Original Research

Comparison of Glenoid Bone Loss After Unidirectional Versus Combined Shoulder Instability in a Military Population

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Background: While glenoid bone loss (GBL) after anterior shoulder instability correlates with poor functional outcomes, the specific effects of GBL in posterior and combined-type shoulder instability remain poorly characterized, especially in a high-risk military population.

Purpose/Hypothesis: The purpose of this study was to compare GBL between unidirectional anterior or posterior instability versus combined-type instability in active-duty servicemembers. It was hypothesized that total GBL and GBL in the direction of instability would be greater in those with combined-type instability compared with unidirectional instability.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Active-duty servicemembers who underwent shoulder stabilization surgery between January 2010 and December 2019 were eligible for inclusion. Patients with multidirectional instability, concomitant rotator cuff tears, osteochondritis dissecans of the glenoid or humeral head, superior labral anterior-posterior tears, biceps pathologies, and humeral avulsion of the glenohumeral ligament were excluded. Patients were grouped according to direction of instability (anterior, posterior, or combined), and patient characteristics, instability characteristics, suture anchor use, and GBL were compared between the 3 cohorts.

Results: In total, 117 patients met the study inclusion criteria. The mean patient age was 29 years, 89.7% were male, the dominant extremity was involved in 63.2%, 65.8% attributed their injuries to a singular traumatic event, and the mean follow-up was 7.9 years. There was no significant difference regarding patient characteristics, injury mechanism, or follow-up time between the 3 cohorts. As compared with the combined-type instability cohort, mean anterior GBL was greater in the anterior instability cohort (8.00% ± 4.40% vs 4.98% ± 5.26% for combined; P = .012), while mean posterior GBL was greater in the posterior instability cohort (7.44% ± 4.54% vs 4.86% ± 5.69% for combined; P = .024). There was no significant difference in mean total GBL between the combined-type (9.84% ± 7.82%) and either of the unidirectional cohorts (anterior: 8.00% ± 4.40% [P = .231]; posterior: 7.44% ± 4.54% [P = .082]).

Conclusion: GBL in the direction of instability was found to be significantly greater in the unidirectional versus combined-type instability cohorts.

Keywords: glenoid bone loss; anterior shoulder instability; posterior shoulder instability; combined shoulder instability

Shoulder instability is significantly more common among active-duty servicemembers as opposed to their civilian counterparts, with incidences of shoulder instability estimated at 1.7 per 1000 person-years in servicemembers and 0.2 to 0.8 per 1000 person-years in the general population.[28] In an active population with unique occupational physical requirements, the high rate of instability is often attributed to mandatory physical fitness events such as push-ups as well as the high shoulder demand of many military occupation specialties.[9] However, while anterior instability from assumed anterior-based pathology is the most common direction of instability among active-duty servicemembers, rates of anterior, posterior, and combined-type instability (defined as instability in both the anterior and posterior planes) are all higher in military populations.[9,13,19,27,28] Subsequently, achieving a greater understanding of the historically less common posterior and combined-type forms of instability becomes especially important in this unique cohort. Glenoid bone loss (GBL)

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after anterior shoulder instability has been well characterized, with osseous defects present in up to 22% of patients after an initial shoulder dislocation and in 88% of patients with recurrent instability.[24] After anterior labral repair, shoulders with a subcritical bone loss of >13.5% correlate with worse functional outcomes in patient-reported outcomes measures such as the Western Ontario Shoulder Instability Index and Single Assessment Numeric Evaluation.[26] Although the role of GBL in anterior instability is well understood, there are limited data on GBL in posterior and combined-type shoulder instability, contributing to a less robust understanding of variations in GBL observed between unidirectional versus combined-type forms of instability.

The purpose of this study was to compare GBL between unidirectional anterior or posterior instability versus combined-type instability. We hypothesized that total GBL and GBL in the direction of instability would be greater among the combined-type instability cohort as compared with the unidirectional-type anterior or posterior cohorts.

METHODS

Inclusion and Exclusion Criteria

Retrospective data were collected from all active-duty military patients who underwent shoulder stabilization surgery between January 2010 and December 2019. Included were patients <50 years with a minimum follow-up of 3 years. All surgical procedures were performed by a single shoulder and elbow fellowship-trained senior surgeon (N.P.). Patients with concomitant injuries including rotator cuff tears, osteochondritis dissecans of the glenoid or humeral head, superior labral anterior-posterior tears, biceps pathologies, and humeral avulsions of the glenohumeral ligament were excluded from further analysis. Patients with multidirectional instability, defined as those with clinical examination findings of a sulcus sign and hyperlaxity with no discrete labral tears on imaging, were also excluded. Institutional review board approval and patient informed consent were obtained before the initiation of this study.

Surgical Technique

All included patients underwent ligamentous stabilization surgery by a shoulder and elbow fellowship-trained surgeon (N.P.). No bony augmentation procedures (eg, Latarjet) were performed. Surgical technique did not change markedly throughout the study period and was replicated as described by Green et al.[14]

All patients were placed in a modified beach-chair position after administration of general anesthesia and an interscalene block. An examination was performed under anesthesia to assess range of motion and stability in the anterior and posterior directions. A Spider hydraulic arm holder (Smith & Nephew) was then utilized to stabilize the operative shoulder, and the patient was draped appropriately. Diagnostic arthroscopy of the glenohumeral joint was performed, and the capsulolabral tears were identified. After the completion of diagnostic arthroscopy, any associated intra-articular abnormalities were documented and addressed as indicated. A trans–rotator cuff portal was then created medial to the rotator cuff cable (the musculotendinous junction) using a spinal needle, and the torn labrum was mobilized from the glenoid neck. A small shaver was used to create a bed of bleeding bone along the neck of the glenoid. Capsulolabral repair was performed with double-loaded Gryphon BR biocomposite suture anchors (DePuy Mitek) from January 2011 through June 2014, and with 1.9-mm double-loaded Suturefix all-suture anchors (Smith & Nephew) from July 2014 onward. A pilot hole was drilled, and the anchor was positioned into the glenoid. A suture passer was then used to shuttle one of the suture limbs through the capsule and labrum. Low-profile sliding knots were tied arthroscopically, with care taken to position the knots away from the glenoid face. After completion of the procedure, adequacy of the repair site was confirmed by using a probe. Portal sites were closed with No. 3-0 nylon sutures, a sterile dressing was applied, and the patient's arm was placed in a neutral rotation sling.

Data Analysis

Patients were grouped into anterior, posterior, and combined-type cohorts based on their direction of instability, and data regarding patient characteristics, instability characteristics, suture anchor use, and GBL were collected and compared between the cohorts. Combined-type instability was defined as instability in both anterior and posterior planes determined by physical examination, examination under anesthesia, and imaging. GBL was measured by 2 shoulder and elbow fellowship-trained orthopaedic surgeons utilizing the "perfect circle" technique as described by Hines et al[16] on 3.0-T magnetic

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Ethical approval for this study was obtained from Carson-Carthage (reference No. 2023-17).

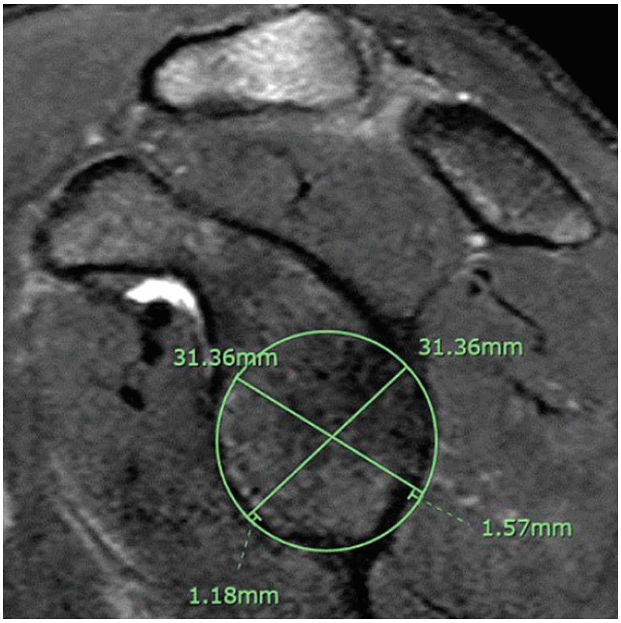

Figure 1. Magnetic resonance arthrogram of a right shoulder obtained in a 34-year-old male patient demonstrating a 3.8% (1.18 mm-wide) anterior glenoid defect and a 5.0% (1.57 mm-wide) posterior glenoid defect measured using the perfect circle technique.[14]

resonance arthrogram using a standard protocol in the coronal oblique plane. Imaging was obtained within 3 months before stabilization surgery, and calculations for GBL were based on glenoid width rather than total surface area (Figure 1).[1,14] Three-dimensional computed tomography was not routinely performed on these patients and was subsequently not included in analysis. For situations in which there was a discrepancy between measurements, the magnetic resonance arthrogram was evaluated by a third shoulder and elbow fellowship-trained orthopaedic surgeon to determine the closest relevant measurement.

Statistical Analysis

Statistical analyses were performed using the IBM SPSS Version 20 software package (IBM Corp). Analysis of variance was used to compare means between the 3 study groups, and chi-square tests with Bonferroni correction when appropriate were used to compare categorical variables between the groups. Statistical significance for all comparisons was determined at a P value <.05. An a priori power analysis based on estimated means from existing research by Green et al[14] demonstrated the achievement of 80% power with the inclusion of 20 patients in the combined-type instability cohort and 20 patients in the unidirectional cohort.

RESULTS

From January 2010 to December 2019, 418 patients underwent operative intervention for shoulder instability. Of these, 291 patients with concomitant injuries or

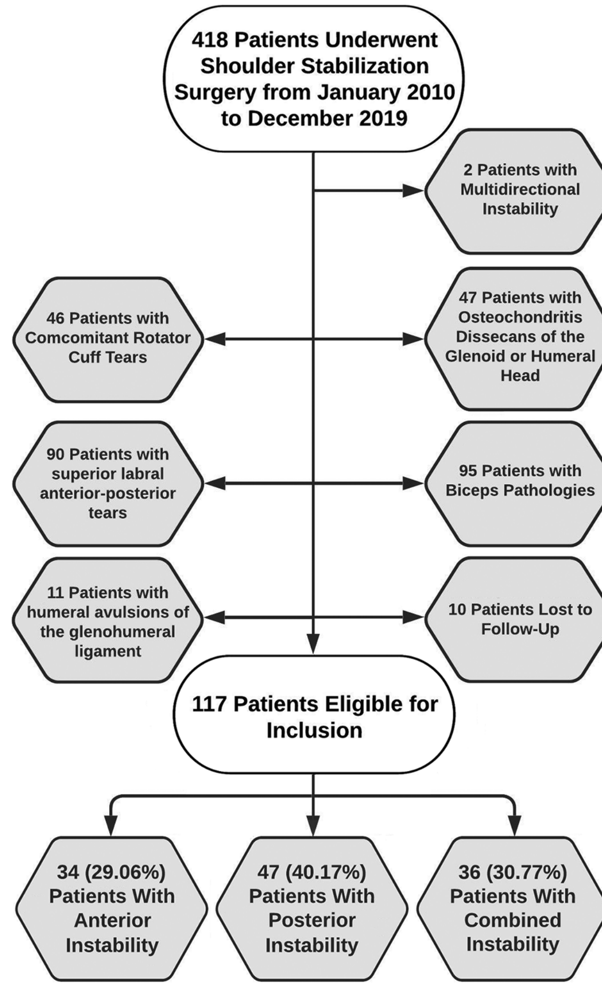

Figure 2. STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) flow diagram of patient inclusion in the study.

multidirectional instability were excluded and 10 patients were lost to follow-up, leaving 117 patients available for analysis. The 117 patients included for analysis were categorized into 3 patient cohorts according to the direction of their instability: anterior (n = 34), posterior (n = 47), and combined (n = 36) (Figure 2).

Patient Characteristics

Overall, the mean patient age was 29 years, and 89.7% (n = 105) were male. The majority of surgeries occurred on the patient's dominant side (mean, 63.2%; range, 61.8%-63.9%; n = 74), with overall laterality favoring the right side (mean, 59.8%; range, 58.3%-61.8%; n = 70). The mechanism of injury was also more commonly attributed to a specific traumatic event rather than repetitive use or absence of a single event that precipitated their symptoms (mean, 65.8%; range, 63.9%-67.6%; n = 77). There were no significant differences between the anterior, posterior, and

TABLE 1
Patient Characteristics Stratified by Study Cohort[a]

Variable	Anterior Instability (n = 34)	Posterior Instability (n = 47)	Combined Instability (n = 36)	*P*
Age, y	28.74 ± 9.96	29.34 ± 6.36	29.75 ± 8.13	.870
Male sex	30 (88.2)	43 (91.5)	32 (88.9)	.874
Dominant side affected	21 (61.8)	30 (63.8)	23 (63.9)	.978
Right side affected	21 (61.8)	28 (59.6)	21 (58.3)	.975
Traumatic onset	23 (67.6)	31 (66.0)	23 (63.9)	.946
No. of anchors	2.30 ± 0.88	2.62 ± 1.01	4.06 ± 1.07	<.001[b]

[a]Data are presented as mean ± SD or n (%).
[b]Statistically significant difference between combined versus anterior instability and combined versus posterior instability ($P < .05$).

combined-type cohorts regarding age (P = .870), sex distribution (P = .874), dominant shoulder involvement (P = .978), right-sided laterality (P = .975), or recollection of a traumatic event (P = .946) (Table 1). Mean follow-up time was 95 months (7.9 years) without significant differences between the cohorts (anterior: 93.9 ± 26.6, posterior: 95.1 ± 25.3, combined: 96.56 ± 26.04; P = .913).

Anchor Use

The mean number of anchors used to address combined-type instability (4.06 ± 1.07) was significantly greater than the mean number used to address anterior instability (2.30 ± 0.88; $P < .001$) or posterior instability (2.62 ± 1.01; $P < .001$), reflecting a 78% and 58% increase in anchor use, respectively (Table 1). There was no significant difference between the number of anchors used for anterior versus posterior instability (P = .332).

Directional GBL

Anterior GBL. When comparing the anterior versus combined instability cohorts, anterior GBL was significantly greater among patients with isolated anterior instability (8.00% ± 4.40% vs 4.98% ± 5.26% for combined; P = .012). In the anterior instability group, 3 patients had anterior GBL >13.5%, while in the combined instability group, only 1 patient had anterior GBL >13.5% (P = .276) (Table 2).

Posterior GBL. Similar to the results for anterior GBL, there was a significantly greater percentage of posterior GBL among patients with isolated posterior instability versus combined instability (7.44% ± 4.54% vs 4.86% ± 5.69%; P = .024). In the posterior instability group, 5 patients had posterior GBL >13.5%, while in the combined instability group there were 3 patients with posterior GBL >13.5% (P = .724) (Table 3).

Total GBL. Total GBL in all planes was measured in all 3 patient groups. The mean total GBL in the combined-type instability cohort was 9.84% ± 7.82%, with no significant differences observed compared with the anterior (P = .233) or posterior (P = .077) cohorts. Similarly, there was no significant difference in total GBL between the combined versus anterior cohort (8.00% ± 4.40%; P = .231) and between the combined versus posterior cohort (7.44% ± 4.54%; P = .082).

DISCUSSION

Contrary to our hypothesis, a significantly higher percentage of GBL in the direction of instability was observed among patients with unidirectional rather than combined-type instability; furthermore, the observed anterior or posterior GBL was greater in the corresponding unidirectional instability cohorts as compared with the combined-type instability cohort. The number of patients with subcritical GBL of 13.5% to 20% was higher in both the anterior and posterior instability cohorts as compared with the combined-type instability cohort, although this comparison did not reach statistical significance given the small sample sizes in our study.

Ultimately, the findings of this study indicate that unidirectional instability may portend greater mean GBL than combined-type instability, without significant differences between anterior versus posterior directionality. The importance of restoring the soft tissue envelope in shoulders with instability remains an important principle of shoulder stabilization, with Bankart repairs and remplissage remaining relevant in the management of shoulder instability.[8,23-25] However, the role of GBL in altering the pathoanatomy and biomechanics of the shoulder is increasingly recognized in recent literature, with failure to address subcritical GBL increasing the risk of recurrent instability and imparting poorer functional outcomes after soft tissue repair for glenohumeral instability.[3,4,6,22,24] With evolving evidence regarding the implications of GBL in restoring shoulder stability, understanding the impact of unidirectional versus combined instability offers insight into the variations of GBL patterns between the 2 types.

As compared with existing research on the role of GBL in anterior instability, there are relatively fewer studies evaluating how GBL impacts posterior and combined-type instability. Dickens et al[11] in 2019 first sought to

TABLE 2
Anterior Versus Combined Instability[a]

	Anterior Instability, % (n = 34)[b]	Combined Instability, % (n = 36)[b]	Mean Difference	P	Anterior Instability and GBL >13.5%	Combined Instability and GBL >13.5%	P
Anterior GBL	8.00 ± 4.40	4.98 ± 5.26	3.02	.012[c]	8.8%	2.7%	.276
Total GBL	8.00 ± 4.40	9.84 ± 7.82	−1.84	.231	—	—	—

[a]GBL, glenoid bone loss.
[b]Data are presented as mean ± SD.
[c]Statistically significant difference between combined and anterior instability ($P < .05$).

TABLE 3
Posterior Versus Combined Instability[a]

	Posterior Instability, % (n = 47)[b]	Combined Instability, % (n = 36)[b]	Mean Difference	P	Posterior Instability and GBL >13.5%	Combined Instability and GBL >13.5%	P
Posterior GBL	7.44 ± 4.54	4.86 ± 5.69	2.58	.024[c]	10.6%	8.3%	.724
Total GBL	7.44 ± 4.54	9.84 ± 7.82	−2.40	.082	—	—	—

[a]GBL, glenoid bone loss.
[b]Data are presented as mean ± SD.
[c]Statistically significant difference between combined and posterior instability ($P < .05$).

quantify GBL per anterior instability event and found that recurrent instability imbues significantly greater GBL as compared with first-time events (22.8% vs 6.8%). Similarly, a 2022 study by Bedrin et al[2] demonstrated that recurrent posterior instability was associated with a greater amount of GBL at 16.8% versus 10.0% in a first-time instability event. A comparison between GBL in anterior versus posterior instability by Ernat et al[12] demonstrated that anterior instability has a higher percentage of GBL (24.9%) compared with posterior instability (9.2%) as well as significantly greater rates of moderate (11%-20%) to high-grade (≥20%) GBL. Livesey et al[18] also described different phenotypes of GBL in posterior instability, which tends to be more inferior and obliquely oriented than the more vertical pattern observed in anterior instability. With GBL emerging as a critical component to the understanding of anterior instability, characterizing the role of GBL in posterior and combined-type instability appears to be similarly important, especially among populations with a higher risk for developing posterior and combined-type instability as observed among active-duty servicemembers.

Our hypothesis that combined-type instability would be associated with greater GBL was rooted in the "circle model" of shoulder stability, which was first conceptualized by Pagnani and Warren[20] in 1994. In this model, shoulder instability is described as a disruption of the capsulolabral complex in at least 2 locations, with the initial labral disruption propagating its forces throughout the entirety of the labrum. Thus, we hypothesized that combined-type instability would have greater GBL due to propagation of bone loss circumferentially in both the anterior-posterior and cephalad-caudad planes. However, contrary to beliefs of a progressive mechanism, previous reports of a single acute mechanism resulting in combined lesions indicate that the circle model may not adequately depict the effects of the attritional forces in GBL.[10]

A biomechanical study by Bryce et al[5] analyzing posterior GBL proposed that asymmetric loading may result in acceleration of glenoid wear. Additionally, bone loss additionally is proposed to proceed more quickly initially through the thinner, peripheral parts of the glenoid and then more slowly through the thicker, central parts of the glenoid.[15] In concert with these biomechanical findings, the loss of the protective "suction cup effect," a model proposed in 2023 by Ishikawa et al,[17] in combined-type instability may account for the findings in the present study. In this model, the authors describe the labrum as a flexible, airtight cone that lies against the curved surface of the humerus and creates a vacuum that resists distractive and shear forces. Subsequently, when a shear force is applied, tension is created to the opposite side of the cone, further increasing the vacuum pressures within the cone. Thus, with loss of one side of the cone representing unidirectional GBL, the ability of the suction cup to resist translational and shear forces is lost on the opposing side, thereby generating instability of the joint in the opposite direction.[17] It, therefore, follows that in combined-type instability, where there is labral disruption in >1 location, there is subsequent loss of the suction cup effect and increased symmetric laxity of the labrum. As a result, acceleration of wear in combined-type instability is less than that observed in unidirectional instability, where asymmetric loading of mechanical forces is concentrated in a single plane. Based on these findings, we hypothesize that loss of the suction cup effect may actually be a protective factor against GBL in combined-type instability.

In patients with anterior shoulder instability, many studies have shown that the associated bone loss necessitates bony augmentation, such as the Latarjet procedure or distal tibial allograft, in order to decrease recurrence rates.[3,4,6,22,24] However, there is evidence demonstrating that bony augmentation of posterior GBL is associated with high rates of clinical failure,[7] and there are currently little data regarding GBL in combined-type instability. While the severity and total percentage of GBL in combined-type instability did not reach statistical significance, our data still suggest that further investigation is needed to determine whether in the presence of substantial GBL, patients with combined-type instability would benefit from bony stabilization procedures. If our hypothesis holds true that asymmetric loading causes increased wear, bony stabilization procedures in combined-type instability will have to equally address the bone loss in the 3-o'clock to 9-o'clock directions or otherwise risk the progression of asymmetric loading and recurrence.

Limitations

There are several limitations to this study. Measurements of GBL on MRI and the absence of 3-dimensional computed tomography are subjective and introduce the likelihood for human error and variability, as demonstrated by the moderate to poor interrater reliability of the perfect circle technique,[21] which this study did not analyze. The duration of symptoms and number of dislocation events were also not factored into this study, which limits evaluation of how attritional bone loss worsens with a longer duration of symptoms or more events.[15] All procedures were additionally solely soft tissue ligamentous procedures without bony augmentation performed by a single shoulder and elbow fellowship-trained surgeon on an exclusively active-duty military patient population, potentially limiting the generalizability of our findings to broader populations.

CONCLUSION

GBL in the direction of instability was found to be greater in the unidirectional versus combined-type instability cohorts. Further research will be required to determine if the loss of the suction cup effect may be a protective factor against GBL in combined-type instability. Given that patients with unidirectional instability benefit from augmentation to address GBL, patients with combined-type instability may require balanced stabilization procedures including bony augmentation when appropriate to potentially decrease the risk of asymmetric loading and recurrence.

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