INTRODUCTION

The primary symptoms of rotator cuff tears are pain, limited range of motion, and reduced muscle strength. Recent epidemiological surveys have revealed that approximately 25% of people aged 50 years and above have a full-thickness rotator cuff tear, and over half of patients with rotator cuff tears have asymptomatic tears that do not exhibit clinical symptoms. These facts complicate the relationship between the clinical condition and the dysfunction, and confuse the treatment guidelines.

The dysfunction in rotator cuff tear patients is linked to a variety of pathologies, including the tear size, the number of torn tendons, and cuff integrity. A greater tear size commonly results in more severe dysfunction. In particular, massive rotator cuff tears (MRCTs), defined as full-thickness
tears of at least two tendons that are retracted at least 5 cm in the coronal plane, have in some cases caused pseudoparalysis (the inability to actively elevate the shoulder more than 90° without neurological damage).4–8 However, other MRCT patients who have undergone conservative treatment, such as rehabilitation without surgical repair, can elevate their arms actively more than 90°.9 The factors affecting active arm elevation recovery in MRCT patients have not been fully elucidated.

Kinematic analysis is performed widely to evaluate the relationship between shoulder disorder pathology and dysfunction. Along with several basic studies, there has been particular interest in scapular kinematics during elevation of the arms.10,11 In general, during arm elevation, the scapula rotates in three dimensions: upward rotation, posterior tilt, and external rotation with respect to the thorax.12,13 Recent studies using electromagnetic sensor-based motion analysis devices have reported that the scapular kinematics of impingement syndrome patients (excluding rotator cuff tears) involve a significant decrease in motion compared to that of healthy individuals.14–16 Studies analyzing the scapular kinematics of rotator cuff tear patients have reported a significant increase in the scapular motion compared to that in healthy individuals;17,18 however, there are far fewer reports on rotator cuff tear patients than on impingement syndrome patients. Moreover, the tear size in the subjects of the reported studies was limited to small to medium tears; to our knowledge, there are no such studies on MRCTs.

We hypothesized that the three-dimensional (3D) motion pattern of the scapula might be able to predict whether active arm elevation can be recovered in the context of a MRCT. Consequently, using an electromagnetic tracking device, we compared the 3D scapular kinematics of MRCT patients capable of active arm elevation to at least 90° with that of healthy elderly individuals with no rotator cuff tears.

## METHODS

### Subjects

We assessed 15 shoulders of 11 MRCT patients and 16 shoulders of 16 healthy age-matched subjects without rotator cuff tears. The MRCT patients had an average age, height, and weight of 75.1 years (range, 70–86 years), 156.9 cm (range, 140–173 cm), and 58.0 kg (range, 39–73 kg), respectively; those of the healthy subjects were 71.9 years (range, 60–81 years), 153.5 cm (range, 145–160.5 cm), and 51.8 kg (range, 39–65 kg), respectively (Table 1).

MRCTs are defined as full-thickness tears found in at least

<table>
<thead>
<tr>
<th>Gender</th>
<th>Healthy subjects (n = 16)</th>
<th>MRCT patients (n = 11)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of shoulders</td>
<td>16</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>Age (years)</td>
<td>71.9 (60–81)</td>
<td>75.1 (70–86)</td>
<td>0.145</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>153.5 (145–160.5)</td>
<td>156.9 (140–173)</td>
<td>0.604</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>51.8 (39–65)</td>
<td>58.0 (39–73)</td>
<td>0.145</td>
</tr>
<tr>
<td>NRS for pain (/10)</td>
<td>N/A</td>
<td>1.7 (0–2)</td>
<td>-</td>
</tr>
<tr>
<td>Number of torn tendons [no. (%)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSP and ISP</td>
<td>N/A</td>
<td>1 shoulder (6.7%)</td>
<td>-</td>
</tr>
<tr>
<td>SSP, ISP, and SSC</td>
<td>N/A</td>
<td>12 shoulders (80.0%)</td>
<td>-</td>
</tr>
<tr>
<td>SSP, ISP, SSC, and Tm</td>
<td>N/A</td>
<td>2 shoulders (13.3%)</td>
<td>-</td>
</tr>
<tr>
<td>Goutallier fatty degeneration (stage)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>N/A</td>
<td>3.9 (3–4)</td>
<td>-</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>N/A</td>
<td>3.8 (3–4)</td>
<td>-</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>N/A</td>
<td>2.9 (0–4)</td>
<td>-</td>
</tr>
<tr>
<td>Teres minor</td>
<td>N/A</td>
<td>3.0 (2–4)</td>
<td>-</td>
</tr>
</tbody>
</table>

Values are presented as mean (range) unless otherwise indicated.

N/A, not applicable; SSP, supraspinatus; ISP, infraspinatus; SSC, subscapularis; Tm, teres minor.
two tendons\(^5\) with a retraction of the torn cuff of at least 5 cm according to magnetic resonance imaging (MRI).\(^1\)\(^9\)

The Goutallier classification\(^2\)\(^0\) was used to evaluate fatty infiltration of the torn rotator cuff muscles. In addition, the numerical rating scale (NRS) was utilized to assess motion pain. The three inclusion criteria were the ability to actively raise the arms by at least 120°, an NRS score ≤ 2,\(^2\)\(^1\) and having received conservative treatment focused on rehabilitation. The exclusion criteria were previous shoulder joint surgery, lipid metabolism disorder, diabetes, posture changes such as thoracic kyphosis (positive wall-occiput test), and pain in the shoulder or neck. Asymptomatic rotator cuff tears were ruled out in the healthy subjects by means of an ultrasound test.

The study objectives and methods were explained to the subjects and their prior consent was obtained. This study was conducted with the approval of the research ethics committee at the Kyoto Prefectural University of Medicine (ERB-C-261).

**Instrumentation**

Three-dimensional kinematic data for the thorax, humerus, and scapula were analyzed using the LIBERTY electromagnetic tracking device (Polhemus, Colchester, VT, USA) integrated with motion monitor software used to collect data at a sampling rate of 120 Hz. This system consisted of a transmitter, seven sensors (receivers), a stylus (digitizer), and a system unit. The transmitter generated a low-frequency electromagnetic field that was detected by several sensors. Angular orientation accuracy has been reported at 1.3°.\(^2\)\(^2\) The root mean square error due to skin motion artifacts was < 5° when the humeral elevation was less than 120°.\(^1\)\(^3\),\(^2\)\(^3\),\(^2\)\(^4\) Consequently, only data corresponding to shoulder elevation angles of up to 120° were analyzed in this study.

**Procedure**

The electromagnetic sensors were attached with double-sided tape to the sternum, the superior acromion process, and the humerus of the dominant arm. A global coordinate system was established by mounting the transmitter on a rigid wooden frame and aligning it with the cardinal planes of the body. The bony landmarks of the thorax, the humerus, and the scapula were palpated and digitized with the stylus sensor to establish the anatomically based local coordinate systems. These procedures were performed with the subjects seated on plastic stools with their arms relaxed at their sides. The local coordinate system was chosen in accordance with the International Society of Biomechanics recommended protocol.\(^2\)\(^5\) The Z-axis was oriented laterally; the X-axis, anteriorly; and the Y-axis, superiorly.

The dominant arm was evaluated in the healthy (control) group, and the affected arm was evaluated in the MRCT (patient) group. Each subject was seated upright on a stool. In the starting position, the arm was at the side with the elbow extended, i.e., the 0° position. Subjects were then asked to elevate their arms in the scapular plane (30° anterior to coronal plane) from the starting position through their full range of motion. The elevation was performed over a standardized count of 3 s to ensure a consistent speed. The arm elevation trial was performed twice, and the mean value of the two trials was analyzed. The subjects underwent three to five practice trials before each elevation trial.

**Data Reduction**

MATLAB software (2013a release; MathWorks, Natick, MA, USA) was used to condense the kinematics data. Scapular kinematics data were selected at 10° intervals and ranged from 30° to 120° of arm elevation. Distal coordinate system rotations were described with respect to the proximal coordinate system using Euler angles in accordance with the recommendations of the International Shoulder Group of the International Society of Biomechanics.\(^2\)\(^5\) The YXZ sequence was used to describe the scapular motions relative to the thorax. The rotational motion of the scapula was defined in the following order: external rotation/internal rotation, upward rotation/downward rotation, and anterior tilt/posterior tilt. The motion of the humerus relative to the thorax was determined using the Y'XY” sequence as the elevation angle (second rotation). All kinematics data were smoothed with a Butterworth filter (low-pass) at a cutoff frequency of 8 Hz.

**Statistical Analysis**

SPSS software, Windows version 22.0 (IBM, Armonk, NY, USA), was used for the data analysis. Two-way (group factor [healthy subjects group/MRCT group] × thoraco-humeral elevation angle) repeated-measures analysis of covariance (ANCOVA) was used to analyze differences in the scapular rotation angles, with the start position of each scapular rotation angle used as a covariate in the analysis. When a significant interaction between the group factor and the humeral elevation angle was observed, a post hoc Bonferroni test was used to determine significant differences between the group factor and the humeral elevation angle. The level of statistical significance was set at P < 0.05.
Table 2. Change in scapular position at each humeral elevation angle (raw data)

<table>
<thead>
<tr>
<th>Upward rotation</th>
<th>Humeral elevation</th>
<th>0°</th>
<th>30°</th>
<th>40°</th>
<th>50°</th>
<th>60°</th>
<th>70°</th>
<th>80°</th>
<th>90°</th>
<th>100°</th>
<th>110°</th>
<th>120°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy subjects</td>
<td></td>
<td>6.6 ± 4.6</td>
<td>6.7 ± 4.9</td>
<td>8.2 ± 5.1</td>
<td>10.1 ± 5.4</td>
<td>12.3 ± 5.6</td>
<td>14.6 ± 5.8</td>
<td>17.3 ± 6.4</td>
<td>20.5 ± 7.0</td>
<td>24.0 ± 7.4</td>
<td>27.4 ± 7.4</td>
<td>30.4 ± 7.2</td>
</tr>
<tr>
<td>MRCTs</td>
<td></td>
<td>-1.6 ± 6.3</td>
<td>1.7 ± 6.7</td>
<td>4.3 ± 7.4</td>
<td>7.1 ± 8.1</td>
<td>10.1 ± 8.6</td>
<td>13.3 ± 9.3</td>
<td>16.4 ± 9.6</td>
<td>19.2 ± 9.5</td>
<td>21.8 ± 9.2</td>
<td>23.8 ± 9.1</td>
<td>25.3 ± 9.1</td>
</tr>
<tr>
<td>Posterior tilt</td>
<td>Healthy subjects</td>
<td>-7.2 ± 6.1</td>
<td>-6.8 ± 6.1</td>
<td>-6.5 ± 6.2</td>
<td>-5.9 ± 6.2</td>
<td>-5.0 ± 6.2</td>
<td>-3.9 ± 6.5</td>
<td>-2.7 ± 7.3</td>
<td>-1.3 ± 8.2</td>
<td>0.3 ± 9.0</td>
<td>2.5 ± 9.5</td>
<td>5.4 ± 9.5</td>
</tr>
<tr>
<td>MRCTs</td>
<td></td>
<td>-6.3 ± 6.5</td>
<td>-5.5 ± 7.5</td>
<td>-4.7 ± 7.9</td>
<td>-3.4 ± 8.5</td>
<td>-2.0 ± 8.9</td>
<td>-0.5 ± 9.3</td>
<td>1.0 ± 10.0</td>
<td>2.7 ± 11.1</td>
<td>4.8 ± 11.8</td>
<td>7.2 ± 12.4</td>
<td>9.4 ± 12.7</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>Healthy subjects</td>
<td>24.2 ± 7.0</td>
<td>25.2 ± 6.3</td>
<td>25.7 ± 6.4</td>
<td>26.1 ± 6.4</td>
<td>26.4 ± 6.8</td>
<td>26.4 ± 7.2</td>
<td>25.7 ± 7.9</td>
<td>24.5 ± 8.5</td>
<td>22.9 ± 9.0</td>
<td>21.5 ± 9.6</td>
<td>22.0 ± 10.3</td>
</tr>
<tr>
<td>MRCTs</td>
<td></td>
<td>30.2 ± 7.1</td>
<td>30.4 ± 7.7</td>
<td>30.1 ± 7.7</td>
<td>29.7 ± 7.9</td>
<td>29.3 ± 8.3</td>
<td>28.8 ± 8.7</td>
<td>28.1 ± 9.1</td>
<td>27.0 ± 9.4</td>
<td>25.5 ± 10.2</td>
<td>24.0 ± 11.0</td>
<td>22.3 ± 11.2</td>
</tr>
</tbody>
</table>

Data are means ±SD of the scapular positions in degrees.
RESULTS

The raw data of the scapular rotation angles during humeral elevation are shown in Table 2.

Scapular Upward Rotation

Significant interaction in scapular upward rotation was observed between the group factor and the humeral elevation angle ($F = 3.91, P < 0.01$). During humeral elevation between $30^\circ$ and $100^\circ$, the scapular upward rotation was significantly greater in the MRCT group than in the healthy group ($P < 0.05$) (Table 2, Fig. 1A).

Scapular Posterior Tilt

No significant interaction was observed between the group factor and the humeral elevation angle with respect to scapular posterior tilt. Therefore, the scapular posterior tilt during arm elevation did not differ between the MRCT patients and the healthy group (Table 2, Fig. 1B).

Scapular Internal Rotation

No significant interaction was observed between the group factor and the humeral elevation angle with respect to scapular internal rotation. Accordingly, there were no significant differences between the MRCT patients and the healthy group in scapular internal rotation during arm elevation (Table 2, Fig. 1C).

Fig. 1. Scapular kinematics during humeral elevation: (A) scapular upward rotation, (B) scapular posterior tilt, and (C) scapular internal rotation. *$P < 0.05$; **$P < 0.01$. 

---

Table 2

<table>
<thead>
<tr>
<th>Angle</th>
<th>MRCTs</th>
<th>Healthy Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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DISCUSSION

We compared the 3D scapular kinematics of healthy elderly individuals with no rotator cuff tears with those of MRCT patients able to actively elevate their arms. We found that the scapular upward rotation for arms elevated 30° to 100° was significantly greater among the MRCT patients than among the healthy elderly individuals. However, no significant difference was noted between the MRCT patients and the healthy individuals with respect to posterior tilt and internal rotation.

Abnormal scapular kinematics is reportedly associated with pain and motor function in subacromial pathology. Mell et al. analyzed the scapulohumeral rhythm of patients with full-thickness rotator cuff tears of at least 1 cm² and stated that scapular upward rotation increased significantly up to the middle range of elevation compared with that of a group without rotator cuff tears. Scibek et al. reported that there was a significant decrease in scapulohumeral rhythm (more scapular upward rotation) at greater tear sizes in rotator cuff tear patients. In the present study, we also noted a significant increase in scapular upward rotation from an elevation of 30° to 100°, a result that supports the findings of these previous studies.

During arm elevation, the rotator cuff must maintain humeral head stability within the glenoid cavity against the upward shearing force generated by the deltoid and pectoralis major muscles. Inman reported that the elevating force generated by the deltoid reaches a peak at 90° abduction; similarly, the humeral head restraining force generated by the rotator cuff reaches a peak at 60° abduction. Moreover, a biomechanical analysis of cadaver shoulders by Hansen et al. indicated that, for large rotator cuff tears (> 6 cm), up to 45% more deltoid force was required to elevate the arm to 90°. Stabilizing the humeral head within the glenoid cavity is most important at low- to mid-range elevations. MRCTs reduce humeral head stability, and, consequently, it becomes more difficult to exert sufficient elevating torque within the glenohumeral joint. This often results in compensatory motion within the scapulothoracic joint (for instance, a shoulder shrug). In the MRCT patients in our study, there is a possibility that the increase in scapular upward rotation to an elevation of 100° was a compensatory function to shorten the elevating torque, and the acquisition of this compensatory function led to the increased possibility of active elevation.

No significant difference was observed between the healthy elderly individuals and the MRCT patients with regard to scapular posterior tilt and external rotation. McCully et al. analyzed scapular kinematics before and after a suprascapular nerve block in healthy individuals and reported that, although a significant increase was noted in the scapular upward rotation until mid-range elevations, the posterior tilt did not change before and after the block. Moreover, Ohl et al. used a stereoradiograph to compare the scapular position at a 90° elevation in rotator cuff tear patients with that of individuals without tears. They found no significant differences between the two groups in the posterior tilt or the external rotation of the scapula. The current study showed that the scapular posterior tilt and the external rotation in MRCT patients capable of active elevation exhibit a kinematic pattern similar to that of healthy individuals without rotator cuff tears.

This study has several limitations. First, the results indicate the characteristics of scapular kinematics only in non-pseudoparalytic shoulders, with no comparison with pseudoparalytic shoulders. Second, muscle strength and the source of joint movements could have had an effect on the scapular kinematics, but these were not measured. Third, the range of motion that was analyzed for arm elevation was limited to less than 120° because this was the range for which the measurement error of the electromagnetic sensors applied to the skin was acceptably low. Finally, the measurements were limited solely to elevation in the scapular plane, and similar characteristics may not necessarily be exhibited in other elevation planes (sagittal or coronal). Resolving these issues may lead to a better understanding of the 3D scapular kinematics of MRCTs.

In summary, differences in the scapular kinematics of MRCT patients and healthy subjects were analyzed using an electromagnetic tracking device. MRCT patients exhibited a significantly greater scapular upward rotation for an arm elevation of 30° to 100° compared with that of healthy elderly individuals. The results of this study could inform the creation of rehabilitation strategies for MRCT patients in a clinical setting. Because of shortening of the elevating torque as a result of the rotator cuff tear, upward rotation of the scapula increased at low- to mid-range elevations. It is important to utilize this supplementary function to enable active arm elevation to at least 90°.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.
REFERENCES


11. Ratcliffe JD, Ludewig PM: Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. Clin Biomech (Bristol, Avon) 2002;17:650–659. [CrossRef]

