Hypertrophic changes of the teres minor muscle in rotator cuff tears: quantitative evaluation by magnetic resonance imaging

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\textbf{Background:} Few reports have assessed the teres minor (TM) muscle in rotator cuff tears. This study aimed to quantitatively analyze the morphologic changes of the TM muscle in patients with or without rotator cuff tears by magnetic resonance imaging (MRI).

\textbf{Methods:} This retrospective study consisted of 279 subjects classified on the basis of interpretations of conventional MRI observations into 6 groups: no cuff tear; partial-thickness supraspinatus (SSP) tear; full-thickness SSP tear; SSP and subscapularis tears; SSP and infraspinatus (ISP) tears; and SSP, ISP, and subscapularis tears. With use of ImageJ software (National Institutes of Health, Bethesda, MD, USA) for oblique sagittal MRI, we measured the areas of ISP, TM, and anatomic external rotation (ISP + TM) muscles on the most lateral side in which the scapular spine was in contact with the scapular body. The occupational ratios of the TM muscle area to the anatomic external rotation muscle area were calculated. Ratios above the maximum of the 95\% confidence intervals of the occupational ratio in the no-tear group were defined as hypertrophy of the TM muscle.

\textbf{Results:} Occupational ratios of the TM muscle in the no-tear group followed a normal distribution, and ratios >0.288 were defined as hypertrophic. Hypertrophic changes of the TM muscle were confirmed in rotator cuff tears involving the ISP tendon. A negative correlation was found between the occupational ratios of TM and ISP (\textit{P} < .001).

\textbf{Conclusion:} The TM muscle appeared hypertrophic in rotator cuff tears involving the ISP, and the progression of ISP muscle atrophy seemed to induce the development of this compensatory hypertrophy.

\textbf{Level of evidence:} Basic Science, Anatomy, Imaging.

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\textbf{Keywords:} Teres minor muscle; hypertrophic change; rotator cuff tear; MRI evaluation; infraspinatus muscle; atrophy

This study was approved by the Institutional Review Board.

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The teres minor (TM) muscle provides 20% to 45% of the external rotation power to the glenohumeral joint and retains the power in large and massive tears involving the infraspinatus (ISP) tendon. Tears of the TM tendon are rare, and the tendon usually remains intact even in large or massive rotator cuff tears. In reverse total shoulder arthroplasty with severe atrophy or fatty infiltration of ruptured rotator cuff muscles, integrity of the TM was shown to be a prognostic factor postoperatively. Recently, reverse total shoulder arthroplasty with latissimus dorsi transfer to restore elevation and external rotation in cases of severe atrophy or fatty infiltration of ISP and TM muscles that were observed preoperatively has been reported. Understanding of the preoperative integrity of the TM should provide valuable prognostic information for achieving successful clinical results.

Muscle atrophy and fatty infiltration of the torn rotator cuff have previously been analyzed on oblique sagittal magnetic resonance imaging (MRI) with use of image software. These studies have focused on the supraspinatus (SSP), the ISP, and the subscapularis (Subsc) muscles, but to the best of our knowledge, there have hardly been any reports that assessed the TM muscle. Although Walch et al introduced a morphologic classification system of the TM muscle based on the arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears, there have been no quantitative evaluations of the TM muscle. The purpose of this study, therefore, was to quantitatively investigate morphologic changes of the TM muscle on the basis of MRI of patients with or without rotator cuff tears. We hypothesized that the TM muscle would appear hypertrophic in rotator cuff tears involving the ISP tendon.

Materials and methods

The Institutional Review Board and ethics committee approved this retrospective study of diagnostic MRI of 331 patients (331 shoulders) with or without rotator cuff tears at our institution between April 2010 and March 2013. Twenty-two shoulders with previous surgical treatment, fractures, dislocation, infection, rheumatoid arthritis, cerebral neuropathy, axillary nerve palsy, or previous physical therapy on the affected side were excluded. Twenty-four shoulders in which the ISP and TM muscles could not be divided correctly on oblique sagittal plane MRI were also excluded. Four shoulders with no TM muscles visible on MRI were excluded. Two isolated Subsc tendon tears were also excluded because the numbers were too small to evaluate. Thus, a total of 279 subjects (155 males, 124 females; age, 10–88 years; average age, 61.2 years) were included in this study.

MRI evaluation

MRI was performed on a 1.5T system (Siemens, Germany). T2-weighted spin-echo images (2500–5000/120, with a 3-mm section thickness) were obtained in the oblique coronal plane, parallel to the SSP muscle; in the axial plane; and in the oblique sagittal plane, parallel to the joint surface of the glenoid. According to the standard findings of these 3 MRI planes, subjects were divided into the following 6 groups: no-tear (N) group; partial-thickness SSP tear (A) group; full-thickness SSP tear (B) group; full-thickness SSP and Subsc tears (C) group; full-thickness SSP and ISP tears (D) group; and SSP, ISP, and Subsc tears (E) group. Demographic data including numbers, ages, dominant side, traumas, and duration of symptoms of the patients in each group are shown in Table I. There were 31 incomplete tears, 26 small tears, 46 medium tears, 37 large tears, and 53 massive tears according to Cofield’s classification.

Occupational ratio of TM muscle

With use of ImageJ software (National Institutes of Health, Bethesda, MD, USA), the areas of ISP muscle, TM muscle, and anatomic external rotation (a-ER) muscle were measured on the most lateral oblique sagittal image in which the scapular spine was in contact with the scapular body; the area of the a-ER muscle, including the areas of ISP and TM muscles, was traced on the lateral margin of the scapula, the inferior margin of the TM muscle, and the medial margin of the deltoid (Fig. 1). The occupational ratios of TM and ISP muscles were then calculated: occupational ratio of TM muscle = area of TM muscle/area of a-ER muscle; and occupational ratio of ISP muscle = area of ISP muscle/area of a-ER muscle. A random sample of 60 muscles (ISP, TM, a-ER muscles) from 30 subjects was reviewed by an orthopedic surgeon (K.K.) twice to quantify intraobserver reliability and by a second orthopedic surgeon (M.M.) to quantify interobserver reliability.

Definition of hypertrophy of the TM muscle

To define hypertrophy of the TM muscle, the distribution of the occupational ratios of the TM muscle of the N group was

### Table I Demographic data of each group

<table>
<thead>
<tr>
<th>Group</th>
<th>Tear pattern</th>
<th>No. of subjects (male, female)</th>
<th>Age (mean ± SD), years</th>
<th>No. of dominant sides</th>
<th>Duration of symptoms (mean ± SD), months</th>
<th>No. of traumas</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>No tear</td>
<td>86 (45, 41)</td>
<td>50.5 ± 17.1</td>
<td>48 (56%)</td>
<td>8.1 ± 14.1</td>
<td>33 (38%)</td>
</tr>
<tr>
<td>A</td>
<td>Partial-thickness SSP tear</td>
<td>31 (20, 11)</td>
<td>62.5 ± 9.7</td>
<td>19 (61%)</td>
<td>6.0 ± 6.9</td>
<td>11 (35%)</td>
</tr>
<tr>
<td>B</td>
<td>Full-thickness SSP tear</td>
<td>66 (34, 32)</td>
<td>65.0 ± 8.8</td>
<td>36 (55%)</td>
<td>10.6 ± 3.3</td>
<td>36 (55%)</td>
</tr>
<tr>
<td>C</td>
<td>Full-thickness SSP and Subsc tears</td>
<td>17 (15, 2)</td>
<td>65.1 ± 8.6</td>
<td>5 (29%)</td>
<td>7.5 ± 15.0</td>
<td>13 (76%)</td>
</tr>
<tr>
<td>D</td>
<td>Full-thickness SSP and ISP tears</td>
<td>50 (23, 27)</td>
<td>69.2 ± 7.8</td>
<td>33 (66%)</td>
<td>12.7 ± 35.7</td>
<td>29 (58%)</td>
</tr>
<tr>
<td>E</td>
<td>Full-thickness SSP, ISP, and Subsc tears</td>
<td>29 (18, 11)</td>
<td>72.2 ± 7.9</td>
<td>21 (72%)</td>
<td>11.3 ± 25.1</td>
<td>15 (52%)</td>
</tr>
</tbody>
</table>

SSP, supraspinatus; ISP, infraspinatus; Subsc, subscapularis.
determined. If a normal distribution applied, the 95% confidence interval (CI) was calculated by an average and standard deviation; values above the 95% CI were considered to represent hypertrophy, values within the 95% CI were considered to be normal, and values lower than the 95% CI were considered to represent atrophy.

**Statistical analysis**

The occupational ratio in each group was checked for normality based on the Shapiro-Wilk test. One-way analysis of variance (followed by Dunnett multiple comparison test) was performed, and statistical significance was established at $P < .05$. Pearson correlation coefficients were calculated for the correlation between the occupational ratios of ISP and TM muscles followed by bootstrapping to 95% CI on 10,000 bootstrap samples. All reported $P$ values are two sided. Intraobserver and interobserver reliabilities for the state of ISP and TM muscles on MRI scans were evaluated with the Cohen $k$ statistic. All calculations were made with SSPS version 20.0 software (SPSS Inc, Chicago, IL, USA).

**Results**

**Definition of hypertrophy of the TM muscle**

The occupational ratios of the N group were confirmed to follow a normal distribution (Shapiro-Wilk test, $P$ values: N: .055, A: .528, B: .532, C: .837, D: .097, and E: .794) (Fig. 2). The 95% CI of the occupational ratio of the TM muscle in the N group was 0.112 to 0.288; therefore, ratios $<0.112$ were defined as atrophic and ratios $>0.288$ as hypertrophic. There were no significant differences in terms of the occupational ratios of the TM muscle according to age distribution or gender (all $P > .05$, Table II).

The occupational ratios of the TM muscle in the N, A, B, C, D, and E groups were $0.20 \pm 0.04$, $0.21 \pm 0.05$, $0.21 \pm 0.06$, $0.21 \pm 0.06$, $0.31 \pm 0.13$, and $0.26 \pm 0.11$, respectively (Fig. 3). The occupational ratios of the TM muscle were significantly higher in the SSP and ISP tear (D) group than in other groups, except for the SSP, ISP, and Subsc tear (E) group (Dunnett multiple comparison test, Fig. 3). The Pearson correlation coefficient was $-0.76$ ($P < .001$; 95% CI, $-0.67$ to $-0.83$), indicating a significant negative correlation between the
occupational ratios of TM and ISP in patients with rotator cuff tears (Fig. 4). There was intraobserver and interobserver agreement for the measures of occupational ratios of ISP and TM areas to a-ER area that showed a significance (P < .0001) by Cohen κ test. Therefore, we concluded that the rates were reliable.

### Classification of TM muscle in each group

Table III shows the classification of the TM muscle according to occupational ratios. Hypertrophy of the TM muscle was observed in 6% to 14% of cases in N, A, B, and C groups with an intact ISP tendon. On the other hand, hypertrophy of the TM muscle was noted in 48% to 54% of cases in D and E groups with a torn ISP tendon.

#### Discussion

In this study, the area of the TM muscle on the most lateral oblique sagittal image in which the scapular spine was in contact with the scapular body was found to differ in each individual with no rotator cuff tears. However, the occupational ratios of the TM muscle area to the area of the a-ER muscle were similar (approximately 0.2 [20%]) irrespective of age or gender. We confirmed the trend of hypertrophic change of the TM muscle in rotator cuff tears involving the ISP tendon, and the progression of ISP muscle atrophy was suggested to induce TM muscle hypertrophy.

Gerber et al. previously reported that the TM does not contribute more than 20% of external rotation strength after

<table>
<thead>
<tr>
<th>Group/</th>
<th>Atrophy</th>
<th>Normal</th>
<th>Hypertrophy</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1 (1%)</td>
<td>80 (93%)</td>
<td>5 (6%)</td>
<td>86 (100%)</td>
</tr>
<tr>
<td>A</td>
<td>1 (3%)</td>
<td>28 (91%)</td>
<td>2 (6%)</td>
<td>31 (100%)</td>
</tr>
<tr>
<td>B</td>
<td>4 (6%)</td>
<td>53 (80%)</td>
<td>9 (14%)</td>
<td>66 (100%)</td>
</tr>
<tr>
<td>C</td>
<td>1 (6%)</td>
<td>14 (82%)</td>
<td>2 (12%)</td>
<td>17 (100%)</td>
</tr>
<tr>
<td>D</td>
<td>2 (4%)</td>
<td>21 (42%)</td>
<td>27 (54%)</td>
<td>50 (100%)</td>
</tr>
<tr>
<td>E</td>
<td>3 (11%)</td>
<td>12 (41%)</td>
<td>14 (48%)</td>
<td>29 (100%)</td>
</tr>
</tbody>
</table>

N, no tear; A, partial-thickness SSP tear; B, full-thickness SSP tear; C, full-thickness SSP and Subsc tears; D, full-thickness SSP and ISP tears; E, full-thickness SSP, ISP, and Subsc tears.

There were no significant differences in terms of the occupational ratios of TM according to age distribution or gender (all P > .05).
suprascapular nerve block was performed in volunteers to achieve SSP and ISP palsy. The authors also stated that in cases of chronic weakness of the ISP, the TM may develop compensatory hypertrophy, which is supported by the results of our quantitative MRI study. It can be supposed that hypertrophic changes of the TM muscle occur in proportion to the progress of ISP muscle atrophy in posterior-superior rotator cuff tears to restore external rotation strength.

Our findings do not support those of Melis et al, which showed that the TM muscle was hypertrophic in anterior-superior tears and atrophic in posterior-superior tears. Instead, we found no change in the TM muscle in anterior-superior tears without ISP tears and hypertrophy in posterior-superior tears. This discrepancy could be explained by the differences in the analytical methods used to assess the TM muscle. In their study, 85% of the patients were evaluated with a preoperative computed tomography scan, whereas 15% were evaluated with preoperative MRI. Furthermore, the definition of TM muscle hypertrophy in their study differed from ours; the thickness of the TM muscle was required to be larger than the anterior-posterior width of the glenoid, and moreover, TM muscle atrophy was defined as the thinning of the muscle in the anterior-posterior width, with tracks of fatty infiltration. In contrast, we analyzed the TM muscle hypertrophy in a quantitative manner by MRI.

Functional outcomes after some shoulder surgeries were found to be affected by the integrity of the TM muscle in a number of studies, including the works of Boileau et al, Simovitch et al, and Sirveaux et al, which focused on the recovery of external rotation strength after reverse total shoulder arthroplasty, and those of Costouros et al, Namdari et al, and Nové-Josserand et al after latissimus dorsi tendon transfer for massive, irreparable posterior-superior rotator cuff tears. Similarly, Pape et al found that the TM is important for patients who underwent resurfacing arthroplasty for cuff tear arthropathy to maintain external rotation strength. These studies indicate that an assessment of the TM muscle should be considered before surgery.

Walch et al previously reported that severe fatty infiltration of the ISP and TM muscles weakens the external rotation strength and suggested that the function of the TM may prove useful in the daily activities of patients after large tears of the rotator cuff. Moreover, atrophic or absent TM resulted in a significantly inferior shoulder function in patients with massive irreparable rotator cuff tears according to Boileau et al. Such shoulders involving tears and severe atrophy of the ISP muscle are likely to show hypertrophic changes to the TM muscle on the basis of our present findings.

This study has some limitations. First, we did not evaluate clinical data including shoulder pain, range of motion, and muscle strength. Moreover, we did not clarify the clinical meaning of TM muscle hypertrophy. Second, patients in the no-tear group were not healthy volunteers. Future studies should analyze the relationship between the MRI findings and shoulder function to understand the impact of TM muscle disease on the eventual clinical outcome.

Conclusions

We investigated 279 shoulders by oblique sagittal plane images of MRI. The TM muscle appeared hypertrophic in rotator cuff tears involving the ISP, and the progression of atrophy of the ISP muscle appeared to induce hypertrophy of the TM muscle. Our results therefore suggest that the TM muscle develops compensatory hypertrophy to restore external rotation strength.

Disclaimer

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References


