedural morbidity. The absence of survival benefit in this carefully defined cohort underscores the importance of histology-specific and modality-specific outcome assessments in neuro-oncological decision-making.[40]

3.4. Prognostic impact of surgical approach and extent of resection

The extent of surgical resection represents a critical determinant of oncological outcomes in brain metastasis management. Yoo *et al.*[41] conducted a comparative analysis of two resection techniques in 94 patients, demonstrating that microscopically complete resection (defined as extending 5 mm into surrounding normal tissue with intraoperative frozen-section confirmation) achieved significantly superior 2-year local control compared to GTR alone (recurrence rates of 29.1% vs. 63.2%, respectively). These findings substantiate the importance of obtaining microscopic margins beyond visible tumor boundaries. The surgical technique itself significantly influences outcomes, as evidenced by Patel *et al.*'s[42] work. Their 2010 study established that *en bloc* resection substantially decreased recurrence risk relative to piecemeal removal**.** This was subsequently corroborated by their follow-up investigation, which confirmed that the *en bloc* approach maintains its safety profile, showing no increased incidence of postoperative complications even when applied to large (>3 cm) or eloquently located tumors.[43] Importantly, *en bloc* resection also mitigates the risk of CSF-mediated tumor cell dissemination, a potential source of leptomeningeal spread. Beyond oncological outcomes, surgical resection provides distinct symptomatic benefits. Shimony *et al.*[30] recently demonstrated that surgery achieves more rapid resolution of peritumoral edema compared to SRS, leading to faster neurological recovery. This advantage is particularly relevant for patients presenting with significant mass effect or progressive deficits. Technical advancements have further refined resection quality. The application of 5-aminolevulinic

Table 1. Patient-tailored therapeutic approaches for brain metastases

Treatment modality	Indications
Systemic therapy	(i) Tumors exquisitely sensitive to chemotherapy.
	(ii) Brain metastases detected on screening magnetic resonance imaging and planned for systemic therapy.
	(iii) Tumors sensitive to targeted therapy.
	(iv) Disease refractory to other treatment modalities.
(i) Whole-brain radiotherapy	(ii) Concurrent central nervous system and systemic tumor progression, limited systemic therapy options, and poor performance status.
	(iii) Multiple brain metastases, particularly when the primary tumor is known to be radiosensitive, such as small cell carcinoma.
	(iv) Tumors exceeding 4 cm in diameter and unsuitable for stereotactic radiosurgery.
	(v) Multiple residual metastases (3 – 10 lesions) persist after gross total resection of the dominant mass.
	(vi) Recurrent brain metastases after prior stereotactic radiosurgery or whole-brain radiotherapy.
(i) Stereotactic radiosurgery	(ii) Tumors resistant to radiotherapy.
	(iii) Post-operative solitary brain metastasis, particularly for lesions >3 cm and/or located in the posterior fossa.
	(iv) Local recurrence after surgical resection of solitary metastasis.
	(v) Recurrence after whole-brain radiotherapy.
(i) Surgical resection	(ii) Undiagnosed central nervous system mass lesion.
	(iii) One or two metastatic brain lesions accompanied by marked edema, causing mass effect.
	(iv) Metastatic lesions involving functionally critical regions.
	(v) Rapidly enlarging brain metastases, with/without associated hemorrhage.
	(vi) Refractory epilepsy secondary to a metastatic epileptogenic focus with poor response to conservative management.
	(vii) Radiation-insensitive conditions (e.g., cystic metastases) with anticipated poor radiotherapy response.
(i) No intervention recommended	(i) Systemic tumor progression with no effective treatment options and poor performance status.

acid-induced protoporphyrin IX fluorescence guidance enables real-time intraoperative tumor margin delineation, facilitating maximal safe resection while preserving neurological function. This technology has been conclusively shown to reduce recurrence risk by improving the completeness of resection.[44] These collective findings underscore that surgical management of brain metastases requires meticulous attention to both the extent of resection and the technical approach, as these factors directly impact local control rates, complication risks, and functional outcomes. The evidence supports a paradigm favoring microscopic complete resection through *en bloc* techniques when anatomically feasible, supplemented by fluorescence guidance where available (Table 1).

4. Conclusion

Contemporary evidence demonstrates that surgical intervention continues to play a critical therapeutic role in carefully selected patients with brain metastases, providing measurable benefits across multiple clinical endpoints. Accumulated data indicate that neurosurgical resection achieves three principal objectives: (i) Immediate improvement in neurological function through rapid decompression of mass effect, (ii) measurable enhancement of quality-of-life metrics, and (iii) statistically significant prolongation of overall survival in appropriately stratified patients. The technical execution of resection appears to substantially influence outcomes, with emerging evidence suggesting that extended resection margins or microscopically complete resection (incorporating 5 mm of histologically normal tissue) may confer additional oncological benefits compared to conventional GTR alone. However, the current body of evidence necessitates more rigorous prospective studies to validate these observations and establish standardized surgical protocols. Optimal management requires a meticulous analysis of individual patient characteristics, including, but not limited to, performance status, primary tumor biology, intracranial disease burden, and extracranial disease control. By implementing such comprehensive assessments and integrating multimodal treatment strategies (combining surgery with radiotherapy, systemic therapy, or emerging modalities), clinicians can simultaneously optimize both survival duration and quality-of-life outcomes. These considerations underscore that while the continued development of novel therapeutic agents remains important, the evolving treatment paradigm emphasizes personalized, integrated care algorithms as the cornerstone of effective brain metastasis management. This strategy prioritizes the judicious combination of existing modalities, guided by precision medicine principles, rather than relying solely on the introduction of new monotherapies.

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Conflict of interest

The authors declare no conflicts of interest.

Author contributions

Conceptualization: Peng Sun
Writing – original draft: Peng Sun, Xinrui Zhang
Writing – review & editing: Jun Xu, Feng Li, Yufang Zhu

Ethics approval and consent to participate

Not applicable.

Consent for publication

The authors have obtained patient consent to publish their images and the images will not disclose the patient's personal privacy.

Availability of data

Not applicable.

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