Article abstract—Severe Broca aphasia and left hemiplegia without right limb apraxia occurred suddenly in a right-handed man with no personal or family history of left-handedness. Postmortem examination showed infarction of the right hemisphere, limited almost entirely to the precentral gyrus. In this patient, cerebral dominance for speech lay in the right hemisphere, but dominance for limb praxis lay in the left. This case provides evidence that cerebral dominance for speech and handedness in dextrals may be dissociated. It also suggests that lesions of the precentral gyrus are of major importance in producing Broca aphasia.

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Crossed aphasia in a dextral: A clinicopathological study

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Aphasia resulting from a right cerebral lesion in a right-handed individual is rare, although its precise incidence is unknown. Roberts[1] reported aphasia after right hemisphere excisions in only 2 (0.8%) of 258 right-handed patients. Ludwig,[2] however, reported 100 (11%) cases of aphasia in 880 right-handed soldiers with unilateral right hemisphere lesions. The large discrepancy in these two series probably reflects lack of pathologic confirmation of the presumed location of the lesions as well as different criteria for the existence of aphasia. The language disturbances in Ludwig's[2] cases were mild. Only 30 (3.5%) patients showed any language disturbance after 3 months. Of these, the overwhelming majority had only mild symptoms, affecting predominantly articulation, speech fluency, and naming. Rasmussen and Milner[3] reported transient aphasia after injection of sodium Amytal into the right carotid artery in 6 (4%) of 134 right-handed patients without evidence of childhood damage to the left hemisphere. However, as the authors pointed out, the patients were selected because of suspicion of anomalous dominance and can hardly be considered representative of the normal right-handed population.

Thus, the occurrence of severe and lasting crossed aphasia in dextrals is quite rare. There has been pathologic confirmation of the lesions in only two previous cases of dextrals with aphasia resulting from right hemisphere infarcts.[4,5] The following case is an example of such crossed aphasia with neuropathologic confirmation of the underlying lesion. Permanent loss of speech resulted from a cerebral infarction that was largely restricted to the right precentral gyrus.

Case report. A 70-year-old candymaker suddenly became mute with left-sided weakness. His past medical history included mild hypertension and adult-onset diabetes mellitus. He had chronic otitis media in each ear, with mildly impaired hearing. He had undergone cholecystectomy at age 50 and transurethral prostatectomy at age 66.

The patient came to the United States from Italy at age 3 years. English was his main language. He attended school only through the fourth grade but read and wrote well and followed sports events avidly in the daily newspaper. He was always right-handed, as were his parents and four siblings. His wife and sister could recall only one left-handed relative. There was no history of childhood neurologic injury or disease.

Examination on the day of his ictus revealed an alert, elderly male who was completely mute except for occasional guttural sounds. He understood much but not all of what was said to him. With his unparalyzed right arm, he could demonstrate a salute and the use of a comb to spoken request. When asked, he could extend the proper number of fingers of the right hand. He was unable to write, forming recognizable letters that did not spell words.

Visual fields were full, but there was extinction on the left with bilateral simultaneous stimulation. He wrote only on the right side of the page and did not attend to parts of pictures on his left. His gaze tended rightward, and leftward gaze was incomplete. However, if he fixated an object and his head was moved passively, full leftward eye movement was present. There was severe weakness of the left face, affecting the lower face more than the upper. His tongue moved poorly and deviated to the right. Swallowing was difficult, and he choked on his saliva.

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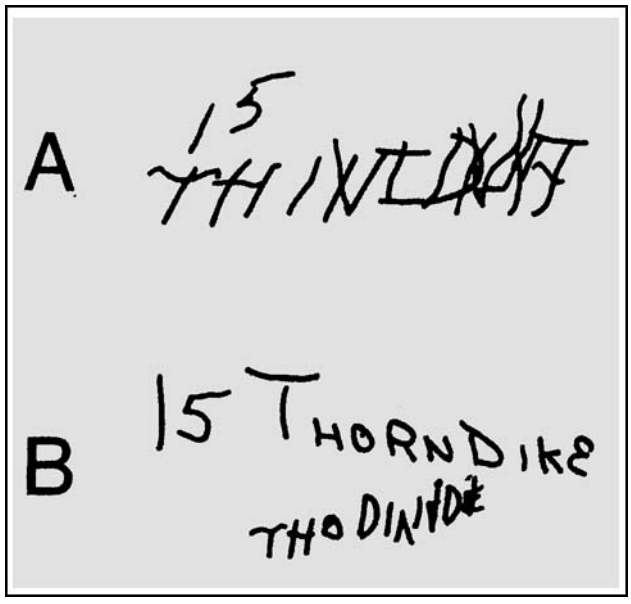

Figure 1. Patient's writing, third hospital day: (A). Attempt to write his address, 15 Thorndike, to dictation. (B). Attempt to copy his address, printed above by examiner.

His left arm and hand were flaccid and immobile; the left leg was only mildly weak. Tendon reflexes were slightly depressed in the left arm and were exaggerated in the left leg. A left Babinski sign was present. Pinprick, light touch, vibration, and passive joint movement were detected bilaterally, but more consistently on the right. There was extinction to touch on the left with bilateral simultaneous stimulation.

Blood count, blood urea, serum enzymes, and electrolytes were within normal limits. Blood sugar was mildly elevated. Skull x-rays were unremarkable, and lumbar puncture revealed clear, colorless fluid under normal pressure. The cerebrospinal fluid protein and sugar content were slightly elevated.

A right brachial angiogram demonstrated delayed flow through the superior division of the right middle cerebral artery, with an intraluminal filling defect in one of the major branches. Computerized tomography revealed a low-density area in the right frontoparietal region. A diagnosis of right frontoparietal infarction, probably embolic in origin, was made, and the patient remained hospitalized for the next 6 weeks.

A more detailed investigation of his speech began on the second hospital day with administration of the Boston Diagnostic Aphasia Examination (BDAE).[6] The patient was mute and capable only of occasional undifferentiated grunts in conversation, repetition, or reading aloud. All rapid repetitive movements of mouth and tongue were impossible. Writing and spelling were also severely impaired. He usually wrote individual letters and numbers (up to three digits) recognizably to dictation, but the letters were coarse and poorly positioned on the page. Words were generally unintelligible whether written spontaneously or dictated. Even copying printed material resulted in severe spelling errors (figure 1).

Although language comprehension was less severely affected than expression, definite abnormalities were present. Auditory language comprehension was moderately impaired: He matched single spoken words to the correct picture 70% of the time. Spoken commands with up to three substantive words were usually performed accurately, but more difficult commands were not. He indicated "yes" or "no" correctly for simple questions about personal identity or about the immediate environment, but he was inaccurate with more complex questions (e.g., "Will a stone sink in water?") and questions testing comprehension of dictated paragraph-length stories. Comprehension of written language was moderately impaired: He was able to match letters or short words printed in different typescripts only 40% of the time, and he matched printed words to an appropriate picture 60% of the time. He was unable to indicate the appropriate printed word or phrase to complete a printed sentence.

Improvement was slow and incomplete. By the second hospital day, his leftward gaze was better, although even at 1 week visual extinction with bilateral simultaneous stimuli persisted. His swallowing gradually improved, and after 1 week he could eat soft solids and liquids. The mild leg weakness improved, and he walked unassisted after a few days. His inability to speak persisted. Occasionally, he could vocalize an "ah" sound. Even at 6 weeks, when his "ah" could be distinguished from his "oh" and he could approximate his lips as though about to utter "b" or "p," he could produce none of the sounds clearly or consistently and could not utter any syllables. Nonverbal movements of lips and tongue remained impaired. The rate and rhythm of his respirations were poorly controlled.

He did not regain the ability to write. Occasionally he wrote a short, dictated word correctly or only mildly misspelled a word. But he remained unable to communicate by writing and often appeared not to realize how nonsensical his writing was. He was unable to use an alphabet chart to spell out words by pointing sequentially. At the end of his hospitalization, he was given a small book with the words "yes" and "no" on the first page, the names of body parts on the next page, and subsequent pages listing names of clothing, feelings, etc. In response to simple spoken or written questions, he was able to open the book and point to the correct word with 80% accuracy. But he never did better, and after leaving the hospital he did not use the book.

Communication by limb gesture was also impaired, although not as severely as speech. Even in the first week he could demonstrate shaving, combing, washing, brushing his teeth, or drinking with his unparalyzed right hand in response to a corresponding request. He frequently gestured to parts of his body that required the physician's attention, but he was unable to consistently express his needs by pantomime.

He lived for 9 months after the onset of aphasia. His speech improved only to the point where he was occasionally able to utter a single word or one of a few short phrases. He understood much of what was said to him, but he no longer read the sports page. His affect and personality were unchanged. He regained the ability to lift his left arm against gravity but never regained any finger movement.

Nine months after his stroke, he developed severe chest pain and was readmitted to the hospital. Electrocardiogram and serum enzymes suggested myocardial infarction. He developed congestive heart failure and hypertension and died on the fifth hospital day.

Postmortem examination. General examination. At

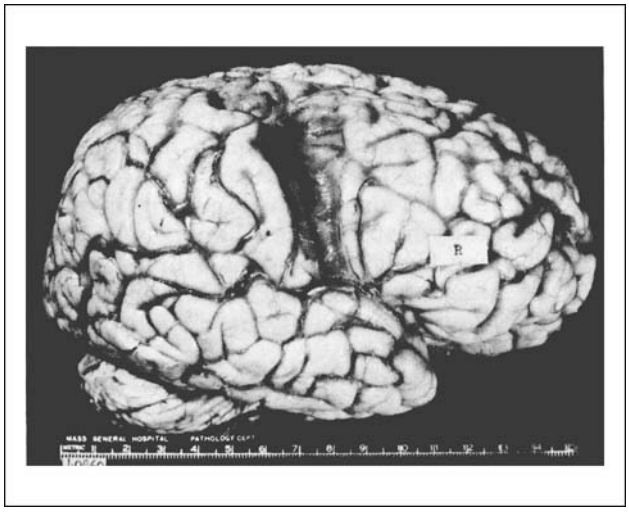

Figure 2. Photograph of the lateral aspect of the right hemisphere. A large cavitary infarct has destroyed nearly the entire precentral gyrus (see text).

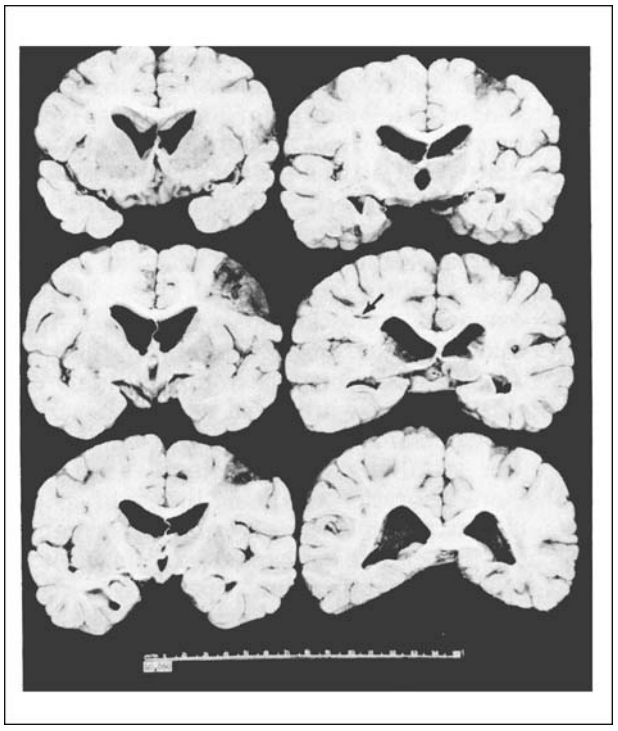

Figure 3. Photograph of serial 0.5- to 1.0-cm-thick coronal sections through the entire extent of the right hemisphere infarct. The sections are sequentially numbered from rostral (1) to caudal (6). See text for further description of the extent of the infarct. An arrow points to the only visible lesion in the left hemisphere, a small slit in the white matter of the supramarginal gyrus.

autopsy, there was an acute myocardial infarction with widespread coronary atherosclerosis. A mural thrombus was present in the hypertrophic left ventricle. There was no evidence of situs inversus.

Neuropathologic examination. The brain weighed 1250 gm. On external examination, a single large cavitary infarction was evident on the convexity of the right cerebral hemisphere (figure 2). It involved primarily the precentral gyrus, extending nearly its entire length—from within 2 cm of the interhemispheric fissure medially to the sylvian fissure ventrolaterally. Anteriorly, the infarct encroached on the posterior portions of the first, second, and third frontal gyri. Posteriorly, it encroached on the anterior portion of the postcentral gyrus. The infarct was approximately 9 cm in mediolateral dimension and 3 cm in anteroposterior dimension. The remainder of the cerebrum, cerebellum, brainstem, meninges, and cranial nerves were normal. There was moderate atherosclerosis of the arteries that compose the circle of Willis, but no occlusions were seen.

The brain was sectioned in the coronal plane at 0.5- and 1.0-cm intervals (figure 3). The infarct was wedge-shaped, with the apex extending into the subcortical white matter. The white matter immediately subjacent to the precentral gyrus was destroyed, and in some sections the infarction extended somewhat deeper into the centrum semiovale to within 0.5 cm of the lateral ventricle. In addition, two much smaller foci of softening and cavitation were seen. One involved a small sector of the right inferior temporal cortex and subjacent white matter (figure 3, section 4). It measured 0.8 cm in its greatest dimension. The second involved the white matter of the left supramarginal gyrus (figure 3, section 5) and measured 1.2 by 0.3 by 0.4 cm. It was the only left-hemisphere lesion visible to the unaided eye.

For microscopic examination, six coronal blocks of the entire cerebrum were cut at 20 μ and stained with cresyl violet or with luxol fast blue or hematoxylin and eosin. The six blocks were evenly spaced along the anteroposterior dimensions of the brain and included the entire extent of the large right frontal infarct. The infarct was nearly completely cavitated, with gliotic walls that also contained hemosiderin-laden macrophages and some residual lymphocytes. The histologic appearance of the infarct suggested that its age was consistent with the onset of the patient's symptoms 9 months before death. The extent of the infarct, by cytoarchitectural criteria, coincided with its topographic limits on gross examination. It was nearly entirely confined to frontal agranular cortex with only minimal posterior encroachment on the granular cortex of the postcentral gyrus ventrally, near the sylvian fissure. Anteriorly, only the most posterior portions of frontal granular cortex were involved.

The small left parietal infarct noted on gross examination had a similar histologic appearance. The small infarct in the right inferior temporal lobe, however, was only a few days old.

In addition, microscopic examination revealed several very small lesions that were not detectable grossly. The large majority were located in the right hemisphere, adjacent to the large infarction in the precentral gyrus. Only six such lesions were present in the left hemisphere, and four of these were only a few days old. The remaining two were located in the superior frontal gyrus—one intracortical and 1 mm in its greatest dimension, the other a slit 2 mm long in the immediately subcortical white matter.

Discussion. The sudden loss of speech in this right-handed patient resulted from extensive in-

farction of the right precentral gyrus. Of the three chronic lesions in the left hemisphere, the only one of more than microscopic dimensions was a small infarction in the left supramarginal gyrus. This lesion, however, could not account for the patient's speech loss. First, it was far too small to result in permanent loss of speech.[7,8] Even far larger lesions of the left supramarginal gyrus do not result in permanent speechlessness, but instead produce milder aphasic disorders.[9] Second, the speechlessness developed simultaneously with left hemiplegia and left visual neglect, manifestations of a right hemisphere lesion. It is highly unlikely that vasoocclusive disease produced two circumscribed lesions at the same instant: a right hemisphere infarction resulting in hemiplegia and a left hemisphere infarction resulting in loss of speech. Thus, in this patient, the severe and permanent speech loss appears to have resulted from the large right hemisphere infarction. Speech was represented primarily, if not exclusively, in the right cerebral hemisphere.

In contrast, the left hemisphere appeared to be dominant for limb praxis. First, although the right-hemisphere lesion produced severe aphasia and left hemiplegia, it did not result in apraxia of the right hand, even in the acute phase of the illness. With the destruction of the entire hand area of the precentral gyrus, a right-sided apraxia should have occurred if the right hemisphere had been dominant for limb praxis.[10,11] Second, the patient had always been strongly right-handed. It has been argued[10,16] that handedness is a manifestation of contralateral cerebral dominance for praxis, i.e., the ability of the contralateral hemisphere to learn some motor tasks more efficiently and to contribute to their performances even by the ipsilateral hand. If so, the patient's right-handedness is further evidence that the left hemisphere was dominant for limb praxis, even though the right hemisphere was dominant for speech.

The anomalous lateralization in this patient is difficult to reconcile with previous views of cerebral dominance.[12,13] These views have stressed the extreme interdependence of handedness and speech lateralization. Bramwell[12] postulated that crossed aphasia in a dextral could occur only in an individual who was "genetically" left-handed but had become right-handed as a result of practice. This view has persisted in those explanations of crossed aphasia in dextrals which postulate a "constitutional sinistrality." For example, Ettlinger, Jackson, and Zangwill[14] found that 13 of 15 previous cases had a family history of left-handedness. The authors concluded that "if an ostensibly right-handed patient develops aphasia from a lesion in the right hemisphere, it is likely that inquiry will reveal some measure of ambilaterality in the patient and/or sinistrality in the family pedigree."

Our case cannot be explained in this manner. Although speech was strongly lateralized to the right hemisphere, the patient was strongly right-handed, and there was no family history of left-handedness. Two previous cases[4,5] with postmortem examination also had no familial sinistrality. Thus, a family history of left-handedness is not a sine qua non for crossed aphasia in dextrals. At least in some cases, the cerebral asymmetries underlying limb praxis and speech lateralization may be independent.

Many previously reported cases are consistent with the hypothesis that the lateralizations of speech and praxis are dissociable. Nearly all reported cases of crossed aphasia in right-handed individuals have resembled our case in showing no right limb apraxia.[15] Although in some cases the lesions may have spared the frontoparietal area controlling limb praxis, the present case demonstrates conclusively that this explanation cannot be applied in all instances. Further evidence comes from other patients with right-hemisphere lesions who develop no aphasia but do show right-sided apraxia.[16] In these patients who are left-handed, it appears that dominance for limb praxis is lateralized to the right cerebral hemisphere, whereas speech is lateralized to the left. Again, a dissociation of lateralization of speech and limb praxis is suggested, but in the direction opposite to the direction in our case and in other cases of crossed aphasia in dextrals.

The precise determinants of lateralization for any single function, such as limb preference, have not been determined. Genetic,[17] prenatal but nongenetic,[18] and postnatal[19] influences have all been suggested. The result of these forces in man is that the left hemisphere is favored both for speech and for limb praxis. The significant correlation between handedness and speech lateralization suggests a definite link between these two asymmetries and argues against each being the result of independent processes that both favor the left hemisphere. However, the correlation coefficient is far from unity. Cases such as ours demonstrate that these two categories of volitional activity—speech and limb movement—are not necessarily linked in a given individual and may be lateralized to opposite hemispheres.

The present case is also of interest with regard to the relationship between the type of dysphasia and the location of the lesion in the right hemisphere. The severely impaired, nonfluent speech, and the marked disorder of writing, in conjunction with only moderate deficits in speech comprehension, were typical of a severe Broca aphasia. Impaired comprehension of written language (alexia) was also present, as it frequently is in Broca aphasia.[20,21] The lesion involved all but the uppermost portions of the precentral gyrus. It en-

croached only very slightly on the postcentral gyrus posteriorly and on the second and third frontal gyri anteriorly.

Such a clinicopathologic correlation at first seems somewhat anomalous. The precentral gyrus was not included in the speech area of classical neurology,[22] even though it was known that lesions of the inferior precentral gyrus could result in nonfluent speech.[23] The reason for this omission was that Dejerine and Liepmann considered the motor cortex of the precentral gyrus to be purely "executive" in function, whereas the "memories" or "engrams" for motor speech were located more anteriorly in the third frontal gyrus. Thus, a lesion of the inferior precentral gyrus might impair speech, but "internal speech" remained intact and manifested itself by intact writing and intact comprehension of spoken and written language.

There has, however, been no clinical or experimental support for the position that distinct cortical regions mediate mnestic and executive motor functions. Lesions confined to the third frontal gyrus and sparing the precentral gyrus do not produce severe Broca aphasia,[7,24,25] even if the lesions are bilateral.[8] Rather, severe Broca aphasia is usually associated with extensive left frontoparietal lesions[7] that appear invariably to affect the precentral gyrus or its outflow.[25] In the monkey, Deuel[26] compared the effects of precentral gyrus lesions and lesions of the immediately anterior cortex (areas 6 and 8) on motor (limb) learning. No qualitative differences suggestive of "executive" versus "mnestic" functions were seen.

The present case demonstrates that a major lesion involving the precentral gyrus and largely sparing the third frontal gyrus can produce the complete syndrome of severe and lasting Broca aphasia. However, two qualifications must be mentioned. First, the unusual lateralization of speech in this patient may be associated with an unusual intrahemispheric functional organization. Second, although the major lesion involved the right precentral gyrus, a small infarction was also present in the white matter of the left supramarginal gyrus. Although the latter was far too small to account for the patient's severe and lasting aphasia by itself, the extent of its possible contribution to the clinical picture is unknown.

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