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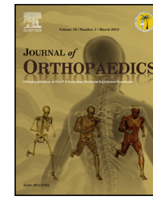

Original Article

Comparison of dynamics in 3D glenohumeral position between primary dislocated shoulders and contralateral healthy shoulders

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ABSTRACT

Backgrounds: After shoulder dislocation, kinematic changes in shoulder, including translation of the humeral head, ensue. There have been many attempts to measure these changes using motion measurement techniques, but in vivo three-dimensional (3D) glenohumeral changes have not been appreciated until now. The purpose of this study was to measure and analyze changes in glenohumeral translation in patients with shoulder dislocation and compare these changes with healthy shoulder.
Methods: We included 20 subjects who had suffered shoulder dislocation for first time, and 3D models of their humerus and scapula were obtained using computed tomography and fluoroscopic images during scapular plane abduction and external rotation of shoulder with elbow flexed at 90° and arm abducted at 90°. We measured the superior/inferior (SI) and anterior/posterior (AP) translations for both shoulders.
Results: No statistically significant difference between healthy and dislocated shoulders was detected in SI translation for scapular plane abduction with increasing elevation angles. In AP translation, the humeral head was located 2.29 mm more anteriorly in the dislocated shoulder than in the healthy shoulder. However, no statistically significant difference was seen. For internal to external rotation, the angle of the rotated arm had an effect on AP translation. However, no statistically significant difference was detected. In the apprehension test, there was no significant difference in the mean value of AP translation.
Conclusion: Compared with the contralateral healthy shoulder, changes in glenohumeral translation during in vivo movement after shoulder dislocation were found to be non-significant.

1. Introduction

Anterior shoulder dislocation is a relatively common injury in young sporting participants. It is known that the recurrence rate of dislocation can reach up to fifty percent in young patients who have experienced primary dislocation. Furthermore, repeated shoulder dislocation results in secondary damage to the soft tissue, cartilage, humeral head, and glenoid bone. The initial treatment of primary dislocation remains controversial. A number of researchers have insisted on initial conservative treatment.[1–4] Recently, there have been reports that placing an arm in an externally rotated position for three to six weeks instead of an internally rotated position could reduce the dislocation recurrence rate.[5–7] However, some authors have described the advantages of early surgery.[1,8–10]

At the center of this controversy is the question of whether after primary shoulder dislocation, translation of the humerus relative to the glenoid can meaningfully be changed in the shoulder with primary dislocation compared with the normal side, during dynamic active movement. If there is no positional difference between the normal and dislocated shoulders in 3D active movement, conservative treatment can be preferred. In contrast, if there is a substantial positional difference between the two treatments, more active interventional treatments such as surgery could be considered.

In the past, 3D measurements of in vivo glenohumeral joint position during shoulder motion have been used. Recently, Bey

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et al.[11–13] measured and compared the dynamics of 3D glenohumeral joint translation during shoulder motion between a control group and rotator cuff repair group through a model-based tracking technique that they had developed. They were interested in identifying whether the differences between the two groups had any clinical significance. Similar to attempts to find a relationship between rotator cuff repair results and 3D motion of the shoulder, there have been attempts to estimate changes in the position of the center of the humerus relative to the glenoid after primary shoulder dislocation. Although a number of studies have examined the kinematic differences between healthy and primary dislocated shoulders through conventional motion measurement techniques, such as 2D analysis and cadaver study, the in vivo dynamics of the 3D movement of the humerus relative to the glenoid have not yet been fully described.

Many people agree that identifying any difference in the position of the center of the humeral head relative to the glenoid between healthy and primary dislocated shoulders could provide a theoretical background to decide on the optimal therapy methods for shoulder dislocation.

The aim of this study was to measure and analyze in vivo 3D glenohumeral joint kinematics, and compare the findings between primary dislocated and healthy contralateral shoulders using 3D-2D model image registration techniques. We hypothesized that glenohumeral joint translations would be greater in the dislocated shoulder than in the contralateral healthy shoulder.

2. Materials and methods

2.1. Subjects

All subjects provided informed consent and the protocol of this study was approved by the Institutional Review Board of Yonsei University (IRB No. YWMR-13-9-042). Abiding by the IRB approval, 10 male subjects (age: 23.4 ± 8.8 years, range: 17–35 years) participated in this study. Each subject had previously experienced primary anterior shoulder dislocation. We defined dislocation as a displacement of the humeral head into a locked position, anterior to the glenoid, and verified radiographically, and primary shoulder dislocation as a one-time occurrence of traumatic anterior shoulder dislocation. The average time from shoulder dislocation to taking fluoroscopy images was 17 ± 11.3 days (range: 10–28 days). We excluded any participants with evidence of multidirectional instability in the shoulder, history of injuries or surgery before shoulder dislocation in either shoulder, previous dislocations, or history of treatment to the shoulder(s) due to various symptoms.

2.2. Image acquisition and 3D modeling

We asked subjects to position their shoulder toward a biplane X-ray system (Infinix Active; Toshiba, Tochigi, Japan). All images were obtained at 30 Hz while patients performed three different tasks. First, they abducted their arm along the scapular plane, following the trunk, to the maximum possible elevation angle. During arm abduction, the elbow was maintained at full extension and externally rotated in a “thumbs-up” position, at a rate of about two seconds per cycle, with one cycle defined as the elevation and lowering of the arm. At that time, we first took fluoroscopic images in the XY-plane and then in the ZX-plane. The second task was an internal to external rotation of the arm in the frontal plane with the elbow in 90° of flexion and the shoulder abducted to 90° (90–90° position). All subjects rotated their arm from the initial position to the maximum angle they could at a rate of about one second per cycle. The final task was a modified apprehension test in a sitting position. While a subject rotated their arm as in the second task, we attached a dynamometer to the subject, loading the hand with 3 pounds for 2–3 s. Participants performed this task twice for each shoulder.

To get more precise data and provide a suitable environment for subjects, approximately 30–40-s breaks were given between cycles. Among the three timed trials, we selected the second cycle of the task.

To compute the radiographic projection parameters containing the positional information of the bones and compensate for image distortion resulting from taking fluoroscopic images, we made and used a calibration file. Bilateral CT scans (SOMATOM Sensation 16; Siemens Medical Solutions, Malvern, PA) of the bones were obtained with a 1 mm slice pitch (image matrix, 512×512; pixel size, $0.9765625 \times 0.9765625$ mm). The CT images were segmented,

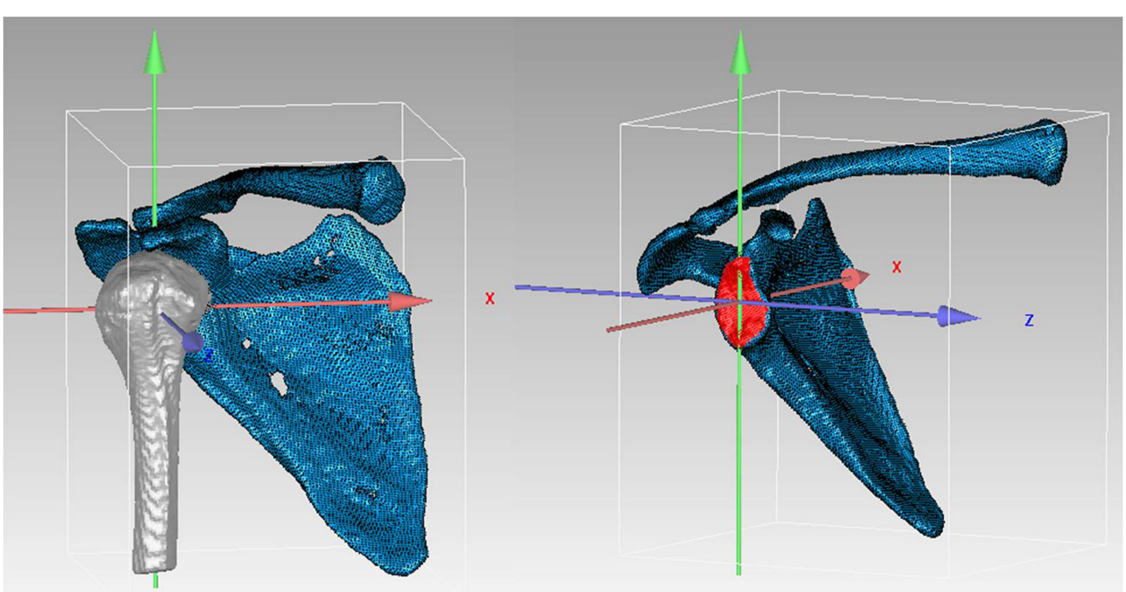

Fig. 1. Three-dimensional models of the humerus (A) and scapula (B). Once the models were created, anatomic coordinates were applied to the models.

and by using these Images 3D models of the humerus and scapula were made (ITK-SNAP; Penn Image Computing and Science Laboratory, Philadelphia, PA) (Fig. 1). Following a previously reported method (Geomagic studio; Geomagic, USA, Morrisville, NC), we set up an anatomic coordinate system for the 3D bone models we made.

2.3. Image registration and data processing

The position of the humerus and scapula in 3D space was identified using the biplane-place X-ray through an open-source software-based (www.sourceforge.net/projects/jointtrack) model image registration method created in our laboratory.

Model image registration measurements were performed by a single operator using a series of fluoroscopic images. The estimated root-mean-square errors of the translation of the glenohumeral joint were 0.43 mm for the in-plane direction and 1.53 mm for the out-of-plane direction. We used Cardan angles (abduction-flexion-external rotation sequence: Z-X-Y planes) to measure the 3D kinematics of the humerus relative to the scapula. Humeral translation in the superior-inferior direction was measured relative to the center of the glenoid, following the method proposed by Matsuki et al. [14]

Abduction of the humerus was defined as rotation in the Z-axis; internal to external rotation was defined as rotation in the Y-axis. Superior-inferior (SI) translation was defined as translation of the humeral origin relative to the Y-axis of the center of the glenoid of the scapula; anterior-posterior (AP) translation of the humeral center was defined relative to the X-axis of the center of the scapula.

Kinematic data were individually plotted as a function of the humeral abduction angle, and polynomial regression lines were used to calculate interpolating values for each 10° increment of humeral abduction from the initial position to maximal abduction. For external rotation, the increment was set at 5° of rotation.

2.4. Statistical analysis

To verify if there was a statistically significant difference between healthy and dislocated shoulders, statistical analysis was conducted for both SI and AP translation. Statistical significance was set at $p = 0.05$. For the SI position (translation of humeral head relative to the center of the glenoid of the scapula), a two-way repeated measures ANOVA was performed with the shoulder (dislocated shoulder vs. contralateral healthy shoulder) and arm abduction angles in 10° increments. Similar to SI translation, the AP position was measured relative to the center of the glenoid. A two-way repeated measures ANOVA was performed with same independent variables as for the SI position, but with 5° increments for external rotation of the arm. If statistically significant differences were detected in the ANOVA, a post hoc Bonferroni-corrected *t*-test was performed. The statistical analysis of the modified apprehension test was performed by comparing results using a paired *t*-test between healthy and dislocated shoulders.

3. Results

The average initial positions of the center of the humeral head in both dislocated and healthy shoulders were located 1–2 mm inferiorly and 0–1 mm posteriorly based on the scapular origin.

3.1. Scapular plane abduction

During arm abduction, there was no significant effect of abduction angle on SI or AP translation ($p > 0.05$). In a comparison between the healthy contralateral shoulder and primary dislocated shoulder, a significant difference in AP translation ($p = 0.0089$) was detected but no significant difference in SI translation ($p = 0.0585$). Both shoulders showed 1–2 mm glenohumeral translation and a similar translation pattern in the SI and AP directions.

In SI translation, the humeral head was located 1–2 mm inferiorly relative to the glenoid in the initial position in both shoulders. When the angle of arm abduction reached 40°–60°, the humeral head gradually moved in a superior direction but was still located inferior relative to the glenoid. However, no significant difference of humeral head position at different angles of arm abduction was observed. During arm elevation, the humeral head in both shoulders was positioned inferior relative to the glenoid (Fig. 2).

In terms of AP translation, there was a significant difference ($p = 0.0089$) between healthy and dislocated shoulders in the starting position. The humeral head of the dislocated shoulder was located 2.29 mm more anterior than the humeral head of the healthy shoulder. However, with an increased angle of arm elevation, the difference in AP translation reduced to 1 mm and at the maximum angle of abduction, there was no difference. The

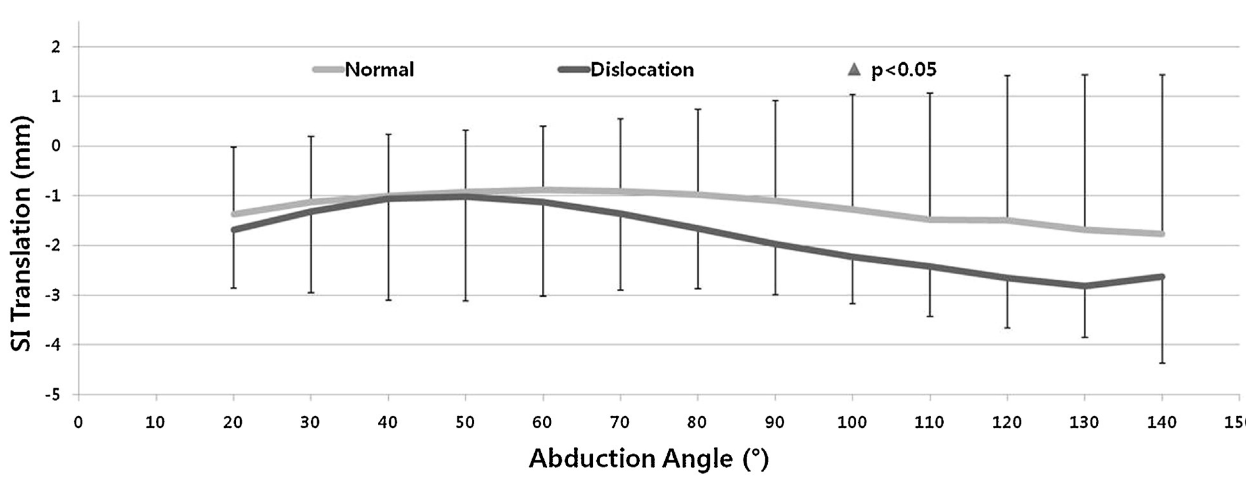

Fig. 2. As the arm was abducted in the scapular plane, the humeral head in both shoulders started moving superiorly. The head gradually translated back in the inferior direction. No statistical significance was found between the shoulders.

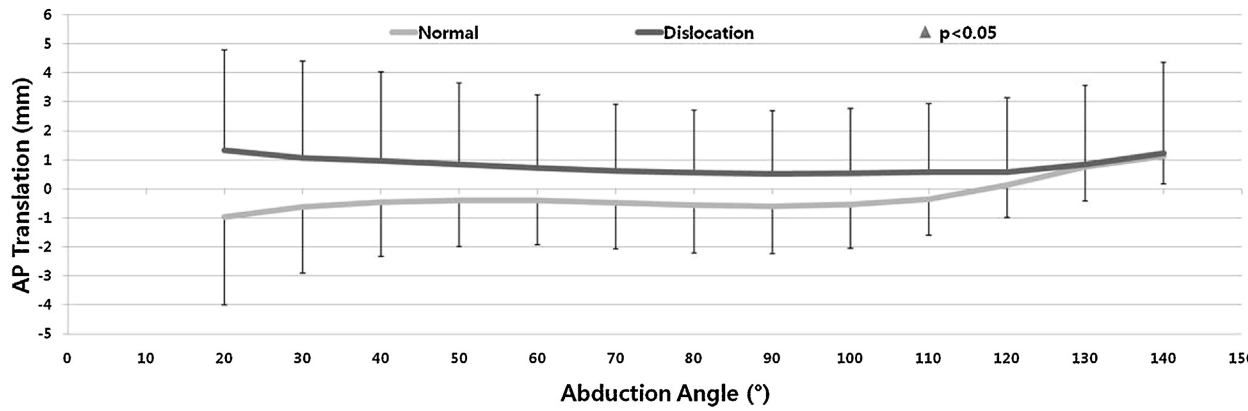

Fig. 3. The initial difference in the position of the humeral head between shoulders was significant (2.29 mm). However, as angle of abduction increased, the difference decreased steadily to within 1 mm. Although a statistical difference was found between the groups except in the humeral head position at maximal abduction, abduction had no statistically significant effect on changes in translation in both shoulders.

humeral head of the dislocated shoulder was located 1 mm anteriorly relative to the glenoid but did not show significant difference ($p = 0.785$) at different angles of abduction. Excluding the starting position, both shoulders showed a trend that the humeral head was translated 1–2 mm inferiorly relative to the glenoid during arm elevation (Fig. 3).

3.2. Internal to external rotation in the 90–90° position

The humerus moved an average of 1.7 mm and 2.1 mm posterior to the glenoid center during external rotation of the arm, for the dislocated and healthy shoulder, respectively. In the starting position, the humeral head of the dislocated should was located 0.4 mm more anteriorly than the head of the healthy shoulder. During active external rotation with the arm in abduction, no statistically significant difference in AP translation was detected at any angle ($p = 0.999$) or in either shoulder ($p = 0.3971$). In external rotation, the angle of the rotated arm had a significant effect on AP translation ($p < 0.001$). In the starting position, the humeral head in both shoulders was located 2 mm posterior relative to the glenoid. With an increasing angle of rotation, the humeral head moved in the anterior direction, i.e., toward the center of glenoid. The humeral head was centered within 1 mm of the glenoid center above 30° internal rotation; from 10° internal rotation, the humeral head in both groups was located 0.1 mm posteriorly for all angles (Fig. 4).

3.3. Modified anterior apprehension test

No subject halted the experiment because of a feeling of apprehension or pain. The amount of movement in the AP direction for this test was found to be -0.246 ± 0.206 mm for the dislocated shoulder and -0.270 ± 0.429 mm for the healthy shoulder; no significant mean difference was observed.

4. Discussion

This is the first study using a monoplane fluoroscopy and shape matching technique to analyze and compare in vivo changes in GH position between primary dislocated and healthy contralateral shoulders. Previous studies using 3D-2D model image registration similar to our method have been carried out to verify variations in normal GH position. However, no study has dealt with changes in GH position in dislocated shoulders. Since there have been several studies that recorded GH position in normal shoulders, we were concerned about any GH positional discrepancy that may be present in a primary dislocated shoulder during abduction in the scapular plane, and we investigated this potential GH positional change in the dislocated shoulder in two planes, SI and AP translations.

Bey et al.[11] and Matsuki et al.[14] reported an analogous pattern of SI GH translation in normal shoulders by using biplane and monoplane fluoroscopies, respectively, and they noted that the

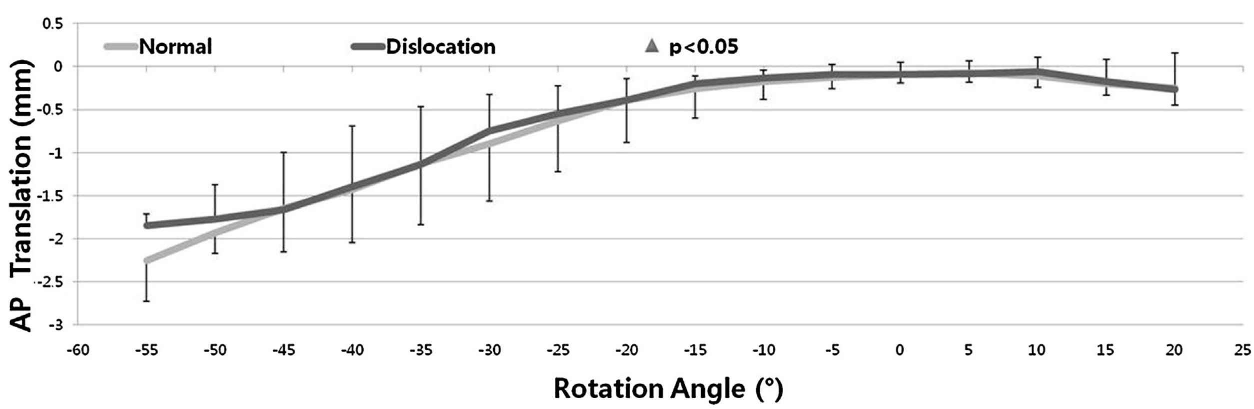

Fig. 4. Position of the humeral head in both shoulders approached to within 1 mm of the glenoid center before the arm was externally rotated. Initially, there was a 4 mm gap between the positions of the humeral head in the shoulder, but the difference became negligible as soon as arm started rotating. No statistical significance was found in the difference in the position of the humeral head between the shoulders, and the rotational angle did not have a statistical effect on translation in either shoulder.

humeral head moves superiorly at the beginning of arm abduction before moving back in an inferior direction. However, Nishinaka et al.[15] reported an approximate 1.7 mm displacement of the humeral head in the superior direction. Our results showed, both in normal and dislocated shoulders, a similar SI translation pattern to that found by Bey et al.[11] and Matsuki et al.[14] In the normal shoulder, their results are thought to be due to the action of the deltoid muscle applying a cranial force that dominantly affects the humeral head, causing it to move superiorly at the beginning of abduction. Subsequently, the rotator cuff muscles are activated and press the humeral head to be centered and stabilized within the glenoid fossa. Although our data demonstrated that the dislocated shoulder had a slightly inferior GH position than the position of the healthy shoulder, the difference was not statistically significant. Thus, the mechanisms found in the normal shoulder in previous studies appear to be applicable to shoulders dislocated for the first time. Furthermore, concern for AP translation during abduction, which is a more frequent motion during average daily activity, was investigated in dislocated shoulders in the present study. We found that the difference of positions between dislocated and healthy shoulders was 2.29 mm when the arm was in the resting position. However, this somewhat large discrepancy between the positions diminished as the arm was abducted, and the difference was less than 1 mm after the abduction angle reached 100°. This result suggests that, as in healthy shoulders, a centralizing effect of the rotator cuff muscles on the humeral head of dislocated shoulders affected the AP displacement of the humeral head as well as SI movement. Thus, we believe that if shoulder musculature, including the rotator cuff, is intact after primary dislocation, it is possible for dislocated shoulders to maintain joint congruency for optimal shoulder function during scapular plane elevation, just as a healthy shoulder would perform.

Although the change may be minimal, some have argued that these changes can lead to a condition causing minor instability. During abduction, the difference in AP translation between shoulders was minimal as it was within 1–2 mm, and above 100° of abduction, the difference was even smaller. Although there is no significance difference in the humeral head positions between shoulders in accordance with the angle of abduction, the result should be interpreted cautiously. A translation less than 1 mm appears to be small. However, this presumably small difference may be associated with clinically significant instability, and further studies are required to investigate its clinical implications.

We also measured AP translation during internal to external rotation of the arm with the shoulder in 90° abduction and elbow in 90° flexion. Both surgeons and physical therapists typically insist that their patients avoid an externally rotated posture, since they believe that the posture may increase translation of the humeral head that makes it more prone to dislocation. In this study, there was no statistically significant difference in the humeral head position during external rotation between dislocated and healthy shoulders. In both groups, the humeral head was initially positioned about 2 mm posteriorly in relation to the glenoid center, and started moving anteriorly as the arm was externally rotated. When the head was rotated to 20° of internal rotation, it was situated within 0.5 mm of the center of the glenoid. We expected that the increase in external rotation would increase translation of the head relative to the glenoid center in dislocated shoulders. However, the difference was negligible compared with normal shoulders in the current study. Thus, it is our belief that if a patient does not complain of pain after first-time dislocation then external rotation exercises will not propagate the problem further.

In the previous literature, there has been an argument regarding the conservative treatment method of bracing in an externally rotated orientation. Itoi et al.[5,6] stated that the tightened anterior soft tissue structure with the arm in external rotation could hold a separated labrum back in the glenoid rim in primary anterior shoulder dislocations. In our study, the humeral head also moved in an anterior direction with an increase of external rotation angle. However, the anterior movement of the head was initiated at 30° of internal rotation. This finding signifies that an externally rotated arm was not necessary for the centralization of the humeral head to the glenoid fossa. While Itoi et al.[6] confirmed the presence of labral injury on magnetic resonance imaging (MRI) and used the imaging to examine the state of reduction, our study did not utilize MRI to confirm and record the state of the displacement. However, we examined the GH position in vivo while externally rotating the arm from an internally rotated position under serial fluoroscopic images and confirmed that even in an internally rotated position, the humeral head was reduced to within 1 mm of the glenoid center. In other words, this study was limited in measuring the degree of soft tissue reduction, but our methodology of using 3D in vivo imaging provided evidence that the GH congruency was maintained in both internally and externally rotated positions of the arm. However, caution should be taken when interpreting our data since there may be discrepancies in the extent of soft tissue injury between our study and that of Itoi et al.[5,6]

Past researchers have wondered how much variation of humeral position relative to the glenoid tests of instability could produce and what variation could occur during passive external rotation even though the mean anterior-posterior difference between both shoulders during dynamic abduction was 1–2 mm in this study. Among the above three tests, we performed the apprehension test as proposed by Farmer. In this test, the scapula was left free, i.e., the scapula was not touched at all during the experiment. During a test, if the scapula were fixed, it may have an effect on humeral translation relative to the glenoid. To compensate for this situation, we asked subjects to sit rather than testing in a supine position. For this experiment we found that anterior-posterior translation was -0.246 ± 0.206 mm in the dislocated shoulder and -0.270 ± 0.429 mm in the healthy shoulder, with no significant difference between the two ($p > 0.05$). In summary, there is no significance between healthy shoulders and those dislocated for the first time during two active movements and one passive modified apprehension test. Anterior-posterior translation during arm abduction was significantly different between healthy and dislocated shoulders, although the difference was fairly small. As mentioned earlier, the nature of the difference should be considered when interpreting the results.

This study demonstrates that glenohumeral position changes are extremely small following primary dislocation. However, because of the large number of parameters that affect the shoulder, shoulder surgeons and physical therapists need to check a subject's background before deciding on the appropriate treatment methods.

Our study has several limitations. First, we did not consider differences between dominant and non-dominant shoulders. Since the scapular kinematics may be different between dominant and non-dominant arms, even in a healthy individual, there may be some dissimilarity in the measurements. The second limitation is the ability to apply our results in a clinical setting. Although we found a statistically significant difference between the dislocated and healthy shoulders, albeit only a 1 mm difference in humeral head translation, further studies are necessary to validate its significance in a clinical setting. Third, we encountered several problems when acquiring fluoroscopic images during abduction in the scapular plane. The problem was more particular when we were obtaining SI direction images since patients' head and skull limited a proper viewing plane of their shoulder joints. Thus, in some patients, the procedure was repeated, and this may raise a concern for over-exposure to radiation. We believe that a biplane fluoroscopy system may provide some solutions to this concern, but it appears to have its own problem concerning radiation exposure while acquiring images. Lastly, expressing the humeral head's center of rotation relative to the glenoid center in models can sometimes be misleading. This may present some discrepancies between the anatomic center of rotation and coordinated center of rotation in our models. These differences can produce inaccuracies in assessing in vivo 3D movement. Care must be taken to include this potential discrepancy when making an interpretation.

5. Conclusion

We analyzed and compared GH translation in primary shoulder dislocation with that in the contralateral healthy shoulder using 3D-2D model image registration techniques. In general, no significant difference between the shoulders was observed. Although in AP translation there was a statistically significant difference as the arm was abducted, it was minimal, suggesting that dislocation induced alteration of GH position is negligible. Therefore, this result may provide some useful background for clinical decisions regarding treatment methods for patients with first-time shoulder dislocation.

Conflict of interest

The authors have none to declare.

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