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Permalink
https://escholarship.org/uc/item/09n7401t

Journal
Neurosurgery, 87(3)

ISSN
0148-396X

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Publication Date
2020-09-01

DOI
10.1093/neuros/nyaa002

Peer reviewed

Pure Apraxia of Speech After Resection Based in the Posterior Middle Frontal Gyrus

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BACKGROUND AND IMPORTANCE: Apraxia of speech is a disorder of articulatory coordination and planning in speech sound production. Its diagnosis is based on deficits in articulation, prosody, and fluency. It is often described concurrent with aphasia or dysarthria, while pure apraxia of speech is a rare entity.

CLINICAL PRESENTATION: A right-handed man underwent focal surgical resection of a recurrent grade III astrocytoma in the left hemisphere dorsal premotor cortex located in the posterior middle frontal gyrus. After the procedure, he experienced significant long-term speech production difficulties. A battery of standard and custom language and articulatory assessments were administered, revealing intact comprehension and naming abilities, and preserved strength in orofacial articulators, but considerable deficits in articulatory coordination, fluency, and prosody—consistent with diagnosis of pure apraxia of speech. Tractography and resection volumes compared with publicly available imaging data from the Human Connectome Project suggest possible overlap with area 55b, an under-recognized language area in the dorsal premotor cortex and has white matter connectivity with the superior longitudinal fasciculus.

CONCLUSION: The case reported here details a rare clinical entity, pure apraxia of speech resulting from resection of posterior middle frontal gyrus. While not a classical language area, emerging literature supports the role of this area in the production of fluent speech, and has implications for surgical planning and the general neurobiology of language.

KEY WORDS: Apraxia of speech, AOS, Premotor cortex, Area 55b, Language deficit

Apraxia of speech (AOS) is a disorder of articulatory coordination and planning in speech sound production[1,2] and is typically reported secondary to ischemic infarcts. Diagnosis is based on deficits in articulation, prosody, and fluency.[3] Almost always, AOS is described coincident with other disorders of speech and language.[2,4-6] Pure AOS following a brain injury is rare.[4,7-11]

Literature around AOS dates back to Broca's original description of what he termed *aphemia*

in the 1860s,[12,13] which he localized to left premotor frontal cortex. Most contemporary etiological literature on AOS focuses on vascular infarct or neurodegeneration. Early studies using maximal overlap of AOS-associated lesions from strokes suggested involvement of the insula.[2,5] However, some have suggested anatomic areas more susceptible to ischemia create a bias in lesion-deficit association.[6,14] Neuroanatomic studies of neurodegenerative AOS point to volume loss in supplementary motor, premotor, and precentral gyri.[4,7-11] While rare, cases of pure AOS demonstrate lesions near the precentral gyrus and premotor cortex in the left hemisphere.[4,7-11]

One cortical area that has re-emerged as a focus of language function is area 55b. The posterior aspect of 55b occupies the medial-lateral midpoint of the precentral gyrus. The anterior aspect of 55b generally occupies the posterior portion of the middle frontal gyrus where it joins the precentral gyrus. That said,

FIGURE 1. *Timeline.*
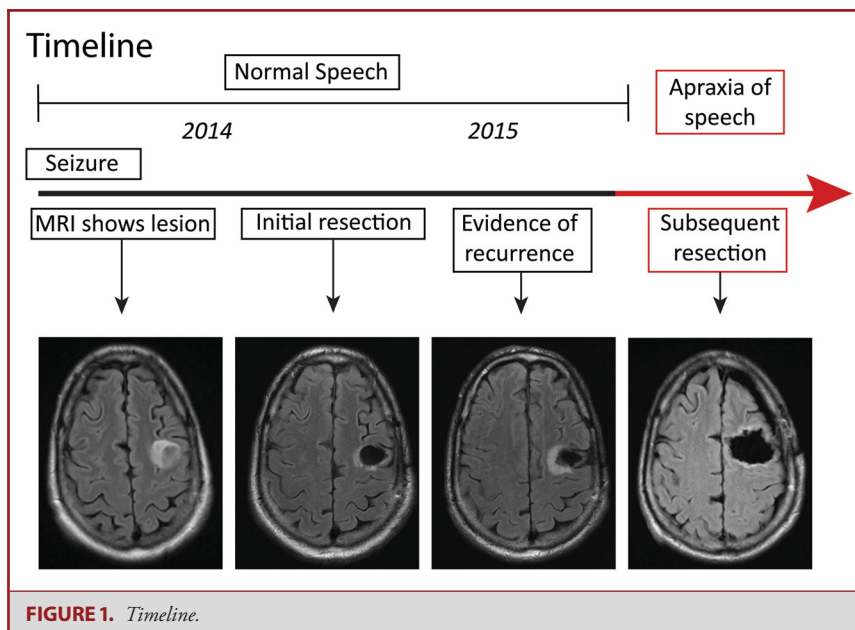
55b is one of the more variable cortical areas, as described in Glasser et al[15] and may be found adjacent to the middle frontal gyrus and precentral sulcus. The boundaries of area 55b stem from early 20th century studies segmenting the cortex into ~200 fields, based on high gradients of myelin content.[16] These data have been re-examined more recently in combination with techniques such as magnetic resonance imaging (MRI)-based myelin mapping.[16-19] A multimodal neuro-anatomic parcellation study from the human connectome project demonstrated that area 55b is selectively activated in language production tasks, and shows distinct functional connectivity from surrounding cortex.[15]

Neurosurgical etiology is a critical piece missing from AOS literature. Here, we report the first detailed characterization of *pure* AOS due to focal surgical resection of left dorsal premotor cortex. This may also represent the first overt documentation of language deficits from a lesion to area 55b.

CLINICAL PRESENTATION

Patient Information and Timeline

The patient is a 49-yr-old, right-handed male accountant, without significant medical or family history, who initially presented with an unprovoked seizure (Figure 1). MRI demonstrated a nonenhancing mass lesion in posterior middle frontal gyrus. He initially underwent a craniotomy for resection of tumor without incident or residual deficits. Pathology showed WHO grade III astrocytoma. A year later, the tumor showed signs of early recurrence around the rim of the prior resection cavity. The patient underwent an awake craniotomy with speech mapping for resection of tumor. Intraoperative motor and speech mapping were performed and neither demonstrate interruption of speech

on counting, naming pictures, or reading tasks nor was there motor arrest during these tasks.

Clinical Findings and Follow-up

Immediately after the procedure, the patient was found to have significant speech production deficits that have persisted for over 3 yr. His comprehension and naming abilities were intact and he has been able to communicate by typing difficult-to-produce words on his phone/tablet.

His communication difficulties suggest a motor speech disorder, but his articulators have preserved muscle strength as demonstrated in formal testing of articulatory musculature, including moving tongue side to side, opening and closing jaw, puffing cheeks, pursing lips, and holding vowel or consonant sounds. This leads to a diagnosis of pure AOS, a disorder involving difficulty of articulation despite having intact language skills and muscular function.[1]

Diagnostic Assessments

Speech, Language, and Motor Assessments

Testing was administered in March 2018. The tests were (1) Arizona Articulation Proficiency Scale, Third Revision (AAPS-3),[20] (2) Western Aphasia Battery (WAB),[21] (3) The Quick Aphasia Battery (QAB),[22] (4) Boston Naming Test (BNT),[23] and (5) customized, nonstandard batteries. The first nonstandard battery was a word/pseudoword repetition task[24]; the second was a supplementary motor battery.[25,26] The patient provided informed consent for data analysis and presentation. Table 1 shows the summary scores from each language test administered. For detailed documentation, see Supplemental Digital Content.

TABLE 1. Tests Administered and Linguistic/Motor Domains Tested

Test	Domains tested	Summary score
AAPS-3	Naming	81.5/100
WAB	Fluency, comprehension, repetition, naming	66.3/100
QAB	Fluency, comprehension, repetition, naming, motor speech	73.3/100
Boston Naming Task, 15-item (BNT)	Naming	86.6/100
50-item word/pseudoword repetition task	Repetition	62/100
Supplementary motor assessment battery	Motor speech	N/A

All scores are reported as normalized out of 100.

TABLE 2. Phonetic Features With Corresponding Error Percentages

Phonetic feature	Examples	# Instances	% Error rate
Bilabial consonants	/p/, /b/, /m/	67	38.03
Labiodental consonants	/f/, /v/	32	46.43
Dental consonants	/θ/, /ð/	10	83.33
Alveolar consonants	/t/, /d/, /n/, /r/, /s/, /z/, /l/	238	46.1
Postalveolar consonants	/ʃ/, /ʒ/, /tʃ/, /dʒ/	29	86.03
Palatal consonants	/j/	6	100
Velar consonants	/k/, /g/, /ŋ/	54	64.25
Glottal consonants	/h/	6	16.67
Labiovelar consonants	/w/	5	20
Front vowels	/i/, /ɪ/, /e/, /eɪ/, /ɛ/, /æ/, /ɑ/, /aʊ/, /aɪ/	148	32.06
Central vowels	/ə/, /ʌ/	97	26.37
Back vowels	/u/, /ʊ/, /o/, /ɔɪ/, /oʊ/	27	36.07

Error rate of individual phonemes and phonetic features. Two matrices were generated to assist with analysis: one that catalogued all the target phonemes implicated in the patient's errors (ie, if the error was [tif] for "teeth," the implicated phoneme would be/θ/), and one that tallied each phoneme in the set of target responses.

AAPS-3

The patient scored "severely impaired" or below the second percentile of speakers. The prose description on this score bracket is "speech is intelligible with careful listening." Aggregate score was 81.5/100.

WAB

Scores were low in fluency (20/100), within normal limits on comprehension (92.5/100), and poor on Repetition (72/100). While the patient's naming ability was near normal, many of the items were scored as partial credit due to apraxic errors (77/100). See Supplemental Digital Content.

QAB

The patient scored 16.6/100 for absence of AOS, indicating severe apraxia. On absence of dysarthria, he scored 83.3/100

(smile slightly asymmetric). As a motor speech assessment, the patient was asked to move his tongue from side to side, say "aah" and sustain, and repeat strings of DDK tokens (eg, /pʌpʌpʌ/,/pʌtʌkʌ/). The patient had no difficulty with any of these tasks except the complex DDK token (/pʌtʌkʌ/), which suggests his articulators are still strong and the difficulty is one of motor coordination as opposed to dysarthria. See **Supplemental Digital Content**.

BNT

Scores were within normal limits (86.6/100).

Word/Pseudoword Repetition

The patient had increasing difficulty with differential diadochokinetic rate (repeating different syllables, /pʌ//tʌ//kʌ/) than sequential diadochokinetic rate (repeating the same syllable,

TABLE 3. Error Codes and Examples

Error code	# Instances	Example error	Example target
Incorrect place	77	pɹeɪn	train
Incorrect manner	66	ka.bi kʌp	coffee cup
Incorrect voicing	23	pɪk	pig
Incorrect vowel	43	bol	ball
Deletion	58	kol	cold
Addition	30	hoʊ.pɛ.fəl	hopeful
Metathesis	6	nɛts	nest

Each error was coded using 7 possible error codes. (1) Incorrect place of articulation, (2) manner, (3) voicing, and (4) vowel. (5) Addition was defined as the insertion of extra phonemes or syllables into the target structure, while (6) deletion was the omission of phonemes or syllables from the target structure. (7) Metathesis was coded when the patient transposed phonemes or syllables in the target word.

/pʌ//pʌ//pʌ/). He also had increasing difficulty repeating longer words (e.g., /tik/, /tik.ən/, /ti.kə.gə.kəg/ for "thick, thicken, thickening"). For oral and manual movements, he scored mostly within normal limits, suggesting normal strength in articulators.

Linguistic Analysis

Table 2 shows the error rate of individual phonemes and phonetic features. The highest error rates were associated with palatal (100%), postalveolar (86%), and dental (83%) consonants. For error codes (Table 3), the most common error was incorrect place of articulation (77), followed by incorrect manner of articulation (66) and deletion (58). See tables and **Supplemental Digital Content** for details on linguistic analyses.

Neuroanatomy

Publicly available imaging data from the Human Connectome Project were obtained for this study (http://humanconnectome.org, release Q3).[27-35] See **Supplemental Digital Content** for location determinates of area 55b.[15,36]
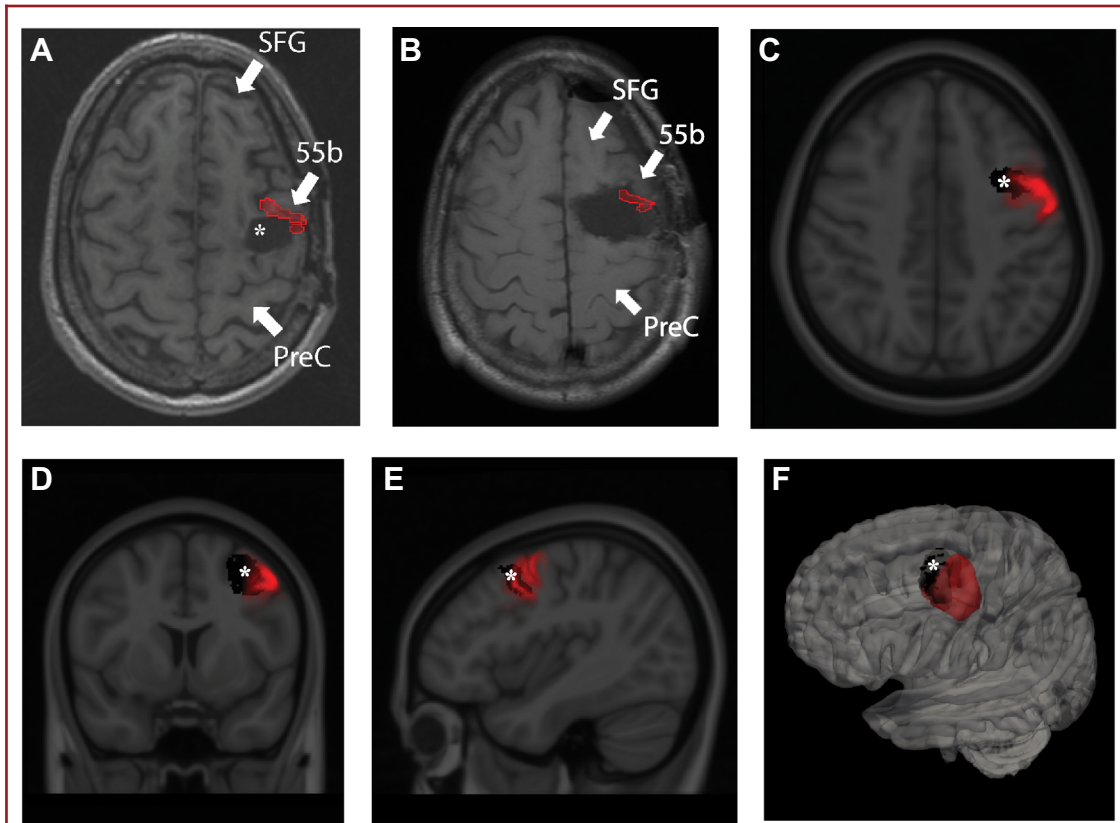

FIGURE 2. **A**, Area 55b projected onto axial MRI of the patient prior to the resection causing his AOS. Asterix marks the first resection cavity sparing Area 55b (corresponding to the panel of Figure 1 labelled "initial resection"), which did not cause language deficits. **B**, Area 55b projected onto the cavity after the resection, which led to AOS deficits. **C**, Axial, **D**, coronal, and **E**, sagittal cuts of the MNI brain co-registered with probability maps of Area 55b (Red) and the defect prior to AOS-causing resection (black). **F**, 3D reconstruction with the probability map of Area 55b depicted in red and the defect prior to AOS-causing resection (black). SFG = Superior frontal gyrus; 55b = Area 55b; PreC = Pre-central gyrus; ∗ = original resection cavity prior to AOS-causing resection.
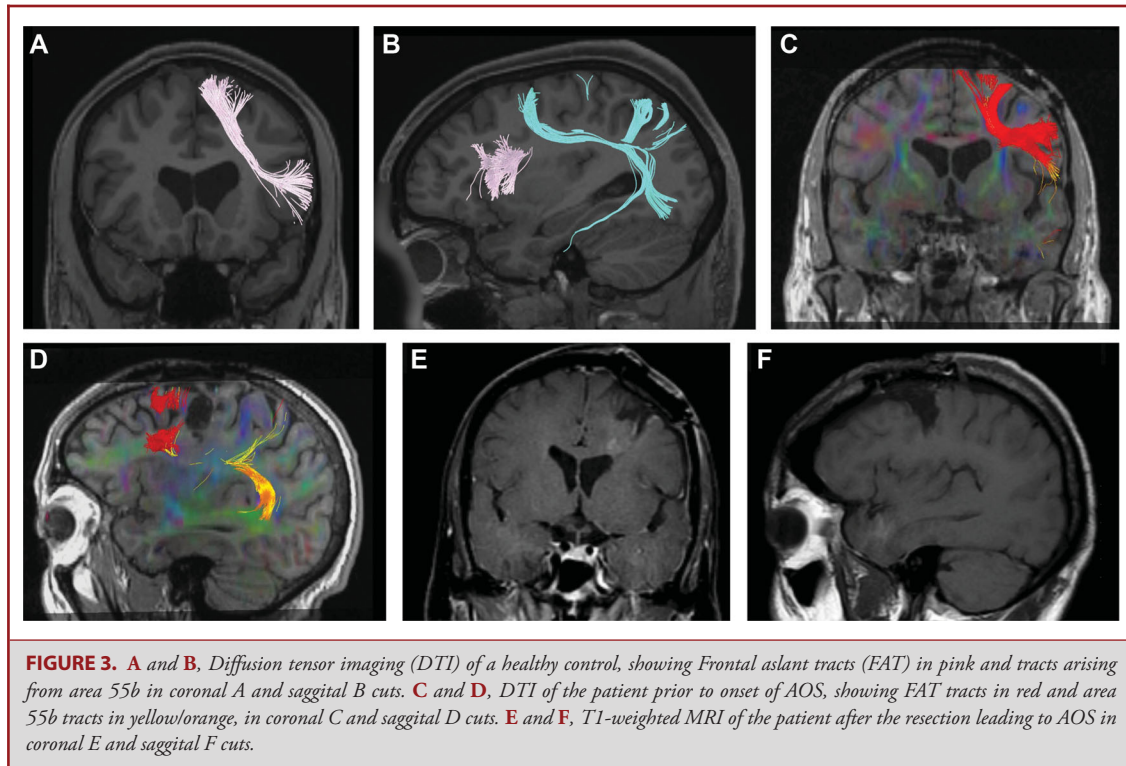
FIGURE 3. **A** *and* **B**, *Diffusion tensor imaging (DTI) of a healthy control, showing Frontal aslant tracts (FAT) in pink and tracts arising from area 55b in coronal A and saggital B cuts.* **C** *and* **D**, *DTI of the patient prior to onset of AOS, showing FAT tracts in red and area 55b tracts in yellow/orange, in coronal C and saggital D cuts.* **E** *and* **F**, *T1-weighted MRI of the patient after the resection leading to AOS in coronal E and saggital F cuts.*

Reconstructions demonstrating approximations of the shape and location of area 55b are shown in Figure 2. Area 55b is subject to individual anatomic variation[37] and our localizing techniques are limited by the patient's nonuniform anatomy status post-resection, the resolution of postoperative imaging, and the neoplasm disrupting native anatomy.

Fiber tractography reveals that area 55b predominantly contributes fibers to the superior longitudinal fasciculus (SLF), as shown in Figure 3. The relationship between the intact frontal aslant tract (FAT) and fibers from area 55b can be seen in Figure 3A and 3B.

Preoperative diffusion tensor images are shown in Figure 3C and 3D. In Figure 3D, the FAT can be identified within the frontal lobe, arising anterior to the patient's initial resection cavity. Post-resection images in Figure 3E and 3F show that the area of resection essentially spares the cortex with terminating FAT fibers. See **Supplemental Digital Content**.

DISCUSSION

We report a case of surgical resection at the posterior middle frontal gyrus, the dorsal premotor cortex, that resulted in pure AOS. Tractography was integrated with human connectome project data to suggest potential localization to area 55b, with functional deficits documented by comprehensive language testing.

The patient had severely non-fluent speech but scores inconsistent with anomia or expressive aphasia. He scored within normal limits on QAB and WAB sections for comprehension, and on BNT, weighing against a diagnosis of expressive or receptive aphasias. The motor segment of the QAB demonstrated intact gross motor function, weighing against unilateral upper motor neuron dysarthric deficits. He exhibited word groping, increasing difficulty with increasing word length,[38,39] and differential diadochokinetic rate,[3,40] as well as slow speech rate, sound distortions and substitutions, and prosodic abnormalities.[41] These results suggest an isolated, pure AOS.

As shown in Figure 3, area 55b contributes to the SLF, a complex white matter tract with connections including higher-order language areas of cortex.[42-44] The areas that are referred to here as SLF may in certain categorizations be associated with arcuate fasciculus (AF), while in others may be referred to as SLF-IV.[45] It should be noted that the tractography presented here is preoperative and can inform, but not confirm, hypotheses on integrity of traversing white matter tracts. Tracts from centers of speech praxis not identified in this report could be interrupted by this focal resection, leading to the observed deficit, rather than cortical dissociation of area 55b.[44,46]

The localization of area 55b comes with a degree of uncertainty in a brain that has anatomic variations induced by an underlying neoplastic process as well as prior neurological surgery. While the association of this lesion with area 55b is not proven by this single

case, better candidates for this patient's neuroanatomic etiology have yet to be described.

CONCLUSION

Through unequivocal documentation of pure AOS with extensive language testing, paired to structural analysis of resection imaging and associated tractography, this case offers a clinically significant example of language deficits from surgical excision of the posterior middle frontal gyrus.

Disclosures

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Acknowledgments

Supplemental digital content is available for this article at *www. neurosurgery-online.com.*

Supplemental Digital Content. Text. Supplemental Information.

COMMENT

The authors describe a persistent pure speech apraxia following re-resection of a tumor in the posterior aspect of the dominant middle frontal gyrus (MFG). The dominant MFG has important speech and language connections via the middle longitudinal fasciculus, the superior longitudinal fasciculus, and the frontal aslant tract (FAT). While the exact connections of the dominant FAT remain conjectural, with a number of putative subcomponents,[1-4] connections to the supplementary motor area have been clearly demonstrated.

In the case presented, the prior resection was extended both medially and anteriorly. The authors' hypothesis, that resection of area 55b is the culprit for the deficits, is interesting. It is also interesting that the posterior MFG is often resected with impunity (as in this patient's first resection). It remains unclear whether the patient's speech apraxia was due to cortical resection, white matter resection, or a combination of the 2.

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