

MANAGEMENT OF INTRACRANIAL MENINGIOMAS: SURGICAL STRATEGIES, RADIOTHERAPY, PROGNOSIS, AND FUTURE DIRECTIONS

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Abstract: The management of intracranial meningiomas has evolved significantly over recent decades. Surgery remains the cornerstone of treatment, while radiotherapy, radiosurgery, and systemic therapies provide additional options for recurrent, aggressive, or surgically inaccessible tumors. This review examines current therapeutic approaches, discusses prognostic determinants, and outlines emerging advances that may shape future management paradigms.

Key words: meningiomas, treatment, prognosis.

Introduction. Although most meningiomas are benign, many require treatment due to mass effect, progressive growth, or neurological deterioration. The complexity of management reflects the diversity of tumor locations, variable biological behavior, and patient-specific factors. A multidisciplinary strategy is essential for optimal outcomes.

Modern treatment emphasizes individualized care, informed by radiological characteristics and genetic profiles. Innovations in microsurgery, neuro-navigation, radiotherapy planning, and molecular oncology have expanded available options while reducing treatment-related morbidity.

Surgical Management

Principles of Resection

Surgical resection aims to achieve maximal safe tumor removal while preserving neurological function. The extent of resection is a key predictor of recurrence. Simpson's grading system, though developed decades ago, remains clinically relevant:

- Grade I: complete resection including dural attachments
- Grade II: complete tumor removal with coagulation of dura
- Grades III–V: subtotal resection with increased recurrence risk

Advances in Surgical Techniques

Recent innovations have enhanced safety and precision:

- Neuronavigation systems for accurate localization
- Intraoperative MRI and ultrasound
- Endoscopic approaches for skull-base tumors
- Fluorescence-guided surgery for distinguishing tumor from normal tissue

▪Multidisciplinary skull-base teams integrating neurosurgery and otolaryngology

Surgical Limitations

Certain locations—cavernous sinus, optic canal, petroclival region—present high surgical risks. In such cases, subtotal resection followed by radiotherapy often offers the best balance between tumor control and functional preservation.

Radiotherapy and Radiosurgery

Stereotactic Radiosurgery (SRS)

SRS is an established option for small, well-defined tumors or postoperative residual disease. Gamma Knife, CyberKnife, and LINAC-based systems deliver high-dose radiation with submillimeter accuracy. Local control rates exceed 90% for benign meningiomas.

Fractionated Radiotherapy

Used for larger tumors, lesions near critical structures, or atypical/anaplastic histology. Fractionation reduces risk of radiation-induced neuropathy while maintaining effective tumor control.

Indications

- Residual or recurrent meningiomas after surgery
- Tumors in surgically inaccessible regions
- High-grade meningiomas as adjuvant therapy
- Elderly or medically fragile patients

Systemic and Targeted Therapies

Systemic therapy is generally reserved for aggressive or refractory cases.

Hormonal Treatments

Although progesterone receptors are frequently expressed, clinical trials have shown limited benefit for hormonal therapy.

Targeted Agents

Molecular discoveries have paved the way for targeted therapies:

- PI3K/AKT/mTOR inhibitors
- Hedgehog pathway inhibitors (e.g., vismodegib)
- Somatostatin analogs
- Anti-angiogenic agents (bevacizumab)

Results remain mixed, but ongoing studies aim to identify subgroups most likely to respond.

Immunotherapy

Immune checkpoint inhibitors such as pembrolizumab have shown promise in early-phase trials for high-grade meningiomas. Immunogenomic profiling may help identify candidates for such therapies.

Prognosis and Predictive Factors

Extent of Resection

Complete resection is the strongest predictor of long-term control in WHO grade I tumors.

Tumor Grade

- Grade I: excellent prognosis, 10-year survival >80%
- Grade II: recurrence up to 40%
- Grade III: aggressive behavior, high mortality

Molecular Classification

DNA methylation-based subtypes have been shown to outperform histological grading in predicting recurrence. Molecular markers are increasingly used for risk stratification.

Patient-Specific Factors

Age, comorbidities, tumor volume, and functional status influence both treatment selection and outcomes.

Quality of Life and Long-Term Follow-Up

Even benign meningiomas can impair quality of life due to seizures, neurocognitive decline, vision loss, or endocrine dysfunction (especially after skull-base treatment). Long-term surveillance with periodic MRI is essential, particularly for atypical or subtotally resected tumors.

Neurorehabilitation, antiepileptic therapy, cognitive training, and psychological support contribute significantly to long-term outcomes.

Future Directions

Personalized Therapeutics

Integration of genomic, transcriptomic, and epigenomic data will refine therapeutic strategies. Biomarker-driven treatments may provide alternatives for recurrent high-grade tumors.

Radiomics and Artificial Intelligence

AI-assisted imaging may improve prediction of tumor grade, recurrence risk, and response to therapy without invasive biopsies.

Novel Drug Delivery Systems

Convection-enhanced delivery and nanoparticle-supported platforms hold promise for bypassing the blood–brain barrier.

Advanced Radiosurgical Techniques

Adaptive radiotherapy and MRI-guided platforms will enhance precision and reduce toxicity.

Conclusion. Management of intracranial meningiomas continues to evolve through innovations in microsurgery, precision radiotherapy, and molecular oncology. Multidisciplinary approaches and personalized treatment planning remain essential. Future advancements in targeted therapy, immunotherapy, and

computational imaging may significantly improve outcomes, particularly for high-risk and recurrent tumors.

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