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Application Value of Multimodal Imaging Three-Dimensional Fusion in Surgery for Central Region Tumors: A Retrospective Controlled Study

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Research Article

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Abstract

Objective

To investigate the clinical value of preoperative multimodal imaging three-dimensional (3D) fusion reconstruction in microsurgical treatment of tumors involving the central region, and to evaluate its impact on the extent of resection, intraoperative venous preservation, and postoperative complications.

Methods

A total of 50 patients with central region tumors who underwent microsurgical treatment in the Department of Neurosurgery, Hubei No. 3 People's Hospital of Jianghan University, from February 2021 to February 2025 were retrospectively enrolled. Based on whether preoperative multimodal imaging 3D fusion was employed to assist surgical planning, patients were divided into the 3D fusion group (n = 25) and the conventional imaging group (n = 25). In the 3D fusion group, 3D reconstruction was performed based on multimodal imaging data to formulate individualized surgical approaches and venous protection strategies. In the conventional imaging group, surgical plans were determined solely by routine imaging interpretation. General baseline characteristics, operative time, intraoperative blood loss, extent of resection, critical superficial venous injury, postoperative complications, and Karnofsky Performance Status (KPS) score at discharge were compared between the two groups.

Results

No significant differences were observed between the two groups in sex, age, pathological type, lesion laterality, maximum tumor diameter, or preoperative peritumoral edema grade (all $P > 0.05$). The gross total resection (GTR) rate was significantly higher in the 3D fusion group than in the conventional imaging group [88.0% (22/25) vs. 64.0% (16/25), $P < 0.05$]. Operative time and intraoperative blood loss were significantly lower in the 3D fusion group [(182.6 ± 34.8) min vs. (214.3 ± 39.7) min; (226.0 ± 82.5) mL vs. (308.0 ± 96.4) mL; both $P < 0.01$]. The incidence of critical superficial venous injury was significantly lower in the 3D fusion group [8.0% (2/25) vs. 32.0% (8/25), $P < 0.05$]. The 3D fusion group demonstrated lower rates of postoperative cerebral edema exacerbation, new-onset or worsened neurological deficits, and overall complications compared with the conventional imaging group, while KPS at discharge was significantly higher (all $P < 0.05$). The agreement rates between preoperative 3D fusion reconstruction and intraoperative findings regarding superficial venous morphological configuration, predominant venous course, and tumor–vein spatial relationship were 96.0%, 92.0%, and 100.0%, with Kappa values of 0.948, 0.881, and 1.000, respectively.

Conclusion

Multimodal imaging 3D fusion reconstruction can accurately delineate the spatial relationships between central region tumors and the superficial venous system, thereby facilitating optimization of surgical strategies, improving the extent of resection, and reducing critical venous injury and postoperative complications. This technique demonstrates substantial clinical application value in surgery for central region tumors.

Introduction

The central region, encompassing the central sulcus and its adjacent cortex, represents a critical cerebral area where motor and sensory functions are highly concentrated. Surgical treatment of tumors involving the central region and its vicinity demands not only maximal lesion removal but also meticulous functional preservation [1, 2]. Conventional surgical planning for central region tumors has primarily emphasized functional cortex localization, white matter tract preservation, and intraoperative electrophysiological monitoring, while preoperative assessment of the cerebral superficial venous system has remained relatively insufficient [3]. In fact, superficial veins of the central region, particularly dominant draining veins and bridging veins, play a pivotal role in maintaining regional cerebral venous return. Intraoperative injury to these structures may precipitate cerebral edema, venous infarction, and postoperative neurological deterioration [4, 5].

Conventional magnetic resonance imaging (MRI) can adequately demonstrate tumor extent, enhancement patterns, and peritumoral edema; however, its capacity to depict the three-dimensional (3D) spatial relationships among tumors, cortical sulci and gyri, and superficial veins remains limited [6]. With advances in post-processing technology, multimodal imaging 3D fusion can integrate contrast-enhanced MRI, MR venography (MRV), and when necessary, MR angiography (MRA) and 3D T1-weighted sequences into a unified coordinate system, enabling simultaneous visualization of the tumor, brain surface, and superficial venous system. This provides more intuitive evidence for preoperative surgical approach design and intraoperative venous protection [7–9]. Recent studies have reported the potential value of this technology in preoperative simulation for complex intracranial lesions; however, clinical outcome evaluations specifically targeting central region tumors remain scarce [10, 11]. The present study utilized the post-processing capabilities of 3D Slicer software (version 4.11, www.slicer.org) for multimodal image fusion and reconstruction. Compared with expensive commercial navigation systems, this approach offers advantages of lower cost, greater operability, and ease of dissemination, making it particularly suitable for clinical scenarios aimed at refined preoperative planning.

This study employed a retrospective controlled design to compare differences in surgical resection outcomes, intraoperative venous preservation, and postoperative complications between central region tumor patients with and without preoperative multimodal imaging 3D fusion-guided surgical planning. Additionally, the anatomical display accuracy of 3D fusion reconstruction was evaluated against intraoperative findings, aiming to provide clinical evidence for the application of this technique in central region tumor surgery.

Materials and Methods

Study Population

Fifty patients with central region tumors who underwent microsurgery in the Department of Neurosurgery at our institution from February 2021 to February 2025 were retrospectively enrolled. Based on the temporal implementation of multimodal imaging 3D fusion technology, patients were divided into two groups: cases from February 2021 to January 2023 (before technology implementation) constituted the conventional imaging group (n = 25), and cases from February 2023 to February 2025 (after technology adoption) constituted the 3D fusion group (n = 25). Throughout both study periods, the surgical team, operative equipment, and perioperative management protocols remained unchanged.

Inclusion criteria were as follows: (1) Preoperative imaging indicating lesion location within the pericentral sulcus, precentral gyrus, postcentral gyrus, or adjacent functional areas; (2) Treatment by craniotomy and microsurgery; (3) Complete preoperative imaging and postoperative follow-up data available; (4) Adequate exposure of central region superficial veins during surgery, permitting retrospective analysis.

Exclusion criteria were as follows: (1) Previous ipsilateral craniotomy or radiotherapy history causing significant alteration of local anatomy; (2) Deep-seated lesions precluding evaluation of the relationship between superficial veins and the lesion; (3) Poor imaging quality or inability to perform reliable 3D reconstruction; (4) Severe systemic comorbidities affecting perioperative outcome assessment.

This study was approved by the institutional ethics committee (Ethics No: LW2021041).

Imaging Examination and Three-Dimensional Reconstruction

All patients underwent preoperative 3.0T MRI examination (Siemens MAGNETOM Skyra, Siemens Healthineers, Erlangen, Germany), including T1-weighted imaging (T1WI), T2-weighted imaging (T2WI), T2 fluid-attenuated inversion recovery (FLAIR), and contrast-enhanced T1WI. Patients in the 3D fusion group additionally underwent MRV (phase-contrast technique, TR/TE = 27/7.1 ms, flip angle 15°, slice thickness 1.0 mm), with supplementary MRA and 3D T1 sequences obtained when necessary. All imaging data in Digital Imaging and Communications in Medicine (DICOM) format were imported into 3D Slicer 4.11 software for automated image co-registration with manual correction, followed by segmentation and 3D reconstruction of the tumor, superficial veins, and brain surface. A comprehensive "tumor–superficial vein–brain surface" 3D model was constructed. The surgeon utilized this model to evaluate the spatial relationships between the lesion, central region superficial veins, and cortical surface anatomy, thereby informing preoperative surgical approach planning and venous protection strategy formulation.

Surgical Procedure

All procedures were performed by the same senior neurosurgeon with more than 15 years of experience in central region tumor surgery. In the 3D fusion group, the 3D reconstruction results guided selection of optimal craniotomy position, dural opening orientation, and exposure trajectory, with maximal preservation of critical superficial veins closely related to the tumor. For veins traversing the tumor surface, adhering to tumor margins, or partially encased by the lesion, an intratumoral decompression followed by piecemeal resection strategy was preferentially adopted. In the conventional imaging group, surgical approaches were designed based on conventional imaging interpretation. Neuronavigation and intraoperative electrophysiological monitoring were employed when necessary.

Outcome Measures

General data included sex, age, lesion laterality, pathological type, maximum tumor diameter, and preoperative peritumoral edema grade.

Surgical outcomes included operative time, intraoperative blood loss, extent of tumor resection (classified as gross total resection [GTR], subtotal resection [≥ 90% removal], or partial resection [< 90% removal]), and incidence of critical superficial venous injury.

Postoperative complications included cerebral edema exacerbation, venous infarction, postoperative hemorrhage, seizures, and new-onset or worsened neurological deficits.

Functional outcomes included preoperative Karnofsky Performance Status (KPS), KPS at discharge, and ΔKPS (KPS at discharge minus preoperative KPS).

3D fusion consistency evaluation: Using intraoperative microscopic observations combined with surgical video review as the reference standard, the consistency between preoperative 3D fusion reconstruction and intraoperative findings was assessed regarding superficial venous morphological configuration type, predominant venous course direction, and tumor–vein spatial relationship.

Statistical Analysis

Statistical analysis was performed using SPSS 26.0 software (IBM Corporation, Armonk, NY, USA). Continuous variables conforming to normal distribution are expressed as mean ± standard deviation ($\bar{x}\pm s$), with intergroup comparisons conducted using independent-sample t-tests. Normality was assessed using the Shapiro–Wilk test. Categorical variables are presented as frequencies and percentages, with intergroup comparisons performed using chi-square tests or Fisher's exact test. Consistency evaluation was assessed using Cohen's Kappa coefficient. A two-sided $P < 0.05$ was considered statistically significant.

Results

Comparison of Baseline Characteristics Between Groups

No statistically significant differences were observed between the two groups regarding sex, age, lesion laterality, pathological type, maximum tumor diameter, or preoperative peritumoral edema grade (all $P > 0.05$), confirming baseline comparability (Table 1).

Table 1
Comparison of baseline characteristics between the two groups of central region tumor patients

Variable	3D Fusion Group (n = 25)	Conventional Imaging Group (n = 25)	Statistic	P value
Male/Female (n)	14/11	13/12	$\chi^2=0.080$	0.777
Age (years, $\bar{x}\pm s$)	51.9 ± 11.4	53.1 ± 12.0	t = 0.362	0.719
Left/Right laterality (n)	14/11	13/12	$\chi^2=0.080$	0.777
Pathological type [n (%)]			$\chi^2=0.163$	0.922
Meningioma	12 (48.0)	11 (44.0)		
Metastasis	4 (16.0)	5 (20.0)		
Glioma	9 (36.0)	9 (36.0)		
Maximum tumor diameter (cm, $\bar{x}\pm s$)	3.8 ± 1.1	3.9 ± 1.2	t = 0.304	0.762
Preoperative peritumoral edema grade [n (%)]			$\chi^2=0.275$	0.872
Grade 0–I (none/mild)	10 (40.0)	11 (44.0)		
Grade II (moderate)	9 (36.0)	9 (36.0)		
Grade III (severe)	6 (24.0)	5 (20.0)		
Tumor location [n (%)]			$\chi^2=0.321$	0.852
Precentral gyrus	11 (44.0)	12 (48.0)		
Postcentral gyrus	8 (32.0)	7 (28.0)		
Central sulcus region	6 (24.0)	6 (24.0)		
Preoperative seizure history [n (%)]	9 (36.0)	8 (32.0)	$\chi^2=0.089$	0.765

Comparison of Surgical Outcomes Between Groups

The gross total resection (GTR) rate was significantly higher in the 3D fusion group than in the conventional imaging group. Operative time and intraoperative blood loss were significantly lower, and the incidence of critical superficial venous injury was significantly reduced in the 3D fusion group (all $P < 0.05$, Table 2).

Table 2
Comparison of surgical outcomes between the two groups of central region tumor patients

Variable	3D Fusion Group (n = 25)	Conventional Imaging Group (n = 25)	Statistic	P value
Gross total resection [n (%)]	22 (88.0)	16 (64.0)	χ^2=4.023	0.045
Subtotal/Partial resection [n (%)]	3 (12.0)	9 (36.0)		
Operative time (min, $\bar{x}\pm s$)	182.6 ± 34.8	214.3 ± 39.7	t = 2.986	0.004
Intraoperative blood loss (mL, $\bar{x}\pm s$)	226.0 ± 82.5	308.0 ± 96.4	t = 3.237	0.002
Critical superficial venous injury [n (%)]	2 (8.0)	8 (32.0)	χ^2=4.500	0.034
Intraoperative use of neuronavigation [n (%)]	22 (88.0)	20 (80.0)	χ^2=0.595	0.440
Intraoperative electrophysiological monitoring [n (%)]	23 (92.0)	21 (84.0)	Fisher	0.667
Craniotomy bone flap adjustment [n (%)]	1 (4.0)	5 (20.0)	Fisher	0.189

Comparison of Postoperative Complications and Short-Term Functional Outcomes

The 3D fusion group demonstrated significantly lower rates of postoperative cerebral edema exacerbation, new-onset or worsened neurological deficits, and overall complications compared with the conventional imaging group. No significant difference in preoperative KPS was observed between groups. The 3D fusion group exhibited significantly higher KPS at discharge [(82.4 ± 8.7) vs. (74.1 ± 10.2), P = 0.003] and superior ΔKPS [(+ 3.8 ± 6.2) vs. (− 2.7 ± 8.4), P = 0.003] (Table 3).

Table 3
Comparison of postoperative complications and short-term functional outcomes between groups

Variable	3D Fusion Group (n = 25)	Conventional Imaging Group (n = 25)	Statistic	P value
Cerebral edema exacerbation [n (%)]	3 (12.0)	9 (36.0)	χ^2=4.000	0.046
Venous infarction [n (%)]	1 (4.0)	4 (16.0)	Fisher	0.349
Postoperative hemorrhage [n (%)]	1 (4.0)	3 (12.0)	Fisher	0.609
Postoperative seizures [n (%)]	2 (8.0)	5 (20.0)	Fisher	0.417
New/worsened neurological deficits [n (%)]	3 (12.0)	10 (40.0)	χ^2=5.094	0.024
Overall complication rate [n (%)]	5 (20.0)	13 (52.0)	χ^2=5.556	0.018
Postoperative ICU stay [n (%)]	3 (12.0)	7 (28.0)	χ^2=2.000	0.157
Postoperative hospital stay (days, $\bar{x}\pm s$)	9.2 ± 3.1	12.4 ± 4.6	t = 2.875	0.006
Preoperative KPS (score, $\bar{x}\pm s$)	78.6 ± 9.1	76.8 ± 10.5	t = 0.651	0.518
KPS at discharge (score, $\bar{x}\pm s$)	82.4 ± 8.7	74.1 ± 10.2	t = 3.105	0.003
ΔKPS (score, $\bar{x}\pm s$)	+ 3.8 ± 6.2	−2.7 ± 8.4	t = 3.142	0.003

Consistency Evaluation Between Preoperative 3D Fusion Reconstruction and Intraoperative Findings

In the 3D fusion group, the agreement rates between preoperative 3D fusion reconstruction and intraoperative findings regarding superficial venous morphological configuration, predominant venous course, and tumor–vein spatial relationship were 96.0%, 92.0%, and 100.0%, respectively, indicating high reliability in demonstrating the central region superficial venous system and its relationship with the lesion (Table 4).

Table 4
Consistency evaluation between preoperative 3D fusion reconstruction and intraoperative findings (n = 25)

Assessment Item	Concordant/Total Cases	Agreement Rate (%)	Kappa Value	95% CI	P value
Superficial venous morphological configuration	24/25	96.0	0.948	0.847–1.000	< 0.001
Predominant venous course direction	23/25	92.0	0.881	0.756–1.000	< 0.001
Tumor–vein spatial relationship	25/25	100.0	1.000	1.000–1.000	< 0.001

Discussion

Surgery for central region tumors encompasses the dual objectives of tumor resection and functional preservation. Compared with non-eloquent area lesions, perioperative risks predominantly arise from complex anatomical relationships, particularly the intimate proximity of lesions to functional cortex, white matter tracts, and the superficial venous system [1–3]. The present study demonstrates that preoperative application of multimodal imaging 3D fusion for surgical planning significantly improves resection outcomes, reduces critical superficial venous injury, decreases postoperative complications, and enhances short-term functional status, suggesting that this technique not only provides anatomical visualization but also translates into tangible clinical benefits.

Regarding surgical resection outcomes, the 3D fusion group achieved a higher GTR rate, shorter operative time, and reduced intraoperative blood loss. This may be attributable to the capacity of 3D fusion to present the tumor, cortical sulci and gyri, and venous system within a unified spatial framework, enabling the surgeon to establish a clear three-dimensional anatomical framework preoperatively. For central region tumors specifically, when the tumor compresses the central sulcus or displaces adjacent gyri, conventional two-dimensional cross-sectional images alone often fail to provide stable spatial judgment, whereas 3D models facilitate intuitive identification of lesion surface projections, venous trunk courses, and safe surgical corridors [7–10]. More precise preoperative planning subsequently reduces intraoperative time required for landmark identification and directional adjustment, thereby improving overall surgical efficiency.

Concerning venous preservation, the 3D fusion group demonstrated a significantly lower incidence of critical superficial venous injury. Damage to cerebral surface veins, particularly bridging veins and dominant draining veins, may result in delayed cerebral swelling, focal venous infarction, and neurological deterioration [4, 5, 12]. Different pathological tumor types affect the venous system through distinct mechanisms: meningiomas predominantly compress and displace veins, while gliomas and metastases may directly invade or encase venous structures. The 3D fusion technique enables surgeons to formulate individualized dissection and preservation strategies based on specific pathological types

and patterns of venous involvement. Preoperative multimodal 3D fusion clearly delineates the spatial relationships between critical veins requiring preservation and the surgical approach, guiding surgeons to design craniotomy and dural opening plans that avoid dominant draining veins, and to plan staged resection strategies for venous high-risk zones. Its core significance extends beyond intuitive venous visualization to achieving refined preoperative surgical decision-making through three-dimensional anatomical information.

Regarding perioperative complications, the 3D fusion group exhibited lower rates of postoperative cerebral edema exacerbation, new-onset or worsened neurological deficits, and overall complications compared with the conventional imaging group. The pathogenesis of postoperative neurological deficits following central region tumor surgery is likely multifactorial, encompassing not only venous drainage compromise but also direct injury to functional cortex and white matter fiber tracts, intraoperative brain retraction, and infiltrative destruction by the tumor itself [13, 14]. Through preoperative 3D modeling, the fusion technique simultaneously visualizes spatial relationships among the tumor, functional cortex, and superficial venous system. The observed clinical benefits likely derive from comprehensive optimization of these multiple anatomical relationships. The reduced incidence of new-onset or worsened neurological deficits in the 3D fusion group (12.0% vs. 40.0%) may reflect the combined effects of multidimensional preoperative planning. By enabling preoperative identification of high-risk zones and minimizing unnecessary retraction and blind dissection, 3D fusion mechanistically contributes to reducing these adverse events. Furthermore, the significantly shorter postoperative hospital stay observed in the 3D fusion group (9.2 ± 3.1 days vs. 12.4 ± 4.6 days, P = 0.006) indirectly reflects the clinical advantages of reduced complication burden and faster functional recovery [15].

This study additionally demonstrated high consistency between preoperative 3D fusion reconstruction and intraoperative findings regarding central region superficial venous morphological configuration, predominant course direction, and tumor–vein spatial relationship, with complete concordance achieved for venous–tumor positional relationships. This provides anatomical validation for clinical application. For central region surgery, the surgeon's principal concern extends beyond venous anatomical classification to whether veins traverse the primary surgical corridor, whether they are encased by the tumor, and whether they constitute critical intraoperative risk points. The high concordance of 3D fusion at this level confers substantial preoperative practical utility [6, 11, 15].

Consistent with existing literature, imaging fusion and 3D visualization have demonstrated favorable adjunctive value in preoperative planning for functional and deep-seated lesions [15, 16]. In recent years, diffusion tensor imaging (DTI), intraoperative navigation, and augmented reality technologies have been increasingly applied in functional area tumor surgery, facilitating tract visualization, enhancing surgical localization accuracy, and optimizing intraoperative visual presentation [16, 17]. However, these technologies remain limited by equipment costs, workflow complexity, and availability. In comparison, the 3D Slicer-based post-processing workflow employed in this study accomplishes preoperative 3D reconstruction using routine MRI and MRV data, offering relatively lower cost and greater flexibility with favorable potential for dissemination to primary healthcare facilities. Particularly in institutions not yet

fully equipped with advanced commercial navigation systems, this technique serves as a valuable supplement for refined preoperative assessment.

This study has several limitations. First, as a single-center retrospective analysis with a limited sample size, selection bias cannot be excluded. For low-incidence events such as venous infarction and postoperative hemorrhage, the statistical power of the current sample may be insufficient, and some negative results cannot exclude the possibility of type II error due to small sample size. Additionally, the limited sample restricts the number of covariates that can be incorporated into multivariable regression analysis. Second, the included pathological types encompass meningiomas, gliomas, and metastases, which differ in biological behavior and effects on cortical veins. Although baseline characteristics were balanced between groups, subgroup sample sizes were insufficient for adequate subgroup analysis. Third, the retrospective design precludes complete differentiation of the independent contributions of venous injury, cortical retraction, and white matter tract damage to postoperative neurological deficits. Fourth, the temporal grouping design (before vs. after technology implementation) may introduce potential confounders related to learning curve effects, although the surgical team and protocols remained unchanged throughout the study period. Future studies incorporating intraoperative neurophysiological monitoring data and postoperative DTI may further elucidate the specific mechanisms by which 3D fusion technology improves neurological outcomes. Future multicenter, large-sample prospective studies should be conducted based on standardized scanning protocols and post-processing workflows, integrating DTI, functional MRI (fMRI), and artificial intelligence (AI)-based automatic segmentation technologies to further refine the precision surgical planning system for central region tumors [16–18].

Conclusion

Multimodal imaging 3D fusion reconstruction can accurately delineate the three-dimensional spatial relationships among central region tumors, superficial veins, and the brain surface, demonstrating high consistency with intraoperative findings. Compared with conventional imaging assessment, preoperative application of 3D fusion-assisted surgical planning facilitates improved resection outcomes, reduces critical superficial venous injury, decreases the incidence of postoperative cerebral edema and neurological deficits, and enhances short-term patient functional status. This technique holds substantial clinical value for widespread application in microsurgery for central region tumors.

List of Abbreviations

Abbreviation	Full Term
3D	Three-dimensional
MRI	Magnetic resonance imaging
MRV	Magnetic resonance venography
MRA	Magnetic resonance angiography
T1WI	T1-weighted imaging
T2WI	T2-weighted imaging
FLAIR	Fluid-attenuated inversion recovery
DICOM	Digital Imaging and Communications in Medicine
KPS	Karnofsky Performance Status
GTR	Gross total resection
ΔKPS	Change in Karnofsky Performance Status (KPS at discharge minus preoperative KPS)
DTI	Diffusion tensor imaging
fMRI	Functional magnetic resonance imaging
AI	Artificial intelligence

Declarations

Ethics approval and consent to participate

This study was approved by the Medical Ethics Committee of Hubei No. 3 People's Hospital of Jianghan University (approval number: LW2021041). All patients or their legal representatives provided written informed consent for surgical treatment prior to the procedure. As this was a retrospective analysis of routinely collected clinical data, the requirement for additional research-specific informed consent was waived by the institutional ethics committee, in accordance with the principles of the Declaration of Helsinki.

Consent for publication

Written informed consent was obtained from the patient whose images are presented in Fig. 1 for publication of the clinical images and associated data.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

J.Y. was responsible for study conception and design, data collection, data analysis, and drafting of the manuscript. J.B.contributed to data collection and interpretation. N.S. and J.L. supervised the study and critically revised the manuscript for important intellectual content. All authors have read and approved the final version of the manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request, subject to institutional data sharing policies and patient privacy protection.

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Figures

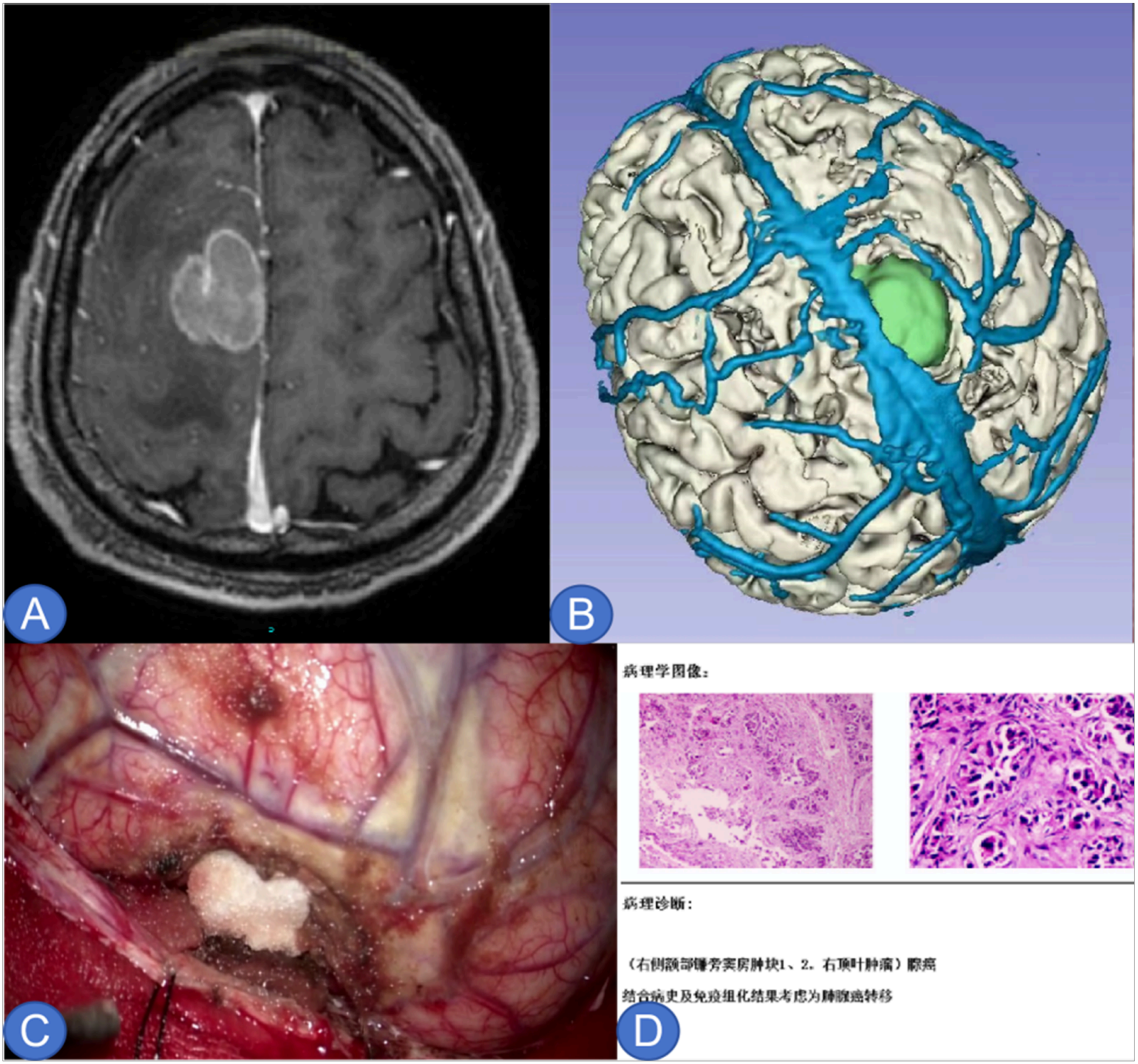


Figure 1

Right frontoparietal metastatic carcinoma. (A) Contrast-enhanced MRI demonstrating significant tumor enhancement with prominent peritumoral edema; (B) Multimodal imaging reconstruction revealing tumor location within the central region with the precentral vein situated anterior to the tumor; (C) Intraoperative findings consistent with preoperative multimodal reconstruction of venous course; (D) Pathological examination confirming adenocarcinoma (pulmonary adenocarcinoma metastasis based on clinical history and immunohistochemistry).

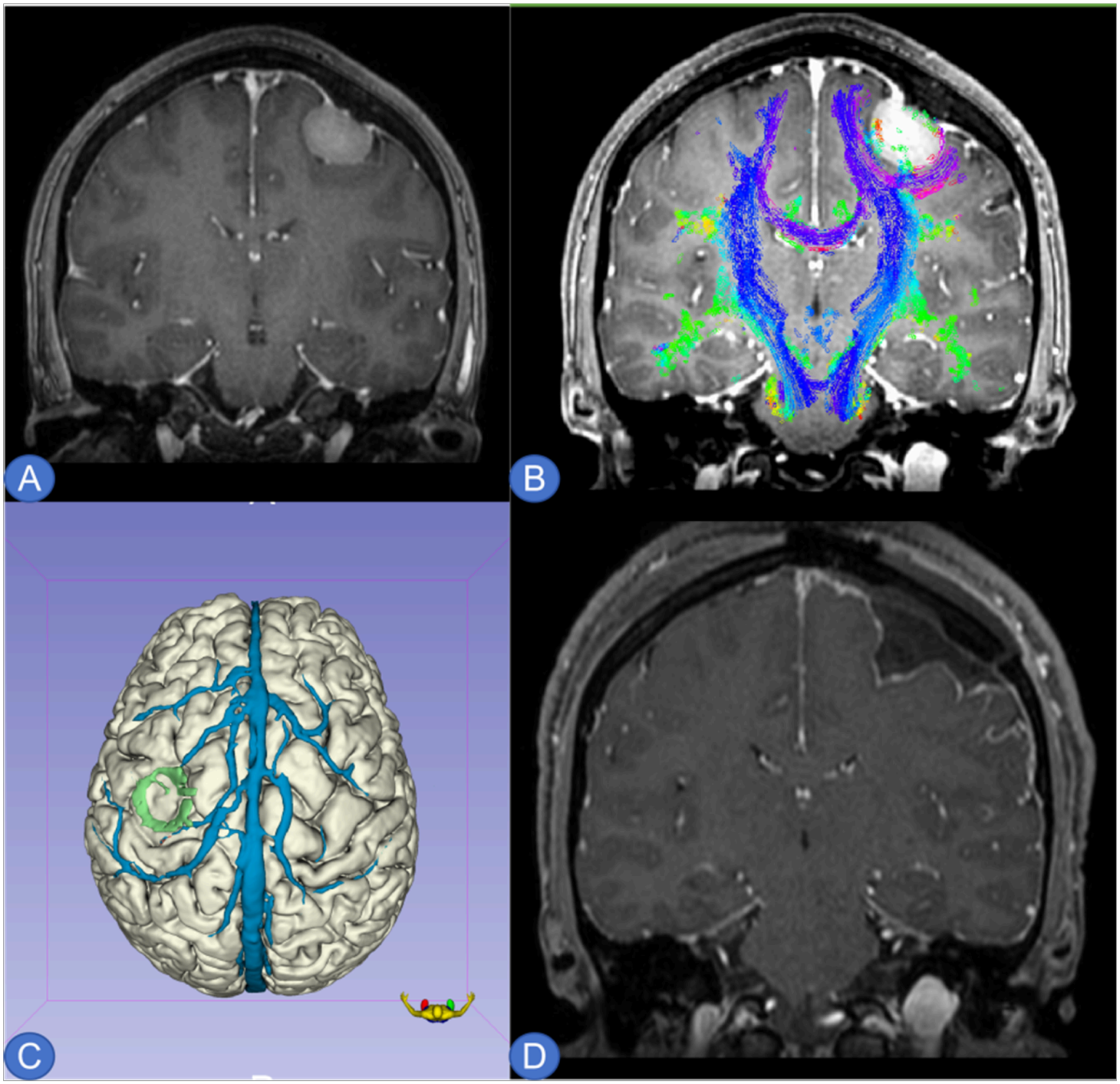


Figure 2

Left frontoparietal meningioma. (A) Left frontoparietal space-occupying lesion with prominent enhancement; (B) Diffusion tensor imaging demonstrating tumor-induced displacement of white matter tracts; (C) Multimodal imaging reconstruction showing tumor location within the central region with precentral vein and central sulcal vein positioned anterior and posterior to the tumor, respectively; (D) Postoperative imaging confirming complete tumor resection.