The Artery of Aphasia, A Uniquely Sensitive Posterior Temporal Middle Cerebral Artery Branch that Supplies Language Areas in the Brain: Anatomy and Report of Four Cases

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■ BACKGROUND: **Arterial disruption during brain surgery can cause devastating injuries to wide expanses of white and gray matter beyond the tumor resection cavity. Such damage may occur as a result of disrupting blood flow through en passage arteries. Identification of these arteries is critical to prevent unforeseen neurologic sequelae during brain tumor resection. In this study, we discuss one such artery, termed the artery of aphasia (AoA), which when disrupted can lead to receptive and expressive language deficits.**

■ METHODS: **We performed a retrospective review of all patients undergoing an awake craniotomy for resection of a glioma by the senior author from 2012 to 2018. Patients were included if they experienced language deficits secondary to postoperative infarction in the left posterior temporal lobe in the distribution of the AoA. The gross anatomy of the AoA was then compared with activation likelihood estimations of the auditory and semantic language networks using coordinate-based meta-analytic techniques.**

■ RESULTS: **We identified 4 patients with left-sided posterior temporal artery infarctions in the distribution of the AoA on diffusion-weighted magnetic resonance imaging. All 4 patients developed substantial expressive and receptive language deficits after surgery. Functional language improvement occurred in only 2/4 patients. Activation likelihood estimations localized parts of the auditory and semantic language networks in the distribution of the AoA.**

■ CONCLUSIONS: **The AoA is prone to blood flow disruption despite benign manipulation. Patients seem to have limited capacity for speech recovery after intraoperative ischemia in the distribution of this artery, which supplies parts of the auditory and semantic language networks.**

INTRODUCTION

Arterial disruption during brain surgery can lead to devastating injuries that involve wide expanses of white and gray matter that might not be appreciated at the initial time of surgery.[1] However, when resecting brain tumors, it is usually necessary to work around arteries to achieve optimal surgical results. Making appropriate decisions regarding arterial blood flow is central during surgery to achieve positive clinical outcomes.[2,3]

With respect to glioma surgery, it is reasonable and expected that neurosurgeons sacrifice the arteries supplying those parts of the brain supplying the tumor.[4] However, it is critical in the process of sacrificing these arteries to avoid injuring the so-called en passage arteries,[5] which course in or near the operative window yet supply more distant areas of brain not necessarily affected by tumor. Poor clinical outcomes have resulted from damage to these arteries during surgery,[6-9] leading to diffuse damage to parts of the brain not otherwise resected or disconnected during the surgery.

Key words
- Aphasia
- Artery
- Audition
- Language
- Network
- Temporal lobe

Abbreviations and Acronyms
ALE: Activation likelihood estimation
fMRI: Functional magnetic resonance imaging
MCA: Middle cerebral artery
MNI: Montreal Neuroimaging Institute
MRI: Magnetic resonance imaging

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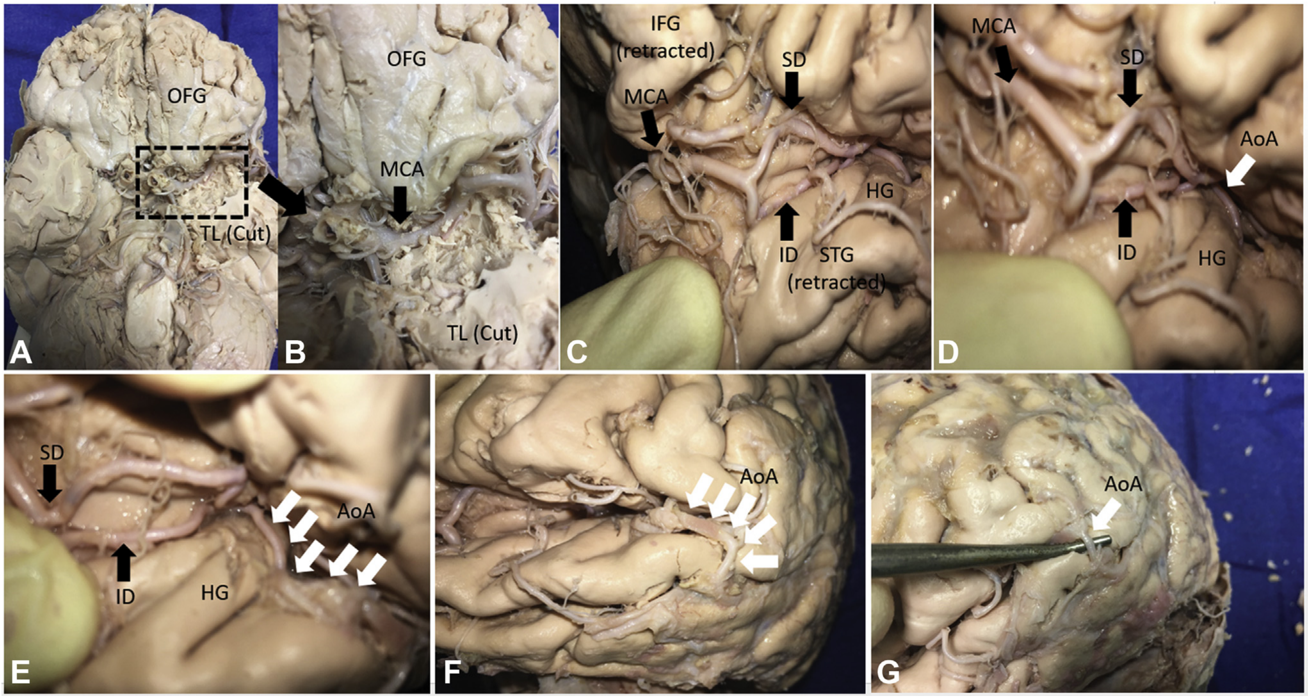

Figure 1. Gross anatomic image of a cadaveric brain showing the artery of aphasia as it branches from the inferior division of the middle cerebral artery (MCA). (**A**) Complete view of the dorsal brain specimen. The black box indicates the location of the MCA as it branches from the internal carotid. (**B**) Magnified view of the anatomy in (**A**) with the MCA identified. The anterior temporal lobe has been cut to better visualize the vasculature. (**C**) Oblique lateral view of the MCA as it dividies into superior division (SD) and inferior division (ID). The superior temporal gyrus (STG) is retracted to better show the anatomy. The Heschl gyrus (HG) is also identfied. (**D**) Magnified view of the inferior division of the MCA. The artery of aphasia (AoA) is now in view (*white arrow*). (**E**) Continuing the posterior dissection of the inferior division of the MCA. The AoA (*white arrows*) is now clearly in view and can be seen traversing the Heschl gyrus (HG) on its path to the posterolateral temporal lobe. (**F, G**) Dissected and in situ identification of the AoA as it leaves the sylvian fissure to supple the lateral posterosuperior aspect of the temporal lobe. *Black arrows* point to individual vascular structures along the length of the middle cerebral artery. OFG, orbitofrontal gyri; TL, temporal lobe.

Almost all brain tumor surgeons have experienced an unexpected, diffusion-weighted change on postoperative magnetic resonance imaging (MRI) in an area of the brain outside the tumor resection cavity that is difficult to explain given the course of events during surgery.[10-12] In this small series, we describe an artery that is not only prone to this problem but also supplies language areas in the brain, leading to devastating effects on the language network if it is damaged during surgery. We name this posterior temporal branch of the middle cerebral artery (MCA), the artery of aphasia, so-named given its ability to derail otherwise positive clinical outcomes during awake brain surgery. Using coordinate-based meta-analytic functional (fMRI) network maps, we show the location of the artery of aphasia and its anatomy relative to functional brain regions involved in language and auditory processing, and we describe 4 clinical cases in which disruption of this artery occurred without any perceived serious intraoperative manipulation of the artery.

METHODS

Data Collection

We performed a retrospective review of all patients undergoing an awake craniotomy for resection of a glioma by the senior author from 2012 to 2018 at our home institution. We identified 4 patients with unexplained posterior left temporal infarction on postoperative, diffusion-weighted MRI. Clinical records, hospital charts, and imaging studies were reviewed until the last available follow-up. Medical histories, operative notes, and hospital course were also reviewed. This study was performed with approval of our institutional review board. Given the retrospective nature of this study, informed consent was not required by our institutional review board.

Outcome Assessment

This report is a descriptive series of 4 cases that analyzed intraoperative events based on the operative note, preoperative and postoperative neuroanatomic imaging, and preoperative and postoperative assessments by a speech language pathologist. Length of hospital stay was defined as the day of operation to the day of discharge. Last known follow-up time was defined as the day of the operation to the last known follow-up in the neurosurgical clinic. Postoperative MRI was completed within 48 hours of surgery.

Auditory Network Literature Search

We searched BrainMap Sleuth 2.4 (Research Imaging Institute, University of Texas Health Science Center, San Antonio,

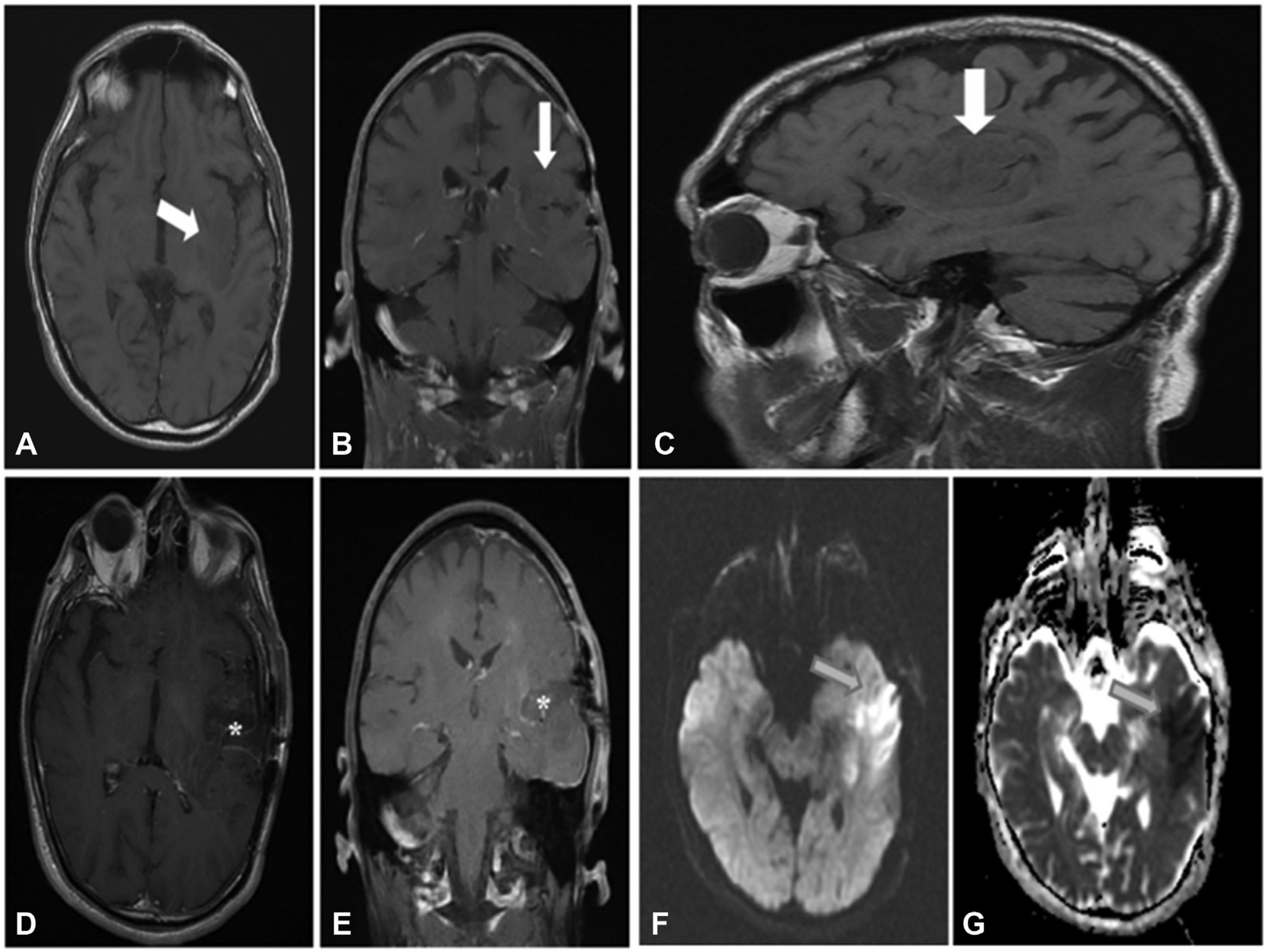

Figure 2. Preoperative and postoperative imaging of a patient with a left temporal astrocytoma (*white arrows*). (**A**) Axial, (**B**) coronal, and (**C**) sagittal views of the patient's tumor on T1-weighted magnetic resonance imaging. (**D**) Axial and (**E**) coronal demonstration of the patient's tumor resection cavity (*) after surgery. (**F, G**) Postoperative imaging also showed the presence of a posterolateral left temporal infarction on diffusion-weighted imaging (**F**) that was confirmed by apparent diffusion coefficient imaging (**G**). Gray arrows indicate the location of the temporal lobe infarction.

Texas, USA) on July 24, 2017 for all relevant task-based fMRI studies related to audition in healthy adult individuals.[13-15] The following search algorithm was used: "A. Experiments: Imaging Modality = fMRI, B. Experiments: Behavioral Domain = Audition, C. Subjects: Diagnosis = Normal, D. Experiments: Activations = Activations Only." The search returned 101 articles that were reviewed for inclusion in this study based on the following criteria: 1) peer-reviewed publication, 2) task-based fMRI study related to the auditory network and audition, 3) based on whole-brain, voxel-wise imaging, 4) including standardized coordinate-based results in the Talairach or Montreal Neuroimaging Institute (MNI) coordinate space, and 5) including ≥1 healthy human control cohort. Only coordinates from healthy individuals were used in our analysis. Overall, 73 articles related to auditory network processing met criteria for inclusion in this study.[16-88]

Semantic Language Network Literature Search

As for the auditory network, we searched BrainMap Sleuth 2.4 (Research Imaging Institute, University of Texas Health Science Center, San Antonio, Texas, USA) on July 24, 2017 for all relevant task-based fMRI studies related to semantic processing in healthy adult individuals.[13-15] The following search algorithm was used: "A. Experiments: Imaging Modality = fMRI, B. Experiments: Behavioral Domain = Cognition: Language, C. Experiments: Paradigm Class = Semantic Monitor/Discrimination, D. Subjects: Diagnosis = Normals, E. Conditions: Stimulus = Auditory Words/ Stories, Visual Words, and Visual Images." As for the auditory network, studies related to semantic processing were included in our analysis if they met the following criteria: 1) peer-reviewed publication, 2) task-based fMRI study related to the semantic processing, 3) based on whole-brain, voxel-wise imaging, 4) including standardized coordinate-based results in the Talairach

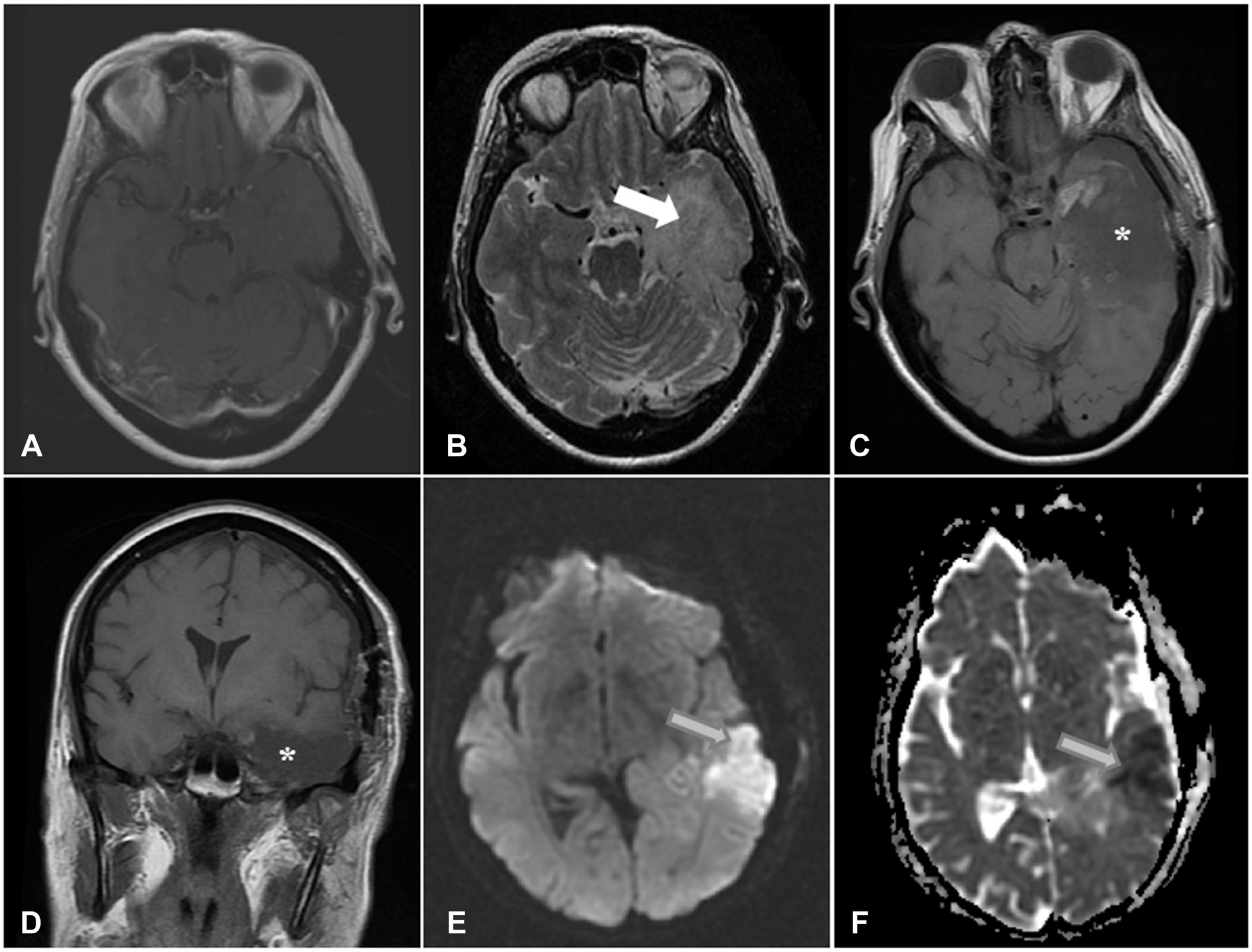

Figure 3. Preoperative and postoperative imaging of a patient with a left temporal astrocytoma (*white arrows*). (**A**) Postcontrast T1-weighted axial magnetic resonance imaging shows no enhancement of the temporal lesion. (**B**) Postcontrast, T2-weighted axial magnetic resonance imaging shows the temporal lesion with significant peritumoral edema. (**C**) Axial and (**D**) coronal demonstration of the patient's tumor resection cavity (*) after surgery. (**E, F**) Postoperative imaging also showed the presence of a posterolateral left temporal infarction on diffusion-weighted imaging (**E**) that was confirmed by apparent diffusion coefficient imaging (**F**). Gray arrows indicate the location of the temporal lobe infarction.

or MNI coordinate space, and 5) including ≥1 healthy human control cohort. Only coordinates from healthy individuals were used in our analysis. Overall, 21 articles related to auditory word stimuli, 114 related to visual word stimuli, and 20 related to visual image stimuli met criteria for inclusion in this study.[15,34,40,89-218]

Anatomic Likelihood Estimation Generation

We used BrainMap Ginger ALE 2.3.6 (Research Imaging Institute, University of Texas Health Science Center, San Antonio, Texas, USA) to extract the relevant fMRI data for creation of an anatomic likelihood estimation (ALE) related to each set of articles for the auditory and semantic language networks.[219-221] All coordinates were exported to Ginger ALE in the MNI coordinate space. We subsequently performed a single study analysis using cluster-level interference (cluster level of 0.05, threshold permutations of 1000, uncorrected P value of 0.001). The ALE coordinate data were shown on an MNI-normalized template brain using the Multi-image Analysis GUI (Mango) 4.0.1 (ric.uthscsa.edu/mango).

Postmortem Dissection of the Artery of Aphasia

Postmortem dissections were performed using a modified Klingler technique,[222] as opposed to using latex-injected heads, to better show the cortical anatomy of the MCA and its branches, including the artery of aphasia from its origin out through the sylvian fissure. Ten specimens were used for this study, obtained from the willed body program of our institution with approval of the state anatomic board. The cadaveric brains were fixed in 10% formalin for ≥3 months after being removed from the cranium. Until the time of dissection, the pia-arachnoid membrane was left attached. After fixation with formalin, specimens were rinsed with water for

Table 1. Patient Characteristics

Age (years)	Sex	Lesion	Preoperative Symptoms	Postoperative Deficits	Procedure Time (hours)	Length of Stay (days)	Follow-Up (years)	Neurologic Status at Last Known Follow-Up
77	Female	Left oligo	Headaches, seizures, word-finding difficulties	Combined receptive and expressive aphasia	4.5	5	2.4	Fluent speech; naming/ repetition intact; comprehension delayed; some word-finding difficulties
62	Male	Left glioblastoma	Complex partial seizures	Combined receptive and expressive aphasia	5.5	10	0.5	Combined receptive and expressive aphasia
63	Male	Left diffuse astrocytoma	Seizures, right hemibody weakness (arm > leg)	Combined receptive and expressive aphasia	4.3	10	2.1	Combined receptive and expressive aphasia; right hemibody weakness (arm > leg)
31	Male	Diffuse astrocytoma	Double vision	Combined receptive and expressive aphasia, hydrocephalus requiring ventriculoperitoneal shunt	3.5	3	5.6	Fluent speech; naming, repetition, and comprehension intact; some word-finding difficulties

2 days, and then frozen at −10°C for 8 hours, causing white matter disruption. After thawing, dissection of the freeze-fractured specimens began with removal of the meninges and identification of cortical anatomy, including gyri and sulci. Relevant cortical areas were identified first including the proximal aspect of the MCA where it branches from the internal carotid artery. Moving dorsolaterally, we followed the MCA to its bifurcation within the sylvian fissure into its superior and inferior divisions. The inferior division was further dissected to show the branching point of the posterior most branch of the MCA supplying the posterior temporal lobe. This anatomy is shown in **Figure 1**.

RESULTS

Clinical Cases

We identified 4 patients who developed substantial language disturbances after surgery in the left posterior temporal region associated with temporal lobe infarction. All 4 patients were treated within a span of 6 months, and all 4 had undergone awake brain surgery for glioma resection in the left temporal lobe. The preoperative and postoperative diffusion-weighted scans showing the infarction pattern seen in 2 of these patients are presented in **Figures 2** and **3**. **Table 1** summarizes the clinical characteristics of all 4 cases.

Possible Mechanisms for Loss of Blood Flow Through the Artery of Aphasia

In the cases presented in this series, no intentional sacrifice of the branches of the MCA was noted. However, in 3 of the 4 cases, the dura was densely adherent to the cortical surface of the posterior temporal lobe, requiring some dissection before tumor removal. Although we did not cauterize or dissect the artery of aphasia to any significant degree, all 3 patients were unable to participate in the requisite language tasks when awakened for speech mapping. All 3 patients showed anomia, dysfluency, and impaired language understanding, despite preoperative testing indicating intact speech. Although surgery was paused, the blood pressure was artificially increased, and the brain was irrigated with cold saline to abort possible focal seizure activity, these patients showed no improvement in their language function.

The fourth case involved a posterior glioma originating in the hippocampus. After cortical mapping, a posterior temporal cut was made down to the temporal horn of the lateral ventricle while the patient performed a continuous naming task. As resection was carried under the superior longitudinal fasciculus to access the posterior extent of the tumor, the patient rapidly developed substantial language disturbance. Topical verapamil was applied to the artery of aphasia in an effort to improve blood flow; however, postoperative imaging showed the characteristic infarct pattern believed to explain these language deficits (**Figures 2** and **3**).

Outcomes After Artery of Aphasia Infarction

All 4 patients showed substantial expressive and receptive language deficits immediately after surgery, including complete anomia. Two of these patients improved to nearly normal language function, except for mild difficulties in word-finding, by their 6-month follow-up visit. Both patients actively participated in speech rehabilitation after surgery. One patient continued to have dense receptive speech problems until his death of glioblastoma 6 months after surgery. One patient showed only minimal improvement in his language function after 2 years of follow-up.

Anatomic Relationships within the Vascular Territory of the Artery of Aphasia

Figure 4 shows the results of the coordinate-based meta-analysis of the auditory and semantic networks. The auditory network is largely confined to the Heschl gyrus in the superior aspect of the temporal lobe, whereas the semantic language network localizes

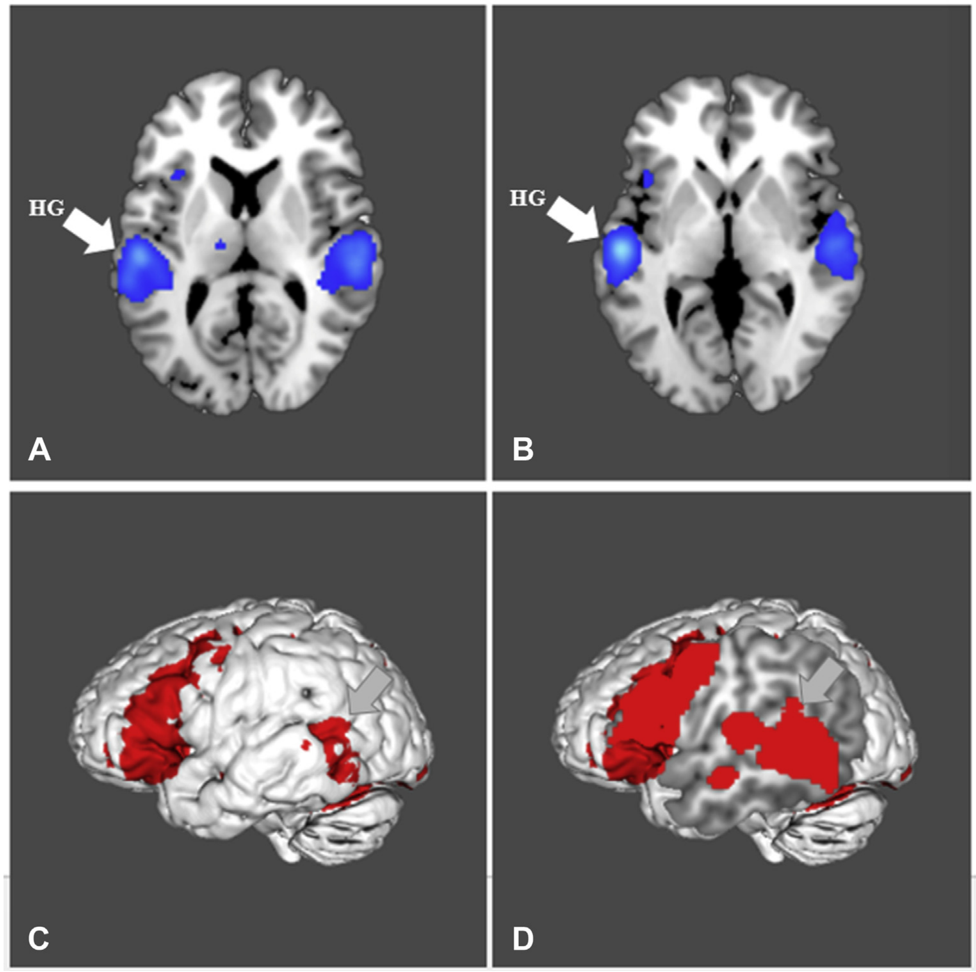

Figure 4. Activation likelihood estimations of the (**A, B**) auditory and (**C, D**) semantic language networks based on Montreal Neuroimaging Institute coordinate-based meta-analysis. (**A, B**) *White arrows* indicate the position of Heschl's gyrus (HG) in the temporal lobe. HG is labeled for the auditory network, which is highlighted in blue. (**C, D**) The posterior temporal lobe is indicated by gray arrows for the semantic language network, which is highlighted in red. These networks lie close to the artery of aphasia as it traverses the Heschl's gyrus and courses out of the sylvian fissure to supply the posterior temporal lobe.

to the lateral posterior temporal lobe, extending across the superior, middle, and inferior temporal gyri.

The approximate locations of the relevant portions of these networks are shown on a gross anatomic image showing the course of the artery of aphasia and its hypothesized vascular territory (Figure 5). The artery of aphasia courses over the posterior aspect of the Heschl gyrus before extending inferiorly onto the lateral surface of the superior temporal gyrus near the bend of the sylvian fissure.

DISCUSSION

In this report, we describe 4 separate occurrences of infarction of the lateral posterior temporal cortex in cases of glioma surgery during which no intentional or unintentional sacrifice of the relevant artery was performed. In these cases, all of which involved left-sided gliomas, significant new language problems resulted during surgery. Functional language improvement during the postoperative period occurred in only 2/4 patients (50%) receiving long-term speech therapy. We suggest that this branch of the MCA is uniquely prone to blood flow disruption with otherwise benign manipulation.

One rationale for naming this vessel the artery of aphasia is the devastating effect that disrupting the artery has on the semantic language network. Semantic function is essential for language processing,[223,224] because it is the repository of what words mean,[225-227] and is critical in naming,[228] word comprehension,[229,230] and speech production.[231] A significant segment of the canonic Wernicke area overlaps with the semantic language network,[232,233] which comprises in part the posterior superior temporal sulcus and posterior middle temporal

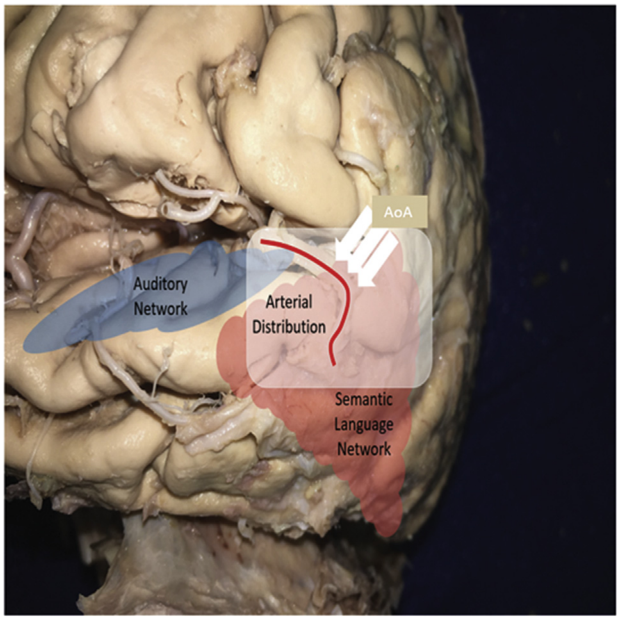

Figure 5. Gross anatomic image of a left cerebral hemisphere in lateral view showing the anatomy and approximate locations of the semantic and auditory networks overlaid onto the anatomic course and proposed vascular territory of the artery of aphasia (AoA). The position of the AoA is indicated by white arrows, and the course of the artery is highlighted by a solid red line. Blue shading corresponds to the location of the auditory network. Red shading corresponds to the location of the semantic language network. White shading corresponds to the overlapping vascular territory of the AoA.

gyrus,[234-236] both of which are supplied by the artery of aphasia. Thus, injuring this artery can have a devastating effect on a patient's speech. Two of our 4 patients did not return to their baseline level of language function after disruption of this artery.

It is unclear why this artery is seemingly sensitive. In 2 cases, the problem likely resulted from dissecting the dura off of the artery while exposing the tumor, possibly causing arterial dissection or vasospasm. In another, disruption likely resulted from traction applied to the artery while working underneath the temporal cortex to resect tumor involving the hippocampus. Still in another, damage to the artery may have resulted from vasospasm secondary to arterial manipulation. In no case in this series did we intentionally sacrifice the artery. Another possibility is that the artery of aphasia is prone to twisting, temporary occlusion, dissection or other injury because of its long course and angle relative to the main direction of the MCA, which is oriented orthogonally to the artery of aphasia (Figure 1). In any case, this artery seems to be uniquely sensitive in a way that has not been adequately explored in the literature to our knowledge.

This problem can also occur on the right/nondominant side of the brain. However, this series focuses on left-sided, posterior temporal infarctions, because these infarctions were causing an obvious intraoperative complication, allowing us to link the speech problems occurring during surgery to a specific intraoperative maneuver, namely manipulating the artery of aphasia.

Knowledge of this problem has led us to modify our approach to tumors in this area. First, we do everything possible in recurrent cases to avoid peeling away dura from the arteries in this region of the temporal lobe. If possible, we also limit recurrent tumor resections involving the superior temporal gyrus to the cortical layer just underneath the pia. This strategy allows us to avoid or limit manipulating the artery of aphasia. We routinely apply topical verapamil to this artery when it is manipulated during surgery, assuming it is easily identified exiting the fissure. Since making these modifications, we have not experienced this problem.

CONCLUSIONS

We describe a series of 4 cases in which speech mapping was rendered impossible because of ischemia in the distribution of a posterior temporal branch of the MCA artery. Patients seemed to have limited capacity to recover from these intraoperative ischemic events. The existence of this problem serves as a warning, particularly in repeat surgery of the left posterior temporal lobe.

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