MRI Assessment of Recurrent Carpal Tunnel Syndrome After Open Surgical Release of the Median Nerve

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OBJECTIVE. The purpose of this study was to retrospectively determine the accuracy of MRI in identification of the morphologic features of median nerve dysfunction after surgical release of the median nerve for carpal tunnel syndrome.

MATERIALS AND METHODS. Two blinded readers independently evaluated axial 1.5-T MR images for retinacular regrowth, morphologic characteristics of the median nerve, and presence of mass effect, fibrosis, and carpal tunnel decompression. All 47 patients (11 men, 36 women; mean age, 55 years; range, 27–81 years) had undergone open surgical release of the median nerve for carpal tunnel syndrome. Thirty-five patients did not have electromyographic evidence of recurrent carpal tunnel syndrome and were the control group.

RESULTS. A statistically significant difference between the recurrent carpal tunnel syndrome and control groups was found for fibrosis (p = 0.009), nerve enhancement (p = 0.04), and median nerve width (p = 0.008) and ratio (p = 0.01) at the pisiform level.

CONCLUSION. MRI may be used in association with electromyography for accurate postoperative evaluation of the carpal tunnel.

Keywords: carpal tunnel, electromyography, MRI, wrist

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patients had undergone MRI because of clinical and electrophysiologic suspicion of ulnar nerve entrapment in Guyon’s tunnel (n = 1), clinical suspicion of tenosynovitis (n = 3), and discrepancy between normal EMG results and clinical examination findings (loss of grip strength, scar discomfort) (n = 8). To eliminate false-positive results, we excluded patients who had undergone EMG or MRI within 6 months after surgery [9].

**Imaging**

MRI was performed with a 1.5-T MRI unit (Signa Excite, GE Healthcare) with a dedicated quadrature wrist coil. All patients were placed in the MR imager in the prone position with the elbow extended overhead and the pronted hand in the center of the coil. The pulse sequences were an axial spin-echo T1-weighted sequence (TR/TE, 400/14; section thickness, 4 mm; field of view, 6 cm; acquisition time, 4 minutes 21 seconds; number of signals acquired, 4; matrix size, 256 × 160; gap, 0.4 mm), an axial fast spin-echo STIR sequence (2,320/14; inversion time, 150 milliseconds; echo-train length, 9; section thickness, 4 mm; field of view, 6 cm; acquisition time, 3 minutes 36 seconds; number of signals acquired, 4; matrix size, 256 × 160; gap, 0.4 mm), and an axial fast spin-echo T1-weighted sequence with fat suppression after IV injection of 0.1 mmol/kg of gadoterate dimeglumine (Dotarem, Guerbet) (600/15; echo-train length, 3; section thickness, 4 mm; field of view, 6 cm; acquisition time, 4 minutes 24 seconds; number of signals acquired, 4; matrix, 256 × 160; gap, 0.4 mm). The mean time between surgery and MRI was 28 months (range, 6–193 months), and the mean time between MRI and electrophysiologic testing was 3 months (range, 0–24 months).

**Electrophysiologic Tests**

Electrophysiologic studies included needle EMG and routine motor and sensory nerve conduction studies. All studies were performed by the same electrophysiologist before MRI. The needle electrode was connected to an EMG system (Viking, Nicolet). The 12 patients in the control group had normal EMG and nerve conduction studies. All studies were performed by the same electrophysiologist, and the temperature of the room and the skin was monitored. All electrophysiologic studies were performed at least 6 months after surgery.

**Image Analysis**

Two musculoskeletal radiologists (4 and 15 years of experience) blinded to electrophysiologic results reviewed the images independently and retrospectively at random using a PACS workstation (Carestream, Kodak). Discrepancies were resolved by consensus.

According to previous MRI descriptions of the preoperative findings of CTS and known operative complications [3, 6, 15–19], the following findings were reviewed. First, regrowth of the flexor retinaculum was defined as a continuous, linear area of low signal intensity superficial to the nerve and thickened in the area deep in relation to the subcubanous scar (Figs. 1 and 2). Regrowth included incomplete resection of the retinaculum, the presence of scar tissue that mimicked retinaculum, and true regrowth of the retinaculum.

Second, median nerve enhancement included the presence of high signal intensity on fast STIR images in comparison with thenar muscle signal intensity (Fig. 3). Median nerve measurements were obtained with an electronic caliper at the proximal (pisiform) and distal (hook of the hamate) levels. The cross-sectional area and ratio of width to height (flattening ratio) were measured in millimeters at the two levels (Figs. 4 and 5). Nerve enhancement after IV gadolinium injection was considered high if stronger than thenar muscle enhancement (Fig. 6B). The shortest distance between the skin and the volar margin of the median nerve was measured on axial images with an electronic caliper at the distal level (Fig. 7).

Third, analysis of mass effect in the carpal tunnel included the presence of bursitis (focal fluid collection > 1 cm in the carpal tunnel), a mass, accessory muscles or distal progression of the muscle belly, bone fracture or fragment, or flexor tendon tenosynovitis (excessive fluid within the tendon sheath with gadolinium enhancement). Fourth, the presence of fibrosis was defined by an extensive area of low signal intensity with an ill-defined nerve margin on T1-weighted images (Figs. 6 and 8). Fifth, to assess the quality of carpal tunnel decompression, we determined the position of the median nerve and leading flexor tendon. This position was compared with the line joining the hook of the hamate to the ridge of the trapezium, according to previous findings [20]. Carpal release was considered successful if the tendon or nerve was located above the line and if no tendon or nerve was entirely located under this line (Fig. 9). In the other cases, carpal tunnel release was considered insufficient (Fig. 10).

**Statistical Analysis**

Quantitative variables were reported with the mean and range (minimum to maximum). Categoric variables were reported as count (percentage). Statistical analysis was performed with a nonparametric test (Mann-Whitney) for quantitative variables and Fisher’s test for categoric variables. All tests were two sided. A value of p < 0.05 was considered significant. Interrater agreement was calculated for MRI findings (kappa). All analyses were performed with statistical software (MedCalc version 8.0, MedCalc Software).

**Results**

The sensitivity, specificity, and positive and negative predictive values of MRI signs are summarized in Table 1. The comparisons of MRI signs for both groups are summarized in Tables 2 and 3. The findings in the recurrent CTS and control groups differed statistically only for presence of fibrosis, nerve enhancement, volar migration of nerve and tendon (carpal decompression), and median nerve width and ratio at the pisiform level. For the following items, there were no

<table>
<thead>
<tr>
<th>Sign</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retinacular regrowth</td>
<td>43</td>
<td>50</td>
<td>71</td>
<td>23</td>
</tr>
<tr>
<td>Carpal tunnel mass effect</td>
<td>26</td>
<td>58</td>
<td>64</td>
<td>21</td>
</tr>
<tr>
<td>Fibrosis</td>
<td>60</td>
<td>83</td>
<td>92</td>
<td>42</td>
</tr>
<tr>
<td>Median nerve enhancement</td>
<td>40</td>
<td>92</td>
<td>94</td>
<td>34</td>
</tr>
<tr>
<td>Median nerve high signal intensity</td>
<td>74</td>
<td>33</td>
<td>77</td>
<td>31</td>
</tr>
<tr>
<td>Carpal tunnel decompression</td>
<td>20</td>
<td>50</td>
<td>54</td>
<td>18</td>
</tr>
<tr>
<td>Good</td>
<td>80</td>
<td>50</td>
<td>82</td>
<td>46</td>
</tr>
</tbody>
</table>

TABLE 1: Sensitivity, Specificity, and Predictive Values of MRI Signs in Diagnosis of Recurrent Carpal Tunnel Syndrome
statistically significant differences between groups: regrowth of the flexor retinaculum; cross-section area of the median nerve, nerve fast STIR signal intensity, shortest distance between skin and volar margin of the nerve, and nerve measurement at the hamate level; and mass effect in the carpal tunnel. There was no statistical difference between groups in time between surgery and MRI or between surgery and EMG ($p > 0.05$). According to criteria commonly used for interpretation of values [21], interobserver agreement for all observed features was nearly perfect, substantial, or moderate, except for direct visualization of retinacular regrowth, which had fair agreement (Table 2).
Discussion

Our study showed that MRI is useful for detecting signs of nerve dysfunction: gadolinium-enhanced areas, fibrosis, abnormal nerve width and ratio, and insufficient carpal release. It also showed that MRI depicts signs of nerve dysfunction but cannot replace electrophysiologic tests. MRI can be performed in association with EMG for patients with pain after carpal tunnel release.

Complications of carpal tunnel release occur in 3–19% of cases in large series and necessitates reexploration of the area for various reasons in as many as 12% of cases [22]. In a previous meta-analysis [23], endoscopic carpal tunnel release was comparable with open release in rate of irreversible nerve damage. Consequently, there likely was no bias in our study sample, all of the patients having undergone open surgical release. The rate of recurrence of CTS ranges from 1% to 25% [7]. The common causes of recurrent CTS after surgery are incomplete resection or regrowth of the flexor retinaculum, fibrous proliferation, flexor tenosynovitis, and extrinsic median nerve compression (accessory muscle belly, cyst) [3–7]. We did not analyze the failure rate of carpal tunnel surgery because only patients who underwent postoperative EMG and MRI were included.

Physical examination of patients who have undergone carpal tunnel surgery is especially difficult because of subjective pain and scar discomfort, which are frequent after CTS surgery [8] and must be differentiated from actual persistent median nerve injury. We chose our patients only on the basis of objective results of electrophysiologic tests, although EMG results sometimes are abnormal for several months. In our study, however, the mean time between surgery and EMG was more than 2 years, probably reducing the number of false-positive cases.

To the best of our knowledge, this report is the first to describe MRI evidence of postoperative changes after systematic IV gadolinium injection with a control group. In one study [24], investigators compared postoperative MRI features in patients with recurrent CTS with those in controls but without gadolinium injection. Another set of authors [25] used gadolinium-enhanced MRI to evaluate recurrent CTS but in only three patients.

Direct visualization of retinacular regrowth had only fair agreement and cannot be used to assess carpal tunnel decompression. The other MRI features described had acceptable interobserver agreement and therefore may be used to assess decompression.

In our study, nerve enhancement was statistically correlated with recurrent CTS. The cause of this enhancement remains unclear. The nerve enhancement we observed might have been the result of persistent nerve edema [26, 27] or partial nerve injury, as usually is found with posttraumatic neuroma [28].
Median nerve signal intensity has been analyzed previously in patients who have undergone surgery, and reduced median nerve T2-weighted signal intensity has been found in patients with good clinical outcome [15, 17, 18, 29]. Our recurrent CTS group had more median nerves with increased T2-weighted signal intensity than did the control group, as was found previously [24]. This difference, however, was not significant, and the criteria for T2-weighted signal intensity of the median nerve could not be used to differentiate pathologic and healthy nerves after surgical release.

The cross-sectional area of the median nerve at the pisiform level has been described [10, 13] as the most accurate criterion in the preoperative diagnosis of CTS. We found nerve height and cross-sectional area at the pisiform and hamate levels to be not significantly different between the recurrent CTS and control groups. These results suggest that these various measurements have limited clinical utility in the evaluation of postoperative CTS.

The median nerve width and flattening ratio at the pisiform level was higher in the recurrent CTS than in the control group, and the difference was statistically significant. This difference has been previously reported [24] and may be an indirect sign of persistent nerve compression.

Because interobserver agreement was only fair for direct visualization of the retinaculum
MRI of Carpal Tunnel Syndrome

TABLE 2: Prevalence of MRI Signs in Wrists With Recurrent Carpal Tunnel Syndrome and Controls

<table>
<thead>
<tr>
<th>Sign</th>
<th>Recurrent Carpal Tunnel Syndrome (n = 35)</th>
<th>Control (n = 12)</th>
<th>p*</th>
<th>Interobserver Agreement (%C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retinacular regrowth</td>
<td>15 (43)</td>
<td>6 (50)</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Carpal tunnel mass effect</td>
<td>9 (26)</td>
<td>5 (42)</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Flexor tendons tenosynovitis</td>
<td>3 (8.6)</td>
<td>4 (33.3)</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Synovial cyst</td>
<td>3 (8.6)</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Accessory muscles</td>
<td>3 (8.6)</td>
<td>1 (8.3)</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Fibrosis</td>
<td>21 (60)</td>
<td>6 (50)</td>
<td>0.009</td>
<td>0.67</td>
</tr>
<tr>
<td>Deep</td>
<td>10 (28)</td>
<td>2 (16.6)</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Superficial</td>
<td>11 (31)</td>
<td>2 (16.6)</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Median nerve enhancement</td>
<td>14 (40)</td>
<td>1 (8.3)</td>
<td>0.04</td>
<td>0.63</td>
</tr>
<tr>
<td>Median nerve high signal intensity</td>
<td>26 (74)</td>
<td>8 (66.7)</td>
<td>0.19</td>
<td>0.46</td>
</tr>
<tr>
<td>Carpel tunnel decompression</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>7 (20)</td>
<td>6 (50)</td>
<td>0.04</td>
<td>1</td>
</tr>
<tr>
<td>Insufficient</td>
<td>28 (80)</td>
<td>6 (50)</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

Note—Data are numbers with percentage in parentheses.

*Fisher’s test.

Although abnormal nerve and tendon migration is related to median nerve dysfunction, the sensitivity and specificity (50%) of this MRI finding are too low and cannot be used in daily practice.

We found nine cases of mass effect, including abnormal muscle belly, synovial cysts, and tenosynovitis, as described previously [6, 15, 16, 19, 22, 30]. Abnormal muscle belly and tenosynovitis were rare but were seen in both groups. Synovial cyst was seen only in the recurrent CTS group and is a well-known cause of compression. The low rate of mass effect may explain the absence of a significant difference of this feature between the recurrent CTS and control groups.

Presence of median nerve fibrosis was a relevant sign of recurrent CTS. We found a 60% rate of fibrosis in the recurrent CTS group versus 17% in the control group. This finding is consistent with findings after surgical revision [22]. The detection of fibrosis is helpful for planning surgical reintervention, and interposition of a composite graft around the median nerve has been proposed [31]. Two patterns of fibrosis were observed in previous surgical studies [22, 32]: superficial extensive fibrosis between the palmaris longus tendon and the volar aspect of the nerve and deep fibrosis on the dorsal aspect of the median nerve with mass effect on the adjacent flexor tendon. In our study, deep fibrosis was seen only in the recurrent CTS group (28%) and was more frequent in our study than in previous surgical observations [22, 32]. These results suggest that deep fibrosis may be more frequent than previously expected [22, 32]. Superficial fibrosis was found more often in the recurrent CTS group (46% versus 17% in control group). This finding is consistent with the results of a surgical study [32] showing a 34% rate of superficial scar tethering.

The mean distance between the skin and the volar aspect of the median nerve was the same in our groups. Wu et al. [24] described a more palmar location of the median nerve in their recurrent CTS group but without a significant difference from controls.

Fibrosis can be detected and median nerve measurements made without gadolinium injection. In our experience, however, in difficult cases, injection of gadolinium was helpful for detecting fibrosis and measuring the median nerve in the presence of fibrosis. Moreover, nerve enhancement was statistically correlated with EMG dysfunction. Thus we believe that use of gadolinium injection leads to more accurate diagnosis, especially in difficult cases, and helps surgeons in the planning of reintervention.

Our study had several limitations. The first was the retrospective design and the small number of patients with full electrophysiologic recovery after surgical treatment (control group). Further prospective studies with a larger number of patients are needed to confirm our results. Second, our patients
were referred to a tertiary care center, which does not allow extension of our results to primary care. Third, the criteria for MRI referral of patients with previous surgery for CTS at our institution were determined by our surgeon, which constitutes inclusion bias in this retrospective study. The fourth limitation was lack of surgical confirmation of the MRI findings.

We conclude that MRI with gadolinium enhancement can depict signs of median nerve dysfunction after surgical release of the nerve and show nerve enlargement at the pisiform level. Moreover, MRI can be used to detect the presence of fibrosis and may be helpful in surgical planning. Thus MRI in association with EMG can be proposed for accurate post-surgical planning. Thus MRI in association with EMG can be proposed for accurate post-surgical planning. Thus MRI in association with EMG can be proposed for accurate post-surgical planning. Thus MRI in association with EMG can be proposed for accurate post-surgical planning. Thus MRI in association with EMG can be proposed for accurate post-surgical planning.

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