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Microsurgical resection of brain metastases: rationale, appropriateness and local control

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ABSTRACT

Objective. To summarize data on indications for microsurgical resection of brain metastases, effect of resection technique on local control and leptomeningeal dissemination, as well as the role of stereotactic radiosurgery in improving local control.

Material and methods. A descriptive review of data on surgical treatment of brain metastases was performed. We reviewed the PubMed/MEDLINE, the Cochrane Library (CENTRAL), PubMed Central, and eLIBRARY/RSCI databases between 2000 and January 2025 using the keywords "brain metastases", "en bloc resection", "piecemeal resection", "local control", "leptomeningeal disease", "preoperative SRS" and "postoperative SRS". Clinical studies, systematic reviews, meta-analyses, guidelines, and consensus documents were included. Studies on primary central nervous system tumors, samples ≤10 patients, and publications without extractable clinical outcomes were excluded.

Results. The first part of the review considers indications for microsurgical resection in relation to clinical goals, survival and functional status. Surgery is reasonable for symptomatic large lesions, mass effect, diagnostic uncertainty, local recurrence, or complications after radiotherapy. Surgical technique should account for growth pattern of brain metastases: en bloc resection and, in selected cases, extended resection of peritumoral zone may improve local control. Retrospective data consistently associate piecemeal resection with higher risk of leptomeningeal dissemination, particularly for posterior fossa lesions and metastases adjacent to cerebrospinal fluid pathways.

Conclusion. Surgical treatment is presented as a component of a personalized multimodal strategy. Decision-making on surgery should rely on survival prognosis and likelihood of clinically meaningful benefit. When technically feasible, en bloc resection may be considered as a preferable approach, especially when the risk of leptomeningeal dissemination is clinically relevant.

Keywords: *brain metastases, microsurgical resection, en bloc resection, local control, leptomeningeal dissemination, stereotactic radiosurgery.*

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Abbreviations

GPA — graded prognostic assessment
RPA — recursive partitioning analysis
LMD — leptomeningeal dissemination
SCLC — small-cell lung cancer
NSCLC — non-small-cell lung cancer

Introduction

Brain metastases are among the most common complications of solid malignant tumors. According to epidemiological data, brain metastases occur in 10—40% of patients. Higher detection rate in recent years is attributed to advances in neuroimaging, longer survival of can-

cer patients and higher efficacy of systemic therapies despite persistent limitations regarding intracranial activity. Clinical significance of brain metastases is due to neurological disorders, impaired functional status and constraints on systemic treatment options. Consequently, local growth control is still a central objective for multidisciplinary treatment, as it alleviates neurological symptoms, preserves functional activity and creates suitable conditions for subsequent systemic therapy [1]. In this context, resection is crucial, as it provides rapid relief of mass effect and clinical improvement. Its role is evident in case of life-threatening or rapidly progressive neurological symptoms. Surgery allows for immediate brain decompression, while neither radiotherapy nor systemic therapy can achieve similar early outcomes.

However, modern surgical treatment of brain metastases goes beyond the mere formal analysis of indications for surgery. This approach entails a simultaneous assessment of appropriateness of surgery, optimal resection technique and role of radiotherapy in ensuring local control. This is especially important in context of evidence suggesting that en bloc resection may be associated with lower risk of local recurrence and LMD. Moreover, advancements in radiotherapy technologies have substantially expanded the scope of local treatment options [2].

The purpose of this review was to summarize current data on indications and feasibility of microsurgical resection of brain metastases, to evaluate the impact of resection technique on local control, risk of LMD and neurological safety, as well as to examine the role of radiotherapy in improving local outcomes.

Literature searching and selection criteria

In this narrative review, target searching for literature data was focused on clinically relevant surgical aspects for brain metastases, including resection technique and radiotherapy. We reviewed the Russian Science Citation Index (RSCI), PubMed/MEDLINE, the Cochrane Library (CENTRAL), and PubMed Central databases between 2000 and 2026. Keywords and their combinations in Russian and English were used: метастазы в головной мозг, резекция единым блоком, фрагментарная резекция, локальный контроль, предоперационная стереотаксическая радиохирургия, послеоперационная стереотаксическая радиотерапия, brain metastases, en bloc resection, piecemeal resection, local control, leptomeningeal disease, LMD, preoperative SRS, postoperative SRS.

We predominantly selected clinical studies, systematic reviews, meta-analyses, clinical guidelines, and consensus statements containing data on local control, LMD, complications or functional outcomes. Studies concerning primary brain tumors, small samples ($\leqslant$10 patients) and studies lacking clinical outcome assessments were either considered only sporadically or excluded from primary analysis. Modern studies with clearly described results and clinically interpretable endpoints were preferable.

Clinical rationale and indications for surgical treatment

Microsurgical resection is still a key component for brain metastases. Its role is particularly significant if therapeutic goal cannot be achieved by other methods or would require an excessively long time. This applies primarily to metastatic lesions with severe mass effect, perifocal edema, intracranial hypertension, and progressive focal neurological deficits. In such cases, surgery provides rapid decompression and can lead to regression of symptoms [3]. Surgery is also important for metastases in functionally critical brain areas. In this context, microsurgical resection under intraoperative monitoring can yield a more rapid and predictable neurological outcome compared to alternative treatment options [4].

Large brain metastases constitute a distinct group of indications for microsurgical resection. In such cases, surgical resection is often preferable for local control. Indeed, stereotactic radiosurgery for large lesions increases the risk of post-radiation complications, while hypofractionated stereotactic radiotherapy does not always yield comparable efficacy across all clinical scenarios [2].

Diagnostic uncertainty is an equally important rationale for surgery. Even in patients with known primary tumor, intracranial lesion is not always metastatic in nature. Thus, surgical intervention provides necessary specimens for morphological and molecular verification. This is important, as brain metastases may harbor clinically relevant molecular alterations absent in primary tumor. These data can expand the scope for subsequent systemic therapy [3, 5].

Finally, surgery is indicated when local recurrence or symptomatic complications following radiotherapy cannot be managed by other means. Surgery is an effective option for local treatment in case of symptomatic local recurrence after SRS. Furthermore, surgery can lead to significant neurological recovery in patients with drug-resistant radiation necrosis [6, 7].

Thus, the indications for microsurgical resection of brain metastases encompass clinically diverse scenarios united by a common principle (unachievable therapeutic goal via other methods). However, clinical indications for surgery do not in itself imply that intervention is unequivocally advisable. Unlike emergency neurosurgery, elective surgery for brain metastases requires assessment of potential benefits and risks in context of anticipated life expectancy. Surgery is justified only when its primary goals (correction of neurological deficits and functional status, as well as creation of conditions for subsequent treatment) are realistically achievable within a clinically meaningful timeframe [8]. This principle is crucial, as many patients die not from intracranial process, but progression of ex-

tracranial disease. Consequently, even technically successful surgery does not always yield clinically significant improvement if survival prognosis is limited. Therefore, decision-making on appropriateness of surgery should be based on preoperative stratification of survival prognosis, rather than feasibility of safe resection alone [8, 9].

Historically, the RPA scale was widely used for such stratification. The last one takes into account the Karnofsky score, age, primary tumor control and extracranial metastases. In classic model, median overall survival was 7.1 months for class I, 4.2 months for class II, and 2.3 months for class III. These data indicated potential benefit from active local treatment in patients with more favorable prognosis [10].

In modern practice, diagnosis-specific GPA scale is more informative, as it incorporates not only clinical factors but also diagnosis-specific characteristics and—for certain disease entities—molecular-biological markers. The GPA scale enables correlation of life expectancy with extent of surgery, neurological status and potential achievement of surgical goals. In case of favorable survival prognosis, more aggressive treatment approaches aimed at long-term local control and subsequent therapy are justified. Conversely, minimally invasive interventions and rapid symptomatic relief are preferable for short-term life expectancy [11].

Thus, clinical indications for surgery and appropriateness of this procedure should be considered together. Neurosurgical treatment for brain metastases is justified not alone, but rather as a part of a strategy where expectable clinical outcomes are weighed against survival prognosis and feasibility of subsequent treatment.

Oncological and morphological rationale for certain resection technique

After decision-making on surgery, choice of resection technique is the next critical issue. Extent of resection is essential for postoperative outcomes. Total resection is associated with superior overall survival compared to subtotal resection [12]. However, the risk of local recurrence is significant even after visually total resection. In a randomized study by Mahajan A. et al. [13], local recurrence rate within 12 months after total resection of brain metastases was 57%. Thus, macroscopic assessment of resection completeness alone is insufficient to ensure stable local control. Furthermore, not only extent of resection but also surgical technique is essential. There are two main approaches for macroscopically total resection of brain metastases: piecemeal resection (intratumoral debulking) followed by removal of residual tumor tissue and en bloc resection with removal of metastasis along with perifocal and perivascular zones of potential infiltration and no prior fragmentation or dissection of tumor. Piecemeal resection is potentially less desirable and can increase the risk of intraoperative dissemination of tumor cells into resection cavity and cerebrospinal fluid spaces [14]. En bloc resection was proposed in this context. Salvati M. et al. [15] described "no internal touch" resection of solitary melanoma metastases without local recurrences and higher survival rates compared to piecemeal technique. This approach was based on premise that metastatic lesions are typically well-demarcated from brain tissue and can be mobilized along tumor-brain boundary without contacting tumor content.

However, research of brain metastasis growth biology has significantly refined understanding of boundary between tumor and brain tissue. Siam L. et al. [16] detected infiltration by metastatic cells beyond visible lesion in 25 (64.1%) out of 39 patients and 58 (34.7%) out of 167 specimens. The highest incidence and depth of infiltrative growth were observed for non-small-cell lung cancer and small-cell lung cancer. Infiltrative growth pattern was associated with poorer overall survival. Baumert B.G. et al. [17] obtained similar results. Infiltrative growth beyond macroscopic margin of metastasis was identified in 48 (63.2%) out of 76 lesions. In NSCLC, the infiltration rate reached 70%. In SCLC and melanoma, maximum depth of infiltration exceeded 1 mm. Thus, microscopic perifocal spread of tumor cells is a clinically significant phenomenon that must be taken into account when assessing resection quality and planning subsequent local treatment.

Finally, the concept of extended or microscopically total resection was proposed. The last one implies excision of adjacent infiltrated parenchyma (up to 5 mm) with intraoperative histological assessment of resection margins. In a comparative study by Yoo H. et al. [18] involving patients with solitary metastases outside functionally critical brain areas, microscopically total resection provided better local control than standard visually total resection of lesion. The two-year local recurrence rates were 29.1% and 63.2%, respectively.

Thus, choice of resection technique should be guided not only by the goal of visually total resection but also understanding of brain metastasis growth biology. En bloc resection and, in certain situations, excision of peritumoral brain tissue appears to be more reasonable than piecemeal resection, as it potentially offers superior local control and lower risk of LMD.

Impact of resection technique on clinical outcomes

Resection technique and local control

Clinical significance of differences between en bloc and piecemeal resection is determined primarily by impact on local control. Two retrospective studies consistently indicate an advantage for en bloc resection. However, they also demonstrate that this effect depends on specific clinical context and cannot be considered universal [19, 20]. Patel A. J. et al. [19] analyzed 570 patients with solitary

brain metastasis and no postoperative whole-brain radiotherapy. Piecemeal and en bloc resections were performed in 201 (35%) and 369 (65%) patients, respectively. The median tumor volume was significantly larger in the piecemeal resection group, and local recurrence occurred in 84 patients across the entire cohort. In univariate analysis, piecemeal resection and tumor volume ⩾9.71 cm³ were associated with higher risk of local recurrence. In multivariate analysis, resection technique was important only for tumors < 9.71 cm³. In this subgroup, piecemeal resection was associated with a 2.7-fold higher risk of recurrence compared to en bloc resection. There were no differences between techniques for tumors ⩾9.71 cm³. Byun J. et al. [20] analyzed 197 patients with NSCLC brain metastases. En bloc resection was performed in 119 (60.4%) patients, while piecemeal resection was performed in 78 (39.6%) cases. En bloc approach was associated with lower rate of local recurrence compared to piecemeal resection (21% vs. 38%; p=0.02) and remained the only favorable factor for local control in multivariate analysis (p=0.02). There was no impact on overall survival.

However, both studies have significant limitations. Resection technique depended on size and location of lesion, and surgical tactics varied. Therefore, their results confirm oncological rationale for en bloc resection, but they do not justify en bloc resection as unequivocally superior in all clinical situations. Its advantages are clear for small well-circumscribed lesions outside functionally significant brain areas.

Resection technique and risk of leptomeningeal dissemination

While data regarding local control are limited, the evidence base concerning leptomeningeal dissemination appears more consistent. Two retrospective studies by Suki D. et al. [14, 21] are ones of the most significant in this field. In a cohort of patients with posterior cranial fossa metastases, piecemeal resection was associated with higher risk of LMD compared to en bloc resection (p=0.006) and stereotactic radiosurgery (p=0.006), whereas no difference was found between en bloc resection and SRS (p=0.98). However, surgical group did not demonstrate significantly higher risk of LMD compared to stereotactic radiosurgery (p=0.09), highlighting the importance of resection technique [21].

A similar conclusion was found regarding patients with solitary supratentorial metastases. Piecemeal resection was associated with higher risk of LMD compared to en bloc resection (p=0.009) and SRS (p=0.002), whereas no difference was observed between en bloc resection and SRS (p=0.21). This effect was particularly pronounced in patients with melanoma (p=0.007) [14].

Thus, both studies indicate that piecemeal technique is associated with higher risk of LMD. Ahn J. H. et al. [22] further refined this finding. In a retrospective study of 242 patients, LMD occurred in 39 (16%) patients after resection of intracranial metastasis. In univariate analysis, piecemeal resection was associated with higher risk of LMD compared to en bloc resection (22% vs. 5.7%; p<0.01). Anatomical proximity of lesion to cerebrospinal fluid pathways was a significant prognostic factor of LMD. Compared to lesions away from CSF spaces, the risk of LMD increased with direct contact between lesion and CSF pathways (p=0.02) and, especially, with their involvement (p<0.01). Thus, the likelihood of postoperative LMD is determined not only by resection technique but also communication between postoperative cavity and CSF spaces.

A systematic review and meta-analysis by Tewarie I.A. et al. [23] summarized these data. This review included 13 retrospective studies and 2.105 patients after resection of brain metastases. LMD occurred in 386 (18.3%) patients. Primary breast cancer and multiple brain metastases were the most significant risk factors. At the same time, qualitative analysis demonstrated that subtotal and piecemeal resection, proximity of lesion to cerebrospinal fluid spaces and intraoperative dissection of ventricular system were consistently associated with higher risk of LMD. Thus, the risk of postoperative LMD is determined not only by primary tumor biology and extent of intracranial disease but likely also some neurosurgical factors, primarily intraoperative contamination of CSF pathways.

Available data suggest that en bloc resection is preferable, particularly for lesions in posterior cranial fossa or near CSF pathways.

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Comment

Better survival rates among cancer patients and advancements in neuroimaging techniques increased the number of patients with brain metastases. Selection of optimal local treatment strategy is a key element of multidisciplinary care. The authors convincingly associate clinical significance of local control with neurological status, functional activity and feasibility of systemic therapy.

The authors discuss epidemiological aspects, clinical context (life-threatening or rapidly progressive symptoms, mass effect, edema) and role of microsurgical resection for rapid decompression in those situations where radiotherapy and systemic therapies do not yield such immediate results. Important questions include resection technique (en bloc versus piecemeal resection) and role of stereotactic radiosurgery.

This aligns with current debates in neuro-oncology and radiosurgery.

A significant advantage of this report is presentation of clear, practice-oriented conclusions: necessary prognostic assessment (GPA scale), advantages of en bloc resection regarding local control and risk of leptomeningeal dissemination, status of postoperative stereotactic radiosurgery as a standard approach. Importantly, certain methodological and editorial aspects could be further refined (e.g., brief characterization of evidence level for key data). However, this does not diminish the relevance or scientific value of this review.

This review will be useful for neurosurgeons and oncologists when determining treatment strategies for patients with brain metastases.

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