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Three-dimensional kinematic features in large and massive rotator cuff tears with pseudoparesis

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Background: Although massive rotator cuff tears occasionally lead to severe impairment of shoulder function, the criteria for losing the ability to elevate the arm are unclear. This study aimed to analyze the features of both tear size and 3-dimensional (3D) shoulder kinematics that correspond to the loss of the ability to elevate the arm in patients with large and massive rotator cuff tears.
Methods: We prospectively enrolled patients with rotator cuff tears, including the supraspinatus and more than half of the subscapularis or more than two-thirds of the infraspinatus, without severe pain. A total of 13 patients (15 shoulders) were divided into 2 groups: 9 shoulders in the pseudoparesis (P) group and 6 shoulders in the non-pseudoparesis (NP) group. Fluoroscopic images were collected during active scapular-plane elevation, and 3D shoulder kinematics was analyzed using 2-dimensional–3D registration techniques. The radiographic findings and 3D kinematic results were compared between the groups. The correlation between tear size and 3D kinematics was also investigated.
Results: The most superior position of the humeral head center was significantly higher in the P group (6.7 ± 3.0 mm in P group vs. 3.6 ± 1.3 mm in NP group, $P = .0321$). Superior migration, which was defined as the most superior position > 5 mm, was significantly more frequent in the P group (7 shoulders and 1 shoulder in the P and NP groups, respectively; $P = .0201$). Thoracohumeral external rotation was significantly smaller in the P group (16° ± 31° in P group vs. 91° ± 21° in NP group, $P < .0001$). The total tear size and the tear sizes of the anterior and posterior rotator cuffs were significantly correlated with the superior ($r = 0.68$, $P = .0056$), anterior ($r = 0.68$, $P = .0058$), and posterior ($r = -0.80$, $P = .0004$) positions of the humeral head center. The tear size of the posterior rotator cuff also tended to be correlated with glenohumeral external rotation ($r = -0.48$, $P = .0719$).
Conclusion: Anterior and posterior rotator cuff tears cause significant superior and anteroposterior translations of the humeral head, and posterior cuff tears may lead to loss of glenohumeral external rotation. With these abnormal kinematics, superior migration and loss of thoracohumeral external rotation were identified as features of pseudoparesis.
Level of evidence: Basic Science Study; Kinesiology

Keywords: Large and massive rotator cuff tears; pseudoparesis; 3D shoulder kinematics; superior migration; humeral abduction; humeral external rotation

This study was approved by the Institutional Review Board of the Academic Clinical Research Center of Osaka University (no. 13106), and all subjects provided written informed consent.

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The rotator cuff tear is a clinically common disease, and some patients with massive rotator cuff tears occasionally lose the ability to elevate the arm. This condition is called ‘‘pseudoparesis’’ and has been considered to be caused by the location and size of the rotator cuff tear.[7,8,21,29] Some researchers reported tears of more than half of the subscapularis (SSC) or the entire infraspinatus (ISP)—or even less than half of the SSC—as risk factors for the development of pseudoparesis.[7,8,21,29] These criteria for assessing pseudoparesis may be accepted by many surgeons; however, in our experience, some patients with extensive tears occasionally show very different angles of arm elevation.

The rotator cuff muscles are extremely important for the movements of the shoulder and the stability of the glenohumeral (GH) joint. During arm elevation, the rotator cuff creates a fulcrum by compressing the GH joint and generates an abduction torque.[19,26] Burkhart[5] stated that the force couple balance supplied by the anterior and posterior rotator cuffs was essential to maintain GH joint stability and function. The mechanism of pseudoparesis associated with massive rotator cuff tears has been investigated in cadaveric studies; they showed that extensive tearing of the rotator cuff induced loss of joint stability and superior migration of the humeral head and, consequently, impaired the elevation of the humerus owing to the decrease in the moment arm of the deltoid muscle.[19,26]

We would like to predict whether patients with massive rotator cuff tears can achieve the ability to elevate their arms if they cannot temporarily do so. To predict the prognosis of shoulder function in these patients, we believe that it would be important to assess whether they have abnormal kinematics as reported in cadaveric studies, such as superior migration of the humeral head and loss of the GH abduction angle.[19,20,24-26] Evaluation of dynamic motion by fluoroscopy, rather than by static imaging, such as radiography and magnetic resonance imaging (MRI), would help capture these abnormal kinematics. This study aimed to elucidate the features of 3-dimensional (3D) shoulder kinematics as well as to identify the tear size that causes the loss of the ability to elevate the arm in patients with large and massive rotator cuff tears.

Materials and methods

Patient selection

We prospectively recruited patients with large and massive rotator cuff tears of $\geq$2 tendons, including the supraspinatus (SSP) and more than half of the SSC or more than two-thirds of the ISP with the third or fourth stage of retraction according to Boileau et al.[2] The exclusion criteria were a score > 6 on a numerical pain rating scale during arm elevation and limited range of passive elevation $> 10°$ compared with the opposite side.

A total of 13 patients (15 shoulders) were divided into 2 groups: 8 patients (9 shoulders) in the pseudoparesis (P) group (6 male and 3 female shoulders; mean age, 76 $\pm$ 9 years) and 5 patients (6 shoulders) in the non-pseudoparesis (NP) group (6 male shoulders; mean age, 76 $\pm$ 6 years). Pseudoparesis was defined as an active arm elevation angle $< 90°$, as measured by a goniometer.

Image evaluation

The Shoulder Abduction Moment (SAM) index, which indicates the ratio of the moment arms of the rotator cuff and the deltoid muscle, was evaluated using the true anteroposterior view of the GH joint on the radiographic image.[4] The moment arm of the rotator cuff was measured as the radius of the humeral head, and that of the deltoid muscle was measured as the radius of a circle that was centered in the humeral head and touched the most lateral edge of the acromion.

Magnetic resonance images were obtained using a 1.5-T MRI scanner (SIGNA Explorer; GE Healthcare, Chicago, IL, USA) and included T1-weighted spin-echo images (repetition time, 500 milliseconds; echo time, 10 milliseconds; slice thickness, 4 mm; field of view, 160 $\times$ 282 mm) in the oblique sagittal and transversal planes, as well as T2-weighted spin-echo images (repetition time, 3200 milliseconds; echo time, 100 milliseconds; slice thickness, 4 mm; field of view, 160 $\times$ 282 mm) in the oblique coronal, oblique sagittal, and axial planes. The shoulder was scanned in the neutral position. Magnetic resonance images were independently evaluated by 2 orthopedic surgeons with 15 and 25 years of shoulder surgery experience, adopting a consensus-based approach for reporting the findings. The tear size of the rotator cuff was expressed as the number of completely torn tendons. If each tendon (SSC, SSP, ISP, and teres minor) was not torn at the entire attachment, the ratio of the tear area to the entire attachment for each tendon was calculated and evaluated in the T2-weighted oblique sagittal plane. The tear sizes of the anterior and posterior rotator cuffs were defined as the tear area of the SSC and tear area of the ISP as well as teres minor, respectively. The total tear size was defined as the number of torn tendons among the 4 tendons. Moreover, the numbers of shoulders with tears of more than half of the SSC and tears of the entire ISP were counted, and the number of shoulders including both conditions was also counted as global tears. Fatty infiltration of all rotator cuff muscles was graded according to the methodology implemented by Fuchs et al[10] (a modification of the Goutallier classification[11]). The ratio between the fat-infiltrated area and the entire muscle area was evaluated for the SSC, SSP, and ISP muscles using oblique sagittal T1-weighted imaging, in which the scapular spine was in contact with the scapular body, and graded as follows: stage 0, no fatty infiltration; stage 1, some fatty streaks; stage 2, <50% of fatty infiltration; stage 3, about 50% of fatty infiltration; and stage 4, >50% of fatty infiltration. The appearance of the teres minor was classified into 4 types according to Melis et al[17]: normal, hypertrophic, atrophic, and absent. The occupational ratio of the teres minor was calculated using the same image; according to Kikukawa et al,[14] ratios < 0.112 were defined as atrophic whereas ratios > 0.288 were defined as hypertrophic.

Fluoroscopic images and 3D modeling of shoulder

Continuous fluoroscopic images of all patients were collected as they elevated the arm by use of a single-plane fluoroscopy system

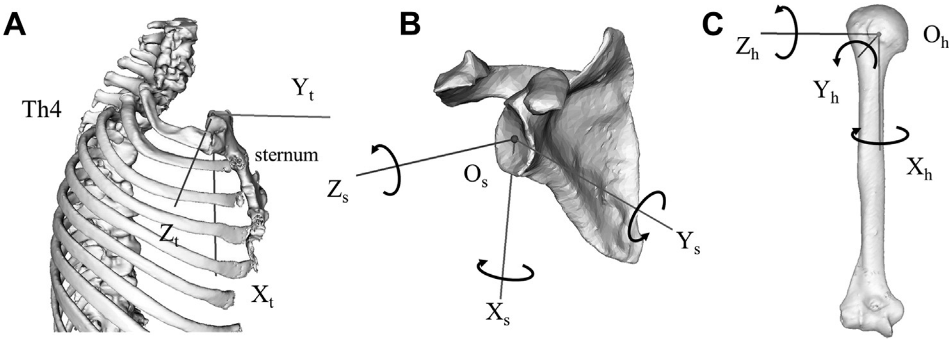

Figure 1 Local coordinate system *(LCS)* of shoulder bones. **(A)** LCS of thorax: The origin of the thoracic LCS *(O_t)* is located at the center of mass of the sternum manubrium. The X_t-Y_t plane is set to include the long axis of the sternum, and the Y_t-axis is collinear to the spinous process of the fourth thoracic vertebra *(Th4)* and the origin. **(B)** LCS of scapula: The origin of the scapular LCS *(O_s)* is the centroid of the glenoid, with the Z_s-axis perpendicular to the glenoid fossa, and the X_s- and Y_s-axes correspond to the inferosuperior and anteroposterior directions of the glenoid, respectively. Scapular rotation relative to the thorax is described as rotation around X_s (positive, retraction; negative, protraction), rotation around Y_s' (positive, downward rotation; negative, upward rotation), and rotation around Z_s'' (positive, posterior tilting; negative, anterior tilting). **(C)** LCS of humerus: The origin of the humeral LCS *(O_h)* is the center of the sphere fitting the humeral head, the X_h-axis is parallel to the humeral shaft, the Y_h-axis is perpendicular to the line connecting the lateral and medial epicondyle, and the Z_h-axis is the lateromedial direction. Humeral rotation relative to the thorax and scapula (thoracohumeral and glenohumeral rotations) is described as rotation around Y_h (positive, adduction; negative, abduction), rotation around Z_h' (positive, flexion; negative, extension), and rotation around X_h'' (positive, external rotation; negative, internal rotation).

(Ultimax-i; Canon Medical Systems, Tochigi, Japan) with 43.2-cm (17-inch) image intensifiers (7.5 Hz, 1024 × 1024 pixels). The patients, while standing between the C-arms and holding their breath to prevent rib movements, were asked to elevate the arm in the scapular plane (30° anteriorly to the coronal plane) as high as possible.

Computed tomography (CT) scans of both shoulders were obtained using the Aquilion 64 CT scanner (Canon Medical Systems). All CT images of bone were automatically segmented, and 3D bone models of the clavicle, scapula, humerus, and first through fourth ribs were generated using a 3D image analysis system (Volume Analyzer Synapse Vincent, version 4; Fujifilm Medical, Tokyo, Japan). The bone contours of the clavicle, scapula, humerus, and first through fourth ribs were extracted from the fluoroscopic images using methods previously described.[22] The 3D orientation of each bone model was calculated using a 2-dimensional (2D)–3D shape-matching registration technique. Regarding the accuracy of this system, the translational and rotational differences in GH motions were 0.4-0.7 mm and 1.1 mm for the in-plane and out-of-plane translations, respectively, and 1.1° and 3.0°-3.8° for the in-plane and out-of-plane rotations, respectively.[22] Those in 3D motions relative to the trunk were 0.7-1.9 mm and 0.3°-1.6°, respectively, for the clavicle; 0.7-1.2 mm and 1.0°-1.4°, respectively, for the scapula; and 0.8-1.4 mm and 0.7°-1.1°, respectively, for the humerus.[22]

Motion analysis

The 3D joint orientation can be expressed as the position of the distal bone in the local coordinate system (LCS) of the proximal bone using Euler angles (a detailed description of Euler angles can be found in Supplementary Fig. S1). First, after having defined the LCS of the thorax, scapula, and humerus (the definition of the LCS is described in detail in Fig. 1), we calculated the thoracohumeral (TH) and scapular motions (ie, humeral and scapular positions relative to the thorax), as well as GH motion (ie, humeral position relative to the scapula). Scapular rotation was described as rotation around X_s (positive, retraction; negative, protraction), Y_s' (positive, downward rotation; negative, upward rotation), and Z_s'' (positive, posterior scapular tilting; negative, anterior scapular tilting) according to the rotational sequence proposed by the International Society of Biomechanics[30] (in the "Results" section, the signs of all rotation values were reversed to allow the values to be easily understood). TH and GH rotations were described as rotation around Y_h (positive, adduction; negative, abduction), Z_h' (positive, flexion; negative, extension), and X_h'' (positive, external rotation; negative, internal rotation) according to the rotational sequence recommended by Bonnefoy-Mazure et al[3] (in the "Results" section, the sign of the abduction angle was reversed). The GH position was calculated as the position of the humeral head center relative to the glenoid center (in the "Results" section, the sign of the inferosuperior position was reversed). All kinematic data were linearly interpolated in 10 equal periods, from the beginning to the end of arm elevation. In addition, the most superior, anterior, and posterior positions of the humeral head center for each elevation were recorded; superior migration was defined as the most superior position of the humeral head center > 5 mm.

Statistical analysis

Radiographic findings and kinematic results were compared between the P and NP groups. The Mann-Whitney *U* test was used for comparisons of the SAM index, tear size, and fatty infiltration between the groups, whereas the χ^2 test was used for comparisons of the numbers of shoulders with tears of more than half of the SSC and tears of the entire ISP, as well as superior migration of

Table I Demographic, radiographic, and MRI data

	P group	NP group	*P* value
Demographic data			
No. of patients/shoulders	8/9	5/6	
Mean age, yr	76 ± 9	76 ± 6	.95
Male/female	6/3	6/0	.15
History of trauma: yes/no	5/4	4/2	.67
Arm elevation angle, °	57 ± 16 (range, 35-75)	140 ± 12 (range, 130-155)	.0017[§]
Radiographic findings			
SAM index[*]	0.74 ± 0.047	0.76 ± 0.057	.29
No. of shoulders with SAM index < 0.77[*]	8 (89%)	3 (50%)	
Tear size[†]			
Anterior RC	0.58 ± 0.28	0.63 ± 0.33	.5
Posterior RC	0.81 ± 0.30	0.57 ± 0.40	.2002
Total	2.39 ± 0.36 (range, 2.0-3.0)	2.20 ± 0.37 (range, 1.67-2.67)	.37
No. of large tears, %			
Tears of more than half of SSC	7 (78)	5 (83)	.79
Tears of entire ISP	6 (67)	2 (33)	.2
Global tear[‡]	4 (44)	1 (17)	.26
Fatty infiltration stage			
SSC	1.9 ± 1.6	2.0 ± 0.8	>.999
SSP	2.6 ± 0.9	2.4 ± 0.9	.76
ISP	2.3 ± 1.2	2.2 ± 1.1	.68
Appearance of teres minor, No. of shoulders			
Normal	7	3	.32
Hypertrophy	1	2	
Atrophy	1	0	
Absent	0	1	
Occupational ratio of teres minor	0.26 ± 0.09	0.29 ± 0.08	.56

MRI, magnetic resonance imaging; *P*, pseudoparesis; *NP*, non-pseudoparesis; *SAM*, Shoulder Abduction Moment; *RC*, rotator cuff; *SSC*, subscapularis; *SSP*, supraspinatus; *ISP*, infraspinatus.

[*] The SAM index indicates the ratio of the moment arms of the rotator cuff and the deltoid muscle. Bouaicha et al.[4] reported that an SAM index < 0.77 was a risk factor for pseudoparesis.

[†] The tear size indicates the number of completely torn tendons. The anterior and posterior RCs include the SSC and the ISP as well as teres minor, respectively. The total tear size indicates the number of torn tendons including the SSC, SSP, ISP, and teres minor.

[‡] A global tear was defined as a tear including both the entire ISP and more than half of the SSC.

[§] Statistically significant ($P < .05$).

the humeral head center. Moreover, 2-way repeated-measures analysis of variance was used for comparisons of kinematic results between the groups. Stepwise regression and Spearman correlation coefficients were used to determine the correlation between tear size and the GH kinematic results. The significance level was set at $P < .05$. Statistical analysis was performed using JMP Pro software (version 14; SAS Institute, Cary, NC, USA).

Results

Clinical data

The mean elevation angles were 57° ± 16° (range, 35°-75°) and 140° ± 12° (range, 130°-155°) in the P and NP groups, respectively (Table I). Moreover, 5 shoulders in the P group and 4 shoulders in the NP group had a history of injury (Table I). The period for which the subjects were incapable of arm elevation in the P group was 3-14 months, with an average of 7 ± 5 months.

Radiographic findings

No significant difference in the SAM index was found between the P and NP groups (0.74 ± 0.047 in P group vs. 0.76 ± 0.057 in NP group, $P = .29$) (Table I). In 8 shoulders (89%) and 3 shoulders (50%), respectively, the SAM index was <0.77, which Bouaicha et al[4] reported as a risk factor for pseudoparesis.

MRI findings

No significant difference in the tear sizes and the number of shoulders with tears of more than half of the SSC and tears of the entire ISP, as well as global tears, was found between the P and NP groups (Table I). Moreover, no significant difference was found in the fatty infiltration stage of the SSC (1.9 vs. 2.0), SSP (2.6 vs. 2.4), and ISP (2.3 vs. 2.2) (Table I). Furthermore, no significant difference was noted in the appearance and occupational ratio of the teres minor (Table I).

Three-dimensional shoulder kinematics

GH positions

After comparison of the values between time 0 and other times (time 0.1 through time 1) by the post hoc Tukey test (10 pairs were compared in both the P group and the NP group), only the P group showed significant superior translation of the humeral head immediately after the beginning of elevation ($P < .0001$ in all pairs in P group and $P > .05$ in all pairs in NP group) (Fig. 2, Supplementary Video S1). Furthermore, the most superior position of the humeral head center in the P group was significantly higher than that in the NP group (6.7 ± 3.0 mm in P group vs. 3.6 ± 1.3 mm in NP group, $P = .032$) (Table II), and the P group showed a significantly larger number of shoulders with superior migration (ie, ≥5 mm) (7 shoulders in P group vs. 1 shoulder in NP group, $P = .0201$).

The NP group showed a good balance between the most anterior and most posterior positions (2.0 mm and –2.9 mm, respectively) (Table II), whereas the P group showed a tendency toward more posterior positions (–0.1 mm and –5.1 mm, respectively), albeit without any significant difference (Table II).

Rotations

Concerning TH rotations, TH abduction at the end of elevation was significantly smaller in the P group (53° ± 25°) than in the NP group (141° ± 20°, $P < .0001$) (Table II), although no significant difference was found at the beginning of elevation. TH external rotation at the end of elevation was also significantly smaller in the P group (16° ± 31°) than in the NP group (91° ± 21°, $P < .0001$) (Table II, Supplementary Video S2), although no significant difference was detected at the beginning of elevation.

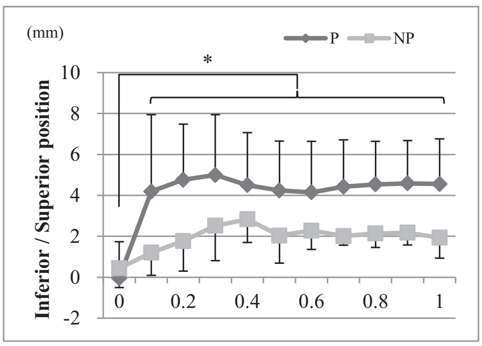

Figure 2 Positions of humeral head center in superoinferior direction. The mean and standard deviation are shown for the pseudoparesis *(P)* and non-pseudoparesis *(NP)* groups. The *horizontal axis* denotes the time of scapular-plane elevation, which is divided into 10 equal periods from the beginning of arm elevation (ie, time 0) to the end of arm elevation (ie, time 1). The positions of the humeral head center in the P group alone were all significantly higher at time 0.1 through time 1 than that at time 0. *$P < .0001$ based on post hoc Tukey test.

Regarding GH rotations, GH abduction at the end of elevation was significantly smaller in the P group (12° ± 25°) than in the NP group (81° ± 16°, $P < .0001$) (Table II), although no significant difference was shown at the beginning of elevation. GH external rotation in the P group tended to be smaller than that in the NP group at the end of elevation (48° ± 24° in P group vs. 76° ± 11° in NP group) (Table II), although no significant differences were observed between the groups either at the beginning or at the end of elevation.

Regarding scapular rotations, the scapula showed upward rotation, protraction, and posterior tilting in both groups during arm elevation. Moreover, no significant differences were found between the groups either at the beginning or at the end of elevation (Table II).

Correlation between tear size and GH motions

The superior, anterior, and posterior positions of the humeral head center showed significant correlations with the total tear size and the tear sizes of the anterior and posterior rotator cuffs ($r = 0.68$ [$P = .0056$] for superior, $r = 0.68$ [$P = .0058$] for anterior, and $r = –0.80$ [$P = .0004$] for posterior) (Table III). GH external rotation also tended to have a negative correlation with the tear size of the posterior rotator cuff but not to a significant extent ($r = –0.48$, $P = .072$) (Table III).

Discussion

Previous studies that investigated the relationship between the tear size and the ability to elevate the arm in patients with massive rotator cuff tears reported tears of more than half of the SSC or the entire ISP were risk factors for the development of pseudoparesis.[7,8,21,29] However, our study showed no significant difference in tear size between the P and NP groups although the P group had slightly larger tears of the posterior rotator cuff. These findings suggest that evaluation of tear size on its own may not completely predict the ability to elevate the arm.

As mentioned in the introduction, abnormal kinematics such as superior migration of the humeral head and loss of the GH abduction angle, which were reported in cadaveric studies, should be evaluated in patients with rotator cuff tears during dynamic elevation of the arm.[19,20,24-26] We believe that kinematic observation using fluoroscopy would provide useful information to assess these patients' ability to elevate the arm. Burkhart[5] observed patients with known massive rotator cuff tears by fluoroscopy during arm elevation and reported that global tears (ie, involving the SSP, a major portion of the ISP, and more than half of the SSC) showed obvious superior translation of the humeral head coming into contact with the lower surface of the acromion. Wieser et al[29] similarly reported that patients

Table II Kinematic results

	P group	NP group	*P* value
Position of humeral head center, mm			
Superior: max	6.7 ± 3.0	3.6 ± 1.3	.032*
Anterior: max	−0.1 ± 2.9	2.0 ± 1.3	.14
Posterior: max	−5.1 ± 5.0	−2.9 ± 2.0	.32
Thoracohumeral rotation, °			
Abduction			
Beginning	11 ± 7	10 ± 4	>.999
End	53 ± 25	141 ± 20	<.0001*
External rotation			
Beginning	−32 ± 14	−15 ± 19	.99
End	16 ± 31	91 ± 21	<.0001*
Glenohumeral rotation, °			
Abduction			
Beginning	−2 ± 10	5 ± 12	>.999
End	12 ± 25	81 ± 16	<.0001*
External rotation			
Beginning	11 ± 10	24 ± 27	>.999
End	48 ± 24	76 ± 11	.73
Scapular rotation, °			
Upward rotation			
Beginning	4 ± 9	−3 ± 9	.99
End	44 ± 10	48 ± 5	>.999
Protraction			
Beginning	42 ± 12	36 ± 6	.99
End	50 ± 9	52 ± 10	>.999
Scapular tilting			
Beginning	28 ± 12	32 ± 8	>.999
End	22 ± 12	23 ± 5	>.999

P, pseudoparesis; *NP*, non-pseudoparesis; *max*, farthest position of humeral head center relative to glenoid center in each direction (superior, anterior, and posterior) during arm elevation.
* Statistically significant ($P < .05$).

Table III Correlation between tear size and GH motions

GH motion	Tear size	Correlation coefficient	*P* value
Superior position (max)	Total tear size	0.68	.0056*
Anterior position (max)	Anterior RC	0.68	.0058*
Posterior position (max)	Posterior RC	−0.80	.0004*
GH external rotation (end)	Posterior RC	−0.48	.072

GH, glenohumeral; *max*, farthest position of humeral head center relative to glenoid center in each direction (superior, anterior, and posterior) during arm elevation; *RC*, rotator cuff.
* Statistically significant ($P < .05$).

with pseudoparesis showed a GH abduction angle of nearly 0°, as evaluated through fluoroscopy. These findings were evaluated 2-dimensionally by fluoroscopy, whereas a 2D-3D registration technique has recently been developed, consisting of a 3D dynamic analysis method by superimposing 2D fluoroscopic images and 3D bone models. Several scholars compared 3D shoulder kinematics between healthy volunteers and patients with rotator cuff tears using this technique and reported small translations of <2 mm on average, which were smaller than those observed in our study. This discrepancy might be because of differences in the severity of rotator cuff tears in the selected patients. More specifically, Kijima et al[13] and Millett et al[18] selected only patients with medium tears, whereas Kozono et al[16] selected those with large and massive tears without pseudoparesis. Our study did not demonstrate significant superior translation in the NP group, which agrees with the results obtained by Kozono et al.

To our knowledge, this is the first study to clarify the correlation between tear size and 3D shoulder kinematics and to show the kinematic features leading to pseudoparesis in patients with large and massive rotator cuff tears. Among the authors who performed cadaveric studies investigating the effects of rotator cuff tears on GH motion, Su et al[24] reported that tears involving the superior half of the SSC led to anterosuperior translation and Oh et al[20] demonstrated that tears of the SSP and half of the ISP led to posterior translation. Several authors also reported significant superior translation in specimens in which either half of the SSC or the entire ISP was added to the SSP tear.[12,20,24,25] Furthermore, Ackland and Pandy[1] stated that the inferior portion of the ISP and the teres minor were the greatest external rotators. These cadaveric findings support our results, which showed that the total tear size was significantly correlated with superior migration and that the tear sizes of the anterior and posterior rotator cuffs were significantly correlated with anteroposterior translation. The tear size of the posterior rotator cuff also tended to affect the loss of GH external rotation in this study. It is interesting to note that, among such abnormal kinematics, superior migration of the humeral head and loss of TH external rotation were identified as features of 3D kinematics in the pseudoparesis in our study. Although superior migration of the humeral head was mentioned in previous reports,[5,29] the loss of TH external rotation was a new finding. By comprehensively interpreting the correlation between tear size and kinematics and the characteristics of 3D kinematics in pseudoparesis, it is considered that large and massive rotator cuff tears may induce abnormal kinematics and lead to pseudoparesis in some cases. We believe that detecting the risk factors for pseudoparesis through MRI and kinematic evaluation would provide help in the decision-making process concerning the need for surgery, as well as in the choice of future operative procedures.

So far, conservative or postoperative rehabilitation protocols for patients with rotator cuff tears have focused on the scapula; in particular, such protocols aimed to improve the range of rotation and the stability of the scapula, and correction of the alignment of the scapular anterior tilting has been considered effective.[9] Previous kinematic studies reported that patients with massive rotator cuff tears showed larger upward rotation than healthy volunteers and patients with only SSP tears.[15,28] A possible reason is that the loss of rotator cuff function led to a decrease in GH abduction torque and the scapula rotated more upwardly through a compensatory mechanism. Our results showed similar rotations of the scapula between the P and NP groups, perhaps because both groups had large and massive rotator cuff tears and reduced abduction torque.

One of the strengths of this study was the collection of 3D shoulder kinematics in patients with pseudoparesis not accompanied by severe pain, which would inhibit forceful active elevation of the arm. Although some authors have injected local anesthetics before analysis, we often observe inadequate pain relief in patients.[23,27,29] This kinematic analysis was considered successful by excluding patients with severe pain. A second strength was the inclusion of the thorax in the 3D kinematic analysis; in fact, previous studies only tracked the 3D positions of the scapula and the humerus in a global coordinate system.[13,16,18] As some of our older patients had unstable trunks and could not stand still, the movements of the scapula and humerus in a global coordinate system could not accurately represent the scapulothoracic and TH movements.

One of the limitations of this study was that the criteria for patient selection were not strict. According to Tokish et al,[27] the term ‘‘pseudoparalysis’’ refers to the absence of active elevation caused by a chronic massive rotator cuff tear whereas ‘‘pseudoparesis’’ refers to a limitation in active elevation with muscle weakness. However, Tokish et al noted that many authors have used the terms ‘‘pseudoparalysis’’ and ‘‘pseudoparesis’’ confusingly. Furthermore, Burks and Tashjian[6] recommended that ‘‘pseudoparalysis’’ be defined as active elevation $< 45°$ due to chronic and atraumatic massive rotator cuff tears, with concurrent fatty infiltration of at least stage II or III. By contrast, our study included some patients with a traumatic onset of symptoms and with low-stage fatty infiltration; therefore, such cases should be referred to as cases of ‘‘pseudoparesis,’’ not ‘‘pseudoparalysis.’’ Another limitation was the small number of cases in the NP group; in fact, a larger sample size would be necessary to detect statistically significant differences. However, because patients with mild pain and an active arm elevation angle $> 90°$ may not present to the hospital or may not agree to participate in the study, it may be difficult to enroll more cases.

Conclusion

We hypothesized that large and massive rotator cuff tears may be associated with abnormal shoulder kinematics, finally leading to pseudoparesis. Anterior and posterior rotator cuff tears cause significant superior and anteroposterior translations of the humeral head, and posterior cuff tears may lead to loss of GH external rotation. With these abnormal kinematics, superior migration (ie, >5 mm) and loss of TH external rotation were identified as features of pseudoparesis.

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Supplementary data

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