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Importance of a three-dimensional measure of humeral head subluxation in osteoarthritic shoulders

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Hypothesis: During total shoulder arthroplasty (TSA), humeral head subluxation may be difficult to manage. Furthermore, there is a risk for postoperative recurrence of subluxation, affecting the outcome of TSA. An accurate evaluation of the subluxation is necessary to evaluate this risk. Currently, subluxation is measured in 2 dimensions (2D), usually relative to the glenoid face. The goal of this study was to extend this measure to 3 dimensions (3D) to compare glenohumeral and scapulohumeral subluxation and to evaluate the association of subluxation with the glenoid version.
Materials and methods: The study analyzed 112 computed tomography scans of osteoarthritic shoulders. We extended the usual 2D definition of glenohumeral subluxation, scapulohumeral subluxation, and glenoid version by measuring their orientation in 3D relative to the scapular plane and the scapular axis. We evaluated statistical associations between subluxation and version in 2D and 3D.
Results: Orientation of subluxation and version covered all sectors of the glenoid surface. Scapulohumeral subluxation and glenoid version were highly correlated in amplitude ($R^2 = 0.71$; $P < .01$) and in orientation ($R^2 = 0.86$; $P < .01$). Approximately every degree of glenoid version induced 1% of scapulohumeral subluxation in the same orientation of the version. Conversely, glenohumeral subluxation was not correlated to glenoid version in 2D or in 3D.
Conclusions: Orientation of the humeral subluxation is rarely within the arbitrary computed tomography plane and should therefore be measured in 3D to detect out-of-plane subluxation. Scapulohumeral subluxation and glenoid version measured in 3D could bring valuable information for decision making during TSA.
Level of evidence: Basic Science, Anatomy, Imaging.

Keywords: Humeral head subluxation; glenoid version; total shoulder arthroplasty; CT scan; 3D reconstruction

Although total shoulder arthroplasty (TSA) is a successful technique to treat primary glenohumeral osteoarthritis, complications have been specifically associated with cases in which shoulders have high preoperative humeral head subluxation.[9,15] It is usually assumed that posterior subluxation of the humeral head can lead to posterior

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erosion of the glenoid.[10] Furthermore, there is a risk of recurrence of the subluxation after TSA that may be responsible for wear and early loosening of the glenoid component.[2,4,6] Although a causality link between humeral head subluxation and glenoid version of osteoarthritic shoulders is intuitively expected, no statistical correlation has been reported yet.[1,4,7,8,10,16,17]

The most accepted measurement of humeral head subluxation was derived by Papilion and Shall.[12] It was then adapted by Badet and Walch[1,17] and used by Walch to propose its classification of glenohumeral osteoarthritis.[16] They defined the glenohumeral subluxation as the percentage of humeral head offset from the glenoid axis relative to the humeral head diameter. This measure is calculated in 2 dimensions (2D) in a computed tomography (CT) slice approximately in the middle of the glenoid surface. Since Badet and Walch, other techniques to measure the subluxation have been developed.

However, the glenoid surface might not be the optimal reference to evaluate the subluxation. The humeral head can indeed perfectly face the glenoid fossa but be highly unaligned with the scapula and the muscle action lines. This is particularly true when the glenoid is significantly eroded or dysplastic. Accordingly, Walch recently proposed using the scapula as a reference to measure the subluxation by evaluating the eccentricity of the humeral head center from the Friedman (scapular) axis.[10,11,13]

The glenohumeral subluxation is measured in the arbitrary plane of CT images, but subluxation occurs in all directions.[5] To date, there is no 3-dimensional (3D) method to measure the humeral head subluxation out of the CT plane, as there is for the glenoid version. Therefore, the goal of this study was to evaluate the advantage of a 3D measurement of shoulder subluxation and to test its correlation with the 3D measure of glenoid version. Thus we compared the glenohumeral and scapulohumeral subluxations in 2D and 3D.

Materials and methods

We performed a retrospective case-control study of 2D and 3D measurements of subluxation and version on a consecutive series of osteoarthritic shoulders for regular TSA planning. We included 78 female and 34 male patients with an average age of 71 years (range, 44-89 years).

Shoulder subluxation

Glenohumeral and scapulohumeral subluxations were first measured in 2D according to the standard method proposed by Walch[16] and extended by Kidder.[10] The 2D subluxations were adapted such that a centered head had 0% subluxation instead of 50%. A subluxation of 55% according to Walch was reported as a 5% posterior subluxation in this study.

We extended the 2D glenohumeral and scapulohumeral subluxations to 3D to evaluate not only the amplitude but also the orientation of the subluxation. We defined the 3D glenohumeral subluxation as the relative distance between the humeral head center and the glenoid center projected onto a plane perpendicular to the glenoid centerline (Fig. 1). We defined the 3D scapulohumeral subluxation with the same distance but projected onto a plane perpendicular to the scapular axis. The 2 projected distances were normalized to the humeral head diameter. A subluxation of 0% corresponded to a centered head, whereas 50% corresponded to a subluxation distance equivalent to the humeral head radius. The orientation of the 3D subluxation was the polar angle of the humeral head center relative to the glenoid center and the anterior-posterior axis (Fig. 1). The orientation of the glenohumeral subluxation was measured in a plane perpendicular to the glenoid centerline, whereas the orientation of the scapulohumeral subluxation was measured in a plane perpendicular to the scapular axis.

Glenoid version

The 2D glenoid version was measured according to a method proposed by Friedman[3] and used by Walch.[16] This 2D version was adapted so that it was always positive. A version of $-10°$ was reported as $10°$ posterior in this study.

We extended the 2D glenoid version measure to 3D so that we could obtain its orientation and compare it to the 3D subluxation measures.[14] The 3D version was the angle between the glenoid centerline and the scapular axis (Fig. 1). The orientation of the version was the angle between the glenoid centerline and the anterior-posterior axis. The orientation of the version was measured in a plane perpendicular to the scapular axis.

3D analysis and bone landmarks

The 3D definitions of glenohumeral subluxation, scapulohumeral subluxation, and glenoid version required 5 anatomic quantities: the scapular plane, the scapular axis, the glenoid centerline, the glenoid center, and the humeral head center. These anatomic quantities were defined from bone landmarks that were placed on a 3D reconstruction of the scapula and the humerus.[14] The scapular plane was fitted on 5 points along the supraspinatus fossa and on 5 points along the axillary border. The scapular axis was fitted on the same 5 points of the supraspinatus fossa, projected onto the scapular plane. The anterior-posterior axis was perpendicular to the scapular axis and the scapular plane. The glenoid surface was identified on the 3D reconstruction. We defined the glenoid center as the centroid (geometric center) of the glenoid surface projected onto the glenoid surface. The glenoid centerline was the axis passing through the glenoid center and the center of a sphere fitted on the glenoid surface. The humeral head center was the center of a sphere fitted on 5 landmarks placed manually. One point was placed at the infraspinatus insertion center, 1 point at the upper part of the bicipital groove, and 3 points on the articular surface (superior, middle, inferior). CT segmentation and landmark positioning were achieved with the visualization software Amira (Visage Imaging GmbH, Berlin, Germany). The geometric analysis was done with MATLAB (MathWorks, Inc, Natick, MA, USA).

Statistical analysis

In 3D, we evaluated the distribution of orientation of glenohumeral subluxation, scapulohumeral subluxation, and glenoid version