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Normal Range of Humeral Head Positioning on the Glenoid on Magnetic Resonance Imaging: Validation through Comparison of Computed Tomography and Magnetic Resonance Imaging

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Background: To determine the normal range of humeral head positioning on magnetic resonance imaging (MRI).
Methods: We selected normal subjects (64 patients; group A) to study the normal range of humeral head positioning on the glenoid by MRI measurements. To compare the MRI measurement method with the computed tomography (CT), we selected group B (70 patients) who underwent both MRI and CT. We measured the humeral-scapular alignment (HSA) and the humeral-glenoid alignment (HGA).
Results: The HSA in the control group was 1.47 ± 1.05 mm, and the HGA with and without reconstruction were 1.15 ± 0.65 mm and 1.03 ± 0.59 mm, respectively, on MRI. In the test group, HSA was 2.67 ± 1.47 mm and HGA with and without reconstruction was 1.58 ± 1.16 mm and 1.49 ± 1.08 mm, on MRI. On CT, the HSA was 1.72 ± 1.01 mm, and HGA with and without reconstruction were 1.54 ± 0.96 mm and 1.59 ± 0.93 mm, respectively. HSA was significantly different according to image modality (p=0.0006), but HGA was not significantly different regardless of reconstruction (p=0.8836 and 0.9234).
Conclusions: Although additional CT scans can be taken to measure decentering in patients with rotator cuff tears, reliable measurements can be obtained with MRI alone. When using MRI, it is better to use HGA, which is a more reliable measurement value based on the comparison with CT measurement (study design: Study of Diagnostic Test; Level of evidence II).
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Key Words: Humeral head position; Rotator cuff tears; Decentering; Humeral-scapular alignment; Humeral-glenoid alignment

Introduction

Glenohumeral joints may be accompanied by instability due to the relatively large humeral head and small glenoid. Glenohumeral joint stability is maintained by static and dynamic restraints. Because of these restraints, minimal translation is observed during various shoulder movements, and the humeral head remains centered on the glenoid. However, when glenoid deformity occurs due to severe arthritis, glenohumeral joint stability can be affected. Soft tissue problems such as a capsulolabral ligamentous complex injury or a rotator cuff tear may also affect the stability of the glenohumeral joint.[1,2]

Humeral head subluxation according to glenoid wear and retroversion has been studied.[3-5] Humeral head position on the glenoid in osteoarthritis is an important clinical factor because it determines the degree of glenoid deformation and is related to prognosis after arthroplasty.[6-9] In massive rotator cuff tear and cuff tear arthropathy, abnormal positioning of the humeral head on the glenoid, such as humeral head upward migration and anterosuperior escape, can also develop, and this finding affects the choice of treatment options and the clinical outcome after surgery.[10-12] We observed subluxation of the humeral head even in patients with small- to medium-sized rotator cuff tear without osteoarthritis or instability, not just those with massive rotator

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cuff tear or cuff tear arthropathy. We are interested in the clinical significance of this phenomenon, but we cannot proceed without first defining the normal range of the humeral head position. Thus, we decided to explore the normal range of the humeral head position.

Studies have been conducted to quantify humeral head positioning and subluxation by computed tomography (CT) and magnetic resonance imaging (MRI). Conventional two-dimensional (2D) CT and three-dimensional (3D) CT are used because of good reliability. 3D CT is considered more accurate than 2D CT because 3D CT can overcome the positional error of the 2D CT method by using axis reconstruction that allows the image to be rotated in the desired direction, or for the axis to be changed to reset the image.

MRI, which is commonly used clinically in rotator cuff tear diagnostics, also can be used to quantify humeral head positioning and subluxation on the glenoid. However, most research on the relationship between the humeral head and glenoid has been conducted in osteoarthritis patients,[3-5,7,8] and few have reported on humeral head positioning on the glenoid in normal healthy subjects.[13-15] Moreover, most literature on the relationship between the humeral head and glenoid involve CT measurements[4,5,13,16,17]; few studies have reported on the use of MRI,[15,18,19] and no study used MRI axis reconstruction. In addition, there is no report comparing CT and MRI methods for quantification of humeral head positioning. Therefore, the purpose of this study is 1) to evaluate the range of humeral head positioning on the glenoid in normal adults by using MRI, and 2) to confirm the accuracy of the MRI method in comparison to the CT measurement method which has previously been studied.

Methods

After approval by the institutional review board (17-0127), we reviewed 2,147 patients who underwent shoulder MRI from January 2012 to June 2017. All MRI were reviewed by a single radiologist (with 10 years of experience in musculoskeletal imaging). The inclusion criteria of subjects for studying the normal range of humeral head positioning on the glenoid (group A) were as follows: (1) normal findings in MRI, (2) simple rotator cuff tendinosis on MRI, (3) simple contusion on MRI. The exclusion criteria were: (1) a rotator cuff tear in MRI, (2) previous history of fractures or surgery on the affected shoulder, (3) arthritic changes of the glenohumeral joint on radiographic studies, (4) history of shoulder dislocation or instability, (5) lesions that may affect stability in MRI (e.g., Bankart lesion, or a superior lateral tear from the anterior to the posterior [SLAP lesion]), and (6) the presence of posterior synovial hypertrophy.[15] We also selected a group of subjects who had both MRI and CT to validate the MRI measurement method by comparing CT and MRI measurements (group B). If the time interval between MRI and CT was longer than 1 month, we excluded the subject. There was no overlap among patients between the two groups.

Sixty-four patients (27 males, 37 females; mean age: 46.72 ± 13.24 years) were selected as final subjects to evaluate and quantify normal positioning of the humeral head by MRI (group A), and 70 patients (27 males, 43 females; mean age: 59.53 ± 7.08 years) were selected to compare MRI and CT methods (group B).

Imaging Protocols of Computed Tomography

All scans were made with the patient in the supine position with the arm by the side and the hand on the lateral aspect of the thigh. All imaging was performed on a Siemens (SOMATOM 128, Definition AS+) scanner (Siemens Healthcare, Forchheim, Germany) with the use of a single-energy CT protocol with 120 kVp, 180 mA with dose modulation 0.6-mm collimation, effective pitch of 0.8, B60 (sharp) reconstruction kernel, reconstructed slice thickness of 1.0 mm, and slice increment of 1.0 mm.

Image Acquisition of Magnetic Resonance Imaging

For indirect magnetic resonance (MR) arthrography, gadobutrol (Gadovist; Bayer Schering Pharma, Berlin, Germany; 0.1 mmol/kg body weight), an MR contrast material, was injected intravenously. Patients were instructed to smoothly exercise their shoulders for 15 minutes, after which MRIs were obtained with a 3-T MR unit (Achieva 3.0 T TX; Philips Medical Systems, Best, The Netherlands) and the use of an eight-element phased-array shoulder coil. All scans were made with the patient in the supine position with the arm by the side and the hand on the lateral aspect of the thigh. Conventional 2D MRI was performed first, followed by 3D isotropic T1-weighted fast-spin echo (FSE) imaging. Conventional 2D MRIs consisted of axial, oblique coronal, and oblique sagittal fat-suppressed T1-weighted FSE sequences and oblique coronal and oblique sagittal T2-weighted FSE sequences. We performed the 3D isotropic fat-suppressed T1-weighted FSE (volumetric isotropic turbo spin-echo acquisition; Philips Medical Systems) sequence with 0.5-mm thickness in the oblique coronal plane, and the source data were reformatted into axial and oblique sagittal planes with 1-mm thickness. Post-processing was performed by a technologist at the imaging workstation immediately after the MRI; the time required for image reformation was approximately 1 minute.

Image Reconstruction and Assessment

Shoulder MRIs and CTs were reconstructed according to the scapular axis using the anatomic analysis method by Sabesan et al.[4] For reconstruction, image analysis software (RadiAnt DICOM viewer; Medixant, Poznan, Poland) was used. The plane passing through the angular inferior, trigonum scapulae, and glenoid center of the scapula was defined as a scapular plane, and an axial plane perpendicular to the scapular plane and passing through the center of the glenoid was obtained (Fig. 1).

To accurately measure the humeral head centering in this image, image measuring software (Rhinoceros 5; McNeel, Seattle, WA, USA) was used. The articular surface of the humeral head was assumed to be part of one circle[20]; two points were assigned to the articular surface, and one point was assigned to the greater tuberosity area; a circle with the best fit to the humeral head passing through these three points was obtained. After obtaining the best-fit circle, the center of the circle was measured. We then measured the humeral-scapular alignment (HSA), which is the distance between the center of the circle and the line passing through the scapular axis. We also measured the humeral-glenoid alignment (HGA), the distance between the center of the circle and the perpendicular line passing through the center of the line between the glenoid plane (Fig. 2). We also measured HGA without performing axis reconstruction, assuming a situation in which the MRI is typically used.

Two orthopedic surgeons specializing in the shoulder took the measurements twice at 2-week intervals to confirm interobserver and intraobserver reliability.

Statistical Analysis

Statistical analysis was performed using IBM SPSS ver. 22.0 (IBM Co., Armonk, NY, USA). For sample size calculation, a power analysis was performed with alpha set at 0.05 and the power set at 0.80. In the pilot study (n=30), the HSA of group A in MRI was 1.59 ± 0.85 mm; the HGA of group A in MRI was 1.07 ± 0.51 mm. The HSA and HGA of group B (n=30, group for comparison between CT and MRI measurement) in MRI were 2.51 ± 1.37 mm and 1.62 ± 1.09 mm, respectively. The number of cases needed to detect a difference between the HGA of groups A and B was 64 and between the HSA of groups A and B was 38. In the present study, 134 cases (64 normal group A and 70 group B) were enrolled. The Mann-Whitney U test was used to assess HSA and HGA between groups A and B. The reliability of the measurements of the radiologic parameters was expressed as an intra-class correlation coefficient (ICC). The ICCs for intra-observer reliability for all measurements (HSA, HGA) were 0.82 to 0.87 in MRI and 0.91 to 0.93 in CT. In addition, the ICCs for inter-observer reliability were 0.79 to 0.84 in MRI and 0.90 to 0.92 in CT. All tests were analyzed with a 95% confidence level. The level of significance was set at 0.05.

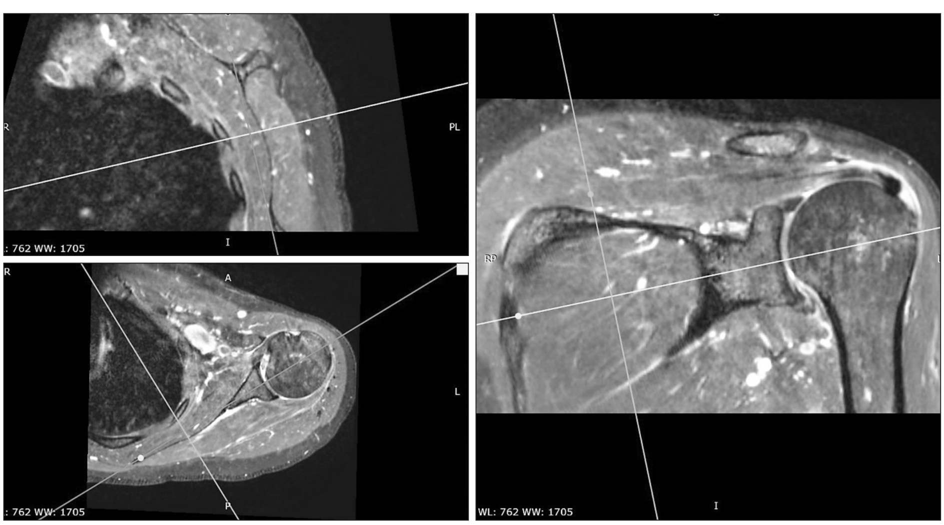

Fig. 1. Reconstruction to scapular axis of normal magnetic resonance imaging (MRI). After setting the axial, coronal, and sagittal views of the MRI to be visible at the same time, we reconstructed the plane passing through the angular inferior, trigonum scapulae, and glenoid center of the scapular using the image analysis software (RadiAnt DICOM viewer). The scapular axis, which is perpendicular to this plane and is the line representing this plane in the axial plane passing through the glenoid center, was obtained.

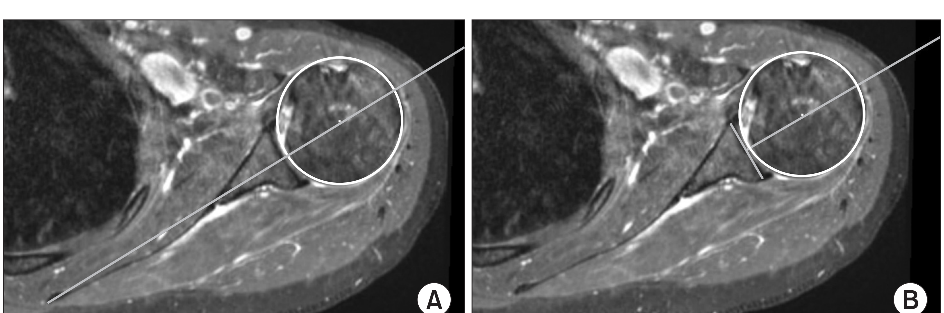

Fig. 2. Measuring of humeral head center. (A) Humeral-scapular alignment. The distance between the center of the circle and the line passing through the scapular axis. (B) Humeral-glenoid alignment. The distance between the center of the circle and the perpendicular line passing through the center of the line between the glenoid plane.

Table 1. Normal Range of Humeral Head Positioning (Group A)

Variable	Normal range (mm)	*p*-value
HSA	1.47 ± 1.05 (1.32–1.63)	HSA-HGA with reconstruction: 0.0075
HGA with reconstruction	1.15 ± 0.65 (1.04–1.25)	HSA-HGA without reconstruction: <0.001
HGA without reconstruction	1.03 ± 0.59 (0.98–1.19)	HGA with-without reconstruction: 0.579

Values are presented as mean ± standard deviation (95% confidence interval).
HSA: humeral-scapular alignment, HGA: humeral-glenoid alignment.

Table 2. Comparison between CT and MRI Measurement (Group B)

Variable	MRI	CT	*p*-value
HSA (mm)	2.67 ± 1.47 (2.22–3.11)	1.72 ± 1.01 (1.43–2.01)	0.0006
HGA with reconstruction (mm)	1.58 ± 1.16 (1.18–1.97)	1.54 ± 0.96 (1.24–1.84)	0.8836
HGA without reconstruction (mm)	1.49 ± 1.08 (1.10–1.88)	1.59 ± 0.93 (1.30–1.91)	0.9234

Values are presented as mean ± standard deviation (95% confidence interval).
CT: computed tomography, MRI: magnetic resonance imaging, HSA: humeral-scapular alignment, HGA: humeral-glenoid alignment.

Results

Normal Range of Humeral Head Positioning with and without Reconstruction (Group A)

In the MRI of normal healthy subjects, HSA was measured as 1.47 ± 1.05 mm (95% confidence interval [CI], 1.32–1.63 mm) and HGA with and without reconstruction were measured as 1.15 ± 0.65 mm (95% CI, 1.04–1.25 mm) and 1.03 ± 0.59 mm (95% CI, 0.98–1.19 mm). There were significant differences between mean HSA and HGA with and without reconstruction ($p=0.0075$, $p<0.001$). HGA without reconstruction was not significantly different from HGA with reconstruction ($p=0.579$; Table 1).

Comparison between Computed Tomography and Magnetic Resonance Imaging Measurement (Group B)

In the MRI measurement of humeral head positioning on the glenoid in subjects who had both MRI and CT, HSA was 2.67 ± 1.47 mm (95% CI, 2.22–3.11 mm), HGA with reconstruction was 1.58 ± 1.16 mm (95% CI, 1.18–1.97 mm), and HGA without reconstruction was 1.49 ± 1.08 mm (95% CI, 1.10–1.88 mm). In CT measurement, HSA was 1.72 ± 1.01 mm (95% CI, 1.43–2.01 mm), HGA with reconstruction was 1.54 ± 0.96 mm (95% CI, 1.24–1.84 mm), and HGA without reconstruction was 1.59 ± 0.93 mm (95% CI, 1.30–1.91 mm). When comparing measurements of HSA and HGA between MRI and CT, HSA was significantly different according to image modality ($p=0.0006$), but HGA was not significantly different according to image modality regardless of reconstruction ($p=0.8836$, $p=0.9234$; Table 2).

Discussion

Few studies have analyzed the normal range of the humeral head in normal healthy subjects by MRI. Kim et al.[18] evaluated the translation of the glenohumeral joint without shoulder lesion by MRI. They selected axial images with maximum glenoid anterior-to-posterior diameter and measured anterior-to-posterior direction translation of the humeral head center relative to the glenoid face. Their normal value without a shoulder problem was 0.61 ± 1.01 mm. In the current study, HGA with reconstruction was 1.15 ± 0.65 mm and HGA without reconstruction was 1.03 ± 0.59 mm. Yun et al.[15] studied humeral head decentering and suggested normal glenohumeral position in an MRI study. They selected axial images at the mid-glenoid level, and measured the shortest distance from the humeral head center to a scapular axis line. Their normal value was 0.75 ± 0.72 mm. In our study, HSA was 1.47 ± 1.25 mm. We cannot conclude that this difference is statistically significant. However, different image acquisition protocols, selection of axial slice by axis reconstruction (such as scapula axis), drawing a best-fit circle for the humeral head, and relatively poor bony contour in MRI may affect measurement values in each study.

A static measurement of the degree of humeral head displacement has been determined, usually on CT scan.[4,5,13,16] Because humeral head displacement is typically measured as the posterior offset of the center of the humeral head in relation to the centerline of the glenoid or the scapular body, CT measurement is a reliable method since it can clearly identify bony contour. However, in the current study, we used reconstructed MRIs to measure and evaluate the normal range of humeral head positioning. To assess the possibility of measurement differences due to image modality differences, we selected group B, who had both MRI and CT, and validated the MRI measurement. In the MRI measurement, the value of HSA was significantly different from HGA with and without reconstruction, but there was no significant difference between HGA with and without reconstruction. MRI and CT measurements were also compared. There was a significant difference in HSA according to image modality ($p=0.0006$), but there was no significant difference in HGA regardless of reconstruction ($p=0.8836$, $p=0.9234$). Humeral displacement difference according to reference plane, that is scapular plane and glenoid plane, has been reported. Terrier et al.[5] compared scapulohumeral measurement and glenohumeral measurement in the osteoarthritic shoulder by 3D methods and suggested that measurement of scapulohumeral subluxation and glenohumeral subluxation are different, and glenohumeral subluxation is usually lower than scapulohumeral subluxation. Their result is in line with the current result regarding the difference between HSA and HGA, even though our imaging modality is different from theirs. However, in the current study, there was difference between HSA values measured by CT and MRI. In the case of MRI, the bone contour may not be precisely confirmed compared with CT, which can accurately confirm the bone contour. Therefore, MRI has the potential to generate measurement errors. More specifically, in the case of CT, accurate reconstruction and imaging can be obtained by confirming the angular inferior, trigonum scapulae, and glenoid center, which determine the scapular plane. However, with MRI, there are some cases in which these points cannot be obtained clearly; therefore, there could be a positional difference in axis reconstruction. That difference may be responsible for the significantly different HSA measurement value between MRI and CT. However, HGA with reconstruction did not significantly differ from the HGA without reconstruction. Moreover, when the MRI and CT measurements were compared, no differences were identified for HGA with and without reconstruction. Unlike HSA, which requires a scapular axis, HGA is a measure of the relationship between humeral head and glenoid. Therefore, there is no difference in the value with and without reconstruction. Jacxsens et al.[13] also suggested that the viewing perspective of the humeral head to the centerline or plane will not change drastically when the image is corrected to axis reconstruction, and they reported no significant difference between axis corrected and uncorrected measurements referring to the glenoid.

However, the current study has some limitations. First, all images were taken in accordance with the authors' hospital's MRI and CT protocols. There may be differences in value according to hospital protocol. However, this study was conducted to measure the normal value of humeral head positioning on the glenoid by MRI and to validate this measure by comparison with CT measure. Although the MRI measurement was validated in the current study, this value should be used with caution. Second, the time interval between MRI and CT image acquisition differed between subjects. Because this study was a retrospective image analysis, taking two image modalities at the same time was impossible. However, we selected subjects that had MRI and CT taken within 1 month. Third, the value unit of the measure was too small. That means that any measurement error might affect the statistical difference when comparing values. To compensate for this, we used a specific measuring software program that can measure as precisely as possible. Fourth, when making axis reconstruction of the MRI, there may be differences in placing reference points; this might also affect the measurement value. To evaluate this error, we measured interobserver and intraobserver reliability and confirmed good reliability.

This study compared the normal value in a relatively large number of normal MRIs, the difference according to measurement method (HSA and HGA), the difference according to image reconstruction, and the difference according to measurement modality (MRI and CT), and made meaningful efforts to obtain more objective and accurate values.

Conclusion

Although additional CT scans can be taken to measure decentering in patients with rotator cuff tears, reliable measurements can be obtained with MRI alone. When using MRI, it is better to use HGA, which is a more reliable measurement value based on the comparison with CT measurements.

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