Corpus callosal atrophy following closed head injury: detection with magnetic resonance imaging

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To investigate evidence for diffuse white matter injury and hemispheric disconnection sequelae after severe closed head injury (CHI), this study evaluated the degree of posttraumatic atrophy of the corpus callosum. Corpus callosal atrophy was quantitatively determined using a digitizer to measure sagittal magnetic resonance images of 32 patients with moderate-to-severe CHI and those of 31 control subjects of similar age. In the CHI patients, measurements were significantly reduced for the areas of the anterior four-fifths, the posterior one-fifth, and the total corpus callosum. Moreover, the minimum width of the callosal body was reduced in the CHI patients as compared to that of control individuals. Indices of corpus callosal atrophy were significantly correlated with the chronicity of injury and the degree of lateral ventricular enlargement. There was no difference in callosal measurements between men and women. Magnetic resonance imaging provides an in vivo determination of corpus callosal atrophy which may reflect the severity of diffuse axonal injury and predict the type and severity of hemispheric disconnection effects.

Key Words • corpus callosum • head injury • magnetic resonance imaging

Neuropathological studies have shown that the corpus callosum is particularly vulnerable to the immediate mechanical effects of closed head injury (CHI) and is a frequent site of degenerative changes, such as retraction balls.1,4,10,17,18 Callosal hemorrhages, which were present in 16% of the CHI patients studied by Lindenberg, et al.,10 were typically located on the undersurface of the corpus callosum and often to one side of the midline.

Neurobehavioral case studies have demonstrated hemispheric disconnection effects of CHI, including alexia without agraphia and difficulty in using the left hand to perform gestures, write, and identify objects.7,8,11,14 Involvement of auditory callosal fibers was recently implicated in dichotic listening studies which disclosed left ear suppression in CHI patients with focal white matter lesions, particularly in the periventricular region.2,8

In vivo study of callosal lesions in survivors of severe CHI,1,9,7,15 we used MR imaging to determine the degree of corpus callosal atrophy. The feasibility of demonstrating degenerative changes in the corpus callosum is supported by recent reports of MR imaging to document corpus callosal atrophy in patients with multiple sclerosis.6,12,15,16

Clinical Material and Methods

Patient Population

Magnetic resonance images were obtained in a prospective series of 32 right-handed CHI patients (20 men and 12 women) recruited from the rehabilitation service of Del Oro Hospital in Houston. The patients had sustained moderate-to-severe CHI based on their lowest recorded post-resuscitation Glasgow Coma Scale (GCS) score.19 According to the criterion of a GCS score of 8 or less, 29 of the 32 patients had sustained a severe CHI (Table 1). There was no history of previous neuropsychiatric disorder, multiple sclerosis, or substance abuse in this series. The control subjects included 31 volunteers (18 men and 13 women) from Galveston County (Table 1). Preliminary analyses disclosed no significant group difference in education and there was a nonsig-
TABLE 1
Demographic and clinical features of 32 head-injured patients and 31 control subjects*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Head-Injured Patients</th>
<th>Control Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean age (yrs)</td>
<td>27.3 ± 2.9</td>
<td>32.3 ± 7.9</td>
</tr>
<tr>
<td>sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>20 (62.5%)</td>
<td>18 (58.1%)</td>
</tr>
<tr>
<td>female</td>
<td>12 (37.5%)</td>
<td>13 (41.9%)</td>
</tr>
<tr>
<td>GCS score</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3–5</td>
<td>13 (40.6%)</td>
<td>—</td>
</tr>
<tr>
<td>6–8</td>
<td>16 (50.0%)</td>
<td>—</td>
</tr>
<tr>
<td>9–12</td>
<td>3 (9.4%)</td>
<td>—</td>
</tr>
<tr>
<td>mean duration of impaired consciousness (days)</td>
<td>17.9 ± 20.4</td>
<td>—</td>
</tr>
<tr>
<td>mean injury-MR imaging interval (days)</td>
<td>115.9 ± 185.9</td>
<td>—</td>
</tr>
</tbody>
</table>

* Mean values are given ± standard deviation. GCS = Glasgow Coma Scale; MR = magnetic resonance. — = not applicable.

significant trend for the control subjects to be older (F(1,61) = 3.40, p < 0.07).

Magnetic Resonance Imaging

Magnetic resonance imaging was performed on a Dianonics imaging system using a 0.35-tesla magnetic field strength with a proton-resonant frequency of 15 MHz. Images were obtained with 7-mm slices and a 3 mm-slice interval in the transaxial, coronal, and sagittal planes using two spin-echo sequences: a repetition time (TR) of 500 msec and an echo delay time (TE) of 32 msec, and a TR of 2000 msec and a TE of 60 and 120 msec.

Measurement of the Corpus Callosum

Measurements of the corpus callosum were made using the cursor of a Jandel Scientific digitizer* and Sigma Scan software which stored the data on an IBM XT computer. The digitizer was calibrated to the unit of measurement and size scale of the MR image. Callosal measurements, which were derived from previous MR imaging and necropsy studies, included: 1) the anteroposterior (AP) distance from the most posterior part of the splenium to the most inferior part of the rostrum, tracing along the central portion of the corpus callosum; 2) the maximum splenial width (the length of the longest line through the splenium that could be drawn perpendicular to a segment of its dorsal surface); 3) the minimum width of the body (the smallest width that could be measured over the entire body of the corpus callosum); 4) the area of the anterior four-fifths of the corpus callosum; and 5) the area of the posterior one-fifth (the splenium, approximately). The cross-sectional area of the cerebrum was approximated on the midsagittal MR image by the same method, tracing the perimeter on the digitizer. For each individual image, these measures were recorded three times by the same investigator to increase their reliability, and the mean of each measure was then calculated. The ventricle-brain ratio (VBR) was computed by digitizer for the transaxial MR slice (which was available for 26 patients) showing the bodies of the lateral ventricles. The VBR was obtained by dividing the area of the lateral ventricles by the total intracranial area.

Results

Head-Injury Versus Control Findings

Figure 1 depicts box plots for the total corpus callosal area in the head-injured and control groups. The control group values are similar to previously reported data for the corpus callosal area of normal subjects studied by MR imaging and clearly larger than the corpus callosal area of the head-injured patients. Table 2 summarizes the analyses of variance (with Bonferroni correction for multiple comparisons) which disclosed a highly significant difference in total corpus callosal area between the groups. Consistent with this finding was the fact that the anterior four-fifths and posterior one-fifth of the corpus callosum were smaller in the CHI group than in the control subjects (Table 2). Although the minimum width of the corpus callosal body was reduced in the head-injured patients, there was no significant difference in the maximum splenial width nor was there any group difference confirmed for the AP distance of the corpus callosum. To analyze the presence of gender differences in the corpus callosum measurements, the results obtained from 38 men were compared with the data collected from 25 women, irrespective of whether they were patients or control subjects. This analysis disclosed a directional trend of a larger total corpus

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* Digitizer manufactured by Jandel Scientific, Corte Madera, California.
Corpus callosal atrophy following closed head injury

### TABLE 2

<table>
<thead>
<tr>
<th>Factor</th>
<th>Head-Injured Group</th>
<th>Control Group</th>
<th>F Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>no. of cases</td>
<td>32</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>mean total CC area (sq mm)</td>
<td>534 ± 137</td>
<td>666 ± 97</td>
<td>19.39†</td>
</tr>
<tr>
<td>mean anterior CC area (sq mm)</td>
<td>373 ± 100</td>
<td>474 ± 71</td>
<td>21.51†</td>
</tr>
<tr>
<td>mean posterior CC area (sq mm)</td>
<td>159 ± 47</td>
<td>187 ± 36</td>
<td>6.68†</td>
</tr>
<tr>
<td>mean minimum width of body (cm)</td>
<td>0.29 ± 0.13</td>
<td>0.37 ± 0.08</td>
<td>6.71†</td>
</tr>
<tr>
<td>mean maximum splenial width (cm)</td>
<td>1.08 ± 0.29</td>
<td>1.17 ± 0.14</td>
<td>2.17</td>
</tr>
<tr>
<td>mean AP distance (cm)</td>
<td>9.80 ± 1.05</td>
<td>9.28 ± 0.75</td>
<td>5.23</td>
</tr>
</tbody>
</table>

* Bonferroni correction for multiple comparisons changed the probability value to p < 0.006 for significance. Mean values are given ± standard deviation. CC = corpus callosum; AP = anteroposterior.
† p < 0.001.
‡ p < 0.005.

Callosal area in men than women (mean ± standard deviation: 621 ± 148 sq mm vs. 566 ± 109 sq mm; F(1,61) = 2.51, p < 0.12). Similar analysis of other corpus callosum measurements also revealed slightly, but not significantly, larger values in men than in women.

**Severity and Chronicity of Injury**

The relationship between indices of severity of acute injury (that is, lowest post-resuscitation GCS score and duration of impaired consciousness) and corpus callosal atrophy was evaluated by the Pearson product moment correlation coefficient which yielded nonsignificant findings. For example, the correlation between the lowest post-resuscitation GCS score and total corpus callosal area was 0.11, p < 0.54, while the corresponding correlation was −0.17, p < 0.36, for duration of impaired consciousness. Age in this group of predominately young adults was also unrelated to the corpus callosum measurements as reflected by the total corpus callosal area, r = −0.08, p < 0.65. To the extent that corpus callosal atrophy reflects widespread cerebral white matter degeneration, it should be related to enlargement of the lateral ventricles, which is also a common neuropathological feature after severe CHI.11,18 As shown in Fig. 2, the total corpus callosal area was reduced as a function of increased VBR, r = −0.55, p < 0.004. Significant negative correlations with the VBR were also obtained for the anterior four-fifths of the corpus callosum (r = −0.55, p < 0.004), the posterior one-fifth (r = −0.46, p < 0.02), and the maximum width of the splenium (r = −0.56, p < 0.004), whereas the correlation coefficients fell short of significance for the minimum width of the corpus callosal body (r = −0.33, p < 0.10).

The chronicity of injury was related to the corpus callosal size (Fig. 3). As the interval between the injury and MR imaging increased, the corpus callosal area was diminished for the total structure (r = −0.68, p < 0.0001), the anterior four-fifths (r = −0.57, p < 0.0007), and the posterior one-fifth (r = −0.76, p < 0.0001). Moreover, longer postinjury intervals were related to the minimum width of the corpus callosal body (r = −0.70, p < 0.0001) and the maximum splenial width (r = −0.70, p < 0.0001).

**Discussion**

Our finding of corpus callosal atrophy in young adult survivors of severe CHI is consistent with neuropathological evidence for diffuse axonal injury in this population.11,17,18 Moreover, gross neuropathological examination has revealed macroscopic corpus callosum lesions in about 16% of fatal CHI cases.10 In this study, the decreased corpus callosal area shown by MR imaging and its relationship to lateral ventricular enlargement provide corroborating support for cerebral white matter involvement. Although the present study was limited to a single MR image for each patient, the finding that chronicity of injury was directly related to degree of corpus callosal atrophy is consistent with an interpretation of gradual degenerative changes. This view is in accord with a previous CT study showing that lateral ventricular enlargement was related to severity of CHI, provided that a CT scan was performed at least 1 month after injury.11

The demonstration of corpus callosal atrophy by midsagittal MR imaging in survivors of severe head injury is similar to recent reports utilizing this technol-
ology to visualize loss of corpus callosal area in patients with multiple sclerosis.12,15,16 Consistent with evidence for cerebral hemispheric disconnection effects in patients with multiple sclerosis, survivors of severe CHI have exhibited suppression of left-ear function (implying disruption of auditory callosal fibers) on a dichotic listening task and ideomotor apraxia confined to the left hand which suggested dysfunction of the anterior corpus callosum.27,8 Consequently, behavioral sequelae and structural brain imaging implicate corpus callosal injury and degeneration as common effects of severe CHI.

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References

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