

Surgical Management of Brain Meningiomas: Techniques and Outcomes in a Systematic Review and Meta-Analysis

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Received: 22- April-2024

Accepted: 26- june - 2024

Abstract

Background: Surgical treatment of brain meningiomas is a challenge because of their various sites, sizes and effects on surrounding neural structures.

Objective: This review aims to integrate the current surgical techniques and results in the management of brain meningiomas.

Study Design: The study is a systematic review and meta-analysis.

Setting and Duration of Study: The study was carried out at the Department of Neurosurgery, Bacha Khan medical college Mardan, for six months, from 8th October 2023 to 8th April 2024.

Methods: A systematic literature search was undertaken to identify recent studies as well as clinical trials about surgical therapy for brain meningioma. It also highlights on microsurgical techniques, endoscopic approaches, advancement in neuro-navigation and intraoperative monitoring.

Results: The inclusive criteria were met by 52 studies which consisted of 18 randomized control trials (RCT), 24 observational studies and ten meta-analysis. The total number of patients included in these studies was 8420 who underwent surgery for brain meningiomas. Gross total resection (GTR) rates ranged between 70% -95%. Recurrence after GTR varied from 5%-15% over a five year follow up period.

Conclusions: Over time, management of Brain Meningiomas has changed due to advancements in technology and technique. Although microsurgical excision remains vital in therapy, endoscopic approaches as well as modern intraoperative adjuncts have widened the neurosurgeons' armamentarium leading to improved patient outcomes.

Keywords: brain meningiomas, microsurgical resection, neuro-navigation.

Citations:

Naeem Ul Haq, Syed Nasir Shah, & Ikram Ullah. (2024). Surgical Management of Brain Meningiomas: A Review of Current Techniques and Outcomes.: Review Article. Pakistan Journal of Advances in Medicine and Medical Research, 2(02), 182–188.
<https://doi.org/10.69837/pjammm.v2i02.44>

INTRODUCTION

Meningiomas of the brain are the most common primary brain tumours that originate from meninges, the membranous layers surrounding the brain and spinal cord ^[1]. Meningiomas account for approximately 30% of all intracranial tumors. They are usually benign, slow growing tumors with a subset being atypical, and malignant ^[2]. Despite changes in technology and surgical techniques, surgical management of meningiomas remains a traditional procedure in neurosurgery ^[3]. For brain meningiomas, the principal aim of surgery is to achieve total resection while preserving neurological function. This goal is complicated by several factors including tumor location, size, vascularity and proximity to vital structures within the brain ^[4, 5]. Additionally, accurate surgical planning and execution are essential for recurrence prevention. Hence, surgery will optimize tumor removal while minimizing residual disease ^[6]. Traditional microsurgical resection has for long been advocated as the treatment of choice for this condition. The technique involves delicate dissection and removal of a tumor under high magnification allowing direct vision and precise manipulation of surrounding normal tissues ^[7]. These approaches have achieved gross total resection in most cases with favorable long-term outcomes ^[8]. Invasiveness however leads to significant postoperative morbidity especially when dealing with skull base tumors that are technically challenging to expose surgically ^[9, 10].

On the other hand; endoscopic approaches have emerged as alternatives to craniotomy over the past few years. Endoscopic surgery is performed through small incisions using specialized instruments which among other benefits reduce surgical trauma, shorten recovery time and produce better cosmetic results ^[11]. It also significantly helps during management of skull base meningiomas where conventional approach may not be feasible at all ^[12]. Nevertheless technical maturity must be obtained because these tumors may not be suitable for endoscopic surgery at all locations. Integration of advanced neuro-navigation systems and intraoperative imaging has resulted in higher precision in meningioma surgeries. Neuro-navigation entails real-time three-dimensional navigation for use in surgical planning and unmatched accuracy during resection execution ^[13, 14]. Intraoperative magnetic resonance imaging (MRI) adds on it by enabling assessment of tumor removal during surgery thereby reducing residual tumor formation thus preventing recurrence scenarios later on ^[15]. Fluorescence-guided surgery is another major breakthrough in this field. It is used

to identify the margins of a tumor where fluorescent dyes selectively accumulate, leading to total resection becoming easier ^[16]. Thus, it can enhance surgical outcomes particularly when differentiating between a brain tumor and normal brain tissue becomes difficult.

Methodology

Study Design: The study is a systematic review and meta-analysis.

Setting and Duration of Study: The study was carried out at the Department of Neurosurgery bacha khan medical college mardan for six months, from 8th October 2023 to 8th April 2024.

Materials and Methods

These searches included peer-reviewed journals, clinical trial databases, medical sources like PubMed and neurosurgical publications as well. Databases such as PubMed, MEDLINE, Scopus, Cochrane Library were used to collect articles published between January 2000 and December 2023. Keywords employed in the search are “brain meningiomas,” “surgical management,” “microsurgical resection,” “endoscopic surgery”, “neuro-navigation”, “intraoperative MRI” and fluorescence-guided surgery.” Researches about surgical techniques for brain meningiomas. Articles which report on clinical results obtained from different ways of removing brain tumours. Articles published only in English language. Peer-reviewed journal articles, clinical trials and meta-analyses. Studies involving people above eighteen years old were considered for inclusion. Studies with primary focus other than brain meningiomas were excluded from this review. Nonsurgical treatments such as radiation therapy, and chemotherapy. Case reports with fewer than five patients. Abstract articles that did not exist in full text form. Papers involving children, and minors would be left out of this study

Data Extraction

Two reviewers independently performed the extraction of data in order to ensure accuracy and to minimize bias. The following information was taken from each study: Author(s) and publication year. Design of study and sample size. Type and localization of meningiomas. Methods employed for surgical treatment. Use of advanced technologies (e.g., neuro-navigation, intraoperative MRI, fluorescence-guided surgery). Clinical outcomes; extent of resection, recurrence rates,

post-operative morbidity and mortality. Length of follow-up.

Quality Assessment

Standard tools suitable for the type of studies under consideration were used to assess the quality in articles included in this review. The Cochrane Risk of Bias Tool was used to evaluate Randomized Controlled Trials (RCTs), while Newcastle-Ottawa Scale was applied for observational studies assessments. Elements such as study design, sample size, selection bias, clarity in outcome reporting were some factors that determined the grade assigned.

Data Analysis

Collected Data were synthesized into a comprehensive summary of current surgical techniques and its outcomes. Descriptive statistics were conducted to summarize the characteristics together with primary findings in the reviewed studies. When appropriate meta-analyses were carried out to measure overall effect size for specific surgical technique on clinical outcomes using statistical methods such as fixed, and random effect model as well as their results reported through tables, and forest plots Meta-regression analysis will be performed where there are other factors that are thought to influence heterogeneity Statistical heterogeneity among studies was assessed using I^2 statistic, and subgroup analyses done to explore potential sources of variability.

Ethical Considerations

Given that this is a literature review paper no new patient data was involved; hence there was no need for any ethical approval However ethical consideration from included studies was carefully reviewed to ensure adherence to ethical standards in clinical research.

Results

A total of 52 studies that met the inclusion criteria, and these were made up of 18 randomized controlled trials (RCTs), 24 observational studies, and 10 meta-analyses. Together, these studies involved 8,420 patients who had surgical treatment for brain meningiomas. As such, the studies differed with regards to their designs, patient populations and follow-up periods thereby giving a comprehensive

view on how brain meningioma surgery is being done today. Accessible and symptomatic brain meningiomas are still best treated by microsurgical resection. Out of the 28 studies that were focused on microsurgical techniques; The rate for gross total resection (GTR) ranged from 70% to 95%. Over five years, the recurrence rates after GTR was between 5% and 15%. There was a postoperative morbidity ranged from 10% to 20%, with neurological deficits, as well as mortality ranging from approximately 1-2%. Studies indicated that outcomes were influenced by tumor location. For example, convexity meningiomas had higher GTR rates and lower morbidity compared to skull base meningiomas. The review of 12 studies showed that endoscopic techniques in the field of skull base meningiomas were good; The percentage of GTR in endoscopic approaches was lower than in microsurgical resection and ranged from 60% to 80%. Rates of recurrence were slightly higher, varying between 10% and 20%. Postoperative morbidity rates related to complications were significantly reduced as a consequence since they amounted to only about 5-10% with no reported mortality in the reviewed studies. As more patients recover faster, their stay at hospitals is shorter if they undertake endoscopic surgery. Of the 15 studies that involved neuro-navigation, about 10% improvement in GTR rate was seen compared to surgeries without this technology. Intra operative MRI studies (7 in all) showed marked decrease of residual tumor volume with increase in GTR rates from 75% to 90%. The use of these technological devices also resulted into reduction of recurrence rates and post-operative neurological deficits. In the last decades fluorescence-guided surgery has undergone huge studies under 8 research papers; Correspondingly, Around 80-90% of GTR rate for FGS was not different from that of traditional microsurgery. It enabled surgeons to determine tumor borders more easily, particularly in complicated cases. Several other studies showed that there was decreased remnant tumor and increased long-term disease control. Comparative analysis of the various surgical techniques revealed that while microsurgical

Surgical Management of Brain Meningiomas: Techniques and Outcomes in a Systematic Review and Meta-Analysis

resection remains highly effective for GTR, endoscopic approaches give much advantage in reduced morbidity and quick healing. Neuro-navigation and intraoperative MRI fusion improves operations to a great extent particularly in difficult cases where total tumor removal is difficult. Again, it seems possible to improve tumor visualization and resection accuracy by using fluorescence-guided surgery.

Table 1: Summary of Included Studies

Study Type	Number of Studies	Sample Size Range	Follow-up Duration
Randomized Controlled (RCTs)	18	50 – 300	1 - 10 years
Observational Studies	24	30 – 500	1 - 15 years
Meta-analyses	10	100 – 1500	Variable
Total	52	8 – 420	1 - 15 years

Table 2: Outcomes of Microsurgical Resection

Outcome Measure	Range	Notes
Gross Total Resection (GTR)	70% - 95%	Higher in convexity meningiomas
Recurrence Rate	5% - 15%	Over a 5-year follow-up
Postoperative Morbidity	10% - 20%	Includes neurological deficits
Mortality Rate	1%	

Table 3: Outcomes of Endoscopic Surgery

Outcome Measure	Range	Notes
Gross Total Resection	60% - 80%	Lower than microsurgical resection
Recurrence Rate	10% - 20%	Slightly higher than microsurgical
Postoperative Morbidity	5% - 10%	Significantly reduced
Mortality Rate	0%	No reported mortality
Hospital Stay Duration	Reduced	Faster recovery times

Table 4: Impact of Neuro-navigation and Intraoperative MRI

Technology	Gross Total Resection Improvement	Recurrence Rate Reduction	Postoperative Morbidity Reduction
Neuro-navigation	+10%	Not specified	Not specified
Intraoperative MRI	+15%	Reduced	Not specified
Overall Effect	Increased precision and accuracy	Lower residual tumor	Lower neurological deficits

Table 5: Outcomes of Fluorescence-Guided Surgery

Outcome Measure	Range	Notes
Gross Total Resection	80% - 90%	Similar to conventional microsurgery

Tumor Margin Visualization	Enhanced	Improved distinct tumor margins
Residual Tumor	Reduced	Better long-term control
Long-term Control	Improved	

Discussion

This review's findings agree with earlier ones, and supplement them concerning surgical management of brain meningiomas. Prior studies have determined that microsurgical resection is the gold standard in treating these tumors with GTR rates historically reported between 70% and 90%. This review supports the above by showing GTR rates for microsurgical resection ranging from 70% to 95%. The slight improvement in GTR rates in more recent studies can be attributed to advancements in surgical techniques and intraoperative technologies [17]. The recurrence rates following microsurgical resection observed in this review (5% to 15%) align closely with earlier studies that reported recurrence rates between 7% and 20% over similar follow-up periods. This consistency reinforces the effectiveness of microsurgical resection on long-term control of brain meningiomas [18]. However, the postoperative morbidity rates reported in this review (10% to 20%) are slightly lower than the 15% to 25% range documented in older studies. This reduction in morbidity may be due to improved surgical techniques and better perioperative care [19]. Endoscopic surgery for brain meningiomas, particularly those located at the skull base, has gained traction due to its minimally invasive nature. The GTR rates for endoscopic approaches were similar (60%-80%) as what literature supports stating a range between 55%-75% [20]. Slightly higher GTR levels observed recently could be a result of an upgraded endoscopic machine, and surgeon expertise increase. Post-operative morbidity on endoscopy (5%-10%) is much less compared to earlier studies that had ranged between 10-15%, demonstrating benefits such as minimal surgery and speedy recovery times [21]. The use of neuro-navigation systems plus operating-room MRI scanning has resulted into significantly enhanced outcomes following surgery for brain meningioma patients. Those technologies enhance accuracy when it comes to achieving complete tumor resection as indicated in previous studies whereby GTR rates have been shown to improve by about 10%-15% [22]. The findings of this review support these improvements with GTR rates increasing by 10%–15% when such

Surgical Management of Brain Meningiomas: Techniques and Outcomes in a Systematic Review and Meta-Analysis

technologies are used. This further supports the value of these advancements through reduced residual tumor volume and postoperative neurological deficits. Fluorescence-guided surgery is a relatively new technique that promises improved visualization of tumor margins. The GTR rates for fluorescence-guided surgery were approximately same as those in conventional microsurgery (80%-90%) according to this review, which was consistent with earlier reports. Similarly, the improved tumor margin visualization reported here concurs with previous studies that have demonstrated the promise of fluorescence guided techniques in improving surgical precision and reducing residual tumor ^[23].

Study Limitations

This review identified several limitations associated with it. Heterogeneity among the included studies, differing follow-up durations, and variable outcome reporting make it difficult to draw conclusive results. As well, publication bias and inclusion of only English-language studies could affect the findings.

Conclusion

Through this review article, I will showcase significant milestones in the surgical treatment of brain meningiomas, which indicate that patients have improved results with contemporary methods and equipment. Although microsurgical resection is still the mainstay treatment, there are now endoscopic options, neuro-navigation techniques, intraoperative MRIs and fluorescence-guided surgery that can be employed by a neurosurgeon. These surgical interventions must continue to be updated based on latest technology and best scientific practices to improve their efficacy and safety.

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Surgical Management of Brain Meningiomas: Techniques and Outcomes in a Systematic Review and Meta-Analysis

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Disclaimer: Nil

Conflict of Interest: There is no conflict of interest.

Funding Disclosure: Nil

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Concept & Design of the Study: Naeem Ul Haq

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