

Evaluation of thenar muscles by MRI in carpal tunnel syndrome

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Abstract. In the present study, the thenar muscles were evaluated using magnetic resonance imaging (MRI), in addition, the correlations between thenar muscle changes, clinical findings and electrodiagnostic results from patients with carpal tunnel syndrome were investigated. The subjects were 13 patients (17 wrists) who were clinically diagnosed with carpal tunnel syndrome. In all patients, a medical history was obtained and physical examination was performed, in addition to assessment using the Kapandji scoring system, visual analogue scale (VAS), quick-disabilities of the arm, shoulder and hand (Q-DASH) score, electrodiagnostic results of the median nerve, and MRI of the thenar muscles. Thenar muscle volume was not significantly correlated with clinical data or the electrodiagnostic results. The thenar muscle major axis was significantly correlated with grasp power ($P < 0.05$) and the Kapandji score ($P < 0.05$), while the thenar muscle minor axis was significantly correlated with abductor pollicis brevis distal motor latency (APB DML) ($P < 0.01$). In addition, the thenar muscle minor axis/thenar muscle major axis ratio was significantly correlated with APB DML and Kanatani's stage. Notably, thenar muscle thinness was significantly correlated with the severity of electrodiagnostic changes, while the grasp power and Kapandji score were correlated with thenar muscle thickness. Furthermore, it was demonstrated that thenar muscle thinness was significantly correlated with the severity of electrodiagnostic changes; in addition, there was a significant correlation between the thenar muscle major axis and the grasp power or Kapandji score. Taken together, these results revealed that thenar muscle atrophy did not affect patient-based assessments, including VAS and Q-DASH, but reflected electrodiagnostic results, particularly DML and

severity. The results of the present study suggest that thenar muscle atrophy can be used to estimate the severity of carpal tunnel syndrome.

Introduction

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy of the median nerve (1), but evaluating the severity of CTS (especially thenar muscle dysfunction) is associated with some uncertainty (2). The thenar muscles play a very important role in efficient hand function. In clinical practice, evaluation of thenar muscle abnormalities in CTS relies on the history, physical examination, and electrodiagnostic studies including electromyography and nerve conduction studies (3,4). However, all of these clinical and diagnostic tests are sometimes insufficient to identify thenar muscle dysfunction in CTS. Use of magnetic resonance imaging (MRI) to assess the thenar muscles of hand in CTS has been reported (5,6). Recent studies have shown the potential of MRI for depicting small anatomical structures of the hand (7) and it is also useful in evaluating the carpal tunnel (8-10). Therefore, MRI can be an important modality for detection and characterization of hand muscle status, especially changes of the thenar muscles in CTS (11).

Previous studies of CTS and rotator cuff disorders have shown that muscle atrophy and decreased muscle volume on MRI may indicate irreversible damage (9,12,13), but there have been no investigations of the correlations between muscle morphology, clinical findings, and electrodiagnostic studies. Information regarding the correlations of thenar muscle morphology on MRI with clinical findings and the results of electrodiagnostic studies may be helpful for assessment of thumb function in CTS patients. Accordingly, we evaluated thenar muscle morphology by MRI and investigated the correlations between thenar muscle morphology, clinical findings, and electrodiagnostic data in patients with CTS.

Materials and methods

Patients. This study was approved by the medical research ethics committee of our university and informed consent was obtained from all patients.

This was a cross-sectional study and data were accumulated from 13 patients (17 wrists) who were clinically

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diagnosed with CTS between January 2015 and May 2016 at our university hospital. Clinical characteristics of the patients were assessed, including the age, sex, affected side, body mass index, and medical illnesses. All patients were evaluated by one of four hand surgeons at our hospital taking a medical history and performing physical examination, including assessment of the Tinel-like sign, Phalen test, presence/absence of thenar muscle atrophy, grip strength (grasp power), Kapandji score, visual analog scale (VAS), and Quick Disabilities of the Arm, Shoulder and Hand (Q-DASH) score. Then electrodiagnostic studies of the median nerve and MRI of the thenar muscles were performed.

Patients with systemic peripheral neuropathy such as diabetic polyneuropathy, neuropathies other than CTS, brachial plexus palsy, cervical radiculopathy, a history of wrist surgery, and patients with contraindications to MRI (e.g., metallic implants or claustrophobia) were excluded.

Magnetic resonance imaging techniques and evaluation. Subjects were scanned on a 3 tesla MRI scanner (MAGNETOM Skyra 3T; Siemens, Tokyo, Japan) with a 16-channel wrist coil from the wrist joint to the metacarpophalangeal (MP) joint. Scanning time was approximately 4.5 min. MRI parameters were as follows: Echo time/repetition time (TE/TR), 5.67/15 msec; field of view, 150 mm; and slice thickness, 0.6 mm. First, images were obtained by the three-dimensional double echo steady state (3D-DESS) method. Second, volume rendering of whole images was performed using a 3D Workstation (Ziostation 2; Ziosoft, Inc., Tokyo, Japan) (Fig. 1A). The thenar muscles were extracted from the original images by drawing an outline (Fig. 1B), and then a 3D thenar muscle image was composed by volume rendering of the extracted images using the 3D Workstation. The thenar muscle volume, major axis, and minor axis were calculated on the workstation (Fig. 1C and D).

Electrodiagnostic studies. All patients underwent electrodiagnostic studies to assess the distal motor latency (DML) of the abductor pollicis brevis (APB) muscle and the sensory conduction velocity (SCV) of the median nerve across the carpal tunnel. DML was measured after stimulating the wrist 7 cm proximal to the APB muscle. Antidromic SCV was measured at the wrist by stimulation of the index finger (a distance of 14-15 cm). Electromyography (EMG) of the thenar muscles was performed in all of the affected hands and then the patients were classified according to severity by the Kanatani grading scale (14) using the following criteria: Stage 1, normal distal motor latency (DML) and normal sensory conduction velocity (SCV); stage 2, DML >4.5 msec and normal SCV; stage 3, DML >4.5 msec and SCV <40.0 m/sec; stage 4, DML >4.5 msec and non-measurable SCV; and stage 5, non-measurable DML and non-measurable SCV.

Statistical data analysis. Demographic variables are presented as the mean \pm standard deviation. Correlation analysis was performed using a Pearson's correlation coefficient with Prism 4 software (GraphPad Software, San Diego, CA, USA). $P < 0.05$ was considered to indicate a statistically significant difference.

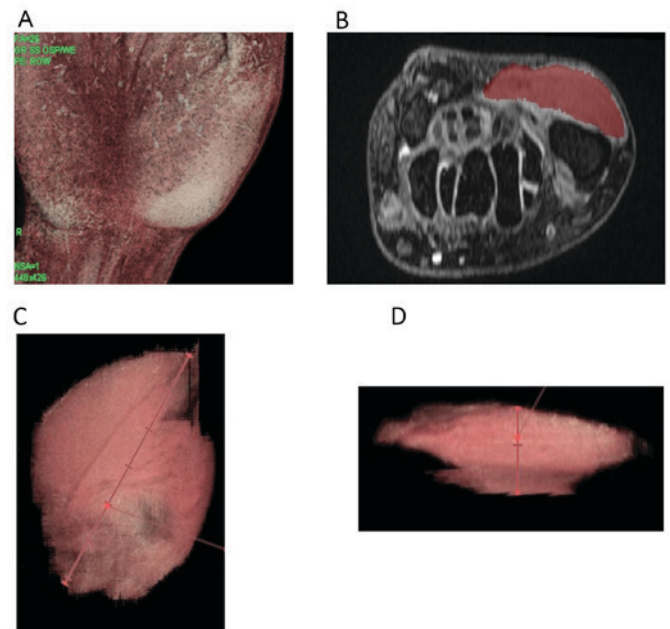


Figure 1. Evaluation of thenar muscle morphology using three tesla MRI. Subjects were scanned on a 3 tesla MRI scanner (MAGNETOM Skyra 3T; Siemens, Tokyo, Japan) with a 16-channel hand wrist coil. First, MRI was performed by the three-dimensional double echo steady state (3D-DESS) method. (A) Second, volume rendering of whole images was performed using a 3D Workstation (Ziostation 2; Ziosoft, Inc., Tokyo, Japan). (B) The thenar muscles were extracted from original whole images by drawing outlines. Then 3D thenar muscle images were composed by volume rendering of extracted images using the 3D Workstation. The thenar muscle volume, (C) thenar muscle major axis, and (D) thenar muscle minor axis were calculated on the 3D Workstation.

Results

First, we investigated the clinical profile of the patients with CTS. The study population of 13 patients (17 wrists) included 2 males and 11 females. All of the patients had clinical evidence of CTS (Tinel-like sign positive/negative in 15/2, Phalen test positive/negative in 11/6, thenar muscle atrophy present/absent in 15/2). The mean age was 68.8 ± 8.7 years (range, 52-80) and the mean body mass index (BMI) was 23.1 ± 3.3 kg/m². All patients were right-handed, with 8 of the patients affected on the right side and 9 affected on the left side. The mean grasp power, Kapandji score, VAS, and Q-DASH score were 20.6 ± 7.4 , 9.5 ± 0.5 , 4.6 ± 2.3 and 37.8 ± 20.5 kg, respectively (Table I).

Next, we performed MRI for evaluation of the thenar muscle volume, major axis, and minor axis and electrodiagnostic studies to investigate the DML of APB (APB-DML) and the SCV of the median nerve across the carpal tunnel. MRI demonstrated that the thenar muscles volume, thenar muscle major axis, and thenar muscle minor axis were 8.3 ± 3.9 cm³, 50.8 ± 4.5 , and 10.0 ± 3.0 mm, respectively. Electrodiagnostic studies demonstrated that the APB-DML was 7.9 ± 1.4 msec and SCV was 33.6 ± 11.1 m/sec (Table I). When the results of the electrodiagnostic studies were classified according to the Kanatani grading scale, the outcome was stage III, IV, and V in 6 (35%), 5 (30%) and 6 cases (35%), respectively.

Furthermore, we analyzed correlations between MRI parameters of the thenar muscles (thenar muscle volume, thenar muscle major axis, and thenar muscle minor axis) and

Table I. Clinical, MRI, and electrodiagnostic data of the patients with carpal tunnel syndrome.

Case no.	MRI parameters of the thenar muscles							Electrodiagnostic variables			
	BMI (kg/m ²)	Grasp (kg)	Kapandji (0-10)	VAS (0-10)	Q-DASH (0-100)	Volume (cm ³)	Major axis (mm)	Minor axis (mm)	APB-DML (msec)	SCV (m/sec)	Kanatani's stage (I-V)
1	25.8	29	10	3	15.91	11.7	49.5	6.1	-	38.1	V
2	21.5	22	9	6	84.09	10.3	53.5	13.0	8.8	-	IV
3	22.1	20	10	3	31.82	8.0	54.4	9.7	-	-	V
4	22.1	25	10	3	31.82	9.4	53.6	11.9	5.5	34.4	IV
5	18.7	15	9	7	59.09	8.2	48.0	11.8	10.0	-	IV
6	18.7	15	10	7	59.09	10.0	54.8	10.9	9.1	23.8	III
7	28.1	14	9	1	20.45	8.7	51.3	13.0	5.9	29.2	III
8	22.1	28	10	4	40.91	8.5	54.6	10.2	8.5	24.0	III
9	27.4	10	9	7	38.64	6.9	44.3	9.7	8.8	49.3	III
10	27.4	16	9	7	38.64	7.6	46.3	9.2	7.0	49.1	III
11	28.1	14	9	3	27.27	2.8	44.1	6.1	-	-	V
12	21.5	29	9	0	4.55	8.4	53.2	9.7	7.7	21.2	III
13	19.1	18	10	7	59.09	6.5	50.9	8.3	-	-	V
14	22.3	29	10	5	29.54	3.9	49.4	6.2	-	-	V
15	22.3	27	10	5	27.27	3.9	46.8	7.8	-	-	V
16	25.5	31	10	7	15.91	20.2	61.5	17.7	9.0	-	IV
17	20.5	8	9	4	59.09	7.0	47.9	9.1	7.2	-	IV

BMI, body mass index; VAS, Visual analog scale; Q-DASH, Quick Disabilities of the Arm, Shoulder and Hand score; MRI, magnetic resonance imaging; APB DML, distal motor latency of abductor pollicis brevis; -, unmeasurable; SCV, sensory conduction velocity.

Table II. Correlation of thenar muscle volume with clinical data (grasp power, Kapandji score, and Q-DASH score) and electrodiagnostic variables (APB DML, SCV, and Kanatani's stage) in CTS patients.

Thenar muscle volume (cm ³)	r	P-value
Grasp power (kg)	0.35	0.17
Kapandji score	0.21	0.40
Q-DASH score	-0.12	0.65
Reciprocal of APB DML (1/msec)	0.37	0.15
Reciprocal of SCV (s/m)	0.14	0.58
Kanatani's stage	-0.25	0.33

Correlation analysis was performed using a Pearson's Correlation Coefficient. Q-DASH, Quick Disabilities of the Arm, Shoulder and Hand; APB, abductor pollicis brevis; DML, distal motor latency; SCV, sensory conduction velocity; CTS, carpal tunnel syndrome.

Table III. Correlation of the thenar muscle major axis with clinical data (grasp power, Kapandji score, and Q-DASH score) and electrodiagnostic variables (APB-DML, SCV, and Kanatani's stage) in CTS patients.

Thenar muscle major axis (mm)	r	P-value
Grasp power (kg)	0.53	0.03 ^a
Kapandji score	0.49	0.04 ^a
Q-DASH score	-0.08	0.77
Reciprocal of APB DML (1/msec)	0.24	0.35
Reciprocal of SCV (s/m)	0.20	0.42
Kanatani's stage	-0.15	0.56

Correlation analysis was performed using a Pearson's Correlation Coefficient. ^aP<0.05. Q-DASH, Quick Disabilities of the Arm, Shoulder and Hand; APB, abductor pollicis brevis; DML, distal motor latency; SCV, sensory conduction velocity; CTS, carpal tunnel syndrome.

clinical variables (grasp power, Kapandji score, and Q-DASH score) or the results of electrodiagnostic studies (APB-DML, SCV, and Kanatani's stage) (Tables II-V). For APB-DML and SCV, reciprocal values were used. MRI parameters showed no significant correlation with BMI, indicating that the thenar muscles were not affected by body habitus. The thenar muscle volume was not significantly corrected with clinical or electrodiagnostic variables (Table II). Thenar muscle major axis displayed significant correlations with grasp power (P<0.05) and the Kapandji score (P<0.05), but no significant correlation with the Q-DASH score or the results of electrodiagnostic studies (Table III). The thenar muscle minor axis demonstrated a significant correlation with APB-DML (P<0.01), but no significant correlation with clinical parameters or other electrodiagnostic variables (Table IV). Of note, the thenar muscle minor axis/thenar muscle major axis ratio was significantly correlated with APB-DML and Kanatani's stage (Table V). Importantly, the thenar muscle thinness was

Table IV. Correlation of the thenar muscle minor axis with clinical data (grasp power, Kapandji score, and Q-DASH score) and electrodiagnostic variables (APB-DML, SCV, and Kanatani's stage) in CTS patients.

Thenar muscle minor axis (mm)	r	P-value
Grasp power (kg)	0.07	0.77
Kapandji score	-0.06	0.82
Q-DASH score	0.11	0.69
Reciprocal of APB DML (1/msec)	0.63	0.007 ^a
Reciprocal of SCV (s/mec)	0.07	0.79
Kanatani's stage	-0.45	0.07

Correlation analysis was performed using a Pearson's Correlation Coefficient. ^aP<0.01. Q-DASH, Quick Disabilities of the Arm, Shoulder and Hand; APB, abductor pollicis brevis; DML, distal motor latency; SCV, sensory conduction velocity; CTS, carpal tunnel syndrome.

Table V. Correlation of the thenar muscle minor/major axis ratio with clinical data (grasp power, Kapandji score, and Q-DASH score) and electrodiagnostic variables (APB-DML, SCV, and Kanatani's stage) in CTS patients.

Thenar muscle minor/major axis ratio	r	P-value
Grasp power (kg)	-0.15	0.57
Kapandji score	-0.28	0.28
Q-DASH score	0.20	0.45
Reciprocal of APB DML (1/msec)	0.72	0.001 ^a
Reciprocal of SCV (s/m)	0.04	0.88
Kanatani's stage	-0.54	0.03 ^b

Correlation analysis was performed using a Pearson's Correlation Coefficient. ^aP<0.01, ^bP<0.05. Q-DASH, Quick Disabilities of the Arm, Shoulder and Hand; APB, abductor pollicis brevis; DML, distal motor latency; SCV, sensory conduction velocity; CTS, carpal tunnel syndrome.

significantly corrected with the severity of electrodiagnostic changes (Tables IV and V). Moreover, the grasp power and Kapandji score (one of the evaluations for thumb opposition) were correlated with thenar muscle thickness rather than the thenar muscle minor axis (Table III).

Discussion

In clinical practice, evaluation of thenar muscle abnormalities in CTS patients is primarily based on obtaining the history and performing physical examination and electrodiagnostic studies. However, such information is sometimes not sufficient to identify thenar muscle dysfunction and predict the clinical outcome, especially recovery of the thenar muscles after surgery. Electrodiagnostic studies are considered to be the gold standard for diagnosis of CTS because of providing information on the physiological health of the median nerve at the carpal tunnel. In addition, electrodiagnostic studies are

necessary for evaluating the severity of CTS, especially thenar muscle dysfunction, because this method is more sensitive than clinical examination. In fact, this method is the most sensitive and accurate technique for evaluation of thenar muscle dysfunction, with a sensitivity of 80-92% and specificity of 80-99% (15). However, electrodiagnostic studies are time-consuming, expensive, and invasive, and most patients find electrodiagnostic studies to be unpleasant (16). Also, this technique produces false-negative and false-positives results in about 10% of patients (17-19).

MRI has an important role in the detection of abnormalities of the skeletal muscles, especially changes in muscle morphology due to many inflammatory, traumatic, degenerative, and neurologic conditions (20). The usefulness of MRI for assessment of the thenar muscles in CTS has already been reported (5,6) and have shown the potential of MRI for depicting small anatomic structures of the hand (7). Previous studies of CTS have shown that thenar muscle atrophy on MRI may indicate irreversible muscle damage (9,11), but the prior investigations did not assess the correlations between MRI thenar muscle parameters and clinical findings or the results of electrodiagnostic studies. Therefore, in this study we aimed to determine the correlations of thenar muscle parameters on MRI with clinical findings and electrodiagnostic data in patients with CTS.

In patients with CTS, thenar muscle atrophy is evidence of severe disease on the basis of clinical criteria and there is a significant correlation between thenar muscle atrophy and the severity of median nerve neuropathy on electrodiagnostic studies. However, inspection and clinical evaluation of the thenar muscles is difficult and sometimes fails to identify thenar muscle atrophy in CTS unlike MRI. The typical electrodiagnostic findings in CTS are slowing of the SCV and an increase of DML across the carpal tunnel caused by focal demyelination.

Kanatani *et al* reported on 112 hands in 96 patients (mean age: 77 years) with CTS, among whom 92% were classified as severe CTS (stages 4 and 5) and 86% demonstrated thenar muscle atrophy which only occurred in stages 4 and 5 (21). This study showed electrophysiological improvement in 86% of elderly patients following carpal tunnel release and improvement of thenar muscle atrophy was demonstrated in 83%, with significantly more stage 4 hands than stage 5 hands showing improvement of thenar muscle atrophy. Norlan *et al* reported that thenar muscle atrophy was present in 15 CTS patients preoperatively (22). In the present study, 13 of the 15 hands showed delay of DML and non-measurable DSL (Kanatani stage 4) and the other two hands showed non-measurable DML and DSL (Kanatani stage 5). Therefore, all patients with thenar muscle atrophy showed abnormal electrodiagnostic studies. In our study of 13 patients (17 wrists) with severe CTS (Kanatani stages 3 to 5), the thinness of the thenar muscles was significantly correlated with the severity of electrodiagnostic changes (Tables IV and V). Therefore, we demonstrated that MRI is particularly useful in assessment of the thenar muscles, and information regarding the correlation between thenar muscle thinness on MRI and electrodiagnostic studies may help in diagnosing and evaluating the severity of CTS, particularly if the clinical findings are equivocal. This correlation may also help to predict patients who would benefit from surgical intervention.

On the other hand, there was no correlation between thenar muscle atrophy and clinical variables. However, there was a significant correlation between the thenar muscle major axis on MRI and the grasp power and Kapandji score (Table III). Both the grasp power and Kapandji score were correlated with thenar muscle thickness rather than the thenar muscle minor axis. Grasp power tests the synergistic function of intrinsic and extrinsic muscles of the hand. The grasp depends on four fingers flexing and more importantly on the ability of thumb to be positioned opposite the fingers and remain stable in this position. For thumb opposition to be effective and stable, thenar muscle function must be good. Therefore, patients with severe CTS may have reduced hand strength and grasp power because of decreased thenar muscle and intrinsic muscle function. For example, Baker (23) compared the grip strength of 124 patients with CTS to age- and sex-matched normative values and found that CTS patients had moderate to large grip strength deficits and showed significant improvement of hand strength after intervention.

In order to evaluate opposition of the thumb, we used the method proposed by Kapandji (24) since it takes into account all the components of opposition and allows measurement without any instruments. Moreover, this method is practical and allows global appreciation of the opposition motion. However, this opposition test is not valid in some patients if the thumb does not move through its full range of motion for various reasons such as severe pain of the first carpometacarpal joint, arthritis of the joint, or uncorrected first web space contracture. The correlation between the thenar muscle major axis and the grasp power and Kapandji score in this study provides additional information about the severity of CTS, which may aid in deciding whether surgical intervention such as opponensplasty should be performed to improve grasp power and thumb opposition.

There were several limitations of our study. First, it was only a cross-sectional study. Another limitation is the small number of patients reflects CTS that has to be thenar muscle atrophy. Also, this is clinical trial study. So, our series were consisted in the patients obtained informed consent, because evaluation of thenar muscles by MRI in CTS patients is a kind of prototypical method today. Furthermore, MRI is an expensive test and therefore is not routinely used. Loss of grasp power in patients with CTS could be due to a variety of causes that may not primarily or exclusively be related to muscles affected by CTS, but we did not distinguish other causes of weakness and we did not assess pinch strength (lateral and palmar). Further prospective research is needed to better understand the correlations of MRI thenar muscle parameters with postoperative outcomes and such information may be useful for predicting functional recovery of the thenar muscles after decompression surgery and aid in deciding on surgical intervention, because some authors have reported that the thenar muscles show satisfactory recovery after carpal tunnel decompression alone even in severe CTS (2), but others have reported unsatisfactory postoperative recovery in patients with severe CTS and recommended single-stage tendon transfer (25-27).

In conclusion, this study showed that thenar muscle thinness on MRI was well correlated with the severity of electrodiagnostic changes, and there were also significant correlations between the thenar muscle major axis and the

grasp power or Kapandji score. Thenar muscle atrophy did not influence patient-based assessments (VAS and Q-DASH), but reflected electrodiagnostic parameters (especially DML) and could estimate the severity of CTS.

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