Correlation of magnetic resonance imaging with neuropsychological testing in multiple sclerosis

S.M. Rao, PhD; G.J. Leo, DO; V.M. Haughton, MD; P. St. Aubin-Faubert, MS; and L. Bernardin, BS

Article abstract—Previous research has suggested that cerebral lesions observed on magnetic resonance imaging (MRI) of MS patients are clinically "silent." We examined the validity of this assertion by correlating neuropsychological test performance with MRI findings in 53 MS patients. We used a semiautomated quantitation system to measure three MRI variables: total lesion area (TLA), ventricular-brain ratio (VBR), and size of the corpus callosum (SCC). Stepwise multiple regression analyses indicated that TLA was a robust predictor of cognitive dysfunction, particularly for measures of recent memory, abstract/conceptual reasoning, language, and visuospatial problem solving. SCC predicted test performance on measures of mental processing speed and rapid problem solving, while VBR did not independently predict cognitive test findings. These findings suggest that cerebral lesions in MS produce cognitive dysfunction and that MRI may be a useful predictor of cognitive dysfunction.

Magnetic resonance imaging (MRI) is extremely sensitive for the detection of focal areas of demyelination in patients with MS. The clinical significance of these lesions remains unclear. Their correlation with neurologic symptoms and degree of disability has been uniformly disappointing, prompting the view that MS lesions occur in brain regions that are clinically "silent." Others have recommended the use of neuropsychological testing to evaluate the possible relationship between cerebral demyelination and cognitive dysfunction.

Two studies attempted to relate cognitive dysfunction to lesions identified by MRI. Franklin et al examined 60 patients with chronic progressive MS and found a significant correlation (r = 0.35) between an overall brain lesion score and a summary score derived from a brief cognitive screening battery. Huber et al administered a brief battery of neuropsychological tests to 30 MS patients, nine of whom were classified as "demented," 11 moderately cognitively impaired, and 12 minimally impaired. These investigators observed no significant group differences on three MRI indexes: total lesion score, cerebral atrophy, and severity of periventricular involvement. On the fourth index, atrophy of the corpus callosum, the "demented" patients had significantly higher ratings than the moderate and minimal cognitive impairment groups.

These two studies found significant correlations between MRI variables and cognitive testing, yet the strength of the correlations was modest. Three methodologic factors may have contributed to their limited success in obtaining meaningful correlations. First, both studies relied on rating scales to measure the size of lesions from MRIs. Rating scales by definition are subjective and prone to human error. In addition, rating scales provide a more restricted range of data values than quantitative systems that measure lesions in area units; this restricted range may seriously limit the size of obtained correlations. Second, both studies used brief cognitive screening examinations. MS does not produce a uniform decline of all cognitive skills; although these brief batteries covered a number of cognitive functions, they may have missed salient cognitive deficits. A more comprehensive neuropsychological examination may be more successful in measuring those cognitive functions that are influenced by MS-related cerebral pathology. Finally, cognitive test performance is affected by education and age. Thus, relatively uneducated or older patients may be classified as impaired on testing when they are functioning close to their premorbid level. Conversely, highly educated or younger patients may have experienced declines in cognitive performance that were undetected because their performance remained in the "average" range. Neither study attempted to control for these potential artifacts either experimentally or statistically.

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cerebral lesions and the degree of ventricular and corpus callosum atrophy were quantified from MRIs. Clinico-
sive neuropsychological test battery to a representative
sample of MS patients from the community. Size of
variate statistical procedures which adjust for pre-
morbid differences in cognitive ability.

**Methods. Patients.** We randomly recruited MS patients from
a membership listing of a local MS society. A review of medical
records allowed determination of the basis for the diagnosis of
MS. We excluded patients not meeting the criteria of Poser et
al13 for definite or probable MS and patients with a history of
alcohol/drug abuse or nervous system disorder other than MS.
Once enrolled, a neurologic examination verified the Poser
diagnostic classification and rated patients with regard to
disease course, length of symptoms, severity of global demen-
tia (Mini-Mental State Examination44), and physical dis-
ability (Kurtzke Expanded Disability Status Scale [EDSS]15).
Patients subsequently underwent neuropsychological testing
and MRI over a 2-day period to minimize fatigue. Patients
gave informed consent according to institutional guidelines.

**MRI.** Imaging was performed on a commercial 1.5 tesla
superconductive magnet (General Electric Signa System). We
obtained sagittal images with a repetition time (TR) of 600
msec, an echo time (TE) of 20 msec, and a 5-mm slice thick-
ness. These images enabled the selection of a series of axial
slices with a TR of 2 seconds and TEs of 25 and 80 msec. The
technical factors included two excitations, a 128 × 256 matrix,
a 5-mm slice thickness, and a 1-mm “skip” between slices.

One investigator, without knowledge of the clinical and
neuropsychological profiles of the patients, obtained measure-
ments of total lesion area (TLA), size of the corpus callosum
(SCC), and ventricular-brain ratio (VBR). This was accom-
plished by tracing the outlines of lesions and cerebral structures
on the MRI computer console. Software routines
available on the GE Sigma System computed the area (in cm²)
subtended by each tracing. We recorded sizes of the following
cerebral structures: the third and lateral ventricles from axial
slices, the entire area of the brain for each axial slice in which
the third or lateral ventricles, or both, could be visualized, and
the corpus callosum from the midsagittal slice (see figure 1).
We computed TLA by adding all measurements of lesion size
for a given patient and VBR by dividing the sum of the
ventricular measurements by the sum of the brain area mea-
urements.

**Neuropsychological tests.** The neuropsychological test
battery consisted of measures of verbal intelligence, memory,
abstract/conceptual reasoning, attention/concentration, lan-
guage, and visuospatial skills. We specifically chose tests that
do not require fine visual acuity or motor speed/dexterity.

Verbal intelligence was assessed with the six subtests con-
stituting the verbal subscale of the Wechsler Adult Intelli-
gen Scale-Revised (WAIS-R)16; vocabulary, information, digit span (see attention/concentration tests below), compre-
hension, similarities, and arithmetic.

The recent memory tests consisted of the Buschke Verbal
Selective Reminding Test,19 the 7/24 Spatial Recall Test,18,19
and the Story Recall Test.20 The Story Recall Test was admin-
istered with immediate, 1-hour, and 24-hour delayed recall.
We assessed remote memory by asking the subjects to recall
the past eight US presidents (President’s Test).20 The Brown-
Peterson Interference Test21*22 assesses the rate of forgetting
from immediate memory; the stimuli were three 3-letter
words, the delay intervals were 0, 3, 9, and 18 seconds, and
the interference task consisted of counting backwards by 3 during
the delay interval. We computed rate of forgetting by subtract-
ning the number of words correctly recalled after 18-second
delay (maximum = 15) from words recalled after no delay
(maximum = 15).

Tests of abstract/conceptual reasoning skills consisted of the
Wisconsin Card Sorting Test,23 Booklet Category Test,24
Standard Raven Progressive Matrices,25 and Stroop Color/
Word Interference Test26 (total time to read a color list was
subtracted from total time to read the color-word list).

Assessment of attention/concentration skills included for-
ward and backward digit span (WAIS-R Instructions), simple
versus two-choice complex reaction time (RT)27 (simple RT
was subtracted from complex RT), Sternberg Memory Scan-
ing Task28 (which yields two measures: slope, a measure of
mental processing speed; and y-intercept, a measure of overall
motor reaction time), and Paced Auditory Serial Addition
Test29 (using two conditions based on different rates of stim-
ulus presentation: for the “easy” condition, 60 single digits
were presented at 3-second intervals, and for the “hard” con-
dition, 60 digits were presented at 2-second intervals).

The language measures used in this study assessed pri-
marily expressive abilities. These included an abbreviated (15-
item) version of the Boston Naming Test,20 Controlled Oral
Word Association Test (F-A-S version),28 and Category Word
Generation Test (animal names version).20

We assessed visuospatial skills with the Hooper Visual Organi-
Data analysis. Statistical analyses were performed with the microcomputer version of the Statistical Package for the Social Sciences. We performed separate stepwise multiple regression analyses for each of the 34 cognitive measures, which served as the dependent (criterion) variables. The independent (predictor) variables were age, education, TLA, VBR, and SCC. Age and education were always entered on the first step to adjust for their effects on the cognitive variables and to adjust for the effects of age on VBR (see below).

We employed cluster analysis (nearest centroid sorting method) to classify patients into two subgroups: patients with relatively substantial cognitive impairment ("Impaired") versus those with relatively minimal impairment ("Intact"). Thus, we selected a two-group cluster solution. This method minimizes individual differences in premorbid ability levels.

Results. A total of 59 patients were enrolled in the study. We eliminated six patients from the final analysis: four did not complete MRI due to claustrophobia, one did not meet the criteria of Poser et al after completion of the neurologic examination, and one had a brainstem arteriovenous malformation diagnosed by MRI. All but two patients were in clinical remission at the time of evaluation. Table 1 presents demographic and illness characteristics for the patient sample.

Table 1. Clinical characteristics of MS sample (N = 53)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (males/females)</td>
<td>13/40</td>
</tr>
<tr>
<td>Age in years (mean)</td>
<td>43.9</td>
</tr>
<tr>
<td>Education in years (mean)</td>
<td>13.6</td>
</tr>
<tr>
<td>Occupation (6-pt. scale, mean)</td>
<td>4.1</td>
</tr>
<tr>
<td>Estimated premorbid IQ* (mean)</td>
<td>106.1</td>
</tr>
<tr>
<td>Length of symptoms in years (mean)</td>
<td>12.2</td>
</tr>
<tr>
<td>Years since diagnosis (mean)</td>
<td>7.8</td>
</tr>
<tr>
<td>Kurtzke Expanded DSS (mean)</td>
<td>3.8</td>
</tr>
</tbody>
</table>

* Estimated from demographic variables using regression formula derived from WAIS-R standardization sample.

Table 2. Results of stepwise multiple regression analyses showing MRI variables (in rank order) making significant contributions to the prediction of cognitive test performance after partialling out age and education

<table>
<thead>
<tr>
<th>Cognitive test</th>
<th>MRI variable</th>
<th>Partial R²</th>
<th>Change R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal Intelligence</td>
<td>SCC</td>
<td>0.37</td>
<td>0.39</td>
</tr>
<tr>
<td>WAIS-R Verbal IQ</td>
<td></td>
<td></td>
<td>0.10*</td>
</tr>
<tr>
<td>Information</td>
<td>TLA</td>
<td>0.31</td>
<td>0.41</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>SCC</td>
<td>0.38</td>
<td>0.23</td>
</tr>
<tr>
<td>Comprehension</td>
<td>SCC</td>
<td>0.38</td>
<td>0.13*</td>
</tr>
<tr>
<td>Analogies</td>
<td>SCC</td>
<td>0.39</td>
<td>0.13†</td>
</tr>
<tr>
<td>Memory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selective Reminding Test</td>
<td>TLA</td>
<td>-0.40</td>
<td>0.31</td>
</tr>
<tr>
<td>Long-term storage</td>
<td>TLA</td>
<td>-0.38</td>
<td>0.32</td>
</tr>
<tr>
<td>Consistent long-term retrieval</td>
<td>TLA</td>
<td>-0.35</td>
<td>0.11*</td>
</tr>
<tr>
<td>T-score-Abbreviated Boston Naming Test</td>
<td>SCC</td>
<td>0.48</td>
<td>0.33</td>
</tr>
<tr>
<td>Scan rate (ms)</td>
<td>TLA</td>
<td>0.34</td>
<td>0.48</td>
</tr>
<tr>
<td>Y-intercept (sec)</td>
<td></td>
<td></td>
<td>0.07*</td>
</tr>
<tr>
<td>Raven Progressive Matrices</td>
<td>TLA</td>
<td>0.54</td>
<td>0.55</td>
</tr>
<tr>
<td>Number correct</td>
<td>TLA</td>
<td>0.38</td>
<td>0.18</td>
</tr>
<tr>
<td>Stroop Interference Test</td>
<td>TLA</td>
<td></td>
<td>0.14*</td>
</tr>
<tr>
<td>Word-color-word condition (sec)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention/Conceptual Reasoning</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Digit span</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forward</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backward</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex—simple RT (msec)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sternberg Memory Scanning Task</td>
<td>SCC</td>
<td>-0.48</td>
<td>0.33</td>
</tr>
<tr>
<td>Scan rate (ms)</td>
<td>SCC</td>
<td>0.39</td>
<td>0.24</td>
</tr>
<tr>
<td>Y-intercept (sec)</td>
<td>SCC</td>
<td>0.47</td>
<td>0.30</td>
</tr>
<tr>
<td>Faced Auditory Serial Addition Test</td>
<td>TLA</td>
<td>0.49</td>
<td>0.25</td>
</tr>
<tr>
<td>Percent correct—easy</td>
<td>SCC</td>
<td>0.47</td>
<td>0.30</td>
</tr>
<tr>
<td>Percent correct—hard</td>
<td>SCC</td>
<td>0.40</td>
<td>0.32</td>
</tr>
<tr>
<td>Visual Form Discrimination Test</td>
<td>TLA</td>
<td>-0.35</td>
<td>0.22</td>
</tr>
<tr>
<td>MRI</td>
<td></td>
<td></td>
<td>0.11*</td>
</tr>
</tbody>
</table>

MRI: Magnetic resonance imaging.
Table 3. Results of cluster analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intact (N = 34)</th>
<th>Impaired (N = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (males/females)</td>
<td>10/24</td>
<td>3/16</td>
</tr>
<tr>
<td>Age in years; mean (SD)</td>
<td>43.7 (7.7)</td>
<td>44.3 (10.0)</td>
</tr>
<tr>
<td>Education in years</td>
<td>13.9 (2.3)</td>
<td>13.0 (2.4)</td>
</tr>
<tr>
<td>Occupation (6-pt. scale)</td>
<td>4.3 (1.3)</td>
<td>3.8 (1.7)</td>
</tr>
<tr>
<td>Estimated premorbid verbal IQ†</td>
<td>107.8 (5.8)</td>
<td>104.7 (8.4)</td>
</tr>
<tr>
<td>Total verbal IQ</td>
<td>105.6 (11.6)</td>
<td>91.8 (11.6)</td>
</tr>
<tr>
<td>Mini-Mental State</td>
<td>29.5 (9.9)</td>
<td>27.6 (4.2)</td>
</tr>
<tr>
<td>Currently employed: number (percent)</td>
<td>15 (44%)</td>
<td>3 (16%)</td>
</tr>
<tr>
<td>Length of symptoms in years</td>
<td>12.0 (7.9)</td>
<td>12.6 (7.1)</td>
</tr>
<tr>
<td>Years since diagnosis</td>
<td>7.5 (7.1)</td>
<td>8.1 (5.8)</td>
</tr>
<tr>
<td>Kurtzke Expanded DSS</td>
<td>3.4 (3.2)</td>
<td>4.6 (1.9)</td>
</tr>
<tr>
<td>Diagnostic category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinically definite (no.)</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Laboratory definite</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Clinically probable</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Clinical course</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relapsing-remitting (no.)</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>Chronic-progressive</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Chronic-stable</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Benign</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>MRI variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TLA</td>
<td>12.2 (13.4)</td>
<td>38.6 (29.2)</td>
</tr>
<tr>
<td>VBR</td>
<td>0.037 (0.020)</td>
<td>0.057 (0.033)</td>
</tr>
<tr>
<td>SCC†</td>
<td>4.9 (1.0)</td>
<td>3.6 (1.3)</td>
</tr>
</tbody>
</table>

TLA Total lesion area.  
VBR Ventricular-brain ratio.  
SCC Size of corpus callosum.

* Estimated from demographic variables using regression formula derived from WAIS-R standardization sample.  
† Intact: N = 30; Impaired: N = 15. 
‡ p < 0.05.  
§ p < 0.01.  
¶ p < 0.001.

Magnetic Resonance Imaging (MRI) measurements. We obtained TLA and VBR measurements for all 53 patients and SCC measurements for 45 of 53 patients in which precise midline sagittal cuts were available. All but one patient had at least a single cerebral lesion. The following summarizes the mean, standard deviation, and range values for the three MRI variables: TLA, 21.7 (in cm²), 23.9, 0 to 95; VBR, 0.044, 0.027, 0.006 to 0.133; and SCC, 4.49 (in cm²), 1.28, 1.01 to 7.08. The three MRI variables correlated significantly with each other: r = 0.61 for TLA and VBR (p < 0.001), r = -0.46 for TLA and SCC (p < 0.01), and r = -0.48 for VBR and SCC (p < 0.001). Age correlated significantly with VBR (r = 0.42, p < 0.01), but not with TLA or SCC.

Stepwise regression analysis. Table 2 presents the results of stepwise multiple regression analyses for each of the cognitive variables. This table includes only those MRI variables making a significant (p < 0.05) contribution to the prediction of cognitive test performance. The partial correlation coefficients (labeled "Partial" in table 2) represent the magnitude of the relationship between the cognitive and MRI variables after the effects of age and education are statistically removed. The sign of the coefficient indicates whether the relationship was positive or negative. The partial correlations ranged from -0.31 (vocabulary subtest of the WAIS-R with TLA) to -0.54 (Raven Progressive Matrices and TLA).

The cumulative amount of shared variance between the dependent and independent variables was estimated by the squared multiple correlation coefficient ("R²" in table 2). Multiplying this value by 100 gives the percent of variance in each cognitive measure accounted for by the MRI variable(s), age, and education. The amount of shared variance ranged from 55% (a strong relationship) for the Raven Progressive Matrices to 16% (a weak relationship) for the Abbreviated Boston Naming Test.

The amount of shared variance accounted for by the specific addition of the MRI variable to the regression equation, excluding the effects of age and education, was estimated by the change in the squared multiple correlation coefficient ("Change R²" in table 2). These values ranged from 24% (p < 0.001) for the Mini-Mental State score to 6% (p < 0.05) for the vocabulary subtest.

At least one MRI variable significantly (p < 0.05) predicted 25 of 34 (74%) cognitive test variables. Of these 25 cognitive variables, TLA predicted 18 and SCC predicted eight; two MRI variables, SCC and TLA, predicted performance on the Booklet Category Test, an abstract/conceptual reasoning test. VBR did not independently predict any of the cognitive variables.

TLA was the best predictor of performance on measures of recent memory and abstract/conceptual reasoning while SCC was the best predictor of information processing speed (scan rate on the Sternberg test), sustained attention and rapid problem solving (hard form of the Paced Auditory Serial Addition Test), and mental arithmetic (arithmetic subtest of the WAIS-R). Various tests of verbal intelligence, linguistic processes, and visuospatial problem solving skills were predicted by both TLA and SCC (see table 2).

Cluster analysis. Table 3 presents the results of the two-group cluster solution. Nineteen patients (36%) performed below expectations on neuropsychological testing ("Impaired" group; mean cluster center = -0.691), while 34 patients (64%) performed at or slightly above expectations ("Intact" group; mean cluster center = +0.358). No significant group differences were observed on demographic variables and on estimated premorbid verbal IQ derived from demographic variables.

In contrast, we observed a significant group difference on current WAIS-R verbal IQ (t = 4.13, df = 51, p < 0.0001). There was also a small but statistically significant difference between the clusters on the Mini-Mental State (t = 2.55, df = 51, p < 0.02); mean values for both groups were in the nondemented range, however.14 While the two groups did not differ in duration of symptoms, disease course, or overall physical disability (Kurtzke EDSS), it is noteworthy that patients in the cognitively impaired group were less likely to be employed than patients in the cognitively intact group (16% versus 44%, respectively; chi-square = 4.36, df = 1, p < 0.04).

Also listed in table 3 are the means and standard deviations of the three MRI variables for the two clusters. The impaired group had significantly greater TLA (p < 0.001) and VBR (p < 0.01), and smaller SCC (p < 0.01), than the intact group. Figure 2 presents MRI values for individual subjects in each cluster. Of the three MRI variables, the TLA variable achieved the
greatest degree of cluster separation. Ten of 12 (83%) patients with TLA greater than 30 cm² were members of the cognitively impaired cluster; conversely, 32 of 41 (78%) patients with TLA less than 30 cm² were in the cognitively intact group.

**Discussion.** The results of this study demonstrate a strong relationship between the severity of cerebral pathology on MRI and cognitive dysfunction in MS patients. The robust MRI correlations in the present study contrast with the weak or nonexistent correlations obtained in previous studies that have relied on the neurologic examination as the indicator of cerebral involvement. This may be explained by the neurologic examination underestimating cognitive dysfunction in MS patients when compared with results derived from neuropsychological testing.

We observed the strongest clinicopathologic correlations on measures of recent memory and abstract/conceptual reasoning, skills that are most often impaired in MS patients. We also observed significant correlations between MRI variables and skills infrequently studied in MS patients: rapid and sustained problem solving, language, and visuospatial skills. These findings suggest that cerebral demyelination may be associated with a wider range of cognitive dysfunction than previously suspected.

The relationship between the degree of corpus callosum atrophy and performance on tasks requiring sustained attention and rapid problem solving raises the possibility that such performance depends on precisely timed interhemispheric communication that is disrupted by demyelinated callosal fiber tracts. This observation also suggests that specific cognitive processes may be disrupted by demyelinating processes involving relatively focal morphologic structures.

Ventricular size did not independently predict cognitive performance beyond what could be predicted by measures of lesion area and callosal atrophy. In a previous study, we demonstrated statistically significant, albeit weak, correlations between ventricular enlargement and cognitive performance in MS patients. Ventricular enlargement presumably results from "thin- ning" of the periventricular white matter as a consequence of demyelination. As such, ventricular enlargement is an indirect, and presumably late, marker of disease activity within the cerebrum.

Results of the cluster analysis suggest that if the total lesion load on MRI is excessive (arbitrarily defined as greater than 30 cm² in the present study), there is a high probability that an MS patient will have cognitive impairment. The practical significance of identifying cognitive dysfunction is highlighted by the observation that MS patients with cognitive impairment are less likely to be employed than patients without cognitive impairment. We observed this relationship despite the fact that the two clusters did not differ in severity of physical disability, duration of illness, or disease course.

We found no relationship between duration of illness and degree of MRI abnormalities; furthermore, this study, as well as others, found no relationship between duration of illness and severity of cognitive disturbance. These negative findings may result from limitations of the cross-sectional research design used in this and other studies. Longitudinal studies are therefore needed to examine the natural history of cog-
nitive dysfunction in MS, particularly in light of disease progression as visualized by MRI.

Acknowledgment

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References
