INTRODUCTION

The rotator interval (RI) is defined as the space between the anterior aspect of the supraspinatus tendon (SST) and superior aspect of the subscapularis tendon (SSC), covered by rotator interval capsule (RIC) (1, 2). It represents a region of capsule that is not reinforced by overlying rotator cuff tendon (1) and its components, coracohumeral ligament (CHL) and superior glenohumeral ligament (SGHL), are suggested to have a role in glenohumeral joint (GHJ) stability. The role of different shoulder stabilizers vary according to different shoulder position. For example, the CHL is shown to be a stabilizer in superior-inferior directions with arm in external rotation, whereas, the intra-articular pressure that is maintained by the intact RIC is suggested to act as a stabilizer in superior-inferior directions with the arm in internal and neutral rotations (3). The role of the RI in shoulder mechanopathology remains a much debated subject, with some authors advocating its role as a negative articular pressure inducer (3), whereas others, in resisting postero-inferior glenohumeral translation (4-7).
Surgical repair of the RI is suggested to be helpful in surgical treatment of posterior and multidirectional instability (4, 5, 7-10), and attempts have been made to diagnose RI injury both clinically and on imaging (6, 9, 11-13); however, there is no definitive means of diagnosing a widened RI objectively yet. RI lesions are classified into 4 types by orthopedic surgeons including; type I, contracture; type II, laxity with GHJ instability; type III, traumatic injury: IIIa tear and IIIb coracoid impingement; and type IV, bicipital instability involving CHL, SGHL, SSC (14). Imaging studies on diagnosis of type I and III lesions have used magnetic resonance arthrography (MRA), especially regarding RI deficiency in instability lesions (2, 15, 16). Clinically, authors have suggested that the sulcus sign, which appears as a depression of the posterior aspect of shoulder just below the acromion upon applying traction in an inferior direction that disappears upon external rotation because of tightening of the RI, persisting on 45 degree external rotation of the arm, would suggest pathologic laxity and RI widening (1-13, 17). Widening of the RI is clinically identified in the arthroscopic field by an increased distance between the SST and SSC tendons and between the biceps long head tendon and anterior edge of the SSC tendons. However, there are few studies on the correlation between clinical examination findings with dimensions of the RI on imaging.

Reports have indicated that standardized anteroposterior radiographs are a reliable and reproducible method for measurement of acromiohumeral (AH) interval (18), which is decreased in patients with SST tear and increased in shoulder dislocation. Therefore, the AH distance would be increased in patients with RI laxity with persistence in external rotation of the arm as in the physical examination for sulcus sign.

In this study, we compared the RI dimensions on direct CT arthrography (CTA) and correlated them with AH distances on neutral and external stress radiographs in patients with clinical instability.

**MATERIALS AND METHODS**

This retrospective study was approved by the Institutional Review Board and the requirement for patients’ informed consent was waived.

**Patients**

Between January 2005 and December 2008, 115 consecutive patients with clinically diagnosed instability of the GHJ with history of dislocation and subluxation (97 shoulders) and undetermined shoulder pain with clinical instability or apprehension (26 shoulders), underwent direct CTA using 16 or 64 channel multidetector CT (MDCT) and shoulder stress radiography in neutral position and external rotation. Eight patients underwent bilateral shoulder examination. Total 123 shoulder CTAs (107 men, 16 women; mean age, 25 years; range, 14–58 years) were enrolled including 78 right and 45 left shoulders.

**Imaging Studies: CT and Stress Radiography**

After intra-articular positioning of a 22-gauge needle through an anterior approach under fluoroscopic guidance, intra-articular injection of 12–20 mL mixed solution of 13 mL meglumine ioxitalamate (Telebrix 30 Meglumine; Guerbet, Aulnay-sous-Bois, France) and 7 mL normal saline was performed until the patient complained of pain or the injecting physician felt pressure. CT scanning was performed with 16- or 64-channel MDCT. In 88 shoulders, axial image were obtained with 16-channel MDCT (Mx 8000 IDT; Philips Medical Systems, Eindhoven, the Netherlands) with the following protocols: rotation speed of 0.75 second per rotation, a current of 240 mAs, a voltage of 120 kVp, and a collimation of 2.5 mm. The field of view (FOV) at acquisition was 30 cm, and section thickness was 1.0 mm, with a section increment of 0.5 mm (50% section overlap). In 35 shoulders, axial images were obtained with 64-section MDCT (Brilliance 64; Philips Medical Systems) with the following protocol: rotation speed of 0.75 second per rotation, a current of 300 mAs, a voltage of 140 kVp, and a collimation of 0.625 mm. The FOV at acquisition was 30 cm, and section thickness was 0.67 mm, with a section increment of 0.33 mm (50% section overlap). Oblique sagittal images parallel to the glenoid fossa and oblique coronal images vertical to the glenoid fossa were reconstructed (1024 × 1024 matrix with 2-mm thickness) using an imaging workstation (Rapidia, version 2.8; Infinitt, Seoul, Korea). All patients were placed in the supine position, with the arm adducted along the body, the shoulder in a neutral position with the thumb pointing upward.

Stress radiographs of the shoulder were obtained in standardized anterior-posterior (AP) direction in upright position, with
a voltage of 60 kVp and a current of 8 mAs. The stress was applied by 10 lb sandbags in both hands. The stress radiographs were obtained in neutral position with the patient’s arm adducted alongside the body and in external rotation positions with the arm adducted but elbow and forearm externally rotated at 90 degrees away from the body.

Image Analysis

The CTA images and stress radiographs of the shoulder were reviewed by 2 musculoskeletal radiologists under consensus (a Fig. 1. A case of "external rotation instability positive".
A. The stress radiograph in neutral position is obtained in a 27-year-old man with right shoulder instability. The acromiohumeral (AH) distance (double-headed arrow) is 1.93 cm.
B. The AH distance on the stress radiograph in external rotation position (double-headed arrow) is 2.51 cm. There is increased AH distance compared to neutral stress radiograph.
C. An oblique sagittal CT arthrographic image shows the rotator interval (RI) dimensions. The width of the RI (long arrow) is 2.29 cm and the depth (short arrow) is 0.88 cm.
D. RI widening (arrows) is seen along with anteroinferior labral tear (arrowheads) at arthroscopy, so RI closure is performed.
fellow in musculoskeletal radiology, a staff radiologist with 8 years of experience, blinded to clinical information) for training, and then independently.

The dimensions of RI on CTA were analyzed on sagittal image, at the section just lateral to coracoid process. The width and depth were obtained (Figs. 1, 2) by measuring the most lateral image in which the coracoid process was present from the superior border of the SSC to the anterior border of the SST and as the longest perpendicular distance from humeral head to the roof of the RI of the RIC, respectively.

The AH distance was measured as the length between the undersurface of acromion and apex of humeral head. The AH distance was measured on neutral and external rotation stress radiographs, respectively. If the AH distance was not changed or increased on external rotation, as compared to neutral position, the case was classified as “external rotation instability positive (+)” (Fig. 1). These criteria were based on the sulcus sign on physical exam for patients with instability (19); the sulcus sign disappears normally in external rotation because of tightening of the RI and the presence of persistent sulcus sign although glenohumeral external rotation may suggest pathologic laxity when symptoms are elicited (19). So in cases with intact RI without pathologic laxity, the AH distance is expected to decrease upon external rotation. If the AH distance was decreased on external rotation, the case was classified as “external rotation instability negative (-)” (Fig. 2).

Statistical Analysis

The software SPSS (version 15.0; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The student t-test was used to compare the diameter of RI (AP and longitudinal diameter) between ‘external rotation instability +’ and ‘external rotation instability -’ group. A p value of < 0.05 was considered statistically significant. The inter-observer reliability was tested for the 2 observers using intraclass correlation coefficient (ICC); ICC was interpreted as indicating poor (ICC, 0–0.2), fair (ICC, 0.3–0.4), moderate (ICC, 0.5–0.6), strong (ICC, 0.7–0.8), or almost perfect (ICC, > 0.8) agreement.

Arthroscopic surgical reports were subsequently reviewed to evaluate RI pathology and RI closure.

RESULTS

After measurement of the AH distance on external and neutral stress radiographs, 79 shoulders (73 male, 6 females; mean age 25.2 years) among total 123 shoulders, were classified as “external rotation instability +” group. In this group, the AP diameter of RI was 2.43–0.31 cm and longitudinal diameter was 0.87–
The “external rotation instability (-)” group included 44 shoulders (34 male; 10 females, mean age 27 years). The width of RI was 2.02–0.45 cm and depth was 0.75–0.2 cm on CTA (Table 1). The width and depth of RI were significantly greater in external rotation instability (+) group (p = 0.000 and 0.003, respectively).

Accompanied lesions included 94 Bankart and variant type of lesions and 78 superior labral tear from anterior-to-posterior (SLAP) lesions; fifty-five had both Bankart/variants and SLAP lesions. External rotation instability (+) group had significantly more Bankart lesions than (-) group (n = 61 vs. 33, p < 0.05 by Student t-test). SLAP was not significantly increased in external rotation instability (+) group. ICC, used to evaluate agreement between the 2 observers for each measurement, was strong (0.75).

Review of clinical records after image analysis revealed that 92 patients underwent arthroscopic surgery, 63 of whom were external rotation instability (+) on preoperative radiographs; RI closure was performed in 8 patients, all these patients had shown external rotation instability (+).

DISCUSSION

The main function of shoulder stabilizers reportedly vary according to shoulder position. In one previous report (3), the superior-inferior stabilizing functions of the CHL and RIC in 6 cadaver shoulders were studied with use of a material testing machine, where axial translation of the humerus with the superior-inferior translation force of 30N applied were recorded under the following joint capsule conditions: 1) intact, 2) vented, 3) the CHL sectioned, and 4) the RIC incised. The conclusion was that the CHL is a stabilizer in superior-inferior directions with the arm in external rotation, and the intact RIC is a stabilizer in superior-inferior directions with the arm in internal and neutral rotations. In a cadaveric study, Harryman et al. (4) showed the importance of the RI in maintaining GHJ stability. They made a transverse incision through the capsule, CHL, and SGHL. Sectioning produced increased translation in all planes particularly, after sectioning of the RI capsule posterior and inferior instability with the arm at 60 degrees of abduction and 60 degrees of external rotation, with dislocation in half of specimens.

Detecting and closing a RI defect arthroscopically may be difficult as the RI is regularly used as the anterior portal in shoulder arthroscopy, decreasing the chance of discovering lesions in this area (20). Recognition of the normal and widened RI can be difficult and is most frequently based on the surgeon’s experience. The RI is generally considered as widened if the interval extends superior to the biceps, when viewed from the posterior portal. So, preoperative detection of the RI injury is necessary if appropriate surgical repair is to be performed. MRA before surgery is helpful in identifying RI injury (21, 22), with the following findings indicative of RI lesions at surgery: gadolinium extending to the cortex of the undersurface of the coracoid process, especially in the presence of a labral tear and/or thickening of the CHL or superior GHL (23).

Laxity of the rotator cuff interval occurs in patients with a broad spectrum of injury. There may be a history of acute trauma, repetitive microtrauma, or underlying ligamentous laxity with superimposed ligament injury. Widening can be seen in a patient with a first-time dislocation, an overhead athlete, or patient with more diffuse multidirectional instability (13). Nobuhara and Ikeda (12) quantified the interval distance in 5 cadavers and reported the average distance from the anterior SST to the superior SSC as 21.6 mm, and 27.8 mm in a distended joint. The reported average distance in distended joint was greater than our study, probably because they measured the distance at the level of glenoid margin (more medial position than our study). Also, in our study, the amount of contrast varied according to each patient and in patients with RI laxity, more contrast was injected, which probably resulted in greater AH distance, including the position of external rotation. In another study (14), measurements of the width of the RI were made on the sagittal images of the MRAs of 32 specimens. In all cases, the capsule was measured at the level of the intra-articular biceps tendon on an image just lateral to the coracoid process, as measured in our study. The width of the RI capsule ranged from 1.7 to 2.0 mm (mean 1.8 mm) (14). The reported width was small-
er than in subjects that showed external rotation instability in our study, probably because these were measured in specimens, as compared with patients with instability.

RI closure in instability surgeries remains controversial with few studies on objective evaluation of the RI dimensions and widening; however, some studies provide evidence for widened RI, which would warrant their closure (10, 13, 24). The widening of the RI may be represented by relatively anterior position of the biceps long head tendon, representing dilatation of the anterior capsule, which would hence lead to failure in this region (25) and increased AH distance. Another study on comparative RI dimensions between subjects with and without instability reported significant differences in the RI dimensions between the 2 groups (26). On MR arthrography, RI dimensions were greater in shoulders with MDI as compared to controls, according to an earlier study (27). In our study, there was no control group per se; however, differences were found in the CTA dimensions between patients with external stress instability and those without. To the best of our knowledge, no study has correlated measurements of RI dimensions on CTA and AH distance measurements on external rotation stress radiographs, which would correspond to imaging assessment of the sulcus sign on external rotation.

Our study had several limitations. First, the study was limited by its retrospective nature and not all cases had surgical or arthroscopic correlation about RI lesion; however, it is difficult to evaluate RI laxity on arthroscopic exam, so the orthopedic surgeon frequently relies on the imaging findings for determination of RI laxity along with physical examination findings. Second, there was no analysis of intraobserver agreement of the measurements. Last, there was no true normal control group because external stress radiographs are not routinely taken in normal controls or patients without instability. Furthermore, we could not use the contralateral side because oftentimes the patients were clinically lax or had instability at both shoulders.

In conclusion, the width and depth of RI on CTA were correlated with increased AH distance on external rotation stress radiographs. Therefore, stress radiographs in neutral and external rotation may be useful in evaluation of RI laxity or injury, supplementing clinical findings on physical examination, and help in preoperative planning.

Acknowledgments
Study materials obtained at previous affiliation of corresponding author, namely, Seoul National University Bundang Hospital.
This study was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2012R1A1A3010896).

REFERENCES
견관절 불안정 환자의 CT 관절 조영술상 회전근개 간격과 외회전 부하 영상과의 연관성

정윤식 · 최희석 · 최정아*

목적: 견관절 불안정 환자의 CT 관절 조영술상 회전근개 간격과 외회전 부하 영상과의 연관성을 알아보고자 하였다.

대상과 방법: 견관절 불안정이 있는 115명의 환자의 123 견관절을 대상으로 하였다. CT arthrography (이하 CTA) 및 중립 자세 외회전 부하 영상을 분석하였다. CTA는 관절 내 조영제 주입 후에 축상면, 관상면 사위, 시상면 사위 CT 영상을 획득하였다. 회전근개 간격의 넓이와 깊이를 오구돌기 직원위면의 CTA 시상면 사위 영상에서 획득하였고, 전봉상완 거리는 중립과 외회전 부하 영상에서 측정하였다. CTA 영상에서의 측정치와 중립 및 외회전 부하 영상에 전봉상완 거리를 외회전 불안정성 유무군과 비교분석하였다.

결과: 중립 자세와 비교하여 외회전시 123 어깨 중 외회전 불안정성이 있는 79개의 어깨에서 전봉상완 거리가 증가하거나 변하지 않았다. 회전근개 간격의 넓이는 2.43 ± 0.31 cm, 깊이는 0.87 ± 0.2 cm로 측정되었다. 중립 외회전 자세에서 외회전 불안정이 없는 44 어깨의 전봉상완 거리 감소가 측정되었다. 회전근개 간격의 넓이는 2.02 ± 0.45 cm, 깊이는 0.75 ± 0.2 cm로 측정되었다. 회전근개 간격의 넓이와 깊이는 외회전 불안정 환자군에서 유의한 증가를 보였다.

결론: 외회전 부하 CTA 촬영에서 회전근개 간격의 넓이와 깊이는 전봉상완 거리와 유의한 연관성이 있다.

한림대학교 의과대학 동탄성심병원 영상의학교실