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ORIGINAL ARTICLE

Three-dimensional quantitative analysis of humeral head and glenoid bone defects with recurrent glenohumeral instability

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Background: Although bone defects of the humeral head and glenoid could affect glenohumeral instability, bone loss has not been sufficiently evaluated. The purpose of this study was to quantify bone defects 3-dimensionally in cases with glenohumeral instability.
Methods: Three-dimensional surface models of bilateral proximal humeri and glenoids were reconstructed from computed tomography scans of 90 patients with symptomatic, unilateral, recurrent glenohumeral instability. The left-side models were mirrored, and intact bone areas were matched to those of the right-side models. The volume, length, width, and depth of identified bone defects were assessed. After the values were corrected by patient height, the characteristics of the bone defects were evaluated.
Results: Bone defects were present in 97.8% of the humeral heads and 96.7% of the glenoids, and women had significantly smaller bone defects than men did. The volume of humeral head defects had a mild correlation with that of glenoid defects. The number of traumatic episodes was not correlated with humeral head bone defects, but it was positively correlated with glenoid bone defects. Patients with recurrent dislocations had significantly deeper and larger Hill-Sachs lesions than the other cases.
Conclusion: Bone defects of the humeral head and the glenoid in cases with symptomatic traumatic glenohumeral instability were quantified 3-dimensionally using a computed tomography surface-matching technique. Almost all cases showed bone defects in the humeral head and glenoid compared with the intact shoulder, and such bone defects may be more common than previously reported. This study suggested that bipolar bone lesions are not always created by the same mechanism.
Level of evidence: Basic Science; Anatomy Study; Imaging

Keywords: Shoulder dislocation; glenohumeral instability; shoulder instability; glenoid defect; Hill-Sachs lesion; humeral head defect; bipolar lesion

In cases of glenohumeral instability, bone defects are often present in the humeral head and glenoid.[11,18,19,25] Significant glenoid bone loss is known to be a risk factor for poor outcomes after reconstruction.[2,3,8,23] A biomechanical study demonstrated that bone stability was significantly decreased with a bone defect larger than 26% of the glenoid

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width.[27] Some abnormal glenoids show erosion at the glenoid rim, whereas others have a bone defect with a bone fragment of the glenoid rim, which is called a bony Bankart lesion.[18,25] The bone fragments are usually absorbed with time,[18] and it is often difficult to distinguish an absorbed fragment from an erosion.[25] A bone defect in the postero-superior aspect of the humeral head is called a Hill-Sachs lesion,[11] and it can also affect patients' prognosis.[2,8,23] Yamamoto et al[28] proposed the glenoid track concept, which defined the glenoid track as the contact area of the humeral head with the glenoid extended from the inferomedial to the superolateral side of the posterior articular surface during arm elevation. In this concept, the humeral head over-rides the glenoid rim when the Hill-Sachs lesion extends more medially than the glenoid track, and the width of the glenoid track itself would decrease in cases with a bone defect of the glenoid. Hill-Sachs lesions and glenoid defects have recently been recognized as bipolar bone loss, and both lesions are thought to reciprocally affect shoulder instability.[6,28]

Although bone defects of the humeral head and glenoid could be clinically important, bone loss has not been sufficiently evaluated, and its characteristics remain unclear. Few studies[9,19] have assessed bipolar lesions in the same shoulders. Because there is individual variation in the shape and size of the glenohumeral joint,[12,15] comparison with the contralateral shoulder is needed for precise assessment of bone defects if applicable. We hypothesized that bone defects of the humeral head and glenoid would be created more often than previously reported in cases with recurrent glenohumeral instability and that there would be a relationship among the size of bone loss, the number of recurrent shoulder dislocations and subluxations, and the type of glenohumeral instability. The purpose of this study was to quantify bone defects 3-dimensionally in cases with traumatic glenohumeral instability using a computed tomography (CT) surface-matching technique and to clarify its characteristics.

Materials and methods

Materials

Consecutive patients who were referred to our institution with symptomatic unilateral instability of the glenohumeral joint and underwent surgical stabilization during the period between August 2009 and August 2016 were retrospectively reviewed. Lesions in the labrum, capsule, and rotator cuff had been detected using magnetic resonance imaging in patients with symptomatic glenohumeral instability. In cases in which surgical intervention was selected, the bone defects of the humeral head and the glenoid were preoperatively evaluated by CT scanning. The inclusion criteria for this study were shoulders with symptomatic glenohumeral instability with >1 traumatic episode and shoulders with unilateral instability. The exclusion criteria were shoulders with bilateral glenohumeral instability (24 cases), previous shoulder stabilization surgery (5 cases), an unclosed epiphyseal plate in the glenohumeral joint on CT (1 case), evidence of glenohumeral arthritis on CT (2 cases), a rotator cuff tear (3 cases), and posterior glenohumeral instability (3 cases).

CT scans of 180 shoulders from 90 patients (68 men and 22 women; mean age, 26.7 ± 10.9 years; age range, 16-67 years) with symptomatic unilateral anterior instability of the glenohumeral joint were retrospectively analyzed in this study. Axial CT scans of bilateral glenohumeral joints were taken and reconstructed with 1-mm-thick slices using a Toshiba whole-body x-ray CT scanner (Aquilion ONE; Toshiba Medical Systems Corp., Tochigi, Japan). Average time from the first episode to CT scanning was 7.4 ± 9.8 years (range, 0.2-53 years). The right shoulder was involved in 56 patients and the left one in 34 patients. Fourteen patients had experienced recurrent dislocations (dislocation group; 11 men and 3 women), 25 had recurrent subluxations (subluxation group; 21 men and 4 women), and 51 had both subluxations and dislocations (combined group; 36 men and 15 women). Shoulder hyperlaxity with external rotation >85° with the arm at the side[1] was found in 14 patients (7 men and 7 women). Because the patients did not always visit medical institutions after the traumatic episodes, the number and type of traumatic episodes at the time of CT scanning were evaluated from the patients' personal statements.[9] In this study, traumatic episodes that could not be reduced by themselves were defined as dislocations, and instability events in which the patient noted spontaneous reduction or achieved self-reduction were classified as subluxations.[8,20,21] Open Bankart repair was performed in 49 cases, arthroscopic Bankart repair was performed in 37 cases, and the open Latarjet procedure was performed in 4 cases. During stabilization surgery, the anteroinferior glenohumeral ligament–labral complex lesions were identified in all cases.

Surface-matching analysis and bone defect measurement

Three-dimensional surface models of bilateral proximal humeri and glenoids were reconstructed from Digital Imaging and Communications in Medicine data of CT scans using AVIZO 6.2 software (Maxnet, Tokyo, Japan) (Figs. 1, *A* and *B*, and 2, *A* and *B*). In cases with a bony Bankart lesion, the lesion was disregarded in surface model reconstruction of the glenoid, and it was separately reconstructed. The left surface models of the proximal humerus and glenoid were then mirrored using MeshLab 1.3.3 software (ISTI, Pisa, Italy) (Figs. 1, *B*, and 2, *B*), and the surfaces of the intact bone area were matched to those of the right surface models using an iterative closest point matching program in Visual Tool Kit 5.10.0 (Kitware, Clifton Park, NY, USA). On humeral head analysis, the anterior half of the humeral head including the lesser tuberosity and bicipital groove was used to match the surface data (Fig. 1, *C*). On glenoid analysis, the posterior half of the glenoid surface was selected for surface matching because the posterior portion was supposed to remain intact (Fig. 2, *C*). No glenoid showed severe dysplasia according to the Harper classification scheme on CT scans.[10]

Bone defects in the humeral head and glenoid of the affected shoulder were identified on MeshLab software. If the affected side was larger than the intact side, it was considered a case without bone loss. To identify the exact area of bone defects and to minimize the effects of side-to-side differences of the bones, an area with a thickness <0.5 mm was determined by measuring the Hausdorff distance between the 2 sides, and the area was removed from the bone defect area in the analyses. The length, width, and depth of bone defects were then assessed by the software (Fig. 3). For the measurement of humeral head defects, the line between the most superolateral point and the most inferomedial point of the defects was determined as