Bipolar Bone Defects in Shoulders With Primary Instability

Dislocation Versus Subluxation

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Background: In shoulders with traumatic anterior instability, a bipolar bone defect has been recognized as an important indicator of the prognosis.

Purpose: To investigate bipolar bone defects at primary instability and compare the difference between dislocation and subluxation.

Study Design: Cohort study; Level of evidence, 3.

Methods: There were 156 shoulders (156 patients) including 91 shoulders with dislocation and 65 shoulders with subluxation. Glenoid defects and Hill-Sachs lesions were classified into 5 size categories on 3-dimensional computed tomography (CT) scans and were allocated scores ranging from 0 (no defect) to 4 points (very large defect). To assess the combined size of the glenoid defect and Hill-Sachs lesion, the scores for both lesions were summed (range, 0-8 points). Patients in the dislocation and subluxation groups were compared regarding the prevalence of a glenoid defect, a bone fragment of bony Bankart lesion, a Hill-Sachs lesion, a bipolar bone defect, and an off-track Hill-Sachs lesion. Then, the combined size of the bipolar bone defects was compared between the dislocation and subluxation groups and among patients stratified by age at the time of CT scanning (<20, 20-29, and ≥30 years).

Results: Hill-Sachs lesions were observed more frequently in the dislocation group (75.8%) compared with the subluxation group (27.7%; $P < .001$), whereas the prevalence of glenoid defects was not significantly different between groups (36.3% vs 29.2%, respectively; $P = .393$). The combined defect size was significantly larger in the dislocation versus subluxation group (mean ± SD combined defect score, 2.1 ± 1.6 vs 0.8 ± 0.9 points, respectively; $P < .001$) due to a larger Hill-Sachs lesion at dislocation than subluxation (glenoid defect score, 0.5 ± 0.9 vs 0.3 ± 0.6 points [$P = .112$]; Hill-Sachs lesion score, 1.6 ± 1.2 vs 0.4 ± 0.7 points [$P < .001$]). Combined defect size was larger in older patients than younger patients in the setting of dislocation (combined defect score, <20 years, 1.6 ± 1.2 points; 20-29 years, 1.9 ± 1.5 points; ≥30 years, 3.4 ± 1.6 points; $P < .001$) but was not different in the setting of subluxation (0.8 ± 1.0, 0.7 ± 0.9, and 0.8 ± 0.8 points, respectively; $P = .885$). An off-track Hill-Sachs lesion was observed in 2 older patients with dislocation but was not observed in shoulders with subluxation.

Conclusion: The bipolar bone defect was significantly more frequent, and the combined size was greater in shoulders with primary dislocation and in older patients (≥30 years).

Keywords: bipolar bone defects; primary subluxation; primary dislocation; 3-dimensional computed tomography; scoring system; patient age

Although nonoperative treatment is usually selected to treat shoulders with primary instability, this treatment has been reported to result in a significantly higher recurrence rate compared with surgical stabilization.[1,2,6,7,9,31] Several studies have shown favorable clinical outcomes after arthroscopic stabilization surgery for primary instability.[10,11,25-27] However, high recurrence rates have been reported after arthroscopic stabilization surgery for shoulders with recurrent instability, especially in active young athletes.[3,16,28] Early surgical stabilization reduces the risk of large bone defects, which have been correlated with the number of instability episodes.[12,21,24] Minimizing bone loss is critically important because increasing bone loss is associated with high recurrence rates after arthroscopic stabilization.[3,4,13,17,19,22]

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Since Sugaya et al[29] reported that 3-dimensional computed tomography (3D-CT) detected glenoid rim abnormalities in shoulders with recurrent anterior instability, preoperative evaluation of glenoid rim morphology has become essential for surgical planning. More recently, in addition to those affecting the glenoid rim, bone defects in the head of the humerus (Hill-Sachs lesions) have been identified, and the combination of these 2 defects has been described as bipolar bone loss.[4] Furthermore, along with assessment of lesion size, evaluation of whether a Hill-Sachs lesion is "on-track" or "off-track" according to the glenoid track concept is now considered to be essential for making decisions about surgery.[33] Because the size of a bipolar bone defect seems to be a crucial determinant of recurrence after stabilization surgery, investigating these defects at primary instability could provide important information.

No simple method has been available for evaluating the size of bipolar bone defects other than the glenoid track concept,[4,33] making it difficult to perform detailed evaluation or comparison of these defects. Nakagawa et al[13,22] recently reported a new scoring system to simply evaluate and compare the size of bipolar bone defects. The investigators reported that the postoperative recurrence rate among male competitive athletes was influenced by the extent of the bipolar defect and the sporting category. Furthermore, using their scoring system, Nakagawa et al[14] reported that bipolar bone defects were smaller in shoulders with primary instability than in those with recurrent instability and that the recurrence rate after arthroscopic stabilization was consistently low in patients with primary instability and was significantly influenced by bipolar bone defects size and patient age in patients with recurrent instability.

Nakagawa et al[21] reported that glenoid defects are enlarged not only by the recurrent dislocation but also by recurrent subluxation without dislocation. With regard to Hill-Sachs lesions, Ozaki et al[24] reported that these lesions are seldom found in shoulders without dislocation and suggested that engagement with the anterior glenoid rim at the time of complete dislocation was essential for their occurrence. Matsumura et al[12] also quantified bipolar bone defects using a 3D-CT surface-matching technique and reported different mechanisms for creation of each bone defect. Accordingly, the type of instability is important to predict the progression of bipolar bone defects, although in previous reports the distinction between dislocation and subluxation was quite vague. To investigate the influence of the instability event on the formation of bipolar bone defects, it is important to investigate bipolar bone defects in shoulders with primary instability. This study was performed using the above-mentioned scoring system to investigate bipolar bone defects using 3D-CT in shoulders with primary instability and to compare the difference between dislocation and subluxation.

We hypothesized that among shoulders with primary instability, bipolar bone defects would be more frequent and would be larger in shoulders with dislocation versus shoulders with subluxation.

METHODS

This retrospective investigation of prospectively collected clinical data received institutional review board approval. We investigated 156 patients (156 shoulders) with primary dislocation or primary subluxation who underwent CT scanning at our hospital within 3 months of a primary traumatic episode between July 2004 and December 2017. Excluded were patients with atraumatic subluxation, those who underwent CT scanning at $\geq$3 months after the primary episode, those who did not undergo CT scanning at the primary episode, and those who underwent previous stabilization surgery.

Subluxation was defined as an episode of shoulder instability that did not require manual reduction by a health care provider, whereas dislocation was defined as instability that required manual reduction by a health care provider.[23] Thus, instability with spontaneous reduction or self-reduction by the patient was classified as subluxation. In all shoulders, primary instability was due to a distinct traumatic episode; the "dead arm" phenomenon while tackling in rugby or American football and sliding to base by baseball players were recognized as causes of traumatic subluxation, which was confirmed via physical examination, imaging studies (magnetic resonance imaging or CT), or both.

CT was usually performed at the first visit to our hospital for most of the patients with primary dislocation or subluxation. Although most patients visited our hospital and underwent CT scanning soon after the primary episode, some patients visited our hospital because of persistent pain after the primary episode and underwent CT scanning later after the primary episode (within 3 months). CT scanning was conducted using a whole-body scanner (spiral scan, 0.5-mm slice thickness, 0.3-mm reconstruction, and 3D edit mode), with the patient lying supine in the center of the gantry table and the affected arm in the neutral position. Data acquired in digital imaging and communications

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Ethical approval for this study was obtained from the institutional review board at Yukioka Hospital.

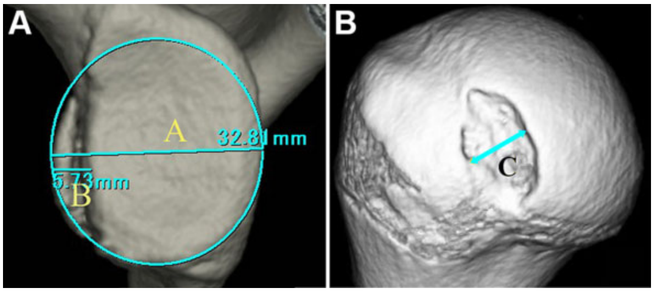

Figure 1. Quantification of glenoid defect size and Hill-Sachs lesion size on 3-dimensional (3D) computed tomography scan. (A) The extent of the glenoid defect: $B/A \times 100\%$, where A is the diameter of the fitted circle and B is the width of the glenoid defect. (B) Through use of en face 3D-reconstructed images that showed the Hill-Sachs lesion, the longest line connecting the medial and lateral edges of the lesion was defined as the lesion width, C. The humeral head diameter was defined as the diameter of the circle on the axial slice with the largest circle. Then, the size of the Hill-Sachs lesion was calculated as a percentage of the humeral head diameter.

in medicine mode were analyzed with dedicated software for multiplanar reconstruction to obtain 3D-CT scans.

All studies were interpreted by a single observer who was blinded to information regarding the type of instability (S.N., a shoulder specialist with >30 years of experience). To quantify the glenoid defect, the inferior portion of the glenoid rim was approximated to a true circle using en face scans reconstructed with elimination of the humeral head, and the extent of the glenoid defect was calculated as a percentage of the glenoid rim width ($B/A \times 100\%$, where A is the diameter of the fitted circle and B is the width of the defect) (Figure 1A).[18,21] Simultaneously, the presence of a bone fragment of a bony Bankart lesion, which was usually accompanied by a glenoid defect, was determined in shoulders with a glenoid defect.[17,18,20] When a bone fragment was not observed despite the presence of a glenoid defect, we defined it as an erosion. A Hill-Sachs lesion was diagnosed if an abnormal groove was detected on the posterolateral aspect of the head of the humerus. The width of each Hill-Sachs lesion was measured on 3D-CT scans reconstructed with elimination of the scapula, according to the method of Ozaki et al[24]; the longest line connecting the medial and lateral edges of the lesion on the en face view was defined as the width of the lesion. The humeral head diameter was measured as the diameter of the circle on the axial slice with the largest circle. Each measurement was normalized to the humeral head diameter (Figure 1B).

To determine whether a Hill-Sachs lesion was on-track or off-track, the width of the glenoid track (GT) was calculated according to the method of Di Giacomo et al[4]: $GT = 0.83 \times A - B$, where A is the glenoid diameter and B is the glenoid defect width. Then, the distance between the rotator cuff attachments and the medial aspect of the Hill-Sachs lesion was measured as the Hill-Sachs interval (HSI). A lesion was classified as off-track if the HSI was larger than the GT, whereas a lesion was on-track if the HSI was smaller than the GT (Figure 2).[13]

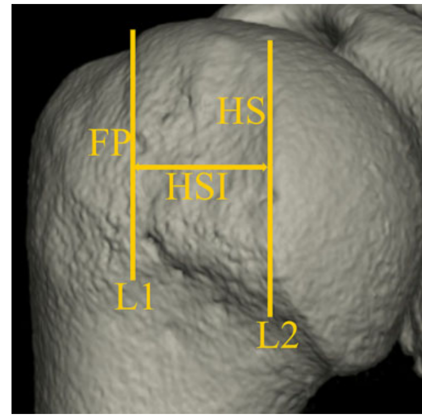

Figure 2. Definition of Hill-Sachs interval (HSI): the length between the rotator cuff attachments (*L1*) and the medial aspect of the Hill-Sachs lesion (*L2*). FP, footprint of rotator cuff attachment; HS, Hill-Sachs lesion.

TABLE 1
Scoring According to the Size of the Bone Defects

	Score, Points				
Bone Defect Size	0 (None)	1 (Small)	2 (Medium)	3 (Large)	4 (Very Large)
Glenoid defect size, % of glenoid rim width	0	>0-10	>10-20	>20-30	>30
Hill-Sachs lesion size, % of humeral head diameter	0	>0-10	>10-20	>20-30	>30

After these parameters were obtained, the presence or absence and features of a bipolar bone defect were investigated as follows. First, each glenoid defect or Hill-Sachs lesion was classified into 5 categories (from 0% to >30%) according to the size of the bone defect with reference to the criteria of Nakagawa et al[13,19,22] (Table 1). Then, to assess the combined size of the glenoid defect and Hill-Sachs lesion, the scores for both lesions were summed, and the lesions were classified based on the total score (range, 0-8 points).[14,22]

The prevalence of a glenoid defect, a bone fragment of bony Bankart lesion, a Hill-Sachs lesion, a bipolar bone defect, or an off-track Hill-Sachs lesion was investigated and compared between patients with primary dislocation (dislocation group) or primary subluxation (subluxation group). Then, the defect size was compared between the 2 groups as well as among patients stratified into 3 groups

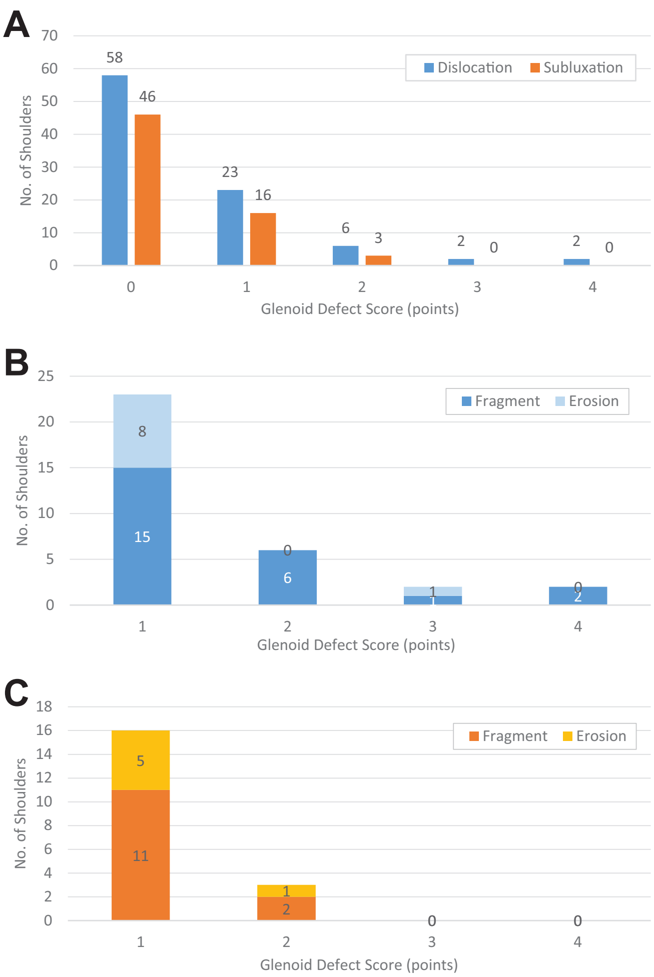

Figure 3. The number of shoulders for each glenoid defect score according to (A) glenoid defect size and according to bone fragment/erosion among shoulders with a glenoid defect at (B) dislocation and (C) subluxation.

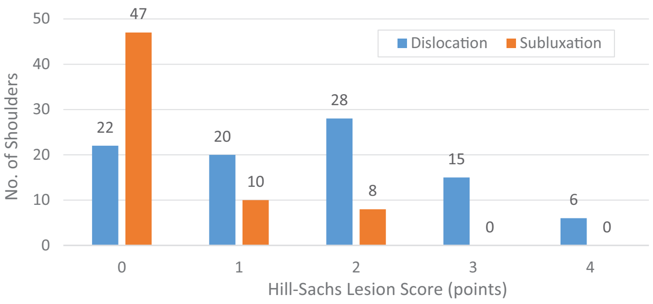

Figure 4. The number of shoulders for each Hill-Sachs lesion score.

according to their age at the time of CT scanning: <20, 20-29, and ≥30 years.

At statistical analysis, data were tested for normal distribution before the appropriate parametric (Student *t* test) or nonparametric (Mann-Whitney *U*) test was used to assess continuous variables for differences between 2 groups. The parametric (1-factor analysis of variance) or nonparametric (Kruskal-Wallis analysis) test was used to assess continuous variables for differences among multiple groups. The Fisher exact probability test was used to assess categorical variables. Significance was accepted at $P < .05$.

RESULTS

Patient Characteristics

The 156 patients consisted of 126 male and 30 female patients. Of these, 132 patients were athletes, including 119 competitive athletes (rugby, n = 34; American football, n = 25; other collision/contact sports, n = 32; overhead sports, n = 23; other sports, n = 5) and 13 recreational athletes. There were 91 shoulders in the dislocation group and 65 shoulders in the subluxation group. The age at the time of CT scanning was <20 years (range, 13-19 years) in 87 patients, 20-29 years in 42 patients, and ≥30 years (range, 30-77 years) in 27 patients (9 patients aged 30-39 years, 8 patients aged 40-59 years, 10 patients aged ≥60 years).

Glenoid Defects and Hill-Sachs Lesions

Glenoid defects were detected in 33 (36.3%) of the 91 shoulders in the dislocation group and in 19 (29.2%) of the 65 shoulders in the subluxation group ($P = .393$). Large glenoid defects (>20%; glenoid defect score ≥3 points) were detected in 4 shoulders (4.4%) in the dislocation group versus 0 shoulders in the subluxation group ($P = .141$) (Figure 3A). Bone fragments of bony Bankart lesion were detected in 24 (72.7%) of the 33 shoulders with a glenoid defect and primary dislocation and in 13 (68.4%) of the 19 shoulders with a glenoid defect and primary subluxation ($P = .76$). Glenoid erosion (no bone fragment despite the presence of a glenoid defect) was predominantly observed in shoulders with a small glenoid defect (≤10%; glenoid defect score = 1 point) regardless of the type of instability (Figure 3, B and C).

Hill-Sachs lesions were detected in 69 (75.8%) of 91 shoulders with primary dislocation versus 18 (27.7%) of 65 shoulders with primary subluxation, showing a significantly higher prevalence in shoulders with dislocation ($P < .001$). Large Hill-Sachs lesions (>20%; Hill-Sachs lesion score ≥3 points) were detected in 21 shoulders (23.1%) with primary dislocation versus 0 shoulders with primary subluxation, also showing significant differences in the prevalence of large lesions between the dislocation and subluxation groups ($P < .001$) (Figure 4).

With regard to bipolar bone defects, either bipolar bone loss or an isolated Hill-Sachs lesion was predominantly found in shoulders with primary dislocation, whereas almost half of the shoulders with primary subluxation had no recognizable lesion. The differences in the prevalence of these characteristics between the 2 groups were significant ($P < .001$ for no lesion, $P < .001$ for isolated Hill-Sachs lesion, and $P = .007$ for bipolar bone loss) (Table 2).

TABLE 2
Bipolar Bone Defects Stratified by Type of Instability[a]

Bone Defect	Dislocation (n = 91)	Subluxation (n = 65)	*P* Value
No lesion	18 (19.8)	36 (55.4)	<.001
Isolated Hill-Sachs lesion	40 (44.0)	10 (15.4)	<.001
Isolated glenoid defect	4 (4.4)	11 (16.9)	.012
Bipolar bone loss	29 (31.9)	8 (12.3)	.007

[a]Values are expressed as n (%).

TABLE 3
Bipolar Bone Defect Scores Stratified by Type of Instability[a]

	Dislocation (n = 91)		Subluxation (n = 65)		
Bone Defect Score	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	*P* Value
Glenoid defect score	0.5 ± 0.9	0 (0-1)	0.3 ± 0.6	0 (0-1)	.112
Hill-Sachs lesion score	1.6 ± 1.2	2 (1-2)	0.4 ± 0.7	0 (0-1)	<.001
Combined defect score	2.1 ± 1.6	2 (1-3)	0.8 ± 0.9	0 (0-1)	<.001

[a]IQR, interquartile range.

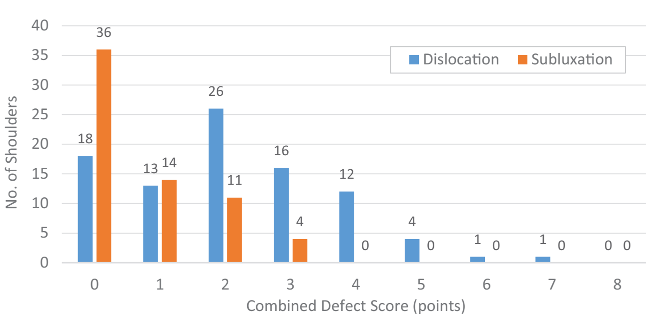

Figure 5. The number of shoulders for each bipolar bone defect score.

Bipolar Bone Defect Size

The mean ± SD and median (interquartile range) scores for glenoid defect, Hill-Sachs lesion, and combined defect were stratified according to dislocation or subluxation group (Table 3). Significant differences were noted between the groups according to Hill-Sachs lesion score and combined defect score ($P < .001$ for both).

A large bipolar bone defect (combined defect score ≥4 points) was observed in 18 (19.8%) of 91 shoulders with primary dislocation, whereas it was not observed in 65 shoulders with primary subluxation ($P < .001$) (Figure 5).

TABLE 4
Combined Defect Scores Stratified by Type of Instability and Age at CT Scanning[a]

	Age at CT Scanning			
Combined Defect Score	<20 y	20-29 y	≥30 y	*P* Value
Dislocation	(n = 46)	(n = 22)	(n = 23)	<.001
Mean ± SD	1.6 ± 1.2	1.9 ± 1.5	3.4 ± 1.6	
Median (IQR)	2 (1-2)	2 (0.25-2.75)	4 (3-4)	
Subluxation	(n = 41)	(n = 20)	(n = 4)	.885
Mean ± SD	0.8 ± 1.0	0.7 ± 0.9	0.8 ± 0.8	
Median (IQR)	0 (0-1)	0 (0-1.25)	0.5 (0-1.25)	
P value	<.001	<.001	<.001	

[a]CT, computed tomography; IQR, interquartile range.

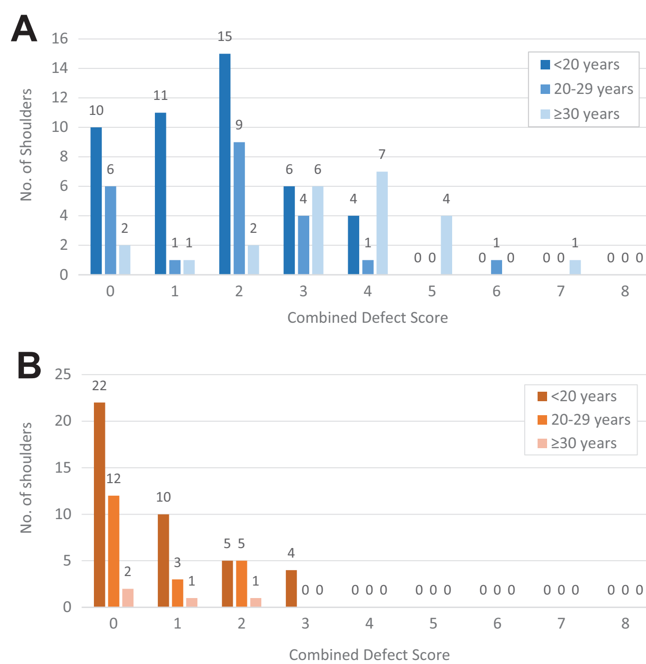

Figure 6. Number of shoulders for each combined defect score stratified by the age at computed tomography scanning for (A) primary dislocation and (B) primary subluxation.

The combined defect scores stratified by type of instability and age at CT scanning are shown in Table 4. A significant difference was seen in scores between the dislocation and subluxation groups for all 3 age groups ($P < .001$ for all). In the dislocation group, a significant difference was seen in scores among all 3 age groups ($P < .001$) as well as between patients aged <20 versus ≥30 years and patients aged 20-29 vs ≥30 years ($P < .001$ for both). No significant difference was seen in scores among the age groups for shoulders with primary subluxation.

In the dislocation group, a large bipolar bone defect (combined defect score ≥4 points) was observed in 4 (8.7%) of 46 patients aged <20 years, 2 (9.1%) of 22 patients aged 20 to 29 years, and 12 (52.2%) of 23 patients aged ≥30 years ($P < .001$) (Figure 6).

An off-track Hill-Sachs lesion was observed in 2 shoulders (2.2%) with primary dislocation but was not found in shoulders with primary subluxation. Among 2 patients with an off-track lesion, the combined defect score was 5 points in 1 patient (a 57-year-old man) and 7 points in the other patient (a 71-year-old woman).

DISCUSSION

Among patients with primary instability, the prevalence and size of bipolar bone defects differed between patients with primary dislocation and primary subluxation. Although the prevalence and size of glenoid defects were not significantly different based on the type of instability, Hill-Sachs lesions were significantly more frequent and larger in patients with primary dislocation than in patients with primary subluxation. Combined defects were larger in patients with primary dislocation than in those with primary subluxation. Combined defects were larger in older patients than younger patients at primary dislocation. Off-track Hill-Sachs lesions were not observed in patients with primary subluxation but were observed in 2 older patients (2.2%) with primary dislocation. The present study clearly shows that the prevalence and size of combined defects were influenced by type of instability and patient age due to a larger Hill-Sachs lesion occurring at primary dislocation.

Although previous studies have shown that the presence of large glenoid defects was one of the most important reasons to treat traumatic shoulder instability,[5,28,32] a large glenoid defect was rare at primary instability in the present study (4.4% at primary dislocation and 0% at primary subluxation). However, because not only a dislocation but also a subluxation similarly influenced the creation of a glenoid defect, the repetitive dislocations and subluxations were considered to induce the formation of a large glenoid defect at recurrent instability, as previously reported by Nakagawa et al[21] and Matsumura et al.[12] In contrast, a large Hill-Sachs lesion was not uncommon (23.1%) at primary dislocation, whereas it was not observed at primary subluxation. The repetitive events of dislocation were also considered to contribute to the formation of a large Hill-Sachs lesion at recurrent instability, as previously shown by Ozaki et al[24] and Matsumura et al.[12] Therefore, it is reasonable that repetitive instability events should be avoided to prevent a large, combined defect. Recently, Nakagawa et al[15] investigated the development of combined defects evaluated using 3D-CT at primary instability and after recurrence; the investigators reported that although Hill-Sachs lesions were almost twice as frequent as glenoid defects at the time of primary instability, glenoid defects increased markedly after recurrence, so the prevalence of bipolar bone loss increased significantly after recurrence. Considering the results of their study and the present study, stabilization surgery might be indicated as soon as possible after recurrence to avoid the formation and enlargement of the combined defects.

The patient's age at the time of CT scanning also influenced the combined defect size, as bipolar bone defects were larger in older patients (≥30 years) than in younger patients (<30 years) at primary dislocation. Furthermore, bipolar bone defects were larger in patients with primary dislocation than in patients with subluxation, regardless of the patient's age. However, Nakagawa et al[14] recently reported that among older patients (≥30 years), the postoperative recurrence of instability after arthroscopic Bankart repair was rare both in those with primary instability and in those with recurrent instability regardless of the size of combined defects. Those investigators also reported that the postoperative recurrence of instability was frequent in patients with recurrent instability, especially among those aged <20 years with combined defect score ≥2 points. Among younger patients (<30 years) in the present study, the size of combined defects was larger in patients with primary dislocation than in patients with primary subluxation; thus, we should be more careful about the prognosis of young patients with dislocation.

Regarding the bone fragment of a bony Bankart lesion accompanying a glenoid defect, favorable clinical outcomes after arthroscopic bony Bankart repair have been reported.[8,17,20,30] Nakagawa et al[18] reported that the bone fragment became smaller due to absorption over time after primary instability and decreased to almost half of the glenoid defect size within 1 year. When there was no bone fragment despite the presence of a glenoid defect, which was defined as an erosion, Nakagawa et al[18] suggested this might mean that a small bone fragment had been completely absorbed. In the present study, a bone fragment was not always seen in shoulders with a glenoid defect at primary instability, especially in shoulders with a small glenoid defect (<10%), and the anterior glenoid rim frequently showed erosive damage resembling a compression fracture in the shoulders without a bone fragment. Because the prevalence of a glenoid defect, a bone fragment, or erosion was not different between primary dislocation and primary subluxation groups, the factors influencing the occurrence of bone fragments and erosive changes are still unclear. However, a bone fragment of bony Bankart lesion was observed in 11 of 13 shoulders with a glenoid defect (>10%), which suggests the possibility that a glenoid rim morphology would be normalized via bony Bankart repair performed at primary instability.[8,17,20,30] Therefore, we should be always cautious about the presence of bone fragments at primary instability because early reduction of a bone fragment is sometimes required.

Among the strengths of the present study is that it appears to be the first detailed investigation into the size of bipolar bone defects in a large series of shoulders with primary instability. Because the size of the defects was determined by use of a scoring system, the differences and changes of size were easily compared. Accordingly, the defect score was shown to be useful for comparing the size of combined defects.

A limitation of this study was that dislocation and subluxation were defined on the basis of information provided by the patients. Some dislocations were reduced spontaneously or by the patient, and we defined such episodes as subluxation in this study. Accordingly, we need to be careful when interpreting possible differences between dislocation and subluxation. Another limitation was the retrospective design of this study. Finally, intraobserver and interobserver reliability for the interpretation of the CT scans was not determined.

CONCLUSION

The bipolar bone defect was more frequent, and the combined size was greater in shoulders with primary dislocation than in shoulders with primary subluxation due to a presence of a large Hill-Sachs lesion that occurred at primary dislocation. Combined defects were larger in older patients than younger patients at primary dislocation.

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