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ORIGINAL ARTICLE

Three-dimensional analysis of the locked position in patients with recurrent shoulder instability

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Background: Although recurrent anterior shoulder instability (RASI) is a common condition in young patients, no studies to date have measured the 3-dimensional (3D) locked position of the glenohumeral joint during an anterior dislocation. Therefore, our goal was to estimate it with 3D computed tomography (CT) scans.

Methods: Patients in this prospective observational study were separated in 3 groups: normal laxity, hyperlaxity, and epilepsy. They were characterized by questionnaires (Western Ontario Shoulder Instability Index, 11-item version of the Disabilities of the Arm, Shoulder and Hand, and Beighton Laxity Score), and a CT scan revealing bipolar bone defects. 3D models of the humeral head and the glenoid were reconstructed from the CT scan, and the rotations and displacements of the humerus relative to the glenoid, from initial to locked position, were calculated. Intraobserver and interobserver reliability by intraclass correlation coefficient (ICC), analysis of variance test, and the Pearson correlation were used to evaluate data.

Results: This study involved 44 patients (46 shoulders): 18 with "normal" laxity, 18 with hyperlaxity and 8 (2 bilateral) with epilepsy. The mean locked position was of 12° of abduction, 90° of external rotation, and 21° of extension. The intraobserver and interobserver reliability was excellent for all the rotations and displacements (ICCs, 0.751-0.977) except the proximal-distal displacement (ICCs, 0.409-0.688). Significant differences were found for external rotation, anterior displacement, and medial displacement among the 3 groups of patients. Correlation was found between locked position and function.

Conclusions: This study produced highly reliable measurements, with abduction angles proving to be lower than expected. Future work should focus on the effect of this low abduction angle on Hill-Sachs lesion management.

Level of evidence: Basic Science Study; Computer Modeling

Keywords: Recurrent shoulder instability; engaging Hill-Sachs lesion; glenoid bone defect; epilepsy; hyperlaxity; 3D kinematic analysis

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The shoulder is the most frequently affected joint by dislocations. Primary acute anterior shoulder dislocations occur in 1.7% of the general population.[14] However, the rate of chronic shoulder instability (ie, recurrent subluxations and

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dislocations of the glenohumeral joint) is higher in young and active patients.[26]

Recurrent anterior shoulder instability (RASI) leads to lesions of the anterior inferior portion of the glenoid, referred to as Bankart lesions, and lesions of the posterior lateral portion of the humeral head, referred to as engaging Hill-Sachs lesions. Bankart and Hill-Sachs lesions are found in 97%[32] and 94%[15] of patients with RASI, respectively, and 90%[24] report glenoid bone defects such as bony Bankart lesions or inverted pear-shaped glenoid lesions. Moreover, the combination of even small glenoid defects and engaging Hill-Sachs lesions is thought to be responsible for recurrent instability of the glenohumeral joint.[1] The severity of the lesions grows with each dislocation, making the shoulder increasingly unstable.[13]

Anterior shoulder dislocation is believed to occur when the shoulder is oriented at 90° abduction in extension and external rotation[27] and receives a blow or a violent traction. However, dislocations can also occur with the shoulder in various other positions, as shown in professional sports footage[8,19] or during epileptic seizures.[9] To the best of our knowledge, no study has accurately measured the position of the glenohumeral joint during an anterior dislocation involving an engaging Hill-Sachs lesion and a glenoid bone defect or the resulting locked position of the glenohumeral joint after an anterior dislocation. This can be explained by ethical considerations and the complexity of measuring this phenomenon.

Only Tanaka et al[27] have evaluated the angle of external rotation at which the humeral head showed anterior translation over the glenoid rim. Patients were under general anesthesia while their arm was maintained at 90° of abduction. Therefore, this study did not analyze the "natural" engaging or locked glenohumeral position of patients because the angle of abduction was imposed. Neither has any study thus far measured the engaging or locked glenohumeral position of patients with hyperlaxity or epilepsy, although they have a higher rate of RASI.[11,29]

Furthermore, the definition of an "engaging" Hill-Sachs lesion is still a topic of significant debate. The classic paper from Burkhart and De Beer[5] defined it as: "Hill-Sachs lesions that we could see arthroscopically that engaged the anterior rim of the glenoid when the arm was brought into a position of athletic function (a position that we defined as 90° abduction combined with external rotation in the range between 0° and 135°)." Boileau et al,[4] in their article about the remplissage procedure, defined an engaging Hill-Sachs lesion as: "a large (Calandra grade-III[7]) Hill Sachs engaging over the glenoid rim at any degree of abduction/external rotation during diagnostic arthroscopy." Yamamoto et al[31] defined an engaging Hill-Sachs lesion using the glenoid track at 60° of glenohumeral abduction and 90° from the trunk and applied it to another report on 100 patients. They concluded that only 7% of patients had a humeral head lesion that needed to be treated.[17]

We believe that a better understanding of the locked glenohumeral position could enhance our comprehension of the engaging glenohumeral position and thus improve the proposed treatments for RASI, especially in patients with hyperlaxity or epilepsy. The objective of this study was to develop a method to assess the 3-dimensional (3D) locked position of the glenohumeral joint in 3 groups with RASI: patients with "normal" laxity, patients with hyperlaxity, and patients with epilepsy. The reliability of intraobserver and interobserver assessments of this method was evaluated, and the mean rotations and displacements obtained from the 3 groups of patients were compared.

Our first research hypothesis was that the mean rotations in the locked glenohumeral position would be lower in epileptic patients because they usually have large bone defects[6,28] and would be higher in patients with hyperlaxity because the tissues are less rigid and allow a greater range of motion before the anterior dislocation. Our second research hypothesis was that smaller rotations and displacements in the locked glenohumeral position might be linked to worse functional outcome.

Materials and methods

The patients included in this prospective observational study were randomly selected from an existing prospective cohort of patients with RASI. All included patients had undergone a computed tomography (CT) scan in rest position for clinical reasons, and an extra visit was not needed. They had completed the Western Ontario Shoulder Instability Index (WOSI) questionnaire[16] and the 11-item version of the Disabilities of the Arm, Shoulder and Hand (Q-DASH) questionnaire,[12] which are standard during outpatient visits to evaluate shoulder disabilities.

The inclusion criteria were age 18 years and older, 2 or more anterior shoulder dislocations (according to the patient's estimate), visible bone defects on the CT scan of the glenoid and the humerus, and presenting one of the following characteristics: normal joint laxity, joint hyperlaxity, or epilepsy (with normal joint laxity). Patients with evidence of another fracture to the glenoid or humerus or a shoulder operation before the CT scan were not included. Joint laxity was evaluated with the Beighton score,[3] with a cutoff at >4/9 for hypermobile joints.

Obtaining 3D bone models

The 3D locked glenohumeral positions were computed by 3D reconstructions of the glenoid and humeral head from a CT scan. The 1.25-mm CT scan slices of each shoulder were segmented by an operator with SliceOmatic software (TomoVision, Magog, PQ, Canada). The resulting 3D bone models (Fig. 1) were imported into the computer-aided design software CATIA V5R21 (Dassault Systèmes, Vélizy-Villacoublay, France), which was used to perform the steps described in the following sections.

Defining anatomical coordinate systems

A glenoid coordinate system (O_g, $\mathbf{X_g}$, $\mathbf{Y_g}$, $\mathbf{Z_g}$) was defined at the scapula, as described in Ohl et al.[21] This anatomical coordinate system was chosen because it is more robust and reproducible than the one proposed by the International Society of Biomechanics,[30] especially