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Research Article

Enhancing Surgical Precision in Language Areas Through Personalized Structural and Functional Connectome- "A Glioma Language Connectome"

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Abstract

Objective: The language function in the human brain is crucial for communication, social interaction, cognition, decision making and problem solving. It is deeply embedded in neural networks, affecting nearly every aspect of our lives. During neurosurgical procedures, particularly those involving the language dominant hemisphere, preserving language function is a primary concern. This can be aided by Multimodal imaging which integrates different imaging techniques to provide a comprehensive brain structure, function, and connectivity. This preoperative mapping with connectome imaging allows seamless trajectory to prevent language deficits and when combined with Intraoperative direct cortical and subcortical mapping gives better results in resection of intra axial lesions around language areas.

Methods: Structural and functional connectome scans were generated using voxelbox explore, a machine learning software to reparcellate a validated template of SENSAAS atlas(for language network) based on individual anatomical and functional connectivity mapped from resting state functional MRI and structural connectivity based on diffusion MRI. Structural connectivity imaging was assessed to identify at-risk parcellations, and seed-based analysis of the region of interest was performed to evaluate functional relationships. Major language tracts were mapped to maximize tumor removal while preserving baseline language.

Results: Six patients with lesions involving left frontal or temporal lobe or both, around language dominant areas were included in the study. Imaging identified unique patterns of structural and functional connectivity, revealing distinct relationships within language networks. Multimodal connectome-guided preoperative planning, intraoperative navigation, and direct cortical-subcortical stimulation were utilized, with four patients maintaining intact language function and two patients demonstrating improved language function on follow-up compared to baseline.

Keywords: Connectome; Language; Machine Learning; fMRI; Brain Networks; Glioma

Key scientific and clinical highlights

- **Goal:** To improve surgical outcomes in language-dominant gliomas using personalized connectome imaging integrating structural and functional brain data.
- **Patient-Specific Mapping:** The study used Voxelbox Explore, an AI-based tool, to generate personalized connectomes based on resting-state fMRI and diffusion MRI.
- **Population:** Six adult patients (3 male, 3 female) with gliomas in the left frontal and/or temporal lobe (language-dominant hemisphere).
- **Imaging Framework:** Combined data from T1w, FLAIR, T1CE MRI, diffusion MRI, and rs-fMRI with voxelwise analysis.
- **Language Mapping Atlases:** SENSAAS atlas and AICHA parcellations were used for accurate identification of Broca's and Wernicke's areas.
- **Tracts Mapped:** Arcuate fasciculus (AF), IFOF, SLF III, FAT, and optic radiation were identified preoperatively for surgical navigation.
- **Intraoperative Strategy:** Awake craniotomy was performed in all patients with direct cortical and subcortical stimulation for real-time speech mapping.
- **Unique Connectomes:** No two patients had identical parcellation of language areas, emphasizing high interindividual variability.
- **Speech Preservation:** 4 of 6 patients retained baseline language, while 2 patients improved postoperatively. No permanent global aphasia occurred.
- **Tumor Grade:** Four of six tumors were high-grade gliomas (Grade III/IV), all of which were IDH-mutated.
- **Follow-up Outcome:** Follow-up ranged from 7 to 18 months (mean = 12.5 months), with no tumor recurrence in any patient.
- **Functional Neuroplasticity:** Bilateral language connectivity in two patients hinted at functional reorganization and neuroplasticity.
- **Speech Assessment Tool:** The Western Aphasia Battery was used pre- and postoperatively to quantify language outcomes.
- **Customized Intraoperative Testing:** Real-time language tasks (naming, reading, verb generation) were used to assess function during tumor removal.
- **Multimodal Advantage:** The integration of fMRI, DTI, and real-time stimulation improved surgical precision, especially in eloquent areas.
- **Histopathology Diversity:** Tumors included oligodendrogliomas, glioblastoma, angiocentric glioma, and astrocytomas (Grade II and III).
- **No Recurrence or Major Morbidity:** Despite large tumor volumes (avg. 54.21 cm^3), gross or near-total resections were achieved without recurrence.
- **Clinical Implication:** The study supports a paradigm shift toward connectome-based resections rather than solely anatomical localization.
- **Limitations:** Small sample size and single-center experience; results need validation in multi-institutional, diverse cohort

Introduction

Language was among the first cognitive functions examined through functional neuroimaging, and three decades of research have identified numerous cortical areas involved in various language processes [1]. The study of language-related brain regions and their connections remains a vital area of research, both for advancing our understanding of human brain function and for minimizing language deficits during neurosurgical procedures [2].

Over the last decade, cutting-edge neuroimaging, neurophysiological techniques, and brain stimulation methods have greatly enhanced the accuracy of language research in the brain, contributing to significant advancements in understanding its neural basis.

The understanding of how the brain processes language has evolved in three key ways.

First, rather than being divided into distinct regions for language production and comprehension, the brain's language functions are now seen as part of widespread cortical and subcortical networks.

Second, there is growing emphasis on hodology- the study of how these regions are interconnected through specific neural pathways [3].

Third, it is increasingly recognized that the brain areas involved in language processing also contribute to other cognitive and sensory-motor functions that were previously thought to be unrelated to language [4].

These recent advancements in structural and functional connectivity have redefined language eloquence, extending it beyond traditional anatomical regions to include both cortical and subcortical networks and tracts.

This Paradigm shift in understanding is especially crucial for language regions, where variability in functional localization and distribution complicates both preoperative and intraoperative mapping [5].

With the emergence of connectome technology, structural and functional brain connectivity can now be visualized using patient-specific maps through functional MRI and diffusion tensor imaging to map neural pathways and crossing tracts.

To optimize the balance between oncological and functional outcomes in glioma surgery, there is a shift toward a connectome-based resection approach. This strategy considers both the relationship between the tumor and essential distributed neural circuits-particularly subcortical pathways-as well as the dynamic and ever-changing nature of the meta-network [6]. This neural spatio-temporal integration allows for functional reallocation, facilitating neurological recovery even after extensive resections in areas traditionally regarded as "inoperable."

A deeper understanding of the connectome enhances the benefit-risk ratio of surgery by

- Refining the selection of resection areas previously considered "eloquent" based on traditional localizationist principles;
- Improving intraoperative awake cognitive mapping and monitoring in so-called non-eloquent regions;
- Enhancing preoperative planning to tailor intraoperative tasks to the patient's individual needs and preferences;
- Advancing the concept of "oncological disconnection surgery"
- Developing a personalized, multistage surgical strategy based on the brain's capacity for reorganization; and
- Ultimately preserving cognitive, social, and behavioral functions, including return to work, while maximizing the extent of resection, even in cases requiring multiple procedures.

Numerous functional neuroimaging studies have demonstrated that phonological, semantic, orthographic, and syntactic processing involve extensive and overlapping networks, highlighting the challenge of precisely defining language areas topographically [7].

Recent MRI-based studies of brain-lesioned dysphasic patients have revealed a broad region of potential language cortex in the left hemisphere, with frontal and temporal epicenters that differ from traditional model [8,9].

Only a limited number of studies have rigorously compared functional MRI(fMRI) and direct cortical/subcortical mapping(DCS/DSCS) for language localization [10-13], primarily using simple oral language tasks such as picture naming and verb generation. The key findings are as follows.

fMRI can detect most language areas identified by DCS/DSCS, but optimal detection requires combining results from multiple fMRI tasks-at least three for adequate sensitivity. Consequently, fMRI is effective at predicting the absence of positive DCS/DSCS sites, demonstrating a high negative predictive value. fMRI tends to identify up to 50% more language areas than DCS/DSCS , which results in a relatively lower positive predictive value. Significant variability exists in fMRI data across patients, tasks, and statistical approaches, making it challenging to generalize findings across different centers.

Currently, DSCS remains the most reliable method for mapping subcortical language regions. While fMRI provides valuable information, it is not sufficient as a standalone tool for surgical planning when language areas are near the surgical site. Therefore, fMRI and DCS/DSCS are best used as complementary techniques.

This comprehensive perspective on neural processing not only improves the precision and effectiveness of connectome-guided oncological surgery but also holds potential applications in restorative neurosurgery [6].

The integration of connectomics data into neuronavigation, combined with awake intraoperative neuro monitoring with DCS/ DSCS , allows for personalized surgical strategies that optimize tumor resection while safeguarding essential language functions.

Here we present six cases of glioma at left frontal or temporal region around language dominant areas where structural and functional connectomics were generated and combined with intraoperative navigation and awake intraoperative mapping facilitating maximal safe resction preserving language function in all the patients.

Material and Methods

Ethics approval and Consent

Study was conducted in compliance with AIG institutional guidelines and have been approved by the institutional ethics committee. (AIG/IEC- Post BH&R 67/07/2023). patient consent was obtained for this study.Patients were informed that AI related algorithms were involved in preoperative network and tracts building and the same is utilized in functional neuronavigation.

Participants

Six patients with intraaxial lesion around language dominant areas were taken in this study during August 2023 to December 2024. Only Adult patients above 18 years of age were considered in this study.

Of the six patients , three were male and three patients were females. All the patients underwent preoperative language assessment , neuroimaging protocol specific for voxelbox explore. All Patients underwent functional neuronavigation along with awake craniotomy, DCS/DSCS and intraoperative speech assessment. Tumor volumes were assessed pre and postoperatively.

Post operative language assessment was documented and compared to baseline. Pathology of lesions was documented. Patients were followed up through in clinic assessment and through telephonic conversation.

Preoperative language networks, tracts were co related with awake intraoperative mapping and results were documented.

Data acquisition

All six patients underwent neuroimaging on a Philips 3Tesla scanner. Diffusion-weighted imaging was performed with the following acquisition parameters: 1.75 × 1.75 × 2.00 mm voxels, FOV = 224 mm, acquisition matrix = 128 × 128 x 85, slice thickness = 2 mm, one nonzero b-value of b = 1000, 32 directions. The TR and TE were 5.813 s and 0.098011 s respectively.

A resting-state functional MRI (rsfMRI) was acquired as a T2-star EPI sequence, with 1.7969× 1.7969 × 3.00 mm voxels, acquisition matrix = 128 × 128 x 60, number of dynamics 160 volumes/ run, a TE = 0.035001 s, a TR = 2883 ms, a field of view - 224 mm, acquisition matrix= 128 x 128 x 48, a flip angle = 90∘ in an 8-min total run time.

Three structural MRI sequences were acquired: T1w (acquisition matrix: 480 x 480 x 200, voxel size: 0.5333 x 0.5333 x 0.8500 mm, TR: 0.0111256 s, TE: 0.005247 s), FLAIR (acquisition matrix: 512 x 512 x 355, voxel size: 0.4883 x 0.4883 x 0.5600 mm, TR: 4.8s, TE: 0.289528 s), and T1CE (acquisition matrix: 480 x 480 x 200, voxel size: 0.5333 x 0.5333x 0.8500 mm TR: 0.0111256 s, TE: 0.005247 s).

Data preprocessing

The structural MRI (sMRI), resting-state functional MRI (rs-fMRI) and diffusion MRI (dMRI) processing and inferencing were performed using Voxelbox Explore (https://www.brainsightai.com/voxelbox-explore, BrainSightIAI pvt. ltd., India), an AI-based connectomics tool for generating personalised brain maps. Figure 1 shows an overview of the steps performed by Voxelbox to generate the end-outputs, namely networks and tracts. The sMRI processing includes reorientation, bias field correction, gaussian denoising, skull stripping, segmentation, MNI normalization, and AC-PC origin correction. The processed sMRI is used subsequently for rs-fMRI and dMRI processing. The rs-fMRI processing comprises of reorientation, slice-time correction, motion correction, coregistration with structural MRI, despiking, skull stripping, normalisation and band-pass filtering. For inference, independent component analysis is used to generate different resting state networks from which specific networks such as language can be identified automatically through template matching [14,15].

The dMRI processing involves denoising, Gibb's artefact removal, motion correction, eddy current correction, bias correction, and skull stripping. The constrained spherical deconvolution is used for estimating the fiber orientation distribution from the processed dMRI data [16]. This is followed by automatic tract generation using templates from the Human Connectome Project and probabilistic tractography [17-19].

Brain atlas and region selection

Specifically for the language function, the sentence supramodal atlas (SENSAAS) was used to select the language network from the independent components generated by rs-fMRI.

The SENSAAS atlas is a specialized brain atlas that maps cortical regions involved in language integration [20]. It identifies 32 multimodal areas that exhibit leftward asymmetry and are activated during sentence production, reading, and listening. These regions are grouped into three distinct networks, one of which consists of 18 critical areas essential for speech comprehension, where damage could lead to deficits. SENSAAS provides valuable insights into sentence-level language processing, making it particularly beneficial for research focused on sentence comprehension and production.

Language parcellation

Within primary areas, the parcellations spanning the Broca's and Wenicke's areas were considered in this study. Specifically, in accordance with AICHA (Atlas of intrinsic connectivity of homotopic areas) atlas [21], parcellations f3t (G_Frontal_Inf_Tri-1) and f3o1 (G_Frontal_Inf_Orb-1) were considered part of Broca's area, and parcellations STS3 (S_Sup_Temporal-3), STS4 (S_Sup_Temporal-4), and t1_4 (G_Temporal_Sup-4) were considered part of Wernicke's area.

Probabilistic diffusion tractography

The Arcuate Fasiculus (AF), Inferior fronto occipital fasiculus (IFOF) Optic radiation (OR), Superior Longitudinal Fasiculus (SLF part -iii), and frontoaslant tract (FAT) were considered in pre-surgical planning for cases in this study.

Preoperative speech assessment

All patients underwent preoperative speech assessment for content, spontaneous speech, fluency, auditory comprehension, repetition, naming, reading, writing, and calculation by western aphasia battery test.

Intraoperative awake neuromonitoring

A multimodal intraoperative neuromonitoring strategy was employed, although transcranial Motor evoked potentials(MEPs) were not used since the patients underwent awake surgery. The monitoring included, EEG, MEPs, High frequency direct cortical stimulation for motor mapping, and low-frequency long train (LFLT) stimulation at 60 Hz using a two-pronged bipolar probe for language mapping. Dynamic subcortical stimulation of language networks was achieved by continuous LFLT at a fixed 5 mA.

Intraoperative language assessment

Intraoperative language was done with customized charts assessing the following

Postoperative language assessment

Patients are evaluated with Western aphasia battery test and findings were documented.

Results

In this series of six patients , males : female ratio is 1:1, there is diverse clinical presentations, though seizures and speech disturbances. Every patient had a unique pattern of preoperative language dysfunction with slurring of speech, difficulty in talking, repetition of words, constructing words/sentences, only one patient had headache with no speech disturbances. The average tumor vol-

Task	Brain Areas	Function Assessed	Errors to look for
Naming Objects: The patient identifies, or names objects presented visually or described verbally	Posterior supramarginal gyrus, posterior middle temporal gyrus, and pars orbitalis	Ability to accurately retrieve words associated with visual or verbal stimuli	Speech arrest, semantic errors, word-finding difficulties, phonological errors, made-up words, and other performance mistakes
Reading: The patient reads short, unfamiliar, and unrelated sentences presented visually	Face homunculus area, postcentral gyrus beneath the sylvian fissure, and ventral sensorimotor cortex. The superior longitudinal fascicle connecting the ventral premotor cortex to the supramarginal gyrus and the 'articulatory loop'	Coordination of phonological and semantic processes with motor, visual, and syntactic functions	Speech arrest, phonological errors, or semantic inaccuracies
Verb Generation: The patient produces verbs associated with given nouns or prompts	Broca's area, surrounding perisylvian regions, and posterior mid-frontal gyrus	Capacity to associate concepts semantically and to manage related syntactic functions	Speech arrest or failure to generate an appropriate verb response
Comprehension and Semantic Retrieval: The patient selects appropriate words to fit a verbal description of an object	Posterior inferior temporal gyrus and prefrontal areas	Ability to access accurate phonological sequences related to presented semantic concepts	Speech arrest or inability to produce a suitable noun or verb corresponding to the description

Table 1: Intraoperative language assessment.

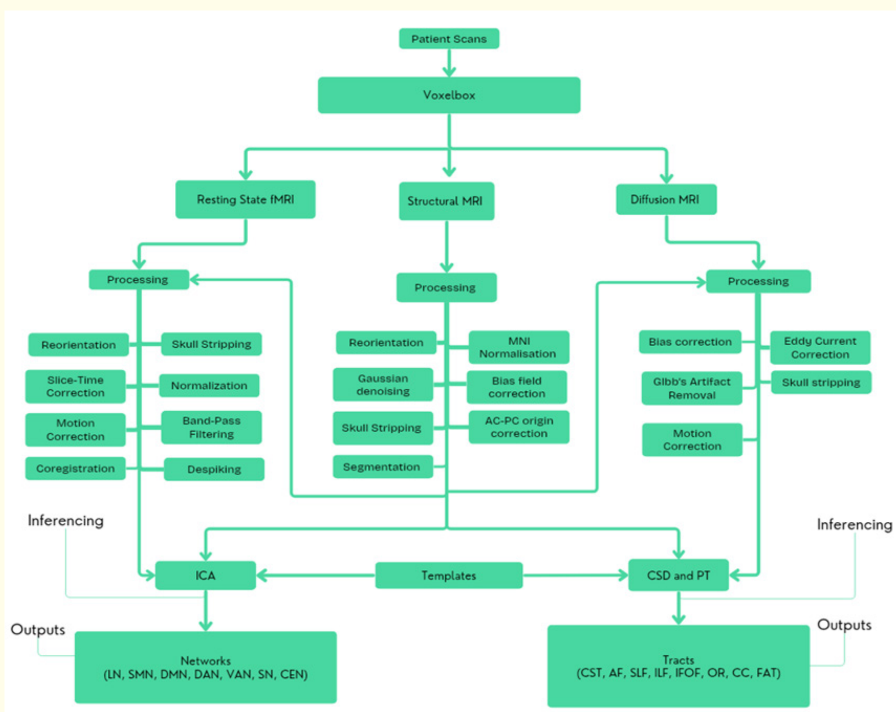

Figure 1: ICA, CSD, and PT represent Independent components analysis, constrained spherical deconvolution, and probabilistic tractography respectively.

Abbreviations LN: Language Network; SMN: Sensorimotor Network; DMN: Default Mode Network; DAN: Dorsal Attention Network; VAN: Ventral Attention Network; SN: Salience Network; CEN: Central Executive Network; CST: Corticospinal Tract; AF: Arcuate fasciculus; SLF: Superior Longitudinal Fasciculus; ILF: Inferior Longitudinal Fasciculus; IFOF: Inferior Fronto Occupital Fasciculus; OR: Optic Radiation; CC: Corpus Callosum; FAT: Frontal Aslant Tract

S.No	Age/Sex	Presenting Symptom	Preoperative Language Dysfunction	Imaging	Preoperative Tumor Volume (cm)	Histopathological Diagnosis	Surgical Approach	Extent of Resection	Postoperative Language Outcome	Postoperative Complications	Follow-up (months) and Status
1	64/Male	Speech disturbances	Slurring of speech	Left temporal contrast enhancing lesion involving medial temporal lobe structures	5.2x4.1x4	Glioblastoma NOS Grade-IV	Awake craniotomy	Gross Total	Improved	None	18 months, no recurrence
2	32/Male	Two episodes of Seizures	Difficulty in talking	Left frontal non contrast enhancing lesion involving middle and inferior frontal gyrus	2.8x2.5x2.3	Oligodendroglioma, Adult diffuse glioma grade-III, 1p19q codeleted and IDH mutated	Awake craniotomy	Gross Total	Baseline	None	14 months, no recurrence
3	34/Female	Seizure during delivery	Difficulty in constructing words	Non enhancing lesion at left inferior gyrus	4.2x3.6x3.2	Angiocentric glioma WHO grade-I	Awake craniotomy	Gross Total	Baseline	None	12 months, no recurrence
4	39/Male	Headache and speech disturbances	Repetition of words	Left temporal peripheral ring like contrast enhancing lesion involving superior and middle temporal gyrus	3.9x3.2x3.4	Oligodendroglioma Grade-III, IDH mutated, 1p19q codeleted	Awake craniotomy	Gross Total	Improved	None	12 months, no recurrence
5	48/Female	Headache	Nil	Left insular non contrast enhancing lesion	3.2x2.9x3	Astrocytoma, IDH mutated, WHO grade-II	Awake craniotomy	Near Total	Baseline	None	12 months, no recurrence
6	34/Female	Seizure & loss of consciousness	Difficulty in constructing words and sentences	Left insul ar non	5.2x4.6x4.4	Astrocytoma, IDH mutated,	Awake crani	Near	Worsened then impro	Worsened motor speec	7 mon ths, no

Table 2: Table showing Patient details, presenting symptoms, preoperative language dysfunctionpre operative tumor volume , extent of resection, language outcome and follow up.

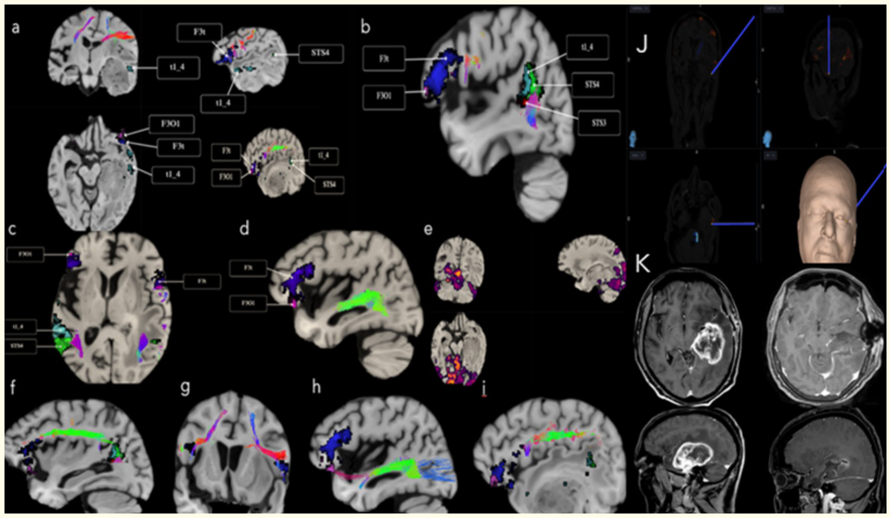

Figure 2: a,b,c,shows parcellations of language areas at frontal and temporal areas , d - optic radiation above temporal horn, e- visual network , f- arcuate fasiculus, g- Fronto aslant tract, h- IFOF, J- neuronavigation integration for selecting transulcal approach away from parcellations. K- pre and post operative MRI showing gross total excision.

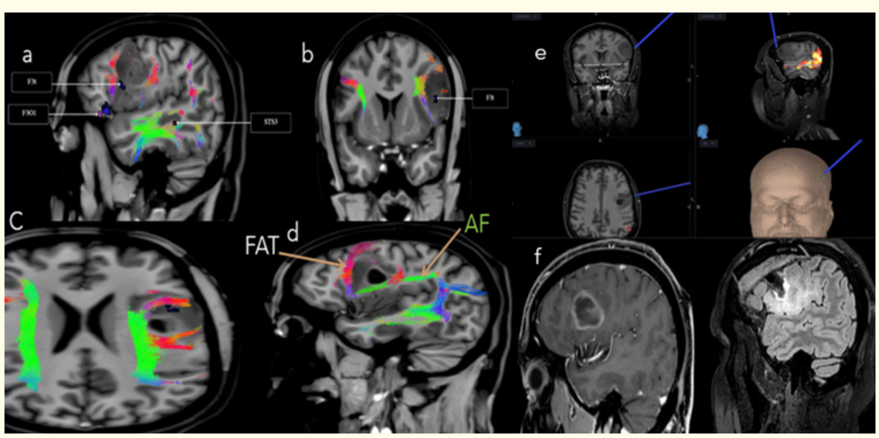

Figure 3: a,b- showing language parcellations, c,d- showing FAT , AF and IFOF, e, neuronavigation integrated functional netwoks, trajectory showing away from parcellation, F- Pre and post operative MRI scans sowing complete tumor excision.

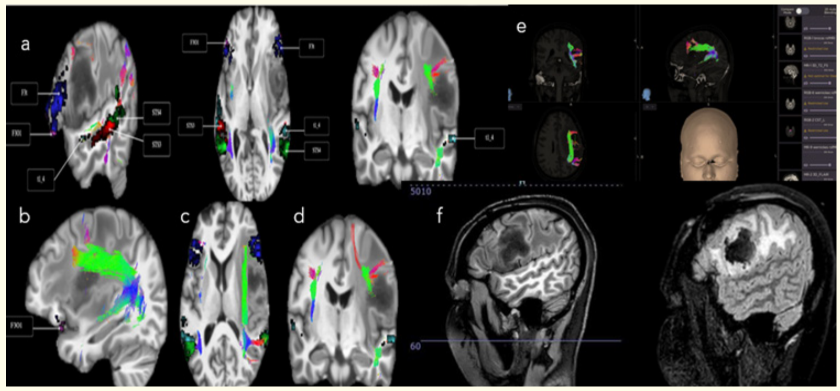

Figure 4: a- language parcellations, b,c- AF, d- FAT, e- Neuronavigation integration, f- Pre and post operative MRI images showing gross total excision.

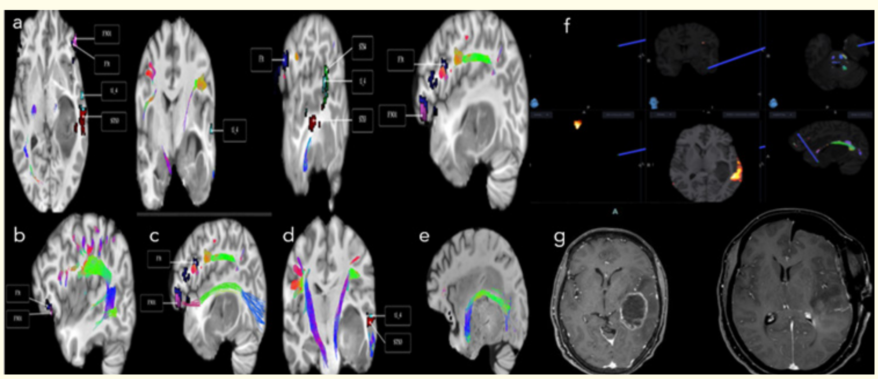

Figure 5: a- language parcellations, b- AF, c- IFOF, d- Medially Cortico spinal tract , e- Optic radiation, f- Neuronavigation integration, g- pre and post operative images showing gross total excision.

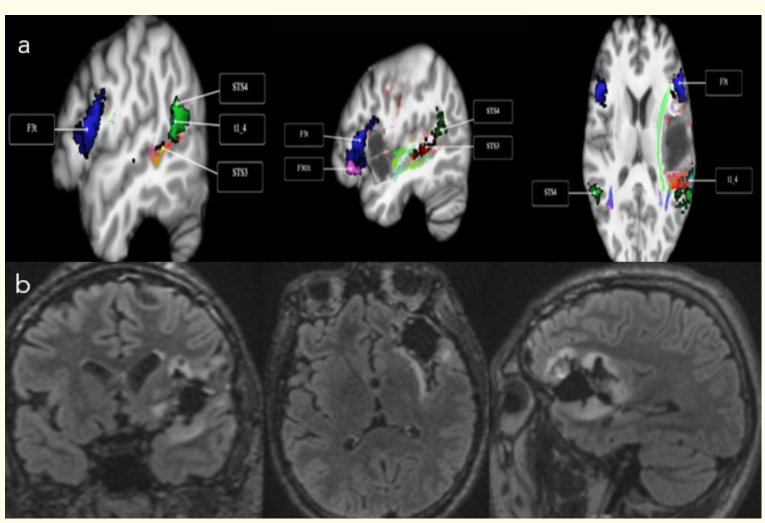

Figure 6: a- Language parcellations in left insular glioma involving frontal and temporal opercula, b, post op images showing near total resection of lesion.

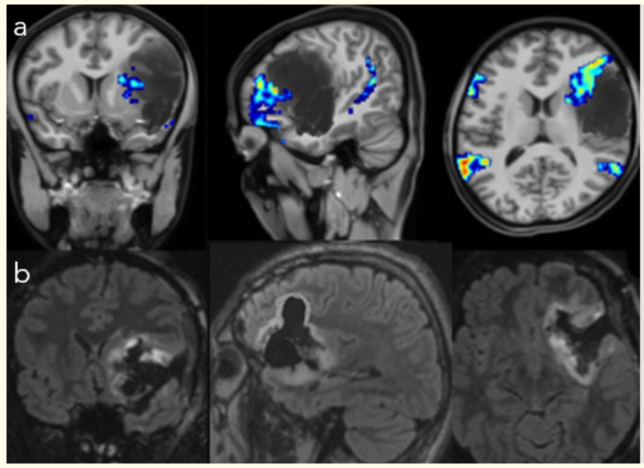

Figure 7: a- Left insular glioma with language parcellations, b- post operative MRI images showing near total excision.

ume size is 54.21 cms^3 suggesting that all tumors in this series are large tumors. Postoperative Language Outcomes Improved immediately in 2 patients (33.3%), baseline (unchanged) in 3 patients (50%), Worsened in 1 patient(16.6%) but later improved after 1 month during follow up.

No patient suffered from permanent global aphasia after surgery which is a good outcome for language-dominant lesions. Histopathological diagnosis was oligodendroglioma - 2 cases (commonest), glioblastoma - 1, angiocentric glioma - 1, astrocytoma Grade II - 1, astrocytoma Grade III - 1. Four of six patients (66.66%) had high-grade gliomas (Grade III/IV). Most interesting finding in this series was most lesions were IDH-mutated. All these four patients with high grade histology received concurrent radiotherapy for 30 cycles with chemotherapy - temozolamide (75mg/m^2) in 2patients, and procarbazine, lomustine and vincristine in two patients. Follow up ranged from 7 months to 18 months, Mean follow up is 12.5 months. No patient in this series had a recurrence requiring resurgery/ radio- chemotherapy.

Discussion

This case series highlights the importance of using structural and functional connectome imaging in planning and performing tumor surgeries in language-dominant brain regions. Precision in these areas is crucial to achieving extensive tumor removal while preserving language function and assessing recovery after surgery. By incorporating individual connectivity maps into neuronavigation systems, connectome imaging helps neurosurgeons pinpoint vital language pathways, evaluate potential risks, and customize surgical strategies to minimize the chance of functional damage.

These cases emphasize the advantages of a multimodal strategy, where connectome-guided imaging enhances the precision of surgical planning in eloquent brain areas. This approach addresses the limitations of conventional imaging and neuronavigation, which often lack the resolution needed to accurately define functional boundaries in the highly variable language cortex.

In all six patients, connectome imaging enabled a more refined approach to surgical planning by generating comprehensive maps of structural and functional connectivity within language networks. This mapping specifically focused on regions such as f3t (G_Frontal_Inf_Tri-1), f3o1 (G_Frontal_Inf_Orb-1), STS3 (S_Sup_Temporal-3), STS4 (S_Sup_Temporal-4), and t1_4 (G_Temporal_Sup-4). By providing patient-specific connectivity maps, we were able to implement targeted resection strategies that minimized the risk of language impairment—an essential factor when dealing with frontal opercular tumors where language localization often varies between individuals, complicating intraoperative identification [22].

Although advances in navigation systems have integrated DTI and task-based fMRI studies to identify anatomical landmarks or crucial structural regions, this series is one among the few to incorporate structural and functional network visualization into a multimodal framework aimed at preserving eloquent areas during surgical planning [23-25]. In particular, rs-fMRI proves valuable by capturing functional variability within language regions, especially for patients who are unable to undergo task-based studies, thereby enhancing its utility as a versatile tool.

Incorporating connectome data into neuronavigation enabled real-time, data-informed adjustments during surgery, thereby minimizing the disruption of functional networks. This integration allowes surgeons to tailor their approach based on connectivity data, which was particularly valuable in setting subcortical stimulation thresholds to identify motor pathways near the posterior tumor margins. As a result, both motor and language networks were preserved more effectively. Recent studies have demonstrated that integrating connectomic data with intraoperative monitoring enhances surgical outcomes by enabling more precise resections while safeguarding eloquent networks [26,27].

Preserving key hubs within language networks is linked to improved recovery and more favorable long-term outcomes in glioma patients [28]. Serial connectomic imaging holds promise for deepening our understanding of functional reorganization over time and may even help identify therapeutic targets during the recovery phase.

Conventional neuronavigation and awake language mapping techniques may fall short in capturing the complexity of language networks, which span multiple interconnected cortical and subcortical areas. Unlike traditional imaging, connectome imaging offers a comprehensive network-based perspective, providing detailed insights into language connectivity that conventional methods may overlook [29,30].

In these cases, connectome-guided imaging facilitated the planning of resection pathways through regions with less critical or already compromised connectivity, thereby minimizing functional impact. This approach aligns with recent studies highlighting that a network-based strategy is particularly beneficial for high-risk language-area tumors, enhancing precision and improving patient outcomes [31,32].

No patient in this series had neither permanent global aphasia nor a recurrence requiring further treatment. Also we made an interesting finding that in patients 3 & 4 , the observed bilateral connectivity in these patients suggests neuroplasticity and reorganization of language areas in response to structural changes.

This case series also highlights that in all the six patients, no two patients had language parcellations at the same area. This essentially translates that Every individual has unique structural and functional connectome which can be used preoperatively to guide surgical approach , trajectory and when combined with intraoperative DCS/ DSCS reduces post operative morbidity.

Our findings underscore the clinical value of connectome-guided imaging as a complementary tool to traditional mapping techniques, with potential applications extending beyond language networks to other critical brain regions. Future studies should prioritize standardizing connectome integration within surgical workflows and further explore its role in developing tailored neurosurgical strategies.

Limitations

While these cases highlight the advantages of connectome imaging, several limitations must be acknowledged. The small sample size, along with the specific language lateralization and predominantly Indian background of the patients, may restrict the broader applicability of our findings. Additionally, differences in language localization across various languages and cultural contexts could influence how connectome imaging is utilized and interpreted in more diverse populations. To confirm the effectiveness of connectome-guided surgical approaches across a wider spectrum of patients, studies involving larger, more diverse cohorts with multi institutional series are essential.

Technical limitations in connectome imaging also warrant further investigation. The use of proprietary connectome mapping software can introduce inconsistencies in processing and interpreting connectivity data, which may compromise reproducibility. Enhancing the reliability of this approach will require advancements in real-time connectome integration, as well as validation studies focused on assessing the accuracy and consistency of connectivity mapping across different platforms.

Moreover, research into the cost-effectiveness and practical accessibility of connectome imaging in clinical settings is crucial. Understanding these aspects could provide valuable insights into how broadly this technique can be applied and how it might be integrated into routine neurosurgical practice.

Conclusion

Connectome-guided imaging proved invaluable for surgical planning and execution, enabling safe and effective resections in patients with language-dominant lesions. By combining structural and functional connectivity data, neurosurgeons can adopt a more individualized approach that enhances functional preservation and improves patient outcomes, particularly in tumors involving language area . The clinical utility of connectome imaging lies in its ability to enhance preoperative decision-making, minimize the risk of functional impairments, and potentially facilitate tumor resection without language network disruption. This highlights its role as a powerful tool in the neurosurgical management of intra-axial brain tumors.

Credit authorship contribution statement

Abhirama Chandra Gabbita: Project administration, Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing-review & editing. Subodh Raju, Saikalyan , Suresh, Raghu: Conceptualization, Formal analysis, review & editing. Sravanthi : Data acquisition,Writing-original draft, Writing-review & editing. Vyshnavi, Priya , Lokesh:, Writing original draft, Writing review & editing.

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