

Comparison of scapular upward rotation during arm elevation in the scapular plane in healthy volunteers and patients with rotator cuff tears pre- and post-surgery

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ABSTRACT

Background: Function loss caused by rotator cuff tears alters the scapular orientation, however, few prior studies have reported on scapular movements after rotator cuff repair. The purpose was to determine the scapular orientations before and after rotator cuff repair.

Methods: We recruited 14 healthy controls, 10 small and six massive rotator cuff tear in patients. The scapular upward rotation during arm elevation was analyzed using fluoroscopic imaging.

Findings: Before surgery, both rotator cuff groups demonstrated greater scapular upward rotation compared to healthy controls. Two months postoperation, the analyses showed significant differences between the patients with small rotator cuff tears and healthy controls at arm elevations of 90°, and between patients with both rotator cuff tear groups and healthy controls at arm elevations of 120°. At five months post-operation, significant differences still existed between the healthy controls and both rotator cuff groups. In regard to the temporal effects in the patients with small rotator cuff tears, the scapular upward rotation decreased significantly over time (2-5 months postoperation) at arm elevations of 120°. We did not identify a main effect owing to time in the patients with massive rotator cuff tears.

Interpretation: In patients with small rotator cuff tears, scapular upward rotation was reduced over the period of 2–5 months postoperation, however, the patients with massive rotator cuff tears showed greater scapular upward rotation throughout the experimental period. The results suggested that the execution of the rehabilitation program should consider that the tear size could affect scapular motion.

Keywords: Rotator cuff tear, Scapular kinematics, Tear size, 2D/3D registration technique

1 **1. Introduction**

2 Rotator cuff tears (RCT) occur in 25-50% of the people who are more than 60 years old
3 (Milgrom et al., 1995; Yamamoto et al., 2010). In these cases, the tear size, muscle atrophy, and
4 fatty degenerations of torn rotator cuff muscles worsen with time (Björkenheim, 1989; Melis et
5 al., 2010; Nakagaki et al., 1994; Safran et al., 2011., Zingg et al., 2007), and a surgical procedure
6 is thus the optimal remedy. Previous studies reported that the clinical outcomes after rotator
7 cuff repairs were good or excellent (Deniz et al., 2014; Galatz et al., 2004; Nobuhara et al.,
8 1994; Wolf et al., 2004), however, there were a few studies that reported on the scapular
9 kinematics after operation. Paletta et al. (1997) reported that 86% of the RCT patients
10 demonstrated normal glenohumeral-scapulothoracic motion during shoulder abduction two
11 years after the operation, and Kolk et al. (2016) reported that scapular lateral and upward
12 rotations during shoulder abduction were normalized one year after rotator cuff repair in small-
13 sized and middle-sized RCT patients. Thus, these studies clarified that a period of
14 approximately one to two years after surgery would be required for RCT to improve the scapular
15 movements during the arm elevation to a normal level. However, it was not clear whether
16 shoulder kinematics could normalize within one year postoperation (postop). In regard to the
17 biological aspects, the remodeling process of the insertion occurred 5-6 months after
18 implantation (McCormack et al., 2014; Uthoff et al., 2000). Hence, scapular kinematics may
19 be restored during this period along with the biological recovery.

20 In addition, patients with massive RCT showed poor integrity and severe atrophy of rotator
21 cuff muscles, thereby resulting in unsatisfactory clinical outcomes and high rates of recurrent
22 tearing after surgery (Deniz et al., 2014; Gladstone et al., 2007). Therefore, the clarification of
23 the restoration process of the shoulder function in the case of massive RCT and after repair of
24 the rotator cuff muscles is thus needed. Scibek et al. (2009) reported the increased reliance on
25 scapular contributions to overall humeral elevation with increasing rotator cuff tear size,

26 however, there were no available data on scapular movements in massive RCT postoperatively.

27 The purpose of our study was to identify the recovery process of scapular upward rotation in
28 the RCT patients within five months after surgery. Secondly, we aimed to clarify the difference
29 in the scapular upward rotation with increases in the rotator cuff tear size postoperatively. We
30 hypothesized that scapular movements in patients with small RCTs could normalize for the arm
31 elevation range of 30–90° five months post-surgery owing to the occurrence of the remodeling
32 phase (McCormack et al., 2014; Via et al., 2013). The improvement in the supraspinatus muscle
33 strength and relief from subacromial pain could contribute to the normalization of scapular
34 kinematics. Conversely, we expected that adequate restoration of scapular kinematics could not
35 be observed in the overall arm elevation in patients with massive RCTs five months post-
36 surgery because the fatty degeneration of rotator cuff muscles does not improve even after a
37 successful rotator cuff repair, as reported by a previous study (Deniz et al., 2014; Gladstone et
38 al., 2007). Therefore, excessive contraction of the deltoid or upper fiber of the trapezius muscle
39 to recover the function of the rotator cuff muscles.

40

41 **2. Methods**

42 *2.1. Participants*

43 We recruited 14 healthy men without any shoulder pain and 21 male patients who were
44 diagnosed with RCT and underwent surgery at Nobuhara Hospital (Hyogo, Japan) from June
45 2014 to June 2016. The patients were excluded if they could not elevate their arms by more
46 than 120° in the scapular plane, or if they suffered from comorbid disease of the cervical spine,
47 or rheumatoid arthritis. Additionally, two patients with re-tears of rotator cuffs after surgery,
48 and three patients who lost contact within five months after surgery owing to the completion of
49 the treatment, were not enrolled in this study. Therefore, the studied group included 16 patients,
50 which were divided into two groups in accordance to the tear size. Massive tear is defined as

51 the conditions that $L \times H$ is more than 5.6 cm^2 (where L is the length of the tear region at the
52 attachment site of the tendon and H is the depth to the tendon end; two or more tears are present
53 and the diameter of exposed humeral head is more than 3cm or the circumference of the ruptured
54 region is more than 9 cm) (Nobuhara, 2003). The small RCT group consisted of 10 patients
55 {mean age, 62.7 years; 8 patients with full-thickness tear of the supraspinatus (SSP), and two
56 patients with partial-tear of the thickness of the SSP}, and the massive RCT group which
57 consisted of six patients {mean age, 64.5 years; six patients with full-thickness tears of the SSP,
58 infraspinatus (ISP), and subscapularis (SSC) muscles} (Table 1). Before the surgery, all patients
59 received medical treatment including steroid injections, medication, or rehabilitation at an
60 orthopedic hospital. This study was approved by the governing Institutional Review Board, and
61 informed consent was obtained from all subjects before participation.

62

63 *2.2. Surgical procedure and Rehabilitation*

64 All the RCT were surgically treated by open rotator cuff repairs with the McLaughlin
65 procedure, and physical therapists started the rehabilitation program on the day after surgery
66 with finger, wrist, and elbow exercises. At four days, gentle passive exercises of shoulder
67 elevation and external rotation were initiated. Since the SSP or ISP muscles had been treated,
68 aggressive shoulder internal rotation and extension stretching were avoided within the period
69 spanning 6-8 weeks after operation. In order to strengthen the rotator cuff muscles, active
70 shoulder exercises were initiated without any gravity forces at three weeks, and gravity load
71 exercises began at six weeks. In the case of the massive RCT patients with severe atrophy or
72 degeneration of the torn rotator cuff, rehabilitation program was delayed for 1-2 weeks. The
73 patients were permitted to perform activities during their daily lives after 2-3 months using their
74 involved arms, and to engage in sports activities or heavy physical works after 5-6 months. A
75 physical therapist with 11 years of experience was involved with the rehabilitation in 14 patients,

76 while each of the other two patients received rehabilitation from physical therapists with 13 and
77 20 years experiences, respectively.

78

79 *2.3. Data collection*

80 Motion analyses were performed using fluoroscopic movies (Stenoscop 6000, GE Medical
81 Systems, Chicago, America) at 30 Hz while subjects elevated their arms in the scapular plane
82 at a rate of 5 s per cycle along with the use of the metronome. Subjects sat perpendicular to
83 the fluoroscopy to minimize the measurement errors and were instructed to elevate their arms
84 from a resting position to the maximum they could reach. The scapular plane was set up in the
85 corresponding arm-dependent positions by the physical therapist and a pole was placed along
86 this scapular plane. The subjects were asked to elevate their arms three times, and the data
87 collected during the third repetition was used for the analysis. Before the trial, the subjects
88 practiced this arm elevation movement several times to prevent excessive trunk motion with
89 instructions from physical therapists. The motion analyses for the RCT patients was
90 performed in the preoperational stage, at two months, and five months after surgery. CT
91 (Multislice CT ECLOS, Hitachi Healthcare Ltd, Chiba, Japan) scans were conducted to
92 reconstruct the three-dimensional images of the humerus and scapula using a commercially
93 available software program (Mimics 14, Materialise Inc., Leuven, Belgium). To achieve this,
94 we used acquired images from the fluoroscopic movies at 30° arm elevation increments. The
95 contour lines of the humerus and scapula were then extracted manually and the three-
96 dimensional bone models from the CT data were matched with the fluoroscopic images using
97 a two dimensional/three dimensional (2D/3D) registration technique (Figure 1).

98

99 *2.4. Data processing*

100 The calibration frame was set perpendicular to the fluoroscopic image system and recorded

101 by fluoroscopy to create the global coordinate system. Humerus and scapular coordinate
102 systems were set to calculate scapular upward rotation during arm elevation, as recommended
103 by the International Society of Biomechanics (Wu et al., 2005). In the set coordinate system for
104 the humerus, the origin matched the center of the humeral head and the Y-axis line was
105 determined along the direction of the vector pointing from the origin to the midpoint of the
106 medial and lateral epicondyles. The X-axis line was vertical to the plane formed by the center,
107 and medial and lateral epicondyles. The Z-axis was calculated by the vectorial outer product of
108 the unit vectors along the X- and Y-axes. The center of the humerus was computed by the
109 spherical approximation of the surface in the humeral head. In the scapular coordinate system,
110 the origin was coincident with the acromial angle, and the Z-axis line was determined by the
111 vector from the medial extent of the scapular spine to the acromial angle. The X-axis line was
112 vertical to the plane formed by the acromial angle, the medial extent of scapular spine, and the
113 inferior angle of the scapula. The Y-axis was calculated by the outer vectorial product of the Z-
114 and X-axes. The scapular upward rotation was calculated using the Euler angles that expressed
115 the rotation of the humeral coordinate system to the scapular coordinate system. Each scapular
116 angle was analyzed based on the angle subtended at the corresponding arm-dependent position.
117 Additionally, shoulder elevation angle was determined by the fluoroscopic images manually.
118 And, we reconfirmed the shoulder elevation angle using the rotation of humerus coordinate
119 system relative to the global coordinate system after the registration process. The humeral
120 root-mean-square orientation error was 3.7° and the mean-square position error was 1.8 mm.
121 Correspondingly, the scapular root-mean-square error of the orientation was 1.7° and the mean-
122 square error of position was 1.0 mm. The root-mean-square error of the orientation of the
123 humerus with respect to the scapula was 3.9° , and the mean-square error of position was 2.5
124 mm.

125

126 2.5. Statistical analysis

127 Two-way Analysis of variance (ANoVA) was used to compare the scapular upward rotation
128 before and after surgery among these groups, and *post hoc* analyses were performed using the
129 Tukey test when required. To investigate the influence of time (preoperation, two months and
130 five months after surgery) on the scapular kinematics in each RCT group, we used repeated
131 measures, and *post hoc* Tukey tests were used for further significant testing. In this study, we
132 analyzed the effects of group and time on the scapular kinematics, and the statistical analyses
133 were conducted without the effect of arm position. Statistical significance was set at $P < 0.05$.

134

135 3. Results

136 The scapular upward rotation angle among the three studied groups at preoperation (preop),
137 two months after surgery, and five months after surgery, are presented in Table 2.

138

139 3.1. Scapular upward rotation preoperatively

140 Comparing the scapular upward rotation among the healthy controls and RCT groups before
141 surgery, there was no interaction effect for the group \times arm position ($P = 0.44$). We found that
142 the main effect was attributed to the group ($P < 0.01$) and that there were significant differences
143 between the healthy controls and small RCT patients ($P < 0.01$), and between the healthy
144 controls and massive RCT patients ($P < 0.01$). No significant difference was observed between
145 the two RCT groups ($P = 0.17$)(Figure 2).

146

147 3.2. Scapular upward rotation at two months after surgery

148 The analysis of the scapular upward rotation among the healthy controls and RCT groups two
149 months postope showed an interaction effect for the group \times arm position ($P = 0.03$). We did
150 observe a main effect for the group ($P < 0.01$). *Post hoc* analyses indicated significant

151 differences in the scapular upward at a 90° arm elevation ($P = 0.04$), while the small RCT
152 patients showed greater scapular upward rotation compared to the healthy controls (mean
153 values of healthy controls vs. small RCT: 34.2° vs. 40.7° , $P = 0.02$). Conversely, there were
154 no significant differences between the healthy controls and massive RCT patients ($P = 0.36$),
155 and between the RCT groups ($P = 0.98$). *Post hoc* analyses also identified significant differences
156 in the scapular upward rotation at an arm elevation of 120°, and both RCT groups demonstrated
157 greater scapular upward rotation compared to the healthy controls (mean values of healthy
158 controls vs. small RCT, massive RCT: 48.2° vs. 61.2° , 61.3° , $P < 0.01$)(Figure 3).

159

160 *3.3. Scapular upward rotation at five months after surgery*

161 For the comparison of the scapular upward rotation among the healthy controls and RCT
162 groups five months after surgery, we noted no interaction effect for the group×arm position (P
163 = 0.76), there was a main effect for the group ($P < 0.01$). Significant differences were found
164 between the healthy controls and small RCT patients ($P = 0.04$), and between the healthy
165 controls and massive RCT patients ($P < 0.01$). However, there were not any significant
166 differences between the RCT groups ($P = 0.48$)(Figure 4).

167

168 *3.4. Scapular upward rotation in each RCT group*

169 The investigation of the temporal influences on the scapular upward rotation in the small RCT
170 patients indicated that the main effect was observed at an arm elevation of 120° ($P = 0.01$), and
171 the mean values of scapular upward rotation decreased significantly over time from 61.2° at
172 two months after surgery to 52.4° at five months after surgery ($P = 0.01$). We did not identify
173 a main effect owing to time at all arm elevation angles in the massive RCT patients.

174

175 **4. Discussion**

176 This study examined the scapular upward rotation during arm elevations in small and massive
177 RCT patients before surgery, two months postop, and at five months postop. As a result, the
178 small RCT patients demonstrated greater scapular upward rotation before and at two months
179 after surgery, compared with the healthy controls. Furthermore, excessive scapular upward
180 rotation decreased at two to five months postop although the scapular movement did not recover
181 to the same level as that of the healthy controls. To the best of our knowledge, this is the first
182 study to show the scapular kinematics outcomes of the RCT patients before surgery and within
183 a period less than five months postop.

184 Our study clarified that the small and massive RCT patients showed greater scapular upward
185 rotation than that of the healthy controls. Previous studies have reported that the small and
186 massive RCT patients yielded greater scapular upward rotations during arm elevations
187 compared to the healthy controls (Scibek et al., 2009; Mell et al., 2005), Conversely, some
188 studies have reported there were not any significant differences of scapular movements during
189 arm elevation between the healthy controls and RCT patients. The results of these studies are
190 controversial because of the static analyses, two-dimensional measurements, and small
191 sample sizes (Paletta et al., 1997; Kijima et al., 2015; Ohl et al., 2015; Yamaguchi et al.,
192 2000). The hypofunction of torn rotator cuff muscles and pain might cause greater scapular
193 upward rotation during arm elevation in the RCT patients before surgery. Casterlein et al.
194 (2017) reported that experimental shoulder pain induced by the injection of hypertonic saline
195 in the SSP reduced the activity of the ISP during arm elevation. McCully et al. (2006) also
196 demonstrated that the suprascapular nerve block is an appropriate model of dysfunction of the
197 SSP and ISP with increased scapular upward rotation and external rotation during arm
198 elevation in the scapular plane. These results indicated that dysfunction and pain of the rotator
199 cuff muscles might have induced greater scapular upward rotation motions during arm
200 elevations in the RCT patients before surgery in our study.

201 The greater scapular upward rotation at a 90-120 degrees of arm elevation were seen in
202 patients with small RCT patients, and the massive RCT patients showed greater scapular
203 upward rotations at a 120 degrees of arm elevation at two months postop compared to the
204 healthy controls. Although there was no study of scapular orientation in the RCT patients two
205 months postop, Bey et al. (2011) reported that the humerus on the repaired side in the case of
206 the RCT patients 3 months after the repair of the SSP tendon tear was positioned more
207 superiorly on the glenoid than the contralateral side during shoulder abduction. Likewise,
208 postoperative bone marrow edema disappeared at 5-6 months after arthroscopic repair surgery
209 (Pfalzer et al., 2017; Stahnke et al., 2016). Although the surgical procedure adopted in our
210 study was different, the reasons for the increased scapular upward rotation at 90–120° of arm
211 elevation observed in patients with RCTs two months post-op reported herein may be
212 attributed to the superior humeral migration and bone marrow edema in order to avoid the
213 acromial impingement of the swollen, repaired tendon. Thus the RCT patients in this study
214 showed greater scapular movement during arm elevation in this period, regardless of the tear
215 size. Therefore, active range of motion exercises should be performed carefully, and therapists
216 may need to construct an alternative rehabilitation program to include exercise paradigms by
217 eliminating gravity from the executed motion for cases with greater scapular motion patterns.

218 The scapular upward rotation at a 120 degrees of arm elevation in the small RCT patient
219 group reduced at two months to five months after surgery, although they still exhibited
220 slightly greater scapular upward rotations compared with healthy controls ($P = 0.04$).
221 Conversely, the massive RCT patients demonstrated greater scapular upward rotation than the
222 healthy controls throughout the experimental period. Paletta et al. (1997) reported that 12 out
223 of 14 patients in the small and massive RCT cases demonstrated normal glenohumeral
224 kinematics during arm elevations at two years after surgery. Additionally, Kolk et al. (2016)
225 clarified that scapular kinematics in the cases of the patients with small and middle RCT

226 normalized toward a symmetrical scapular motion pattern one year after surgery. Thus, these
227 studies clarified that it could take one to two years to restore the scapular orientation during
228 arm elevations in the same manner as the normal controls after surgery for RCT. Our study
229 showed that the scapular upward rotation in the cases of patients with small RCT decreased at
230 two months to five months after surgery although there were still differences compared with
231 the healthy controls. The reduction in the scapular upward rotation at 120° of arm elevation in
232 patients with small RCTs two–five months post-op may be attributed to the absence of bone
233 marrow edema, relief from subacromial pain, and improvement in the repaired cuff muscle
234 strength. Previous studies demonstrated that postoperative bone marrow edema disappeared at
235 5-6 months after surgery (Pfalzer et al., 2017; Stahnke et al., 2016). Furthermore, Kurowicki
236 et al. (2017) clarified that 89% improvement in pain was seen in the small and middle RCT
237 patients at six months after surgery. In fact, nine out of 10 small RCT patients in this study
238 were relieved of pain. With regard to the shoulder muscle strength, Shin et al. (2016) reported
239 that it took six months for patients with small RCTs to recover and reach the muscle strengths
240 of an uninjured contralateral shoulder for flexion, and for internal and external rotations. In
241 conclusion, and based on these previous studies, the scapular upward rotation in patients with
242 small RCTs decreased five months post-surgery because of the absence of bone marrow
243 edema, relief from acromial pain, and improvement in rotator cuff strength. Conversely, the
244 patients with massive RCT demonstrated greater scapular upward rotation compared to the
245 healthy controls at five months after surgery. Gladstone et al. (2007) reported that fatty
246 infiltration and muscle atrophy before surgery affect the functional outcome one year after
247 rotator cuff repair, and neither fatty infiltration nor muscular atrophy were reversed after
248 surgery. Additionally, Deniz et al. (2014) demonstrated that the functional outcome 24-43
249 months after surgery was affected negatively by the preoperative and postoperative fatty
250 degeneration, and that the preoperative fatty degeneration and atrophy of rotator cuff muscles

251 did not improve even after a successful surgery. These previous studies suggest that the
252 scapular upward rotation was greater in the massive RCT patients in this study because
253 preoperative atrophy and degeneration might deteriorate the function of rotator cuff muscles
254 even after a successful repair. This could lead to excessive contraction of the deltoid or upper
255 fiber of the trapezius muscle to recover the function of the repaired rotator cuff muscles.
256 Further studies are needed to clarify when or by how much the function of rotator cuff
257 muscles have been restored postoperatively

258 This study is associated with some limitations. First, the healthy controls were younger than
259 the RCT patients. Yamaguchi et al. (2000) reported that the scapular upward rotation during
260 arm elevation was similar between the young healthy controls and asymptomatic RCT
261 patients. Hence, we thought that aging had little influence on the scapular movements if the
262 subjects did not have any symptoms. The other reason was that we would like to exclude the
263 influence of RCT on the control group. Milgrom et al. (1995) demonstrated that the
264 prevalence rate of RCT was approximately 50 % of asymptomatic adults between 60-69 years
265 and 5% of asymptomatic adults between 30-39 years, therefore we recruited healthy subjects
266 under 30 years. However, since some previous studies showed that increased thoracic
267 kyphosis altered the scapular movements during arm elevation (Finley and Lee, 2003;
268 Kebaetse et al., 1999), we should have considered the effects of aging on scapular movements.
269 Secondly, the sample size of massive RCT group was small. Post hoc power analysis
270 indicated that a sample size of 10 subjects in every group would be necessary (effect size 0.4,
271 α error 0.05, Power 0.8). Although significantly greater scapular upward rotation was seen in
272 massive RCT patients compared to healthy group, a study in large size of massive RCT
273 patients might reveal the difference which was not found in this study. Lastly, only scapular
274 upward rotation was analyzed in the frontal plane with single fluoroscopy because of the
275 small measurement error. The measurement error using biplane fluoroscopy was calculated

276 for orientation (0.1-0.7°) and position (0.2-0.3 mm) (Millett et al., 2016). Therefore, further
277 studies are needed to analyze the multidirectional movements of the scapula using the
278 proposed method associated with small measurement errors.

279

280 **5. Conclusion**

281 We analyzed the scapular upward rotation during arm elevation in patients with small and
282 massive RCT with a 2D/3D registration technique preoperatively, and at two and five months
283 after surgery. Consequently, the small RCT patients yielded greater scapular upward rotation
284 two months after surgery. The scapular upward rotation decreased over the period of 2-5 months
285 postop although the scapular upward rotation was greater compared to healthy controls.
286 Additionally, patients with massive RCT demonstrated greater scapular upward rotation before
287 operation and at two and five months postop.

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Highlight

- The scapular upward rotation during arm elevation was analyzed.
- Rotator cuff tears patients participated at preop, two and five months postop.
- The patients with small tears showed greater movement at two months postop.
- However, this movement decreased over the period of 2-5 months postop.
- The massive tears led to greater motion throughout the experimental period.

Figure and Table Legends

Figure 1 An example of an arm elevation measurement and 2D/3D registration technique.

(2D/3D; two dimensional/ three dimensional)

Upper left: Subjects elevated their arm at a rate of 5 s per cycle with the metronome targeting the pole which was placed along the scapular plane.

Upper right: Three-dimensional images of humerus and scapula reconstructed from the Computed tomography data.

Bottom left: Segmentation of humerus and scapula using manually placed contour lines in fluoroscopic images.

Bottom right: Three-dimensional bone model from the Computed tomography data were matched with the fluoroscopic images using a 2D/3D registration technique.

Figure 2 Scapular upward rotation for healthy controls and RCT patients preoperatively (RCT; Rotator Cuff Tear)

*Significant differences between healthy controls, small RCT ($p = .003$), and massive RCT ($p < .001$)

Figure 3 Scapular upward rotation for healthy controls and each RCT patients two months after surgery (RCT; Rotator Cuff Tear)

*Significant difference at an arm elevation of 90° between healthy controls and small RCT patients ($p = .017$)

**Significant differences at an arm elevation of 120° between healthy controls, small RCT ($P < .001$), and massive RCT patients ($p < .001$)

Figure 4 Scapular upward rotation for healthy controls and RCT patients five months after surgery (RCT;Rotator Cuff Tear)

*Significant differences between healthy controls, small RCT ($p = .048$), and massive RCT patients ($p = .004$)

Table 1 Demographic profile data of RCT patients and healthy subjects. Values are means followed by standard deviation and 95 percent confidence intervals in parentheses. (RCT; Rotator Cuff Tear, CI; Confidence intervals, SSP; Supraspinatus muscle, ISP; Infraspinatus muscle, SSC; Subscapularis muscle, mo; months, op; operation).

*Significant differences between healthy controls and RCT patients ($P < 0.01$)

Table 2 Scapular upward rotation for all groups before operation at two- and five-months post-operation. Values are means followed by standard deviation and 95 percent confidence intervals in parentheses. (RCT; rotator cuff tear, CI; confidence intervals, op; operation, mo; months, ANOVA; Analysis of variance)

*: Two-way ANOVA indicated no significant interaction effect for the group \times arm position.

The main effect was identified as the group compared to healthy controls ($P < 0.01$).

† : Two-way ANOVA indicated a significant interaction effect of group \times arm position ($P = 0.03$), and *post hoc* analyses revealed significant differences compared with healthy controls ($P < 0.05$).

§ : A repeated measure ANOVA and *post hoc* Tukey tests yielded a significant difference compared at two months postop ($P = 0.01$).

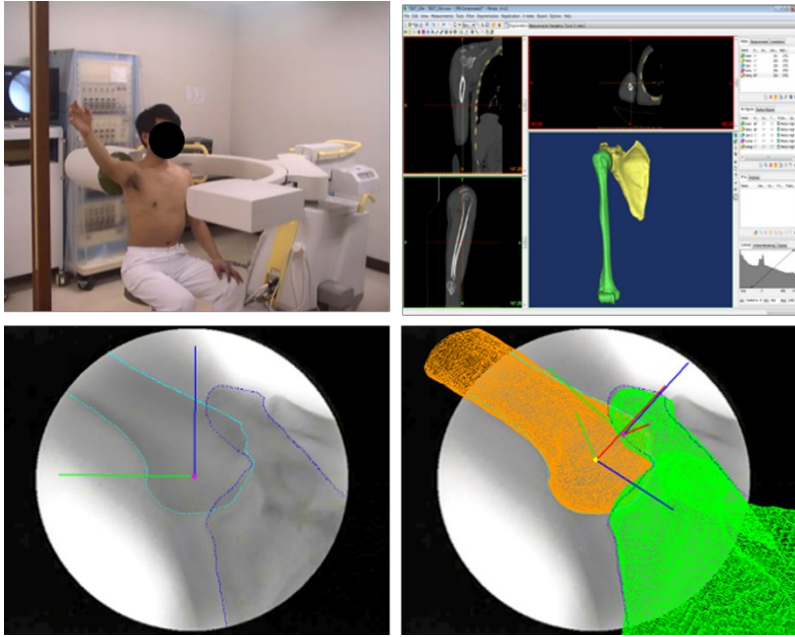


Figure 1

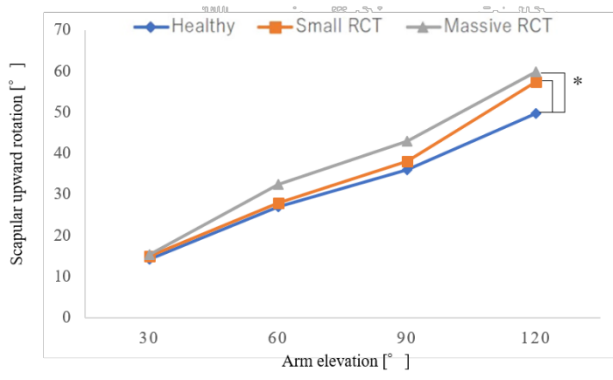


Figure 2

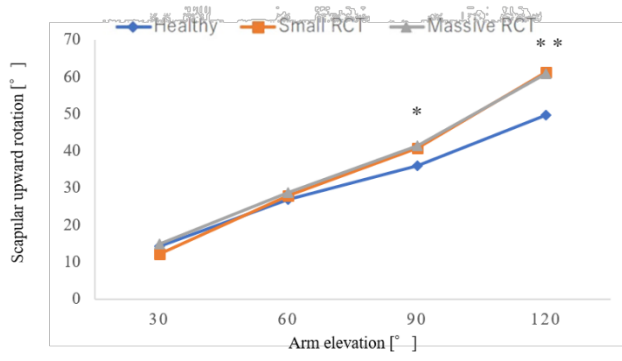


Figure 3

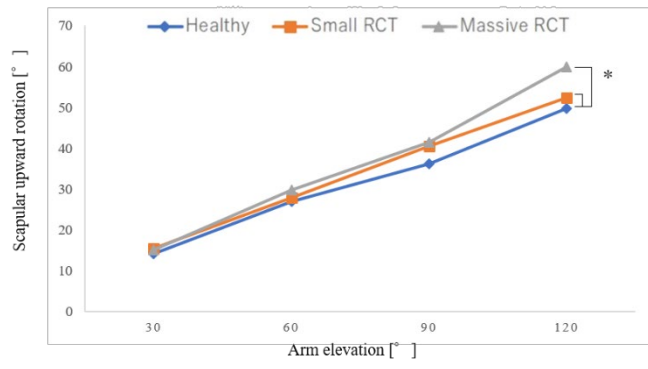


Figure 4

Table 1

	Small RCT (n=10)	Massive RCT (n=6)	Healthy (n=14)	<i>P</i> value
Age (y)	62.7 (7.7; 57.2-68.1)	64.5 (9.5; 54.5-74.4)	24.7 (4.5; 22.1- 27.3)	< 0.01*
Body mass index (kg/m ²)	23.9 (2.5; 22.5-25.2)	23.5 (1.1; 21.8-25.2)	21.3 (1.9; 20.2- 22.4)	0.01
Period until repair (mo)	5.8 (4.1; 3.4-8.1)	2.5 (2.1; 0.5-5.6)		0.04
Tear	SSP full-thickness tear: 8 SSP partial-thickness tear: 2	SSP, ISP and SSC full-thickness tear: 6		
Goutallier stage	Stage I: 7 Stage II: 2 Stage III: 1	Stage I: 2 Stage II: 3 Stage III: 1		0.35
Active scaption (°)	Preope: 147.9 (15.6; 136.7-159.1) Postope 2 mo: 149.4 (12.2; 140.7-158.2) Postope 5 mo: 151.2 (13.6; 141.4-160.9)	Preope: 157.0 (8.4; 148.2-165.8) Postope 2 mo: 156.9 (9.4; 147.1-166.8) Postope 5 mo: 161.1 (14.5; 145.9-176.2)	159.0 (10.3; 153.0-164.9)	0.10 0.12 0.22
Pain during arm elevation	Preope: 10/10 Postope 2 mo: 5/10 Postope 5 mo: 1/10	Preope: 6/6 Postope 2 mo: 2/6 Postope 5 mo: 0/6	0/14	1 0.52 0.42

Table 2

	Small RCT	Massive RCT	Healthy
Arm elevation			
<i>30°</i>			
Preope *	14.9 (5.5; 10.9-18.9)°	15.3 (2.6; 12.5-18.1)°	12.4 (8.0; 7.3-17.5)°
Postope 2 mo	12.2 (6.0; 7.9-16.6)°	14.9 (3.4; 11.3-18.5)°	
Postope 5 mo *	15.5 (6.2; 11.0-19.9)°	15.0 (4.0; 10.7-19.2)°	
<i>60°</i>			
Preope *	27.9 (6.5; 23.2-32.6)°	32.3 (9.5; 22.3-42.4)°	24.7 (6.1; 20.8-28.6)°
Postope 2 mo	27.8 (4.8; 24.3-31.3)°	28.7 (11.7; 16.3-41.0)°	
Postope 5 mo *	27.9 (9.7; 20.9-34.9)°	29.6 (12.1; 16.9-42.4)°	
<i>90°</i>			
Preope *	38.1 (7.5; 32.7-43.5)°	42.9 (10.2; 32.1-53.6)°	34.2 (4.0; 31.6-36.8)°
Postope 2 mo	40.7 (5.5; 36.8-44.7)° †	41.5 (11.5; 29.4-53.5)°	
Postope 5 mo *	40.4 (9.0; 33.9-46.9)°	41.4 (13.2; 27.6-55.3)°	
<i>120°</i>			
Preope *	57.3 (3.5; 54.8-59.8)°	59.8 (7.1; 52.4-67.3)°	48.2 (4.3; 45.5-51.0)°
Postope 2 mo	61.2 (5.4; 57.3-65.1)° †	61.3 (4.3; 56.7-65.9)° †	
Postope 5 mo *	52.4 (10.5; 44.8-59.9)° §	59.8 (8.5; 50.8-68.8)°	