Visible Changes in Lesion Borders on CT Scan after Five Years Poststroke, and Long-Term Recovery in Aphasia

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This study examined 12 aphasia patients at approximately 1 year poststroke (Time 1) and again at 5–12 years poststroke (Time 2) with language testing and CT scan. Significant increases in naming scores, and phrase length in nonfluent speech were observed after 5 years poststroke. Significant expansion in visible lesion borders (lesion size) was observed after 5 years poststroke; an increase in lesion size of >1% was present in 9/12 cases (75%). Not one case had a second stroke. Thus, it appears that even though lesion expansion may occur after 5 years poststroke, as long as this expansion is unilateral and gradual, it has no adverse effect on language, and in fact, continued recovery in naming and nonfluent speech may also occur. Long-term recovery patterns in aphasia which may be associated with brain reorganization deserve further study, especially with functional brain imaging techniques.

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INTRODUCTION

Previously published reports on the appearance of areas of infarction on CT scan have focused on changes within the first 3 months poststroke (Alcala et al., 1978; Inoue et al., 1980; Brott et al., 1989). To date, however, there have been no studies that focus on changes in the appearance of infarction on CT scan over a long period of time poststroke (i.e., more than 5 years poststroke), and on the relationship to long-term recovery in aphasia.

Aphasia recovery studies have generally reported more recovery in auditory comprehension than in speech output (Kenin & Swisher, 1972; Kertesz, 1979; Kertesz & McCabe, 1977; Lomas & Kertesz, 1978; Prins et al., 1978; Vignolo, 1964). Sarno and Levita (1979, 1981) have reported, however, that a subset of global aphasia patients demonstrate recovery in comprehension only after the first 6 months poststroke.

Examination of language behavior after 5 years poststroke is rare; however, Kertesz and McCabe (1977) studied a few patients with aphasia out to several years poststroke. They observed a flat profile for general language behavior after 1 year poststroke. This was even observed in one Broca’s patient at 10 years poststroke, and one global patient at 17 years poststroke.

Long-term aphasia recovery (after 5–15 years poststroke) was studied by Fitzpatrick et al. (1988). They were the first to report that chronic aphasia patients continue to improve in their ability to name pictures, even after 5–15 years poststroke. Although single-word auditory comprehension and repetition improved initially, the recovery for these language functions reached a plateau at one year poststroke. Only naming continued to recover long-term out to 5–15 years poststroke.

The purpose of the present study was twofold: (1) To compare lesion borders and specific lesion sites on an early chronic CT scan (obtained at 2–12 months poststroke) to lesion borders and lesion sites on a late chronic CT scan (obtained at 5–12 years poststroke) in the same aphasia patients; and (2) to study any relationship between possible change in lesion borders and long-term recovery in aphasia, as measured by picture naming, auditory comprehension, word repetition, and phrase length.

METHOD

Subjects

Twelve patients who had suffered only one stroke (left hemisphere) were included in the study. There were 11 men and 1 woman (case J.Z.) who were 51 to 71 years of age at stroke onset (mean, 57.8 years; SD, 6.4); and 58 to 78 years at Time 2 (mean, 65 years; SD, 6.5). See Table 1. Etiology was nonhemorrhagic in 11 cases, and a ruptured arteriovenous malformation in 1 case. All patients were aphasic from the left hemisphere lesion; 11 were right-handed (including one patient who was switched to right-handedness
TABLE 1
CT Scan Lesion Sizes and Naming Scores for 12 Aphasia Patients at Time 1 Testing (Approximately 1 Year Poststroke) and at Time 2 Testing (Approximately 5 to 12 Years Poststroke)
The Patients are rank-ordered by the amount of increase in lesion size on the Time 2 CT scan.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Onset Age</th>
<th>Type of Aphasia</th>
<th>CT Scan % Lesion Size</th>
<th>Naming Scores (Max. 114)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Time 1</td>
<td>Time 2</td>
</tr>
<tr>
<td>P.P.</td>
<td>63</td>
<td>Broca's Nonfluent</td>
<td>2.26</td>
<td>9.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 Mo.</td>
<td>6.25 Yr.</td>
</tr>
<tr>
<td>G.A.</td>
<td>54</td>
<td>Unclassified Variable Fluent/Nonfluent</td>
<td>4.18</td>
<td>10.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7 Mo.</td>
<td>7.16 Yr.</td>
</tr>
<tr>
<td>Deceased</td>
<td>8 Yrs.</td>
<td>Poststroke</td>
<td>R.B.</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Mo.</td>
<td>10 Yr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Mo.</td>
<td>6.25 Yr.</td>
</tr>
<tr>
<td>L.S.</td>
<td>51</td>
<td>Wernicke's</td>
<td>5.33</td>
<td>9.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 Mo.</td>
<td>7.16 Yr.</td>
</tr>
<tr>
<td>J.A.</td>
<td>52</td>
<td>Mixed Nonfluent Poor Comprehension</td>
<td>6.20</td>
<td>10.21</td>
</tr>
<tr>
<td></td>
<td>Deceased</td>
<td>11 Yrs.</td>
<td>Poststroke</td>
<td>J.Z.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11 Mo.</td>
<td>4.7 Yr.</td>
</tr>
<tr>
<td>J.W.</td>
<td>53</td>
<td>Global</td>
<td>21.13</td>
<td>23.83</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11 Mo.</td>
<td>5.6 Yr.</td>
</tr>
<tr>
<td>E.M.</td>
<td>59</td>
<td>Broca's Nonfluent</td>
<td>5.47</td>
<td>8.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 Mo.</td>
<td>12.2 Yr.</td>
</tr>
<tr>
<td>S.Z.</td>
<td>52</td>
<td>Transcortical Motor</td>
<td>4.67</td>
<td>6.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 Mo.</td>
<td>6 Yr.</td>
</tr>
<tr>
<td>S.M.</td>
<td>61</td>
<td>Wernicke's</td>
<td>4.15</td>
<td>4.83</td>
</tr>
<tr>
<td></td>
<td>Deceased</td>
<td>13 Yrs.</td>
<td>Poststroke</td>
<td>A.A.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9 Mo.</td>
<td>5.5 Yr.</td>
</tr>
<tr>
<td>W.J.</td>
<td>71</td>
<td>Orig. Wernicke's Evolved to conduction</td>
<td>1.54</td>
<td>1.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12 Mo.</td>
<td>6.8 Yr.</td>
</tr>
</tbody>
</table>
as a child, case J.W.), and one patient was left-handed (case P.P.). Table 1 shows there was a wide variety of aphasia patients represented in this study, i.e., three Broca’s, two mixed nonfluent, one global, two unclassified, one transcortical motor, 2 Wernicke’s, and 1 conduction. Education ranged from 9 to 16 years (mean, 12.25, SD, 1.96). All patients received intensive speech therapy during the first few months poststroke, and in most cases, less intensive therapy out to 2 years poststroke.

The 12 patients examined in the present study were some of the original patients studied by Fitzpatrick et al. (1988), where long-term recovery of naming had been observed. That study had not included CT scan data. In the present study, we have examined the CT data using early chronic and late chronic CT scans.

**Design**

All subjects were examined at least two times at the Boston University Aphasia Research Center at the Boston V.A. Medical Center (Neurology, Speech Pathology, and Radiology Services). The patients were evaluated in an early chronic phase poststroke, and again in a late chronic phase poststroke after 5 years. At each time, all patients received language evaluation with portions of the Boston Diagnostic Aphasia Exam (BDAE) (Goodglass & Kaplan, 1972; 1983), and neurological evaluation including a CT scan.

**Language Testing**

Language testing was performed with the BDAE (Goodglass & Kaplan, 1972; 1983) by Speech/Language Pathologists at two times: Time 1, which was taken beyond the acute 6-month spontaneous recovery period, ranged from 7 to 16 months poststroke (mean, 10.3 months; SD, 2.8); and Time 2 ranged from 4.7 to 12.2 years poststroke (mean, 7.5 years; SD, 2.2). See Table 1.

The BDAE tests that were examined for long-term recovery in all 12 patients included the following: Visual Confrontation Naming, Auditory Comprehension z-Score (including the 4 subtests—Word Discrimination, Body Part Identification, Commands, Complex Ideational Material), and Word Repetition. In addition, long-term recovery of nonfluent speech (Number of Words per Phrase) was examined for the 7 patients who had had impaired spontaneous speech (no speech or nonfluent speech) at Time 1.

**CT Scan Acquisition and Analyses**

The CT scans were obtained for each aphasia patient at two times: Time 1 ranged from 2 to 12 months poststroke (mean, 6.8 months; SD, 3.5); and Time 2 ranged from 4.7 to 12 years poststroke (mean, 7.4 years; SD, 2.2).
At Time 1, most CT scans were performed on an Ohio Nuclear Delta CT scanner. At Time 2, most CT scans were performed on a Picker PQ 2000 CT scanner.

Most CT scans were obtained at approximately 20° to the canthomeatal line, with 10-mm slice thickness, with a 3-mm overlap through the ventricles beginning at the level of the suprasellar cistern. Diagrams that show the location of major cortical and subcortical language areas in relationship to the shape of the ventricles on CT scans performed at this angle are presented in Fig. 1. Scans that were performed at slightly different angles were analyzed with CT scan atlases showing brain anatomy at various scanning angulations (Hanaway, Scott, & Strother, 1977; Matsui & Hirano, 1978; Damasio & Damasio, 1989; Damasio, 1995).

Lesion Size Analysis

In this study, the border of a lesion (presumed area of infarction/lesion size) was defined as an area of visible low-density signal, which was separate from ventricles and fissures. No attempt was made to distinguish between cavity of the lesion, scar-tissue formation, or penumbra. The terms low-density area, area of infarction, and lesion size are used synonymously. The pathology contained within the presumed borders of the area of infarction is beyond the scope of this paper. Possible physiological mechanisms involved with late changes in the borders of the area of infarction are presented under Discussion.

The size of the area of infarction on CT scan was computed for each patient at Time 1 and Time 2, using a program developed by the National Institutes of Health (NIH Image, version 1.41). A MacTablet Summagraphics board was interfaced with a Macintosh llsi computer and used as follows: (1) The borders of the lesion were manually traced onto the Summagraphics board for each CT scan slice where lesion was present, beginning at the first slice above the suprasellar cistern and continuing, if necessary, to the vertex. These lesion area values were summed for each CT scan. (2) The borders of the inner table of the skull for the whole brain were also manually traced for each CT scan slice beginning at the first slice above the suprasellar cistern and continuing to the vertex. These whole brain area values were summed for each CT scan. (3) The total lesion area value was divided by the total brain area value to yield an approximate percentage lesion size in relation to the whole brain.

The percentage ventricle size on CT scan was also computed for each patient at Time 1 and Time 2, using the program described above. The percentage ventricle size was computed at one representative slice level, at the bodies of the lateral ventricle (slice SM in Fig. 1). This is a methodology that has been used in our laboratory in studying ventricle size in normal aging (Albert et al., 1987).
FIG. 1. Location of cortical and subcortical areas on CT scans which are performed at 20° to the canthomeatal line. The CT scan slices B, B/W, W, SM and SM + 1 are labelled according to the Naeser and Hayward (1978) slice labeling system. Each area was examined for extent of lesion using a 0–5 point rating scale (0 = no lesion; 5 = entire area has lesion, see text). The areas rated in relationship to recovery of auditory comprehension were, Wernicke’s area (W) on slices B/W and W; and the subcortical anterior temporal isthmus (Ti) on slices B and B/W. The areas rated in relationship to recovery of nonfluent speech were, the medial subcallosal fasciculus area (M Sc F) on slices B and B/W; and the middle 1/3 periventricular white matter area (M 1/3) on slice SM. Key to other abbreviations: B = Broca’s area (45 on slice B; 44 on slice B/W); T = temporal lobe anterior-inferior to Wernicke’s area on slice B; I = insular structures including insula, extreme capsule, claustrum, external capsule; P = putamen; GP = globus pallidus; ALIC = anterior limb, internal capsule; PLIC = posterior limb, internal capsule; C = caudate; Mot = motor cortex; PM = premotor cortex; Sens = sensory cortex; A Sm = anterior supramarginal gyrus; P Sm = posterior supramarginal gyrus; Ang = angular gyrus; A 1/3 = anterior 1/3 periventricular white matter (PVWM); M 1/3 = middle 1/3 PVWM; and P 1/3 = posterior 1/3 PVWM.

Lesion Site Analysis

The extent of lesion (degree of damage/relative amount of infarction) within each separate cortical and subcortical area on the CT scan slices shown in Fig. 1 was visually assessed for each patient at Time 1 and Time 2, by the first three authors. An extent-of-lesion rating scale that ranged from 0 to 5 was used: 0 = no lesion is present in that area; 1 = equivocal lesion
is present; 2 = small, patchy or partial lesion is present; 3 = lesion is present in half of that area; 4 = lesion is present in more than half of that area; and 5 = lesion is present in that entire area. Special attention was directed to the extent-of-lesion ratings for neuroanatomical areas associated with recovery of nonfluent speech, as explained below.

Lesion Site Analysis and Nonfluent Speech

Previous CT scan studies have observed that persistent nonfluent speech is not necessarily related to presence of lesion in Broca’s area; rather, various portions of the left peri-sylvian cortex may be involved (Mohr et al., 1978; Knopman et al., 1983; Alexander et al., 1990). We have observed that presence of nonfluent spontaneous speech after 6 months poststroke is related to extent of lesion within two subcortical white matter areas (Naeser et al., 1989). The two white matter areas are (1) the medial subcallosal fasciculus area and (2) the middle one-third periventricular white matter (PVWM) area. The locations of these two areas on CT scan are diagrammed on Fig. 1 and explained below.

The medial subcallosal fasciculus area is located deep to Broca’s area, antero-lateral and adjacent to the left frontal horn, containing white matter pathways from the supplementary motor area and supraventricular cingulate gyrus area 24, to the head of the caudate. See CT scan slices B and B/W, Fig. 1. This area is believed to be important in part, for initiation of speech.

The middle one-third PVWM area is located deep to the motor/sensory cortex area for mouth, containing efferent and afferent white matter pathways for the mouth, as well as other important intra- and interhemispheric pathways (Naeser et al., 1989). See CT scan slice SM, Fig. 1. It is believed to be important, in part, for motor/sensory aspects of speech production.

Our previous research has observed that when extent-of-lesion ratings are $>3$ (lesion is in more than half) in only one of these two areas, meaningful nonfluent spontaneous speech (two- to four-word Phrase Length) is usually possible (Naeser et al., 1989). However, when extent-of-lesion ratings are $>3$ in both of these two white matter areas, a patient usually has no recovery of meaningful spontaneous speech, and speech output is limited to no speech, or only stereotypies.

The extent of lesion in the medial subcallosal fasciculus area and the middle one-third PVWM area was rated on the Time 1 and Time 2 CT scans only for those seven patients who had had speech output impairment at Time 1. Impaired speech output was defined as a phrase length of $<4$ words, for the spontaneous speech section (cookie theft picture description) on the BDAE. Impaired speech output at Time 1 was observed in three Broca’s (cases P.P., R.B., and E.M.), two mixed nonfluent (cases J.A. and J.Z.), one global (case J.W.), and one unclassified aphasia patient with no speech but moderate comprehension (case A.A.). It was inappropriate to include patients who had
fluently at Time 1 (phrase length of six or seven words), because their phrase length was already near-normal.

RESULTS

Language Recovery

There was significant improvement in Visual Confrontation Naming from Time 1 to Time 2 (mean change, +23.58, SD, 19.9, p < .002). See Table 2. Intermediate Time Naming scores (between Time 1 and Time 2) were available for five patients in the present study, ranging from 2 years to 7.8 years poststroke. See Table 3. These Intermediate Naming scores were between those obtained at Time 1 and those obtained at Time 2. Thus, it is possible that the change in naming ability between Time 1 and Time 2 was a gradual process.

Table 2 further shows that there was no significant improvement in the Auditory Comprehension z-Score (including each of the four subtests), or Word Repetition from Time 1 to Time 2. There was a significant increase in Number of Words per Phrase from Time 1 to Time 2, for the seven patients who had had impaired speech output (no speech or nonfluent speech) at Time 1 (mean change, +2.2 words, SD, 2.2, p < .039, n = 7). See Table 2.

CT Scan Analyses

Lesion size. The lesion sizes at Time 1 and Time 2 for each patient are presented in Table 1. A significant increase in lesion size from Time 1 to Time 2 was observed (mean change, +3.29%, SD, 2.43, p < .001). See Table 2. The change in lesion size from Time 1 to Time 2 ranged from 0 to +6.9%. Table 1 shows that 9/12 (75%) of the patients had an increase of at least 1% in lesion size. There was no significant correlation between amount of increase in lesion size and size of the lesion at Time 1 (r = -.143) or Time 2 (r = .162). There was no significant correlation between amount of increase in lesion size, and age of the patient at Time 1 (r = -.314) or Time 2 (r = -.277).

Intermediate Time lesion size data were available in two patients; i.e., a CT scan had been performed between Time 1 and Time 2 as part of a separate follow-up aphasia study in our laboratory. For case J.A., the lesion sizes at Time 1 (7 months), Intermediate Time (19 months), and Time 2 (7.25 years) were 6.2, 6.56, and 10.21%, respectively. For case J.W., the lesion sizes at Time 1 (11 months), Intermediate Time (22.5 months), and Time 2 (5.6 years) were 21.13, 22.46, and 23.83%, respectively. These data show that the Intermediate Time lesion size data were between those obtained at Time 1 and Time 2. Thus, it is possible that the increase in lesion size between Time 1 and Time 2 was a gradual process.
TABLE 2.
Paired t-tests for Boston Diagnostic Aphasia Exam (BDAE) Language Subtests and CT Scan Lesion Size and
Ventricle Size for 12 Aphasia Patients—Time 1 vs. Time 2
(Significance calculated at two-tail level).

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
<th>Δ (Time 2-Time 1)</th>
<th>t value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
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<tr>
<td>Language Data</td>
<td></td>
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</tr>
<tr>
<td>Visual Confrontation Naming</td>
<td>49.25</td>
<td>37.08</td>
<td>72.50</td>
<td>35.87</td>
<td>+23.58</td>
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<tr>
<td>Auditory Comprehension z-score</td>
<td>+.08</td>
<td>+.62</td>
<td>+.10</td>
<td>-.62</td>
<td>+.03</td>
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<tr>
<td></td>
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</tr>
<tr>
<td>Word Discrimination</td>
<td>57.54</td>
<td>12.81</td>
<td>58.71</td>
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<td>Commands</td>
<td>11.25</td>
<td>3.39</td>
<td>10.67</td>
<td>3.75</td>
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<tr>
<td>Complex Ideational Material</td>
<td>6.75</td>
<td>3.02</td>
<td>6.50</td>
<td>3.29</td>
<td>-.25</td>
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<tr>
<td>Repetition of Words</td>
<td>6.42</td>
<td>2.91</td>
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<td>Number of Words per Phrase</td>
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<tr>
<td>Only Patients with Impaired Speech at Time 1 (n = 7)</td>
<td>1.93</td>
<td>1.46</td>
<td>4.14</td>
<td>2.59</td>
<td>+2.21</td>
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<td>CT Scan Data</td>
<td></td>
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<td>CT Scan Lesion Size</td>
<td>6.84</td>
<td>5.90</td>
<td>10.13</td>
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<tr>
<td>CT Scan Ventricle Size</td>
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<td></td>
</tr>
<tr>
<td>Left and Right Bodies of Lateral Ventricle</td>
<td>11.61</td>
<td>3.32</td>
<td>14.20</td>
<td>3.01</td>
<td>+2.59</td>
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<td>Left Body of Lateral Ventricle</td>
<td>6.88</td>
<td>1.87</td>
<td>8.46</td>
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<td>+1.57</td>
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<tr>
<td>Right Body of Lateral Ventricle</td>
<td>4.72</td>
<td>1.67</td>
<td>5.73</td>
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<td>+1.01</td>
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<td>CT Scan Ventricle Size by Age</td>
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<td></td>
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<tr>
<td>Left and Right Bodies of Lateral Ventricle</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cases &lt;65 Yrs. at Time 2 (n = 6)</td>
<td>11.74</td>
<td>3.56</td>
<td>13.20</td>
<td>3.00</td>
<td>+1.45</td>
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<tr>
<td>Cases &gt;65 Yrs. at Time 2 (n = 6)</td>
<td>11.47</td>
<td>3.38</td>
<td>15.20</td>
<td>2.92</td>
<td>+3.73</td>
</tr>
<tr>
<td>Left Body of Lateral Ventricle</td>
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<td></td>
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<td></td>
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<tr>
<td>Cases &lt;65 Yrs. at Time 2 (n = 6)</td>
<td>6.98</td>
<td>2.27</td>
<td>8.07</td>
<td>2.249</td>
<td>+1.10</td>
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<td>Cases &gt;65 Yrs. at Time 2 (n = 6)</td>
<td>6.79</td>
<td>1.59</td>
<td>8.86</td>
<td>1.89</td>
<td>+2.05</td>
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</tr>
<tr>
<td>Cases &lt;65 Yrs. at Time 2 (n = 6)</td>
<td>4.77</td>
<td>1.43</td>
<td>5.11</td>
<td>.82</td>
<td>+.35</td>
</tr>
<tr>
<td>Cases &gt;65 Yrs. at Time 2 (n = 6)</td>
<td>4.67</td>
<td>2.02</td>
<td>6.35</td>
<td>1.34</td>
<td>+1.68</td>
</tr>
</tbody>
</table>
### TABLE 3
Naming Scores for 5 Aphasia Patients at Time 1, an Intermediate Time and Time 2
(All scores are out of a possible 114).

<table>
<thead>
<tr>
<th>Patient</th>
<th>Time 1</th>
<th>Intermediate Time</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.P.</td>
<td>13</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td>MPO</td>
<td>10 MPO</td>
<td>48 MPO</td>
<td>75 MPO</td>
</tr>
<tr>
<td>L.S.</td>
<td>64</td>
<td>78</td>
<td>87</td>
</tr>
<tr>
<td>MPO</td>
<td>16 MPO</td>
<td>41 MPO</td>
<td>86 MPO</td>
</tr>
<tr>
<td>E.M.</td>
<td>74</td>
<td>83</td>
<td>102</td>
</tr>
<tr>
<td>MPO</td>
<td>7 MPO</td>
<td>60 MPO</td>
<td>146 MPO</td>
</tr>
<tr>
<td>A.A.</td>
<td>11</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>MPO</td>
<td>8 MPO</td>
<td>18 MPO</td>
<td>62 MPO</td>
</tr>
<tr>
<td>S.M.</td>
<td>97</td>
<td>94</td>
<td>92</td>
</tr>
<tr>
<td>MPO</td>
<td>13 MPO</td>
<td>70 MPO</td>
<td>117 MPO</td>
</tr>
</tbody>
</table>

MPO = Months Poststroke Onset

**Ventricle size.** The mean ventricle size at Time 1 was 11.61 (SD, 3.32); all patients but one were <65 years of age at Time 1. There was a significant increase in ventricle size from Time 1 to Time 2 (mean change, +2.59%, SD, 2.7, p < .007). See Table 2. Because previous CT scan research with normal aging cases has observed that ventricle size increases after age 65 (Albert et al., 1987), the patients were separated into two subgroups based on age at Time 2 (<65 years, n = 6; and >65 years, n = 6). When the patients were divided into these two subgroups, there was only a significant increase in ventricle size for those who were >65 years of age at Time 2. See Table 2.

The mean ventricle size for the bodies of lateral ventricle at CT scan slice SM for normal controls <65 years of age is 6.0%, SD, 2.3; and for normal controls >65 years, 8.42%, SD, 2.65 (Albert et al., 1987). At Time 2, the mean ventricle size for the <65 years stroke group in the present study (13.2%) and the mean ventricle size for the >65 years stroke group (15.2%) exceeded the mean ventricle size for their respective normal control groups (6.0 and 8.42%) by greater than 2 SD’s. This was to be expected, in part, as a result of the *ex vacuo* process, especially at Time 2 (4.7–12 years poststroke).

There was a significant correlation between age at Time 2 and amount of increase in ventricle size at Time 2 ($r = +.576$, $p < .05$). There were no other significant correlations between age, ventricle size (or change), or lesion size (or change), at Time 1 or Time 2. Even when patients who were >65 years at Time 2 were studied separately, there was no significant correlation between amount of increase in ventricle size at Time 2 and amount of increase in lesion size at Time 2 ($r = +.071$). For the >65 years stroke patients, the
increase was probably related, in part, to normal aging, since ventricle size has been observed to increase after age 65 (Albert et al., 1987).

Lesion site. At Time 2, 11/12 patients had lesion expansion into various subcortical white matter areas, e.g., medial expansion into the periventricular white matter area (PVWM area) near the body of the lateral ventricle (slices SM and SM + 1, Fig. 1); anterior expansion, deep to the middle frontal gyrus and anterior one-third PVWM area; and/or posterior expansion deep to the supramarginal and angular gyrus areas, and posterior one-third PVWM area.

At Time 2, 11/12 patients also had lesion expansion into various left hemisphere cortical areas, including inferior and middle frontal gyrus areas, Broca’s area, pre-motor, motor, and sensory cortex areas for mouth, Wernicke’s area, supramarginal gyrus, angular gyrus, and/or the superior parietal lobule.

All nine patients who had at least a 1% increase in lesion size at Time 2, had lesions at Time 1 that included the frontal lobe. These nine patients had frontal lobe lesions that were associated with occlusion of a branch of the superior division of the left middle cerebral artery. Two of the three patients who had less than a 1% increase in lesion size at Time 2 had lesions at Time 1 that excluded the frontal lobe; these two patients had only temporo-parietal lesions (cases S.M. and W.J.). The third patient who had less than 1% increase in lesion size at Time 2 had a complex lesion pattern that included only the inferior division of the left middle cerebral artery, and the most superior portion of the left anterior cerebral artery (case A.A.).

It is unlikely that the changes in lesion borders (lesion size) which occurred after 5–12 years poststroke were artifactual and associated with inferior spatial resolution on CT scans performed in the 1970s or early 1980s, because the increase in lesion size did not occur in all cases. It occurred in 9/12 cases. If lesion expansion was due to machine artifact, then it seems it would be more likely to have been present in all 12 cases. In this retrospective study, however, it is probably not possible to discern whether potential machine artifact played any role in the overall lesion size on the Time 1 CT scans. Future studies with the more advanced neuroimaging technology available today may be able to better define lesion size at Time 1, as well as after 5 years poststroke onset.

CT Scan Changes and Long-Term Language Recovery

Lesion size and naming recovery. There was a significant negative correlation between lesion size at Time 1 and Naming score at Time 1 ($r = -.60, p < .05$). There was also a significant negative correlation between lesion size at Time 2 and Naming score at Time 2 ($r = -.821, p < .01$). Previous studies have also observed a significant negative correlation between lesion size and naming (Kertesz, 1979, Naeser et al., 1987, Knopman et al., 1984). The larger the left hemisphere lesion size, the more impaired was the naming
ability. Thus, a significant negative correlation between lesion size and naming at both Time 1 and Time 2 in the present study is compatible with this previous research.

There was a significant positive correlation, however, between amount of increase in left hemisphere lesion size from Time 1 to Time 2 and amount of increase in the Naming score from Time 1 to Time 2 ($r = +.745, p < .01, n = 12$). Only one patient (case W.J.) had obtained a maximum Naming score at Time 1 testing. In 1981, he had been tested with the 1972 version of the BDAE (maximum Naming score, 105); in 1986 he was tested with the 1983 version of the BDAE (maximum Naming score, 114). Because it could be argued that this case started with a high naming score at Time 1, and therefore had little potential for improvement in naming at Time 2, his data were omitted from a second correlation performed between amount of increase in left hemisphere lesion size and amount of increase in Naming score, from Time 1 to Time 2. Similar results were observed, however, without inclusion of this case, where a significant positive correlation was still present ($r = +.736, p < .01, n = 11$).

Thus, there appeared to be a paradoxical relationship between increase in lesion size and improvement in naming, where the amount of improvement in naming at Time 2 was significantly correlated with the amount of increase in left hemisphere lesion size at Time 2. In fact, for the nine cases who had increase in lesion size of at least 1% at Time 2, seven of these cases improved by at least 20 points in the Time 2 Naming score. The three cases with less than 1% increase in lesion size at Time 2 improved by less than 20 points in the Time 2 Naming score and in one case, the Naming score was even worse (case S.M., the only case whose Time 2 score was worse).

Case Examples

The CT scans at Time 1 and Time 2, for a patient who had marked increase in lesion size from Time 1 to Time 2, are shown in Fig. 2, top and bottom (case G.A.). The CT scans at Time 1 and Time 2, for a patient who had almost no increase in lesion size from Time 1 to Time 2 (less than 1%), are shown in Fig. 3, top and bottom (case S.M.).

Lesion site and nonfluent speech recovery. As mentioned above, the extent of lesion was rated in two subcortical white matter areas associated with recovery of nonfluent speech. These two areas are (1) the medial subcallosal fasciculus area located deep to Broca’s area, adjacent and antero-lateral to the frontal horn; and (2) the middle one-third PVWM area located deep to the motor/sensory cortex area for mouth, and near the body of the lateral ventricle (Fig. 1). These two white matter areas were rated for extent of lesion on the Time 1 and Time 2 CT scans only for the seven patients who had had impaired speech output (no speech or nonfluent speech) at Time 1. See Table 4. Lesion in more than half of only one of these two areas is
compatible with nonfluent speech (two- to four-word phrase length); lesion in more than half of both of these two areas is compatible with no meaningful spontaneous speech (Naeser et al., 1989).

Table 4 shows that based on the Time 1 extent-of-lesion ratings for these two white matter areas, five cases had lesion in half, or more than half, of only one of these two white matter areas (cases P.P., R.B., J.A., J.Z., and E.M.). Four of these latter five cases had meaningful, nonfluent spontaneous speech at Time 1 with a phrase length of two to four words (cases P.P., R.B., J.A., and E.M.). This lesion site pattern and nonfluent speech at Time 1 are compatible with our previous research (Naeser et al., 1989).

Table 4 also shows that based on the Time 1 extent-of-lesion ratings for these two white matter areas, two cases had lesion in more than half of both of these two areas; these patients had no meaningful spontaneous speech at Time 1 (cases J.W. and A.A.). This lesion site pattern and no spontaneous speech at Time 1 are also compatible with our previous research (Naeser et al., 1989).

Table 4 also shows that four patients who had had lesion in more than half of only one of these two white matter areas at Time 1 had lesion in more than half of both of these two white matter areas at Time 2 (cases P.P., R.B., J.A., and J.Z.). This was a lesion pattern at Time 2 that would have been compatible with no speech. Despite this new white matter lesion pattern, however, each of these four nonfluent aphasia patients continued to maintain or increase his/her Number of Words per Phrase from Time 1 to Time 2. At Time 1, they had had a phrase length which ranged from two to four words; at Time 2, however, despite new white matter lesion expansion, the phrase length now ranged from four to six words. A detailed analysis of the nonfluent speech produced by these patients is beyond the scope of this paper and is the topic of another paper (Fitzpatrick et al., 1988).

Case P.P., shown in Fig. 4, is a case example of a patient who continued to improve in Number of Words per Phrase, despite lesion expansion into more than half of a second white matter area (the middle one-third PVWM area) at Time 2. At Time 1, this patient already had lesion present in more than half of the medial subcallosal fasciculus area. Thus, at Time 2, his CT scan extent-of-lesion ratings (lesion in more than half) for the medial subcallosal fasciculus area and the middle one-third PVWM area were compatible with no speech, but he had increased his phrase length from three words at Time 1, to six words at Time 2.

Although the lesion expansion at Time 2 into the middle one-third PVWM area did not have an adverse effect on the speech of case P.P., it did have an adverse effect on his right hemiparesis, with measured reduction in knee flexion, knee extension, shoulder abduction, and forearm supination (Naeser et al., 1994). The motor pathway areas for contralateral limbs are clustered in the deepest portions of the PVWM area, just superior to their descent into the posterior limb, internal capsule (Schulz et al., 1993).
Although case P.P. was the only left-handed patient in the present study, this same lesion expansion pattern and continued recovery of nonfluent speech was also observed in three right-handed patients. Thus, it is unlikely that the left-handedness in case P.P. had any special effect on his continued recovery of nonfluent speech from Time 1 to Time 2. Indeed, several studies have observed language recovery in many non-right-handed cases to be similar to that in right-handed cases, who were aphasic from left hemisphere lesion, especially when left hemisphere lesion sites were documented and matched between the two groups (Gloning et al., 1969; Naeser & Borod, 1986; Basso et al., 1990).

The two patients who originally had lesion in more than half of both white matter areas, and who had a phrase length of zero to one word at Time 1, continued this lesion pattern at Time 2, and severe deficit in spontaneous speech output with only a zero- to one word phrase length at Time 2 (cases J.W. and A.A.). This persistent severe language behavior of no speech or only stereotypies also was observed in chronic aphasia patients with this lesion pattern as long as 8 and 9 years poststroke in our previous study (Naeser et al., 1989).

In summary, the extent-of-lesion ratings for the two subcortical white matter areas on the Time 1 CT scans, and the Time 1 phrase lengths, were compatible with our previously published research for expected phrase lengths based on CT scan lesion site analysis. The extent-of-lesion ratings for these two white matter areas on the Time 2 CT scans, and the Time 2 phrase lengths, however, were not compatible with our previously published re-
search. For four patients at Time 2, there was now lesion in more than half of both white matter areas (compatible with no speech), yet phrase lengths were four to six words. There was an unexpected paradoxical relationship between increase in lesion within two neuroanatomical areas usually associated with poor speech recovery, yet improvement in phrase length was present.

**DISCUSSION**

This retrospective long-term recovery study evaluated aphasia patients during an early chronic phase poststroke (Time 1) and again during a late chronic phase poststroke at 5–12 years poststroke (Time 2), with BDAE language testing and CT scan. Language testing showed a significant improvement in the naming scores after 5 years poststroke, and a significant increase in the phrase length in nonfluent speech. A significant change in the borders of the lesion (significant increase in total lesion size) was observed at Time 2. In 9 of the 12 patients, the increase was at least 1% after 5 years poststroke. This increase was not expected, and was not observed in all cases (3/12 cases presented after 5 years poststroke with <1% increase in lesion size). The overall increase in lesion size in the majority of the cases (9/12 or 75%) presented a paradox regarding continued language recovery in two areas of language behavior.

The first area of language recovery involved a significant improvement in Visual Confrontation Naming, despite a significant increase in lesion size. The second area of language recovery involved an increase in phrase length in nonfluent speech, despite an increase in extent of lesion in two white matter areas important for recovery of nonfluent speech: (1) the medial subcallosal fasciculus area located deep to Broca’s area, adjacent and anterolateral to the frontal horn; and (2) the middle one-third PVWM area located

**FIG. 3.** Time 1 (Top) and Time 2 (Bottom) CT scans for patient S.M., who had minimal increase in lesion size at Time 2 (less than 1%). Top: Time 1 CT scan performed at 3 months poststroke for case S.M., a man age 61 years. Lesion was present in most of Wernicke’s area (slices B/W and W), with superior extension into all of the posterior supramarginal gyrus, and approximately half of the angular gyrus area. There was deep extension into more than half of the posterior 1/3 PVWM area. There was small cortical extension into the superior parietal lobule (slice SM + 2). Bottom: Time 2 CT scan performed at almost 10 years poststroke for case S.M., now 71 years. Small subcortical lesion expansion was present in the white matter deep to area 37 (lateral to the atrium portion of the occipital horn); and into most of the posterior 1/3 PVWM (slices SM and SM + 1). There was small lesion expansion into the white matter in the superior parietal lobule (slice SM + 2). No cortical lesion expansion was present. The increase in lesion size for this temporo-parietal lesion was minimal (less than 1%). The naming score was generally good, however, there was a small decrease at Time 2; Time 1, 97; Time 2, 92.
### TABLE 4
Long-Term Recovery of Nonfluent Speech in Seven Patients - Relationship to Extent of Lesion in the Medial Subcallosal Fasciculus Area and the Middle 1/3 Periventricular White Matter Area on Time 1 and Time 2 CT Scans

<table>
<thead>
<tr>
<th>Patient and Type of Aphasia</th>
<th>Time 1 Lesion in Medial Subcallosal Fasciculus</th>
<th>Time 1 Lesion in Middle 1/3 PVWM</th>
<th>Time 1 No. Words per Phrase on Time 1 CT Scan Extent-of-Lesion Ratings</th>
<th>Time 2 Lesion in Medial Subcallosal Fasciculus</th>
<th>Time 2 No. Words per Phrase on Time 2 CT Scan Extent-of-Lesion Ratings</th>
<th>Time 2 No. Words per Phrase</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.P.</td>
<td>&gt;1/2</td>
<td>&lt;1/2</td>
<td>Nonfluent (1–4)</td>
<td>&gt;1/2</td>
<td>&gt;1/2*</td>
<td>No Speech (0)</td>
</tr>
<tr>
<td>R.B. Broca's</td>
<td>&gt;1/2</td>
<td>&lt;1/2</td>
<td>Nonfluent (1–4)</td>
<td>&gt;1/2</td>
<td>&gt;1/2*</td>
<td>No Speech (0)</td>
</tr>
<tr>
<td>J.A. Mixed Nonfluent J.Z.</td>
<td>0</td>
<td>&gt;1/2</td>
<td>Nonfluent (1–4)</td>
<td>0–1</td>
<td>&gt;1/2*</td>
<td>No Speech (0)</td>
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<tr>
<td>Global</td>
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<td>&gt;1/2</td>
<td>No Speech (0)</td>
<td>0–1</td>
<td>&gt;1/2</td>
<td>No Speech (0)</td>
</tr>
<tr>
<td>E.M. Broca’s</td>
<td>1/2</td>
<td>&lt;1/2</td>
<td>Nonfluent (1–4)</td>
<td>1/2</td>
<td>Nonfluent (1–4)</td>
<td>6</td>
</tr>
<tr>
<td>A.A. Unclassified</td>
<td>(&gt;1/2)</td>
<td>&gt;1/2</td>
<td>No Speech (0)</td>
<td>&gt;1/2</td>
<td>&gt;1/2</td>
<td>No Speech (0)</td>
</tr>
<tr>
<td>Mod. Comprehension</td>
<td>(Lesion is in SMA and Cingulate Cortex— i.e., Origin of the Medial Subcallosal Fasciculus)</td>
<td></td>
<td></td>
<td>(&gt;1/2)</td>
<td>Lesion is in SMA and Cingulate Cortex</td>
<td></td>
</tr>
</tbody>
</table>

* Indicates an expansion of the lesion into more than half (>1/2) of this area on the Time 2 CT scan.

**Extent-of-Lesion Rating Scale:**
- 0 = No lesion is present in that area; <1/2 = Lesion is present in less than half of that area; 1/2 = Lesion is present in half of that area; >1/2 = Lesion is present in more than half of that area.

**Medial Subcallosal Fasciculus Area** is located deep to Broca’s area, antero-lateral and adjacent to left frontal horn (CT scan slices B and B/W, Figure 1).

**Middle 1/3 Periventricular White Matter (PVWM) Area** is located deep to motor/sensory cortex area for mouth, lateral to the body of the left lateral ventricle (CT scan slice SM, Figure 1).

An extent-of-lesion rating which is >1/2, in both of these white matter areas is usually compatible with a phrase length of 0–1, i.e., No Speech.
deep to the motor/sensory cortex area for mouth, near the body of the lateral ventricle.

The increase in left hemisphere lesion size and lesion expansion into left hemisphere lesion site areas important for recovery of nonfluent speech appeared to have no negative effect on the patients’ language behavior, as long as it was a gradual process. Not one case had a second stroke, and the lesion increase had apparently occurred gradually, over the 5- to 12-year period poststroke. This gradual increase in lesion size would appear to permit long-term brain reorganization (perhaps bilateral or primarily in the right hemisphere). This is an unknown process.

The physiological mechanisms underlying the visible changes in the low-density areas (lesion expansion) observed in the present study are not understood. At the site of an original brain infarct, the end result of necrotic brain tissue is a fluid-filled cavity (Garcia et al., 1992). Since cavitation of a brain infarct is completed within several months, the low-density areas visible on CT scan at Time 2 in the present study primarily correspond to this cavity. Although systematic histological studies on stroke evolution have been limited to 4 weeks post onset (Chaqui & Tapia, 1993), the following three neuropathophysiological processes may account for expansion of the borders of the low-density areas observed in the present study.

First, it is plausible that increase in the low-density area represents Wallerian degeneration contiguous to the original infarct. Wallerian degeneration is an anterograde axonal degeneration and demyelination, secondary to necrosis of the neuron, and most frequently seen as a consequence of cortical infarction (Duchen, 1984). Studies of MRI have demonstrated that Wallerian degeneration after 10–14 weeks following a stroke could be detected as T2 high signal intensity (Kuhn, 1989). DeWitt et al. (1986) correlated the MRI alterations in cerebrovascular disease with the neuropathological findings and concluded that prolonged T1 and T2 areas were determined to be infarct plus the adjacent areas of Wallerian degeneration. Thus, Wallerian degeneration may reasonably contribute to the increase in the size of low-density areas on CT scan from Time 1 to Time 2, particularly when the expansion is primarily within the subcortical white matter.

Second, a chronic hypoperfusion area surrounding the original infarct could be detected as low density. This is likely when a low-density area extends into the watershed zone. The pressure boundary between two adjacent arteries is susceptible to the alteration of hemodynamic conditions (van der Zwan et al., 1992), and an infarct around the watershed zone may reasonably change the hemodynamics, resulting in serious hypoperfusion. Kudo et al. (1993) demonstrated that chronic hypoperfusion caused significant neuropathological changes in the gerbil brain in the watershed zone, which may produce neuronal death. All nine cases in the present study who had an increase in lesion size greater than 1% had lesion that originally included the frontal lobe and it is likely that some of the lesion expansion, especially
expansion deep to the middle frontal gyrus and into the PVWM areas, was located in a watershed zone.

Third, the increase in low-density area may reflect other small vessel involvement. Chronic hypoperfusion discussed above may not be limited to the watershed area. Rodriguez et al. (1992) reported that asymmetric hypoperfusion was detected in 92.0% of stroke patients, and the presence of carotid obstruction further decreased the regional cerebral blood flow in the affected hemisphere. Thus, a considerable number of stroke patients who have risk factors might suffer from chronic hypoperfusion throughout the affected hemisphere. In the present study, some subjects had expansion of low-density areas into the supramarginal gyrus and the angular gyrus areas, suggesting involvement of another vessel. Although new cerebrovascular events were not clinically evident, overall hypoperfusion in the affected hemisphere may cause occlusion of a small vessel adjacent to a primary stroke lesion.

Results from the present study are, in fact, compatible with those of a recently published stroke study with 3-year follow-up (van Zagten, Boiten, Kessels & Lodder, 1996). In that study, about 26% of the stroke cases were observed to have a progression of white matter lesions and increase in the numbers of small deep or territorial infarcts after 3 years poststroke. No increase in the degree of handicap (Rankin score) was observed, however, between 3 months and the 3-year follow-up. The degree of cognitive impairment was not yet determined. Those authors speculated that ‘...marked progression of white matter lesions and small deep infarcts ... are caused by a similar vasculopathy that affects small vessels, which is progressive despite standard stroke treatment’ (p. 650). It is of interest that at 3-year

**FIG. 4.** Time 1 (Top) and Time 2 (Bottom) CT scans for patient P.P., who continued to improve in phrase length at Time 2, despite increased white matter lesion at Time 2 which would have been compatible with no speech. Top: Time 1 CT scan performed at 4 months poststroke for case P.P., a man age 63 years. Lesion was present in most of Broca’s area with deep extension to include all of the medial subcallosal fasciculus area (arrow, slice B-B/W), with small, patchy superior extension into the anterior 1/3 PVWM (arrow, slice SM). Bottom: Time 2 CT scan performed at 6 years poststroke for case P.P. now 69 years. Subcortical lesion expansion was present into the white matter deep to the middle frontal gyrus; into most of the anterior 1/3 and middle 1/3 PVWM areas (slice SM, arrow, and SM + 1); and in higher white matter (slice SM + 2). Cortical lesion expansion was present in the motor/sensory cortex area for mouth (slice SM). The extensive lesion in both of the two white matter areas usually compatible with no speech, are marked with arrows—i.e., the medial subcallosal fasciculus area (slice B-B/W) and the middle 1/3 PVWM area (slice SM). At Time 1, the phrase length was 3 words, as would be expected from extensive lesion in only the medial subcallosal fasciculus area. At Time 2, the phrase length was 6 words, despite extensive lesion now present in both the medial subcallosal fasciculus area and the middle 1/3 PVWM area. The naming score at Time 1 was 13, and at Time 2, 72, despite an increase in lesion size of +6.9%, for this fronto-parietal lesion.
follow-up, the increase in white matter lesions in that study was present in only around 26% of the cases, whereas in the present study at 5- to 12-year follow-up, lesion expansion was present in 75% of the cases.

As mentioned above, the physiological mechanisms underlying the changes in lesion borders in this study are not understood. It is possible that the new low-density areas visible on the Time 2 CT scans were located in already nonfunctioning areas on the Time 1 scans, and there was no change in the amount of ‘‘nonfunctioning tissue.’’ This is not likely, however, because we have previous research that has observed that CT scans performed in the early chronic phase poststroke (around 2–3 months to 1 year poststroke) can be used to discriminate between patients who produce nonfluent speech (two- to four-word phrase length), versus those who produce no meaningful spontaneous speech (zero- to one-word phrase length) (Naeser et al., 1989). The latter study showed that following a first stroke, when visible lesion was present in more than half of both of the two subcortical white matter areas (the medial subcallosal fasciculus area and the middle one-third PVWM area), there was severe limitation in speech output (phrase length zero to one word), whereas when visible lesion was present in more than half of only one of these areas, there was nonfluent speech (phrase length two to four words). The small differences in the visible depth of lesion in these two subcortical white matter areas was compatible with large differences in speech output production in the Naeser et al., 1989 study. Therefore, it is not likely that in the present study, the deeper white matter tissue (new lesion expansion areas at Time 2) was already nonfunctioning tissue at Time 1. There was a visible difference in the depth of white matter lesion at Time 1, for cases with nonfluent speech versus those cases with no speech, in the present study.

Table 4 of the present study shows that at Time 2, when new lesion expansion was now present in more than half of both of these two subcortical white matter areas in four cases who had lesion present in more than half of only one of these two white matter areas at Time 1, these four cases were still nonfluent at Time 2 (phrase lengths of four to six words), despite new lesion expansion compatible with zero- to one-word phrase length. Therefore, because the language behavior at Time 1 was compatible with the lesion borders present at Time 1, and the language behavior at Time 2 should have been much more severe in order to be compatible with the lesion borders present at Time 2, it seems that brain reorganization had taken place in some manner in these four cases at Time 1, to permit continued production of nonfluent speech (four- to six-word phrase length) at Time 2.

For these four cases with continued production of nonfluent speech at Time 2, despite new lesion expansion at Time 2, brain reorganization may actually have taken place twice. The first reorganization may have taken place during the early recovery phase after the first stroke (perhaps first 3–6 months), when lesion was present in more than half of only one of the
The second brain reorganization phase may have taken place over a longer period of time, when lesion became present in more than half of both of the subcortical white matter areas. This latter lesion pattern would have been compatible with no speech (zero- to one-word phrase length): however, the phrase length was four to six words at Time 2. It appears that the brain reorganization that took place sometime during the early chronic phase poststroke which permitted nonfluent speech production at Time 1 was perhaps the more important reorganization. This early chronic phase brain reorganization possibly used completely different parts of the brain to produce the nonfluent speech (areas unknown). When the lesion expansion took place at Time 2, into more than half of both white matter areas, either the original early chronic phase brain reorganization was so strong that the new lesion expansion had no effect or additional reorganization again took place. These are unknown at this time.

Only when visible lesion was present in more than half of both white matter areas at Time 1 and at Time 2 was there severe limitation in speech output (zero- to one-word phrase length) at Time 1 and at Time 2. For these cases, perhaps brain reorganization for speech never took place, or was quite limited, because there was such severe limitation in phrase length (zero to one word) early and late, even after 5 years poststroke. It may be that when lesion is present in more than half of both of the white matter areas following the first stroke, the damage is so severe that no brain reorganization for speech production can take place and the brain is reorganized for “no speech.” These are areas that need to be further studied with more advanced neuroimaging technology, such as functional brain imaging in early and late phases poststroke.

Not all cases had lesion size increases of greater than 1%. Only 9/12 cases had this amount of lesion size increase. It seems to vary from case to case; in 6 cases there was an increase of greater than 3.5%, up to 7%. Nor is the increase in lesion size a universal physiological phenomenon. If it occurred in all cases with infarction, then all the lesion sizes would increase by the same amount, but they do not. The changes in lesion borders that did occur in the present study, however, were quite visible to the naked eye. These were not subtle changes only visible by detailed planimetric measurements.

The observation of lesion expansion on CT scans performed after 5 years poststroke in 9/12 patients (75%) in the present study suggests that when future brain/behavior research is being conducted with stroke patients who are greater than 5 years poststroke, an earlier CT scan performed after 3 months poststroke, but within a few years poststroke, should be obtained if possible. The early chronic CT scan would be important to have, in order to better understand the original lesion sites that were present when the early chronic phase of brain reorganization was likely to have taken place.
Previous studies have suggested that when aphasia is due to a left hemisphere stroke, the recovery that occurs appears to involve right hemisphere activity (Geschwind, 1985; Fazzini et al., 1986). For example, it has been observed with EEG studies that patients with bilateral slowing have poor language outcome (Tikofsky, 1960). Dichotic listening studies have observed that as aphasics improve in language, cerebral dominance becomes more firmly established in the right hemisphere (Petit & Noll, 1979; Moore, 1984; Papanicolaou et al., 1988). In aphasia patients who have had unilateral left hemisphere stroke, injection of intracarotid amobarbital into the left side produces no alteration on the aphasic speech, whereas injection into the right side produces the customary speech arrest (Kinsbourne, 1971; Czopf, 1972). When aphasia patients with unilateral left hemisphere stroke have a new right hemisphere stroke, there is marked deterioration in language (Levine & Mohr, 1979; Lee et al., 1984; Basso et al., 1989). Cerebral blood flow studies have observed an increase in the right hemisphere in aphasia patients who have good recovery (Meyer et al., 1980; Yamaguchi, 1980; Knopman et al., 1984). In addition, recent studies examining motor recovery in stroke patients who originally had a hemiparesis have observed an increase in blood flow in specific cortical areas ipsilateral to the hemiparesis, in cases where motor recovery has occurred (Chollet et al, 1991; Weiller et al., 1992; Weder et al., 1994).

The results from the present study may be supportive of these previous studies regarding right hemisphere participation in aphasia recovery, because the gradual increase in lesion size in the left hemisphere in the present study had no adverse effect on language recovery in naming and phrase length in nonfluent speech, after 5–12 years poststroke. The specific task of visual confrontation naming, in fact, may have a right hemisphere activation component. For example, a recent study using functional MRI has observed that verb generation produced a more asymmetric left/right activation pattern than did naming (Benson et al., 1994). Thus, the continued improvement in naming that was observed in the present study with left hemisphere-damaged stroke patients may be compatible with continued involvement from the right hemisphere. This is unknown.

There has been a recent trend in aphasia research to emphasize a systems approach, where several parts of the brain are recognized to be important together in producing a specific language behavior (Damasio, 1989; Alexander, 1990; Mesulam, 1990). Thus, the long-term language improvement in naming and speech output observed in this study may be associated in part with left hemisphere and/or right hemisphere activity that is part of one or more language systems important for naming and speech output. Certain portions of a system or systems may become gradually more active only after several years poststroke.

In the present study, the paradoxical long-term improvements in naming and phrase length in nonfluent speech, despite visible expansion of the bor-
ders of the low-density area after 5 years poststroke, suggest that brain reorganization is present in long-term aphasia recovery. It appears that as long as lesion expansion is unilateral and gradual (over a 5-year period or more), the remaining undamaged brain may adapt to the expanding low-density area, and even produce improvement in naming and phrase length in nonfluent speech. Future studies with SPECT, PET, or functional MRI with precise lesion site information in recovering aphasia patients should be able to delineate this brain reorganization process more clearly.

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