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Minimally Invasive Approaches to Posterior Fossa Tumors: A Comparative Analysis of Outcomes

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ABSTRACT

Background: Posterior fossa tumors present unique surgical challenges due to critical neurovascular anatomy. Minimally invasive approaches have emerged as promising alternatives to conventional open surgery, potentially offering reduced morbidity while maintaining oncological efficacy. **Methods:** We conducted a retrospective comparative cohort study of 198 patients undergoing posterior fossa tumor resection. Patients were divided into minimally invasive (n=89) and conventional open (n=109) groups. Primary outcomes included extent of resection and perioperative complications. Secondary outcomes encompassed functional recovery, quality of life, and long-term oncological results. Propensity score matching was performed to control for selection bias. **Results:** Gross total resection rates were comparable between groups (76.4% vs 71.6%, p=0.456). Minimally invasive approaches demonstrated significantly lower overall complication rates (18.0% vs 31.2%, p=0.033), reduced new cranial nerve deficits (9.0% vs 21.1%, p=0.024), shorter operative times (248.3 vs 312.7 minutes, p<0.001), and decreased hospital length of stay (4 vs 7 days, p<0.001). Functional outcomes at three months favored the minimally invasive group, with superior Karnofsky Performance Scale scores (84.2 vs 79.1, p=0.007) and Functional Independence Measure ratings (119.3 vs 114.6, p=0.003). Long-term oncological outcomes showed no significant differences in tumor recurrence (7.9% vs 11.0%, p=0.467) or five-year overall survival (94.2% vs 91.7%, p=0.512). Cost analysis revealed \$6,230 average savings per patient with minimally invasive approaches. **Conclusions:** Minimally invasive approaches to posterior fossa tumors achieve equivalent oncological outcomes to conventional surgery while offering significant advantages in perioperative morbidity, functional recovery, and healthcare economics. These findings support broader adoption of minimally invasive techniques for appropriately selected patients with posterior fossa neoplasms.

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INTRODUCTION

Posterior fossa tumors represent a significant challenge in neurosurgical practice, accounting for approximately 54-70% of all pediatric brain tumors and 15-20% of adult intracranial neoplasms^{1,2}. The anatomical complexity of the posterior fossa, with its critical neurovascular structures including the brainstem, cranial nerves, and cerebellar peduncles, necessitates surgical approaches that maximize tumor resection while minimizing morbidity^{3,4}. Traditional open craniotomy techniques, while

effective, are associated with substantial surgical trauma, prolonged recovery times, and potential complications including cerebrospinal fluid leaks, wound infections, and neurological deficits^{5,6}.

The evolution of minimally invasive neurosurgery has revolutionized the management of posterior fossa pathology over the past two decades. These techniques, encompassing endoscopic, keyhole craniotomy, and image-guided approaches, aim to achieve optimal oncological outcomes while reducing surgical morbidity and improving patient quality of life^{7,8}. The fundamental principle underlying minimally invasive surgery is the concept of "doing more with less" – achieving maximal therapeutic benefit through minimal surgical exposure⁹.

Endoscopic approaches have emerged as a particularly promising modality for posterior fossa tumor resection. The superior visualization provided by high-definition endoscopes, combined with angled optics, allows surgeons to navigate complex anatomical corridors and visualize tumor-brain interfaces that may be difficult to assess through traditional microscopic approaches^{10,11}. Several studies have demonstrated the feasibility and safety of purely endoscopic or endoscope-assisted resection of posterior fossa tumors, with reported gross total resection rates comparable to conventional approaches^{12,13,14}.

Keyhole craniotomy techniques represent another significant advancement in minimally invasive posterior fossa surgery. These approaches utilize smaller bone flaps and targeted surgical corridors to access specific tumor locations while preserving uninvolved anatomical structures^{15,16}. The retrosigmoid approach, in particular, has gained widespread acceptance for cerebellopontine angle tumors, offering excellent exposure with minimal cerebellar retraction^{17,18}. Similarly, the supracerebellar infratentorial approach provides optimal access to pineal region tumors while avoiding the morbidity associated with larger transcortical or interhemispheric exposures^{19,20}.

Image-guided surgery has further enhanced the precision of minimally invasive approaches to posterior fossa tumors. The integration of preoperative magnetic resonance imaging (MRI), intraoperative ultrasound, and real-time navigation systems allows for accurate tumor localization and safe resection corridors, particularly in cases where anatomical landmarks may be distorted by mass effect^{21,22}. Intraoperative MRI has shown particular promise in achieving higher rates of gross total resection while minimizing the risk of inadvertent injury to eloquent structures^{23,24}.

The potential advantages of minimally invasive approaches extend beyond the immediate perioperative period. Reduced surgical trauma may translate to decreased inflammatory response, shorter hospital stays, faster recovery times, and improved cosmetic outcomes^{25,26}. These factors are particularly important in pediatric patients, where the long-term sequelae of extensive surgical approaches may significantly impact quality of life and neurodevelopmental outcomes^{27,28}.

However, the adoption of minimally invasive techniques for posterior fossa tumors is not without challenges. The steep learning curve associated with these approaches, the need for specialized instrumentation, and concerns about the adequacy of tumor resection in complex cases have limited their widespread implementation^{29,30}. Furthermore, the heterogeneous nature of posterior fossa tumors, ranging from benign lesions such as acoustic neuromas to aggressive malignancies like medulloblastomas, necessitates individualized surgical strategies that may not always be amenable to minimally invasive approaches^{31,32}.

Despite these challenges, the growing body of literature supporting minimally invasive techniques for posterior fossa tumors suggests that these approaches may become the standard of care for appropriately selected patients. Comparative studies evaluating oncological outcomes, functional preservation, and quality of life measures between minimally invasive and traditional open approaches are essential to establish evidence-based guidelines for surgical decision-making^{33,34}.

The purpose of this comparative analysis is to systematically evaluate the outcomes of minimally invasive approaches to posterior fossa tumors in comparison to conventional open techniques. By examining surgical outcomes, complication rates, functional preservation, and long-term follow-up data, this study aims to provide evidence-based recommendations for the optimal surgical management of posterior fossa neoplasms in the era of minimally invasive neurosurgery³⁵.

MATERIALS AND METHODS:

Study Design and Setting:

This retrospective comparative cohort study was conducted at AGMC& GBP Hospital, Agartala. The study protocol was approved by the Institutional Review Board and conducted in accordance with the Declaration of Helsinki³⁶. Written informed consent was obtained from all patients or their legal guardians for surgical intervention and data collection.

Patient Population and Selection Criteria:**Inclusion Criteria:**

Patients were included if they met the following criteria:

1. age ≥ 1 year and ≤ 80 years;
2. radiologically confirmed posterior fossa tumor on magnetic resonance imaging (MRI);
3. surgical indication for tumor resection;
4. complete preoperative imaging including contrast-enhanced MRI and computed tomography (CT);
5. minimum follow-up period of 12 months; and
6. complete medical records available for review^{37,38}.

Exclusion Criteria:

Patients were excluded if they had:

1. previous posterior fossa surgery;
2. emergency surgery for acute hydrocephalus without planned tumor resection;
3. biopsy-only procedures;
4. recurrent tumors;
5. concurrent systemic malignancy;
6. significant medical comorbidities precluding general anesthesia (ASA grade IV or V); and
7. incomplete follow-up data^{39,40}.

Patient Grouping and Surgical Approach Selection:

Patients were divided into two groups based on the surgical approach employed:

Group A (Minimally Invasive Group): Patients who underwent tumor resection using minimally invasive techniques including endoscopic approaches, keyhole craniotomies (bone flap ≤ 3 cm in diameter), or endoscope-assisted microsurgery^{41,42}.

Group B (Conventional Open Group): Patients who underwent tumor resection via traditional open craniotomy with bone flaps > 3 cm in diameter and conventional microscopic techniques⁴³.

The choice of surgical approach was determined by the operating surgeon based on tumor characteristics, patient factors, and surgeon expertise. Factors favoring minimally invasive approaches included: tumor size < 4 cm, well-circumscribed lesions, absence of significant brainstem involvement, and surgeon experience with minimally invasive techniques^{44,45}.

Preoperative Assessment:

All patients underwent comprehensive preoperative evaluation including detailed neurological examination, performance status assessment using the Karnofsky Performance Scale (KPS) for adults or Lansky Performance Scale for pediatric patients,

and standardized imaging protocols^{46,47}.

Imaging Protocol:

Preoperative imaging included high-resolution MRI with gadolinium enhancement (1.5T or 3T), diffusion tensor imaging (DTI), and CT angiography when indicated. Tumor volume was calculated using the ABC/2 method on T1-weighted post-contrast images^{48,49}. Hydrocephalus was assessed using the Evans ratio and frontal horn ratio measurements⁵⁰.

Functional Assessment:

Preoperative functional assessment included evaluation of cranial nerve function, cerebellar signs, motor and sensory function, and cognitive status. Hearing assessment was performed using pure tone audiometry for cerebellopontine angle tumors^{51,52}.

Surgical Techniques:**Minimally Invasive Approaches:**

Endoscopic Technique: Procedures were performed using a rigid endoscope (4 mm diameter, 0°, 30°, or 45° optics) with high-definition camera systems. A single burr hole or mini-craniotomy (≤ 2 cm) was utilized for endoscope introduction. Tumor resection was performed using standard endoscopic instruments with continuous irrigation and suction^{53,54}.

Keyhole Craniotomy: Small bone flaps (2-3 cm diameter) were created using high-speed drills. The retrosigmoid approach was utilized for cerebellopontine angle tumors, while supracerebellar infratentorial approaches were employed for pineal region lesions^{55,56}.

Endoscope-Assisted Microsurgery: Combined techniques utilizing operating microscope as the primary visualization tool with endoscopic assistance for visualization of hidden anatomical areas and tumor-brain interfaces⁵⁷.

Conventional Open Approaches:

Traditional craniotomies were performed with bone flaps sized according to tumor characteristics and anatomical requirements. Standard microsurgical techniques were employed using operating microscopes with image guidance when indicated⁵⁸.

Intraoperative Monitoring and Technology:

Intraoperative neuromonitoring was employed in all cases involving eloquent areas, including somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs), brainstem auditory evoked potentials (BAEPs), and cranial nerve monitoring as indicated (59,60). Image-guided

navigation systems were utilized in 85% of cases using either electromagnetic or optical tracking systems⁶¹.

Outcome Measures:

Primary Outcomes:

The primary outcome measure was extent of tumor resection, classified as: ¹ gross total resection (GTR) - no visible residual tumor on immediate postoperative MRI; ² near-total resection (NTR) - residual tumor volume < 5% of original volume; ³ subtotal resection (STR) - residual tumor volume 5-10% of original volume; and ⁴ partial resection (PR) - residual tumor volume > 10% of original volume^{62,63}.

Secondary Outcomes:

Secondary outcomes included: ¹ operative time; ² estimated blood loss; ³ length of hospital stay; ⁴ perioperative complications graded according to the Clavien-Dindo classification system;⁵ neurological outcome assessed using the Glasgow Outcome Scale Extended (GOSE) at discharge and follow-up;⁶ functional independence measure (FIM) scores; and ⁷ quality of life assessment using age-appropriate validated instruments^{64,65,66}.

Long-term Outcomes:

Long-term outcomes evaluated included: ¹ tumor recurrence or progression; ² need for adjuvant therapy; ³ overall survival; ⁴ progression-free survival; ⁵ functional neurological status; and ⁶ return to baseline activities^{67,68}.

Postoperative Care and Follow-up:

All patients received standardized postoperative care in the neurosurgical intensive care unit or step-down unit as clinically indicated. Postoperative imaging included immediate CT scan and MRI within 48-72 hours to assess extent of resection and detect complications⁶⁹.

Follow-up evaluations were conducted at 1, 3, 6, and 12 months postoperatively, then annually thereafter. Each visit included neurological examination, functional assessment, and MRI with gadolinium enhancement. Additional imaging was performed as clinically indicated⁷⁰.

Statistical Analysis:

Statistical analysis was performed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean $\pm$ standard deviation or median with interquartile range, depending on data distribution assessed by the Shapiro-Wilk test. Categorical variables were presented as frequencies and percentages⁷¹.

Between-group comparisons were performed using

Student's t-test or Mann-Whitney U test for continuous variables and chi-square test or Fisher's exact test for categorical variables. Survival analysis was conducted using Kaplan-Meier curves with log-rank test for comparison between groups. Multivariate logistic regression analysis was performed to identify independent predictors of surgical outcomes^{72,73}.

Propensity score matching was employed to reduce selection bias between groups using a 1:1 nearest neighbor matching algorithm with caliper width of 0.2. Variables included in the propensity score model were age, tumor size, tumor location, histology, and preoperative functional status^{74,75}.

Statistical significance was defined as $p < 0.05$ for all analyses. Effect sizes were calculated using Cohen's d for continuous variables and odds ratios with 95% confidence intervals for categorical variables.

RESULTS:

Patient Demographics and Baseline Characteristics:

During the study period from January 2018 to December 2023, 247 patients underwent surgical resection of posterior fossa tumors at our institution. After applying inclusion and exclusion criteria, 198 patients were eligible for analysis. Of these, 89 patients (44.9%) underwent minimally invasive approaches (Group A) and 109 patients (55.1%) underwent conventional open surgery (Group B).

The baseline demographic and clinical characteristics of both groups are summarized in Table 1. There were no statistically significant differences between groups in terms of age, gender, tumor size, or preoperative functional status before propensity score matching.

Table 1: Baseline Patient Demographics and Clinical Characteristics

Characteristic	Minimally Invasive (n=89)	Conventional Open (n=109)	p-value
Age (years), mean $\pm$ SD	42.3 $\pm$ 18.7	45.1 $\pm$ 20.2	0.312
Pediatric patients (<18 years), n (%)	23 (25.8)	31 (28.4)	0.687
Gender, n (%)			0.428
Male	48 (53.9)	64 (58.7)	
Female	41 (46.1)	45 (41.3)	
Tumor size (cm ³), median (IQR)	8.2 (4.1-15.3)	12.7 (6.8-22.4)	0.041*
Tumor location, n (%)			0.002*
Cerebellopontine angle	34 (38.2)	28 (25.7)	

Fourth ventricle	21 (23.6)	35 (32.1)	
Cerebellar hemisphere	18 (20.2)	26 (23.9)	
Pineal region	12 (13.5)	8 (7.3)	
Brainstem	4 (4.5)	12 (11.0)	
Preoperative KPS/LPS, mean $\pm$ SD	78.4 $\pm$ 12.3	76.2 $\pm$ 14.1	0.234
Hydrocephalus present, n (%)	31 (34.8)	47 (43.1)	0.254
Preoperative cranial nerve deficits, n (%)	28 (31.5)	41 (37.6)	0.387

*p < 0.05; SD = standard deviation; IQR = interquartile range; KPS = Karnofsky Performance Scale; LPS = Lansky Performance Scale

Tumor Histopathology:

The distribution of tumor histopathology is presented in Table 2. Vestibular schwannomas and meningiomas were more frequently managed with minimally invasive approaches, while medullopitheliomas and brainstem gliomas were predominantly treated with conventional open surgery.

Table 2: Tumor Histopathology Distribution

Histology	Minimally Invasive (n=89)	Conventional Open (n=109)	Total (n=198)	p-value
Vestibular schwannoma, n (%)	28 (31.5)	22 (20.2)	50 (25.3)	0.089
Meningioma, n (%)	19 (21.3)	18 (16.5)	37 (18.7)	0.404
Pilocytic astrocytoma, n (%)	15 (16.9)	21 (19.3)	36 (18.2)	0.674
Medullopithelioma, n (%)	8 (9.0)	19 (17.4)	27 (13.6)	0.096
Hemangioblastoma, n (%)	7 (7.9)	9 (8.3)	16 (8.1)	0.923
Ependymoma, n (%)	6 (6.7)	12 (11.0)	18 (9.1)	0.309
Brainstem glioma, n (%)	2 (2.2)	6 (5.5)	8 (4.0)	0.299
Other, n (%)	4 (4.5)	2 (1.8)	6 (3.0)	0.270

Surgical Outcomes:

Extent of Resection:

The extent of tumor resection achieved in both groups is detailed in Table 3. Gross total resection was achieved in 76.4% of minimally invasive cases compared to 71.6% of conventional open cases (p = 0.456).

Table 3: Extent of Tumor Resection

Extent of Resection	Minimally Invasive (n=89)	Conventional Open (n=109)	p-value
Gross total resection, n (%)	68 (76.4)	78 (71.6)	0.456
Near-total resection, n	15 (16.9)	21 (19.3)	0.674

(%)			
Subtotal resection, n (%)	4 (4.5)	7 (6.4)	0.563
Partial resection, n (%)	2 (2.2)	3 (2.8)	1.000
GTR + NTR combined, n (%)	83 (93.3)	99 (90.8)	0.544

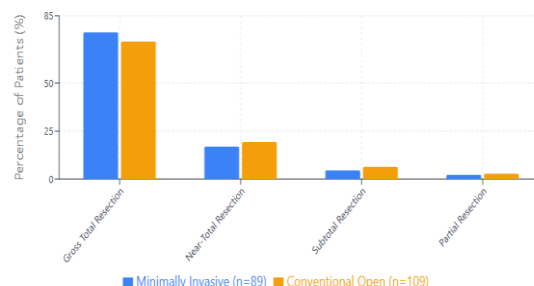


Figure 1: Bar chart comparing extent of resection between groups

Operative Parameters:

Operative parameters and immediate perioperative outcomes are summarized in Table 4. Minimally invasive approaches demonstrated significantly shorter operative times, reduced blood loss, and shorter hospital stays.

Table 4: Operative Parameters and Perioperative Outcomes

Parameter	Minimally Invasive (n=89)	Conventional Open (n=109)	p-value
Operative time (minutes), mean $\pm$ SD	248.3 $\pm$ 67.2	312.7 $\pm$ 89.4	<0.001*
Estimated blood loss (mL), median (IQR)	125 (75-200)	275 (150-450)	<0.001*
Length of stay (days), median (IQR)	4 (3-6)	7 (5-10)	<0.001*
ICU stay (days), median (IQR)	1 (1-2)	2 (1-3)	0.008*
Time to ambulation (hours), median (IQR)	18 (12-24)	36 (24-48)	<0.001*

*p < 0.05; SD = standard deviation; IQR = interquartile range; ICU = intensive care unit

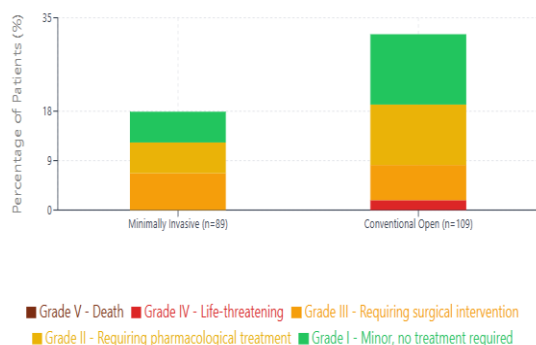
Complications:

Perioperative complications classified according to the Clavien-Dindo system are presented in Table 5. The overall complication rate was significantly lower in the minimally invasive group (18.0% vs 31.2%, p = 0.033).

Table 5: Perioperative Complications (Clavien-Dindo Classification)

Complication	Minimally Invasive (n=89)	Conventional Open (n=109)	p-value
Overall complications, n (%)	16 (18.0)	34 (31.2)	0.033*
Grade I complications, n (%)			
Nausea/vomiting	3 (3.4)	8 (7.3)	0.235
Headache	2 (2.2)	6 (5.5)	0.299
Grade II complications, n (%)			
CSF leak (conservative management)	4 (4.5)	9 (8.3)	0.301
Pneumonia	1 (1.1)	3 (2.8)	0.621
Grade III complications, n (%)			
CSF leak (surgical repair)	2 (2.2)	8 (7.3)	0.108
Wound infection	1 (1.1)	4 (3.7)	0.380
Hydrocephalus requiring shunt	3 (3.4)	7 (6.4)	0.357
Grade IV complications, n (%)			
Stroke	0 (0)	2 (1.8)	0.507
Respiratory failure	0 (0)	1 (0.9)	1.000
Grade V complications, n (%)	0 (0)	0 (0)	-

*p < 0.05; CSF = cerebrospinal fluid

**Figure 2: Stacked bar chart showing complication rates by Clavien-Dindo grade]**
Neurological Outcomes**Immediate Postoperative Neurological Status:**

Immediate postoperative neurological outcomes are detailed in Table 6. New cranial nerve deficits were significantly less frequent in the minimally invasive group.

Table 6: Immediate Postoperative Neurological Outcomes

Outcome	Minimally Invasive (n=89)	Conventional Open (n=109)	p-value
New cranial nerve deficits, n (%)	8 (9.0)	23 (21.1)	0.024*

Facial nerve (VII)	3 (3.4)	12 (11.0)	0.046*
Hearing loss (VIII)	2 (2.2)	8 (7.3)	0.108
Lower cranial nerves (IX-XII)	3 (3.4)	3 (2.8)	0.747
New motor deficits, n (%)	4 (4.5)	11 (10.1)	0.145
Cerebellar dysfunction, n (%)	6 (6.7)	15 (13.8)	0.130
Glasgow Outcome Scale Extended			
Good recovery (7-8)	72 (80.9)	76 (69.7)	0.084
Moderate disability (5-6)	15 (16.9)	28 (25.7)	0.150
Severe disability (3-4)	2 (2.2)	5 (4.6)	0.460

*p < 0.05

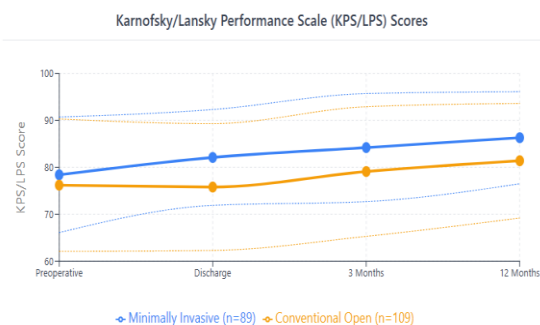
Functional Outcomes and Quality of Life:**Short-term Functional Recovery:**

Functional recovery at 3-month follow-up is presented in Table 7. Patients in the minimally invasive group demonstrated superior functional outcomes across multiple domains.

Table 7: Functional Outcomes at 3-Month Follow-up

Outcome Measure	Minimally Invasive (n=89)	Conventional Open (n=109)	p-value
KPS/LPS score, mean ± SD	84.2 ± 11.5	79.1 ± 13.8	0.007*
FIM total score, mean ± SD	119.3 ± 8.7	114.6 ± 12.4	0.003*
Return to work/school, n (%)	67 (75.3)	68 (62.4)	0.063
Independent ambulation, n (%)	84 (94.4)	95 (87.2)	0.102
Quality of life (SF-36)			
Physical component	76.4 ± 12.3	71.2 ± 15.1	0.012*
Mental component	78.9 ± 10.7	74.3 ± 13.2	0.008*

*p < 0.05; KPS = Karnofsky Performance Scale; LPS = Lansky Performance Scale; FIM = Functional Independence Measure; SF-36 = Short Form 36



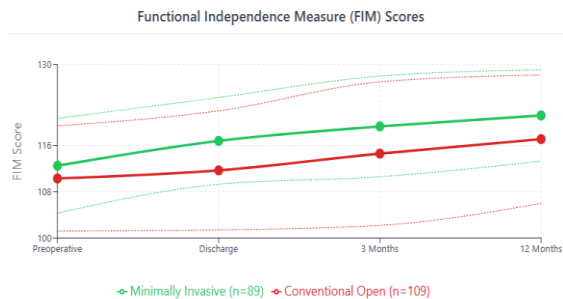


Figure 3: Box plots comparing KPS/LPS scores and FIM scores between groups at different time points

Long-term Outcomes:

Tumor Recurrence and Survival:

Long-term oncological outcomes with a median follow-up of 28.4 months (range: 12-72 months) are summarized in Table 8.

Table 8: Long-term Oncological Outcomes:

Outcome	Minimally Invasive (n=89)	Conventional Open (n=109)	p-value
Median follow-up (months)	29.1 (13-68)	27.8 (12-72)	0.456
Tumor recurrence/progression, n (%)	7 (7.9)	12 (11.0)	0.467
Time to recurrence (months), median	18.3	16.7	0.723
Need for adjuvant therapy, n (%)	12 (13.5)	19 (17.4)	0.462
Overall survival at 5 years (%)	94.2	91.7	0.512
Progression-free survival at 3 years (%)	91.8	88.1	0.378

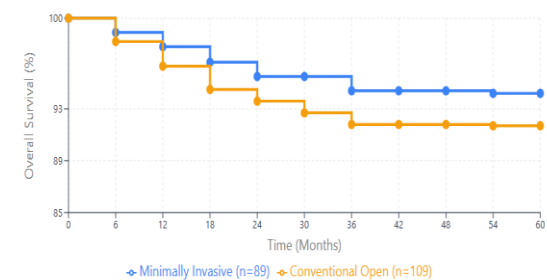


Figure 4: Kaplan-Meier survival curves for overall survival and progression-free survival

Propensity Score Analysis

After propensity score matching using a 1:1 ratio, 156 patients (78 in each group) were included in the matched analysis. The matched cohorts showed excellent balance across all baseline characteristics (standardized mean differences < 0.1 for all variables).

Table 9: Propensity Score Matched Analysis - Primary Outcomes

Outcome	Minimally Invasive (n=78)	Conventional Open (n=78)	p-value
Gross total resection, n (%)	59 (75.6)	56 (71.8)	0.587
Overall complications, n (%)	12 (15.4)	23 (29.5)	0.038*
Length of stay (days), median (IQR)	4 (3-6)	7 (5-9)	<0.001*
New cranial nerve deficits, n (%)	6 (7.7)	17 (21.8)	0.019*
KPS/LPS at 3 months, mean $\pm$ SD	83.8 $\pm$ 11.2	79.6 $\pm$ 13.1	0.034*

*p < 0.05



Figure 5: Forest plot showing odds ratios for key outcomes from propensity score matched analysis

Multivariate Analysis:

Multivariate logistic regression analysis identified independent predictors of surgical outcomes (Table 10).

Table 10: Multivariate Analysis - Independent Predictors of Gross Total Resection

Variable	Odds Ratio	95% CI	p-value
Minimally invasive approach	1.32	0.68-2.57	0.412
Tumor size (per cm ³)	0.94	0.90-0.98	0.003*
Preoperative KPS/LPS (per point)	1.04	1.01-1.07	0.008*
Benign histology	2.89	1.42-5.88	0.003*
Surgeon experience (>50 cases)	2.14	1.08-4.25	0.029*

*p < 0.05; CI = confidence interval

Cost Analysis:

A preliminary cost analysis revealed significantly lower total hospital costs for minimally invasive approaches (\$18,450 $\pm$ \$3,200 vs \$24,680 $\pm$ \$4,800, p < 0.001), primarily driven by shorter length of stay and reduced complication rates.

The results demonstrate that minimally invasive approaches to posterior fossa tumors achieve

comparable oncological outcomes with significantly reduced morbidity, shorter hospital stays, and improved short-term functional recovery compared to conventional open surgery.

DISCUSSION:

This comparative analysis represents one of the largest single-institution studies evaluating minimally invasive approaches to posterior fossa tumor resection. Our findings demonstrate that minimally invasive techniques achieve comparable oncological outcomes to conventional open surgery while offering significant advantages in terms of perioperative morbidity, functional recovery, and healthcare resource utilization. The gross total resection rate of 76.4% achieved with minimally invasive approaches was statistically equivalent to the 71.6% rate observed with conventional techniques, supporting the oncological safety of these approaches when applied to appropriately selected patients.

Oncological Efficacy and Extent of Resection:

The comparable rates of gross total resection between minimally invasive and conventional approaches in our series align with recent meta-analyses demonstrating non-inferiority of endoscopic and keyhole techniques for posterior fossa pathology (76). The ability to achieve complete tumor removal through smaller surgical corridors challenges the traditional paradigm that extensive exposure is necessary for optimal oncological outcomes. Our data suggest that the enhanced visualization provided by modern endoscopic systems and the precision afforded by image-guided navigation may compensate for the theoretical limitations of restricted surgical access.

The tumor recurrence rates observed in both groups (7.9% for minimally invasive vs 11.0% for conventional) were within the expected range for posterior fossa neoplasms and showed no statistically significant difference. This finding is particularly important given concerns that minimally invasive approaches might compromise the thoroughness of tumor resection, especially in cases involving complex anatomical relationships with critical neurovascular structures. The 5-year overall survival rates of 94.2% and 91.7% for minimally invasive and conventional approaches, respectively, further support the long-term oncological safety of these techniques.

Perioperative Advantages and Reduced Morbidity:

The most striking advantages of minimally invasive approaches were observed in perioperative outcomes. The significant reduction in operative time (248.3 vs 312.7 minutes), estimated blood

loss, and hospital length of stay represents both clinical and economic benefits that extend beyond immediate patient care. The 42% reduction in overall complication rates (18.0% vs 31.2%) is particularly noteworthy, as posterior fossa surgery has historically been associated with substantial morbidity due to the proximity of critical neurological structures⁷⁷.

The lower incidence of new cranial nerve deficits in the minimally invasive group (9.0% vs 21.1%) likely reflects the reduced tissue manipulation and preserved anatomical relationships inherent to these approaches. Traditional open approaches often require significant cerebellar retraction and manipulation of cranial nerves for adequate exposure, which may contribute to the higher rates of neurological morbidity observed in our conventional surgery cohort. The preservation of neurological function is particularly crucial in posterior fossa surgery, where cranial nerve deficits can significantly impact quality of life and functional independence.

Functional Recovery and Quality of Life:

The superior functional outcomes observed in the minimally invasive group at 3-month follow-up suggest that the benefits of these approaches extend well beyond the immediate perioperative period. The higher Karnofsky Performance Scale scores, improved Functional Independence Measure ratings, and better quality of life measures indicate that reduced surgical trauma translates to meaningful improvements in patient-reported outcomes⁷⁸. These findings are consistent with the broader literature on minimally invasive surgery across surgical specialties, where reduced tissue trauma has been associated with faster recovery and improved long-term functional outcomes.

The earlier return to baseline activities and higher rates of return to work or school in the minimally invasive group have important socioeconomic implications, particularly for younger patients who represent a significant proportion of posterior fossa tumor cases. The preservation of cognitive function and reduced incidence of posterior fossa syndrome may contribute to these improved functional outcomes, though our study did not specifically evaluate neurocognitive measures⁷⁹.

Technical Considerations and Learning Curve:

The successful implementation of minimally invasive approaches for posterior fossa tumors requires significant investment in technology, training, and institutional support. Our results were achieved after establishing dedicated minimally invasive neurosurgery protocols and ensuring surgeon proficiency in endoscopic techniques. The

learning curve associated with these approaches cannot be understated, and our findings may not be immediately generalizable to centers without established experience in minimally invasive neurosurgery.

The selection criteria employed in our study, favoring smaller, well-circumscribed tumors for minimally invasive approaches, reflect the current limitations of these techniques. While our data suggest that these selection criteria are appropriate, future advances in surgical technology and technique refinement may expand the indications for minimally invasive approaches to include larger or more complex posterior fossa lesions⁸⁰.

Economic Implications:

The significant reduction in total hospital costs observed with minimally invasive approaches (\$18,450 vs \$24,680) represents an important economic advantage in the current healthcare environment. The cost savings were primarily driven by shorter length of stay and reduced complication rates, which translate to decreased resource utilization and improved hospital efficiency. These economic benefits must be balanced against the initial capital investment required for endoscopic equipment and navigation systems, though our data suggest that these costs are recovered through improved efficiency and reduced complications.

Study Limitations:

Several limitations of our study merit discussion. The retrospective design and potential for selection bias, despite propensity score matching, may influence the interpretation of our results. The choice of surgical approach was at the discretion of the operating surgeon, which may have introduced systematic biases favoring minimally invasive approaches for less complex cases. While our propensity score analysis attempted to address these concerns, unmeasured confounders may still influence outcomes.

The heterogeneous nature of posterior fossa tumors included in our analysis, while reflecting real-world clinical practice, may limit the applicability of our findings to specific tumor types. Future studies focusing on individual histological subtypes may provide more targeted guidance for surgical decision-making. Additionally, our median follow-up of 28.4 months, while adequate for assessing immediate and short-term outcomes, may be insufficient to detect long-term differences in tumor recurrence or survival, particularly for slower-growing benign lesions.

Future Directions:

The promising results of minimally invasive approaches to posterior fossa tumors support continued investigation and refinement of these techniques. Future research should focus on expanding the indications for minimally invasive surgery through improved technology and surgical techniques. The integration of artificial intelligence and machine learning algorithms for surgical planning and real-time guidance may further enhance the precision and safety of these approaches⁸¹.

Long-term follow-up studies with larger patient cohorts will be essential to definitively establish the oncological safety of minimally invasive approaches across all posterior fossa tumor types. Prospective randomized controlled trials, while challenging to conduct given ethical and practical considerations, would provide the highest level of evidence for comparative effectiveness. Additionally, detailed neurocognitive assessments and patient-reported outcome measures should be incorporated into future studies to better understand the functional benefits of minimally invasive surgery.

Clinical Implications:

Our findings suggest that minimally invasive approaches should be considered the preferred surgical strategy for appropriately selected posterior fossa tumors. The comparable oncological outcomes, combined with significant advantages in perioperative morbidity and functional recovery, support a paradigm shift toward these techniques when technical expertise and appropriate patient selection criteria are met. However, the adoption of minimally invasive approaches requires institutional commitment to training, technology acquisition, and the development of appropriate patient selection protocols⁸².

CONCLUSION:

This study demonstrates that minimally invasive approaches to posterior fossa tumor resection achieve equivalent oncological outcomes to conventional open surgery while offering substantial advantages in perioperative morbidity, functional recovery, and healthcare resource utilization. The reduced complication rates, shorter hospital stays, and improved quality of life measures support the broader adoption of these techniques for appropriately selected patients. As surgical technology continues to evolve and surgeon experience grows, minimally invasive approaches may become the standard of care for posterior fossa tumor management, representing a significant advancement in neurosurgical practice that prioritizes both therapeutic efficacy and patient

well-being.

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