Journal Pre-proof

The clinical impact of glenoid concavity and version on anterior shoulder stability

Sebastian Oenning, MD, Clara de Castillo, Elena Jacob, MD, Arne Riegel, MD, Philipp A. Michel, MD, Jens Wermers, MSc, Prof., Michael J. Raschke, MD, Prof., J. Christoph Katthagen, MD, Prof.

PII: S2666-6383(24)00440-7

DOI: https://doi.org/10.1016/j.jseint.2024.09.029

Reference: JSEINT 1121

To appear in: *JSES International*

Received Date: 24 September 2024

Accepted Date: 26 September 2024

Please cite this article as: Oenning S, de Castillo C, Jacob E, Riegel A, Michel PA, Wermers J, Raschke MJ, Katthagen JC, The clinical impact of glenoid concavity and version on anterior shoulder stability, *JSES International* (2024), doi: https://doi.org/10.1016/j.jseint.2024.09.029.

The clinical impact of glenoid concavity and version on anterior shoulder stability

Short title: Glenoid concavity & version in shoulder instability

Sebastian Oenning, MD [1]; Clara de Castillo [1]; Elena Jacob, MD [2]; Arne Riegel, MD [3]; Philipp A. Michel, MD [1]; Jens Wermers, Prof., MSc [4]; Michael J. Raschke, Prof., MD [1]; J. Christoph Katthagen, Prof., MD [1]

[1] Department of Trauma, Hand and Reconstructive Surgery, University Hospital Muenster, Muenster, Germany

[2] Department of Orthopaedics, Trauma and Reconstructive Surgery, University Hospital RWTH Aachen, Aachen, Germany

[3] Department of Radiology, University Hospital Muenster, Muenster, Germany

[4] Faculty of Engineering Physics, FH Muenster, Muenster, Germany

Corresponding author: Sebastian Oenning, MD Email: sebastian.oenning@ukmuenster.de Department of Trauma, Hand and Reconstructive Surgery, University Hospital Muenster, Waldeyerstraße 1, 48149 Münster, Germany

Disclaimers:

Funding: No funding was yet received for conducting this study. IThe Open Access Publication Fee will be paid by the Open Access Publication Fund of the University of Münster. In this case the following acknowledgement statement has to be inserted.

Conflict of interest: The authors have no relevant financial or non-financial interests to disclose.

Ethical approval was sought from the institutional review board (IRB No. 2021-607-f-S, University of Münster, Germany)

Acknowledgements: The authors acknowledge support by the Open Access Publication Fund of University of Münster. There was no additional external funding received for this study. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.”

The clinical impact of glenoid concavity and version on anterior shoulder stability

Background:

In recent biomechanical studies, the importance of glenoid concavity and version for anterior shoulder stability has been highlighted. With this study, we aimed at assessing their clinical relevance as stabilizing factors. We hypothesized that low glenoid concavity and low retroversion are associated with anterior glenohumeral instability.

Methods:

In this single-center, retrospective case-control study, CT scans of n=34 patients following acute anteroinferior glenohumeral dislocation between 2015 and 2021 were included. Patients with glenoid fractures and preexisting glenohumeral pathologies were excluded. In the control group, n=68 polytrauma patients referred to our level-I-trauma center were included, who neither showed acute nor chronic glenohumeral pathologies. Both groups were matched age- and gender-specifically in a 2:1 ratio.

Glenoid concavity was measured according to the BSSR in anterior-posterior (a.p.) and superior-inferior (s.i.) direction. Version was measured by the glenoid vault method.

Results:

The instability cohort presented with a lower BSSR(s.i.) compared to the control group (49.8% vs. 56.9%, p=0.001). The BSSR(a.p.) did not differ significantly (30.2% vs. 33.7%, p=0.163). A higher retroversion was seen in the instability cohort (-13.1° vs. -11.4°; p=0.041). Subgroup analyses showed higher BSSR(s.i.) in ≥60-year-old patients compared to ≤30-year-old patients. BSSR(a.p.) and glenoid version did neither differ age- nor gender-specifically.

Conclusion:

Glenoid concavity is a relevant factor for anterior shoulder stability in the clinical setting. In contrast to recent biomechanical studies, glenoid version appears to have only limited clinical impact on anterior stability. Regarding the individual treatment of anterior glenohumeral instability, glenoid concavity should be focused on as an essential bony stabilizing factor.

Keywords: Glenoid concavity, BSSR, glenoid version, anterior shoulder instability, shoulder joint dislocation

Level of evidence: Level III; Retrospective Case-Control Design; Prognosis Study

The understanding of shoulder stability has become more differentiated throughout the last years and glenoid concavity as well as glenoid version have been investigated in recent studies. Still, the clinical relevance of glenoid concavity and version as bony stabilizing factors in the context of anterior shoulder stability is unknown, yet.

The principle of concavity-compression describes the synergy of both, the glenoid concavity and the rotator cuff's compressive force, centering the humeral head within the glenoid and therefore providing glenohumeral stability[7,15,16]. Regarding glenoid concavity, recent biomechanical studies include finite elements analyses, bony glenohumeral models as well as active-assisted shoulder models, considering the concavity-compression mechanism[20,21,23,30]. Here it has been shown that the glenoid concavity is an essential factor for anterior shoulder stability, and instability is mainly caused by the loss of concavity[30]. Highly concave-shaped glenoids were shown to tolerate up to 20% glenoid bone loss, until stability was reduced to the level of native joints with low concavity[23]. Moroder et al established the computed tomography (CT) based bony shoulder stability ratio (BSSR), describing the glenoid concavity considering the glenoid radius and depth[21]. However, the role of the glenoid concavity in a clinical setting and physiological ranges of concavity are yet unknown.

Regarding the glenoid version, a mild retroversion can be observed in physiological conditions. In the following, 0° equals a neutral glenoid version, while positive and negative numeric values describe anteversion and retroversion, respectively. The most common methods of measuring glenoid version include the Friedman method and the glenoid vault method. According to

Friedman et al, a line is drawn from the most medial point of the scapula to the center of a line connecting the anterior and posterior glenoid rim[4]. According to Matsumura et al describing the glenoid vault method, a line connecting the tip of the triangular-shaped glenoid vault and the center of the glenoid articular surface is used for measuring glenoid version. Thus, the individual morphology of the scapula body cannot confound the measurement[17]. For the glenoid vault method, physiological ranges of -8.9° (±2.7°)[17] and -8° (±4.9°)[2] retroversion are described in literature. Regarding the Friedman method, smaller numeric values are described with a physiological range of -2.1° (±4.7°)[2].

Biomechanically, Eichinger et al could show that the glenoid version influences both, anterior and posterior shoulder stability in a linear correlation. In their model, every 1° increase of anteversion led to a 6% decrease of anteroinferior dislocation force[3]. Also, the humeral head position is influenced by glenoid version, as Imhoff et al pointed out. With every 5° increase of retroversion, the humeral head was positioned about 2 mm more posteriorly within the glenoid cavity[9].

Clinically, a correlation between increased retroversion and posterior shoulder instability is described in several studies[5,6,11,12,18,24,26,28]. Regarding anterior shoulder stability, however, the clinical impact of glenoid version is not as clear. Only few studies have yet analyzed patient cohorts with anterior instability. In some of these studies, anterior instability collectives were associated with a slightly decreased retroversion, compared to control cohorts without shoulder instability[1,8]. However, glenoid version in the instability groups did not clearly exceed physiological ranges. Furthermore, Privitera et al found no significant difference in glenoid version between asymptomatic and anteriorly unstable patients[28]. Thus, the clinical relevance of glenoid version in the context of anterior shoulder stability yet remains unclear.

In this study, the clinical impact of glenoid concavity and glenoid version on anterior shoulder stability were analyzed. Comparing patients with anterior instability to a control cohort without shoulder instability, we hypothesized that anterior instability is associated with lower glenoid concavity and less glenoid retroversion.

Materials and Methods:

Study design

This retrospective case-control study was performed at the Department of Trauma, Hand and Reconstructive Surgery of the University Hospital Münster, Germany, a level-1-trauma center, and approved by the institutional review board (IRB No. 2021-607-f-S, University of Münster, Germany). CT scans of patients presenting with an acute, anteroinferior shoulder joint dislocation between 2015 and 2021 were evaluated and compared to a control cohort. Exclusion criteria included glenoid fractures, incomplete glenoid imaging in the CT scan, previous episodes of shoulder joint dislocation, multidirectional shoulder instability and preexisting shoulder joint pathologies. Patient data were obtained via the hospital's documentation system Orbis (Dedalus, Bonn, Germany) and n=34 patients were included in the instability cohort. Detailed numbers of patients after applying inclusion and exclusion criteria are presented in figure 1.

The control cohort was comprised of polytraumatized patients admitted to our hospital from January 2020 to October 2021, receiving polytrauma CT scans, including glenohumeral joint imaging. Patients without acute and chronic glenohumeral pathologies were included in the control collective. A gender and age dependent matching in a 2:1 ratio was performed between instability and control cohort, resulting in n=68 patients within the control group. Specifically, for every patient within the instability cohort, two same-gender patients were matched, in which the equal-sided shoulder was analyzed. Age-specific matching was performed as precise as possible. For n=20 instability patients, two control patients of ±2 years of age were matched. The maximum age difference within the remaining matched patients was six years.

In addition, subgroups were formed in order to examine the influence of gender (female vs. male) and age (≤30 vs. ≥60 years of age) on glenoid concavity and version.

Measurements:

Radiological measurements were acquired with Aquarius iNtuition (version 4.4, TeraRecon, Durham, NC, USA) using individual multiplanar reconstruction of the CT scan data. CT scan thickness was 1-1.5mm.

Joint-specific coordinate systems were established by creating superior-inferior (s.i.) and anterior-posterior (a.p.) axes aligned to the most superior, inferior, anterior and posterior points of the glenoid rim, respectively. The mediolateral axis was added orthogonally to both, the s.i. and a.p. axes.

Glenoid concavity was measured according to the CT-based BSSR including glenoid radius (r) and depth (d)[21].

$$BSSR = \frac{1 - (\frac{r-d}{r})^2}{\frac{r-d}{r}}$$

Measurement of the BSSR were performed in both, coronal and axial planes, so that the superior-inferior concavity (BSSR(s.i.)) and anterior-posterior concavity (BSSR(a.p.)) were analyzed, respectively. The glenoid radius was measured using the best-fit-circle method as described by Kuberakani et al[14] (see figure 2). The glenoid depth (d) was measured by defining the widest s.i. and a.p. glenoid diameter, which equal the s.i. and a.p. axes, respectively. Orthogonally to each axis, the maximum glenoid depth was measured at each axis' center point in both, coronal and axial planes (see figure 2).

The measurement of glenoid version was based on the glenoid vault method as described by Matsumura et al.[17] While Matsumura et al aligned the planes of CT scans to the individual scapula body, in this study the previously described coordinate system aligned to the glenoid was used. Except different CT plane alignments, the measurement of glenoid version was performed analogously to Matsumura et al. In an axial plane a line was then drawn connecting the tip of the triangle-shaped glenoid vault and the center of the glenoid articular surface. A perpendicular line indicated 0° of glenoid version and was then used for measuring the individual, patient-specific version (see figure 3).

Statistical Analysis:

An *a priori* power analysis using G*Power (version 3.1.9.7; Heinrich Heine Universität, Düsseldorf, Germany) was performed to determine the necessary sample size. Here, the mean BSSR(a.p.) values of the cadaveric study of Wermers et al were used and compared to five BSSR(a.p.) test measurements within the instability cohort of this study. With an alpha level of 0.05, a power of 0.95 and an effect size of d=0.942, required numbers of patients for unpaired t-tests were calculated. Here, numbers of n=23 patients for the instability cohort, and n=45 patients for the control group were defined.

Statistics were performed using GraphPad Prism® (GraphPad Software Inc., San Diego, CA, USA). Descriptive statistics including median and mean values, standard deviation, range, as well as 25th and 75th percentiles were calculated for all variables. Normal distribution was assessed graphically via quantile-quantile-plot (QQ-Plot) as well as the Shapiro-Wilk-test.

A level of $p<0.05$ was deemed significant. For group comparisons, the t-test was used. For parameters not showing normal distribution, the Mann-Whitney-U-Test was applied, additionally. This was performed for both, comparing instability and control cohort, as well as analyzing age- and gender-specific subgroups. Correlation between different parameters was tested using a linear regression model. Binary logistic regression was used to analyze the impact of concavity on the occurrence of shoulder instability, presented with Odds ratios (OR) and the OR's 95% confidence intervals (CI). A post-hoc power analysis was performed to verify the preliminarily set confidence interval of 95%.

Results:

Study population:

In the instability cohort, n=34 patients were included, while the control cohort consists of n=68 patients after matching. Throughout all included patients, the mean age was 48 years (±19.9; 18 – 92). Within instability and control cohort, the patients' mean age was 46.9 (±20.3) and 48.6 (±19.9) years, respectively. Within each group, 26.5% of patients were female, 73.5% were male. Within the instability cohort, n=19 patients presented with a right shoulder injury, while in n=15 patients the left shoulder was affected. Regarding the mechanism of injury within the instability cohort, two patients presented with atraumatic shoulder dislocations and hyperlaxity. Five patients sustained dislocations after seizures, while the remaining n=27 patients described adequate trauma (falling, sports injuries, vehicle/traffic accidents). A spontaneous glenohumeral reposition was observed in three patients, while n=31 patients required closed reduction.

Primary Outcome:

Glenoid concavity and version were measured and compared between instability and control cohort (see figure 4). The mean BSSR(s.i.) in the instability group was 49.8% (±9.0), while the control cohort showed a mean BSSR(s.i.) of 56.9% (±9.9). Therefore, patients in the instability cohort presented with a significantly lower concavity in the superior-inferior axis compared to the control group (p=0.0007). Regarding the glenoid concavity in the anterior-posterior axis, the difference between instability and control group showed no statistical significance (p=0.1634). Here, the instability group showed a mean BSSR(a.p.) of 30.15% (±13.63), while the control group presented with a BSSR(a.p.) of 33.72% (±11.44). Details are described in table 1.

Binary logistic regression analyses showed that with every 1% increase in BSSR(s.i.), the risk of anteroinferior shoulder instability decreases by 8% (OR 0.92; 95% CI 0.87 – 0.97; p=0.0017). Regarding a 1% increase of the BSSR(a.p.), the decreased risk of shoulder instability was not significant (OR 0.98; 95% CI 0.94 – 1.01; p=0.1695).

In the overall study population, BSSR(s.i.) and BSSR(a.p.) showed a low correlation with a determination coefficient of R^2=0.23 in a linear regression model.

For evaluation of the BSSR, glenoid radius and depth were assessed in both, axial and coronal planes. Radius and depth were analyzed separately to detect specific differences, masked by the BSSR. Here, the instability group presented with a significantly higher glenoid radius in both planes. Regarding glenoid depth in coronal planes, significantly higher values were seen in the control group compared to patients in the instability cohort (p=0.0115), while in axial planes the glenoid depth did not differ significantly (p=0.5974). These results are consistent with the BSSR providing significant differences only in coronal planes. Details are shown in table 1.

Assessment of glenoid version showed more retroversion in the instability cohort with a mean glenoid version angle of -13.14° (±4.38; -22.6 – -5). In the control group a mean glenoid version of -11.44° (±3.66; -18.7 – -3.3) was seen, showing significantly less retroversion (p=0.0407). In the linear regression model, the glenoid version did not correlate with BSSR(s.i.) and BSSR(a.p.) with determination coefficients of R^2=0.0144 and R^2=0.0016, respectively.

Subgroup analyses:

Within the instability and control cohorts, age and gender-specific subgroups were defined (see figures 5a/b, 6).

To evaluate age-dependent differences in concavity and version and their impact on shoulder stability, patients ≤30 years of age were compared to patients ≥60 years of age (see figure 5a). Regarding the BSSR(a.p.), no significant differences were seen between ≤30 and ≥60-year-old patients within both, instability and control cohort (p=0.4409; p=0.19, respectively). In contrast, ≤30-year-old patients showed a lower mean BSSR(s.i.) than ≥60-year-old patients within the instability cohort (44.75% (±9.02) vs. 56.11% (±8.98), p=0.0218). While a significantly lower BSSR(s.i.) in the instability cohort compared to the control group was evident in ≤30-year-old patients (44.75% (±9.02) vs. 56.33% (±9.73), p=0.0064), in ≥60-year-old patients, no difference was seen between instability and control cohort (56.11% (±8.98) vs. 62.4% (±10.12), p=0.1647). Within the control group, BSSR(s.i.) differences between ≤30 and ≥60-year-old patients were not significant (p=0.091). Regarding glenoid version, no age-specific differences were found (p≥0.347) (see figure 6).

Comparing female to male patients within each cohort, no significant differences were seen regarding BSSR(a.p.) (p≥0.1157) and BSSR(s.i.) (p≥0.8273) (see figure 5b). Also, glenoid version did not show gender-dependent differences within instability cohort (female -11.24° (±5.1) vs. male -13.82° (±3.99), p=0.1326) and control cohort (female -11.08° (±3.59) vs. male -11.56° (±3.51), p=0.6321).

Discussion:

In this study evaluating the clinical relevance of glenoid concavity and version for anterior shoulder instability, we can summarize the following main findings: (1) Anterior shoulder instability is associated with a lower glenoid concavity in coronal planes. In axial planes, the same tendencies were seen, however, without showing statistical significance. (2) The role of glenoid version in the context of anterior glenohumeral stability remains controversial, since in this study a higher retroversion was seen in the instability cohort compared to the control group.

Regarding glenoid concavity, the results of this study fall in line with previous biomechanical studies. Moroder et al described the stabilizing effect of glenoid concavity by finite element analysis. In case of osseous Bankart lesions, they suggested that the loss of concavity might be a more precise parameter indicating anterior glenohumeral instability than conventional, two-dimensional methods measuring the glenoid defect size[20,21]. Previous biomechanical results of our working group confirmed the importance of glenoid concavity. In an osteochondral model using cadaveric glenoids and humeral heads, a high correlation between concavity and stability was found, while the loss of concavity served as a precise predictor for anterior shoulder instability[30]. This was confirmed in an active-assisted cadaveric model including soft tissue and the rotator cuff's compressive forces, resembling the physiological, stabilizing mechanism of concavity compression[16,23].

This study underlines the importance of glenoid concavity in a clinical setting. Superior-inferior concavity was lower in the instability cohort. The same tendency of lower a.p. concavity was found in the instability group and the difference might become significant with a larger study population. One could also suggest, that inferior glenoid concavity plays a more important role in preventing anteroinferior glenohumeral dislocation than anterior concavity. This could be explained by other, mainly anteriorly located, anatomical structures like the coracoid or the conjoint tendons, as well as individual labral morphology and anterior capsular tension, helping to prevent anterior humeral head translation. However, further biomechanical studies are required to draw final conclusions to this assumption. The specific anteroinferior concavity within the track of humeral head dislocation as well as the correlation of glenoid concavity, version and inclination should be included.

Regarding glenoid version in the context of anterior shoulder stability, the results in this study do not support the findings of previous biomechanical and clinical studies. Biomechanically, Eichinger et al found a linear correlation between glenoid version and both, anterior and posterior stability with increased anteversion causing anterior instability and vice versa[3]. Imhoff et al described a more posterior humeral head position in case of increased glenoid retroversion, leading to increased posterior instability[9]. While the association of increased glenoid retroversion and posterior glenohumeral instability became apparent in several clinical studies[5,6,12,24,26,28], the clinical correlation of glenoid anteversion and anterior stability remains ambiguous. Only few studies compared a cohort with anterior instability to patients without shoulder instability. Privitera et al did not find a significant difference in glenoid version between both groups[28]. Hohmann et al and Aygün et al describe a slightly higher anteversion in anterior instability cohorts, however, the amount of glenoid version barely exceeds physiological ranges[2,17]. In this study, the anterior instability cohort controversially presented with higher retroversion compared to the control cohort, leading to the assumption that glenoid version provides only limited influence on anterior glenohumeral stability.

Another possible explanation for the presented results could be a reciprocal, anatomical adaption of glenoid version and concavity. For example, an increased glenoid retroversion would counteract a low native concavity, reducing anterior instability. However, a low correlation between glenoid concavity and version in this study does not support this theory. Still, we consider the relation between concavity and version to be worth analyzing in larger, differentiated patient cohorts to produce more detailed results.

In subgroup analyses, it was evident that especially in coronal planes, older patients presented with a higher glenoid concavity. We consider this finding to be mainly caused by degenerative changes leading to increased, central glenoid depth and, therefore, increased concavity[10,29]. It was striking that in ≥60-year-old patients, axial and coronal glenoid concavity did not differ between instability and control cohort. This leads to the suggestion that concavity only plays a minor role in older patients, while low concavity in young patients was evidently associated with anterior shoulder instability. Regarding gender-specific analyses, no relevant differences were seen. Glenoid version did neither show age- nor gender-specific differences.

Limitations of this study include the retrospective study design. A higher number of patients included in this study would have been desirable, however, the required study population according to the power analysis was exceeded. The higher mean age of the instability cohort compared to larger shoulder dislocation cohorts[13,22,25] must be mentioned, as well. A reason for this could be the fact that younger patients were shown to have a higher risk of sustaining Bankart fractures[19], making them not eligible for inclusion. Also, a relevant number of especially younger patients suffering from anteroinferior shoulder dislocation without glenoid bone loss could not be included, due to reasonable diagnostic algorithms. Especially in younger patients, magnetic resonance imaging (MRI) is preferred over CT scans in the absence of signs for bony glenoid injury in the initial X-ray images.

Another factor limiting the accuracy of the results is the comparably high slice thickness of 1 – 1.5 mm of the polytrauma CT scans, which were performed in an emergency setting and retrospectively used to generate the control cohort. Minimal changes in concavity and version can significantly alter the measurements and, therefore, thinner CT scan slices would have increased the validity of this study. Also, possible degenerative, cartilage lesions, especially in older patients, as well as individual labral morphology were not detected by CT scans.

The method of measuring glenoid version has to be mentioned as a possible limitation, as well. The most commonly used techniques include the Friedman method as well as glenoid vault methods[4,17,27]. Since the polytrauma CT scans of the control cohort do not regularly include the most medial aspects of the scapula body, the Friedman method could not be applied in this study. Also, the glenoid vault method according to Matsumura had to be adjusted, since originally the entire scapula body is necessary for CT plane alignment[17]. In this study, the coordinate system aligned to the glenoid surface in order to measure concavity was also used for assessing glenoid version. This slight CT plane deviation might explain that previously published ranges of retroversion are exceeded in both, instability and control cohort of this study. Still, we assume that the comparison of version between both cohorts and the correlation between version and concavity within this study remains reliable.

Future studies including a higher number of patients and high-quality CT imaging should be performed to confirm the clinical relevance of the glenoid concavity in both, native joints and in the presence of glenoid bone loss. Also, the yet controversial role of glenoid version in the context of anterior shoulder stability should be addressed. Furthermore, MRI scan evaluation could include the morphology of glenoid cartilage and labrum, resulting in individual glenolabral concavity and version.

Conclusion:

Glenoid concavity is a relevant factor for anterior shoulder stability, not only in biomechanical models but also in a clinical setting.

The role of glenoid version remains controversial, since in this study it appears to have only limited clinical impact on anterior stability.

In an individual therapeutic approach on anterior glenohumeral instability, glenoid concavity should be focused on as an essential bony stabilizing factor.

References:

1. Aygün Ü, Çalik Y, Işik C, Şahin H, Şahin R, Aygün DÖ. The importance of glenoid version in patients with anterior dislocation of the shoulder. J Shoulder Elbow Surg. 2016 Dec;25(12):1930–1936. doi:10.1016/j.jse.2016.09.018

2. Cunningham G, Freebody J, Smith MM, Taha ME, Young AA, Cass B, et al. Comparative analysis of 2 glenoid version measurement methods in variable axial slices on 3-dimensionally reconstructed computed tomography scans. J Shoulder Elbow Surg. 2018 Oct;27(10):1809–1815. doi:10.1016/j.jse.2018.03.016

3. Eichinger JK, Massimini DF, Kim J, Higgins LD. Biomechanical Evaluation of Glenoid Version and Dislocation Direction on the Influence of Anterior Shoulder Instability and Development of Hill-Sachs Lesions. Am J Sports Med. 2016 Nov 19;44(11):2792–2799. doi:10.1177/0363546516659281

4. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am. 1992 Aug;74(7):1032–7.

5. Galvin JW, Parada SA, Li X, Eichinger JK. Critical Findings on Magnetic Resonance Arthrograms in Posterior Shoulder Instability Compared With an Age-Matched Controlled Cohort. Am J Sports Med. 2016 Dec 20;44(12):3222–3229. doi:10.1177/0363546516660076

6. Gottschalk MB, Ghasem A, Todd D, Daruwalla J, Xerogeanes J, Karas S. Posterior Shoulder Instability: Does Glenoid Retroversion Predict Recurrence and Contralateral Instability? Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2015 Mar;31(3):488–493. doi:10.1016/j.arthro.2014.10.009

7. Halder AM, O'Driscoll SW, Heers G, Mura N, Zobitz ME, An KN, et al. Biomechanical comparison of effects of supraspinatus tendon detachments, tendon defects, and muscle retractions. Journal of Bone and Joint Surgery. 2002;84(5):780–785. doi:10.2106/00004623-200205000-00013

8. Hohmann E, Tetsworth K. Glenoid version and inclination are risk factors for anterior shoulder dislocation. J Shoulder Elbow Surg. 2015 Aug;24(8):1268–1273. doi:10.1016/j.jse.2015.03.032

9. Imhoff FB, Camenzind RS, Obopilwe E, Cote MP, Mehl J, Beitzel K, et al. Glenoid retroversion is an important factor for humeral head centration and the biomechanics of posterior shoulder stability. Knee Surgery, Sports Traumatology, Arthroscopy. 2019 Dec 28;27(12):3952–3961. doi:10.1007/s00167-019-05573-5

10. Jawa A, Shields M V. The Evolution of the Walch Classification for Primary Glenohumeral Arthritis. Journal of the American Academy of Orthopaedic Surgeons. 2021;29(13):E635–E645. doi:10.5435/JAAOS-D-20-00880

11. Katthagen JC, Tahal DS, Montgomery SR, Horan MP, Millett PJ. Association of Traumatic and Atraumatic Posterior Shoulder Instability With Glenoid Retroversion and Outcomes After Arthroscopic Capsulolabral Repair. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2017 Feb;33(2):284–290. doi:10.1016/j.arthro.2016.07.020

12. Kim S-H, Noh K-C, Park J-S, Ryu B-D, Oh I. Loss of Chondrolabral Containment of the Glenohumeral Joint in Atraumatic Posteroinferior Multidirectional Instability. J Bone Joint Surg. 2005 Jan;87(1):92–98. doi:10.2106/JBJS.C.01448

13. Kraeutler MJ, McCarty EC, Belk JW, Wolf BR, Hettrich CM, Ortiz SF, et al. Descriptive Epidemiology of the MOON Shoulder Instability Cohort. Am J Sports Med. 2018 Apr 5;46(5):1064–1069. doi:10.1177/0363546518755752

14. Kuberakani K, Aizawa K, Yamamoto N, Shinagawa K, Suzuki T, Hatta T, et al. Comparison of best-fit circle versus contralateral comparison methods to quantify glenoid bone defect. J Shoulder Elbow Surg. 2020 Mar;29(3):502–507. doi:10.1016/j.jse.2019.07.027

15. Lazarus MD, Sidles JA, Harryman DT, Matsen FA. Effect of a chondral-labral defect on glenoid concavity and glenohumeral stability: A cadaveric model. Journal of Bone and Joint Surgery. 1996;78(1):94–102.

16. Lippitt SB, Vanderhooft JE, Harris SL, Sidles JA, Harryman DT, Matsen FA. Glenohumeral stability from concavity-compression: A quantitative analysis. J Shoulder Elbow Surg. 1993;2(1):27–35.

17. Matsumura N, Ogawa K, Ikegami H, Collin P, Walch G, Toyama Y. Computed tomography measurement of glenoid vault version as an alternative measuring method for glenoid version. J Orthop Surg Res. 2014;9(1):17. doi:10.1186/1749-799X-9-17

18. Mehl J, Hedgecock J, Otto A, Flaherty E, Jacoby B, DiVenere J, et al. Glenoid version is associated with different labrum tear patterns in shoulder instability. J Shoulder Elbow Surg. 2020 Aug;29(8):1642–1649. doi:10.1016/j.jse.2020.03.043

19. Milano G, Grasso A, Russo A, Magarelli N, Santagada DA, Deriu L, et al. Analysis of risk factors for glenoid bone defect in anterior shoulder instability. Am J Sports Med. 2011 Sep;39(9):1870–6. doi:10.1177/0363546511411699

20. Moroder P, Damm P, Wierer G, Böhm E, Minkus M, Plachel F, et al. Challenging the Current Concept of Critical Glenoid Bone Loss in Shoulder Instability: Does the Size Measurement Really Tell It All? American Journal of Sports Medicine. 2019;47(3):688–694. doi:10.1177/0363546518819102

21. Moroder P, Ernstbrunner L, Pomwenger W, Oberhauser F, Hitzl W, Tauber M, et al. Anterior Shoulder Instability is Associated with an Underlying Deficiency of the Bony Glenoid Concavity. Arthroscopy - Journal of Arthroscopic and Related Surgery. 2015;31(7):1223–1231. doi:10.1016/j.arthro.2015.02.009

22. Nordqvist A, Petersson CJ. Incidence and causes of shoulder girdle injuries in an urban population. J Shoulder Elbow Surg. 1995 Mar;4(2):107–112.

23. Oenning S, Wermers J, Taenzler S, Michel PA, Raschke MJ, Christoph Katthagen J. Glenoid Concavity Affects Anterior Shoulder Stability in an Active-Assisted

Biomechanical Model. Orthop J Sports Med. 2024 Jun 12;12(6). doi:10.1177/23259671241253836

24. Owens BD, Campbell SE, Cameron KL. Risk Factors for Posterior Shoulder Instability in Young Athletes. Am J Sports Med. 2013 Nov 27;41(11):2645–2649. doi:10.1177/0363546513501508

25. Owens BD, Dawson L, Burks R, Cameron KL. Incidence of Shoulder Dislocation in the United States Military: Demographic Considerations from a High-Risk Population. The Journal of Bone and Joint Surgery-American Volume. 2009 Apr;91(4):791–796. doi:10.2106/JBJS.H.00514

26. Parada SA, Eichinger JK, Dumont GD, Burton LE, Coats-Thomas MS, Daniels SD, et al. Comparison of Glenoid Version and Posterior Humeral Subluxation in Patients With and Without Posterior Shoulder Instability. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2017 Feb;33(2):254–260. doi:10.1016/j.arthro.2016.06.023

27. Poon PC, Ting FSH. A 2-dimensional glenoid vault method for measuring glenoid version on computed tomography. J Shoulder Elbow Surg. 2012 Mar;21(3):329–335. doi:10.1016/j.jse.2011.04.006

28. Privitera DM, Siegel EJ, Miller LR, Sinz NJ, Higgins LD. Glenoid version and its relationship to glenohumeral instability and labral tears. J Shoulder Elbow Surg. 2016 Jul;25(7):1056–1063. doi:10.1016/j.jse.2015.11.013

29. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the Glenoid in primary glenohumeral osteoarthritis. J Arthroplasty. 1999 Sep;14(6):756–760.

30. Wermers J, Schliemann B, Raschke MJ, Michel PA, Heilmann LF, Dyrna F, et al. Glenoid concavity has a higher impact on shoulder stability than the size of a bony

defect. Knee Surgery, Sports Traumatology, Arthroscopy. 2021 Aug 11;29(8):2631–2639. doi:10.1007/s00167-021-06562-3

Figure 1) Flow diagram showing the number of patients eligible and included in this study after applying inclusion and exclusion criteria.

Figure 2) Measurement of the glenoid radius with the best-fit-circle method (a, b) and the glenoid depth (c, d). Both were measured in axial (a, c) and coronal (b, d) planes.

Figure 3) Measurement of the glenoid version based on the glenoid vault method, described by Matsumura et al.

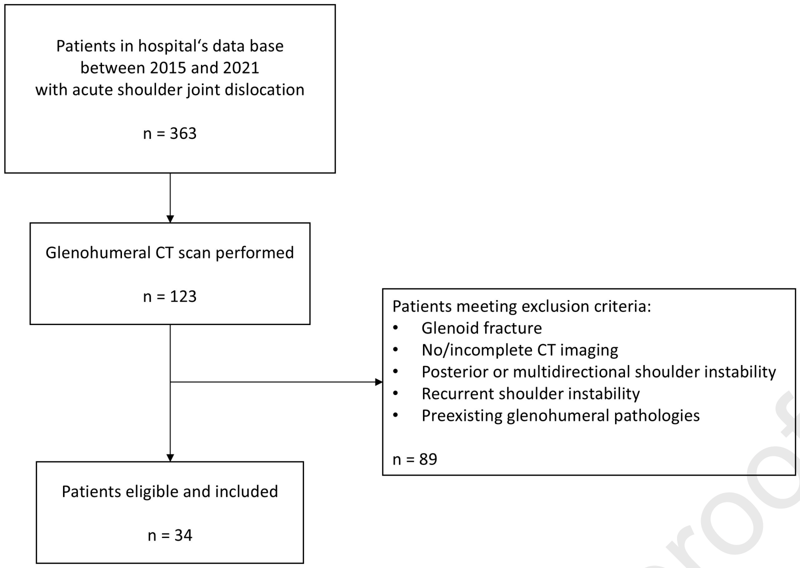
Figure 4) Boxplots and analyses of glenoid concavity (a) and version (b) between instability cohort (dark blue) and control cohort (light blue).

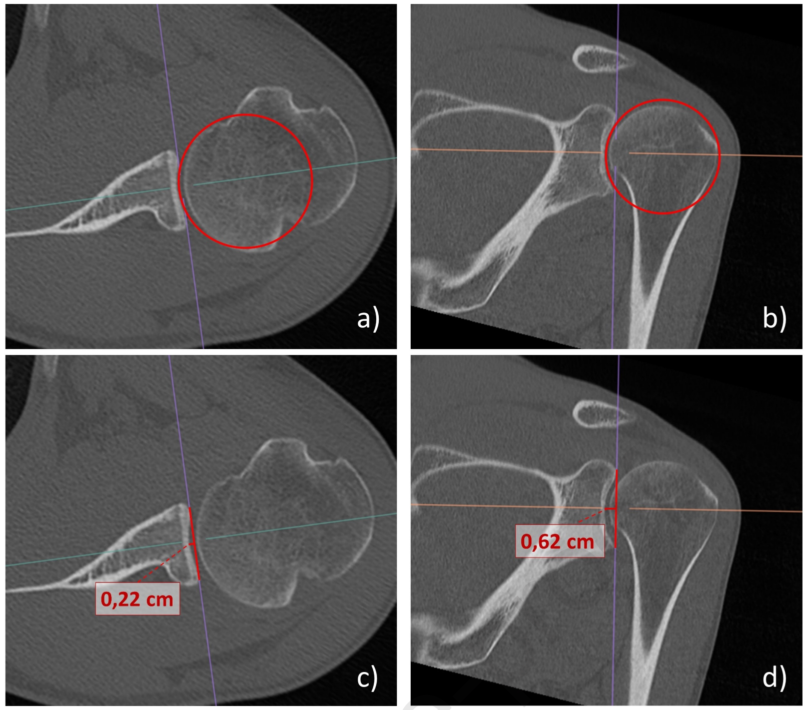
Figure 5) Age-specific (a) and gender-specific (b) subgroup analyses of the glenoid concavity in axial planes (a.p., blue) and coronal planes (s.i., green) are shown. Patients were compared regarding (a) age (≤30 years old vs. ≥60 years old) and (b) gender (female vs. male).

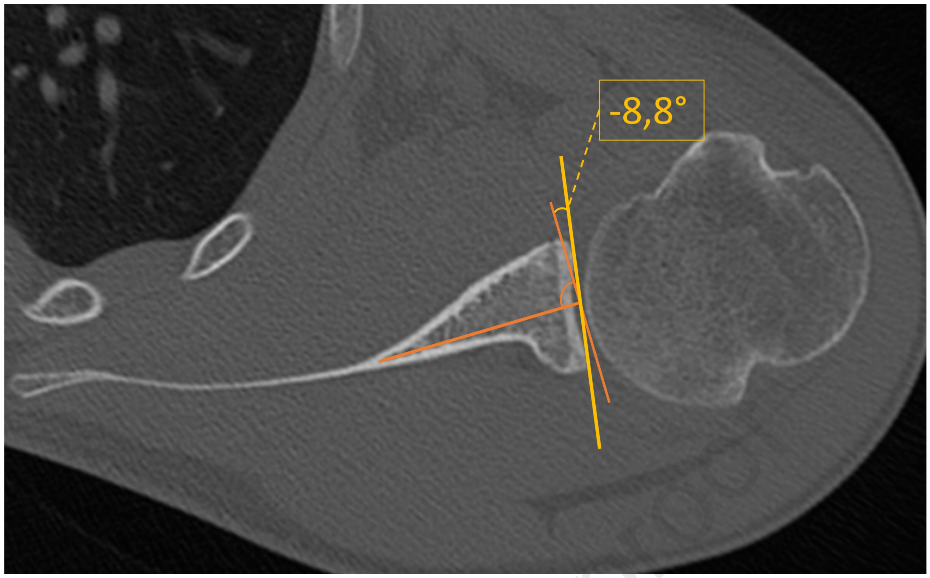
Figure 6) Age-specific and gender-specific subgroup analyses of the glenoid version. Patients were compared regarding age (≤30 years old vs. ≥60 years old) and gender (female vs. male).

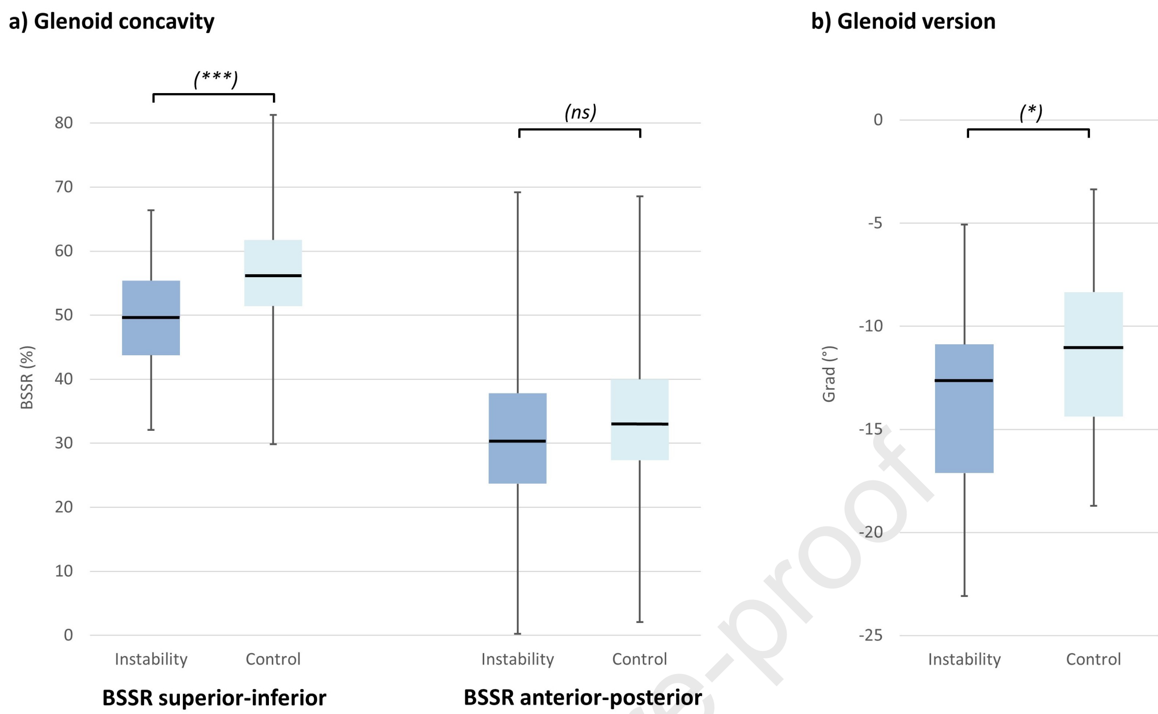
Table 1) Detailed values (mean, standard error of mean, range) and statistical analyses of glenoid radius, depth, the bony shoulder stability ratio (BSSR) and glenoid version. Radius, depth and BSSR were assessed in coronal planes in a superior-inferior (s.i.) axis, as well as in axial planes in an anterior-posterior (a.p.) axis. Statistical analysis was either performed by t-tests [(a)] or Mann-Whitney-U-Tests [(b)] depending on the distribution of values.

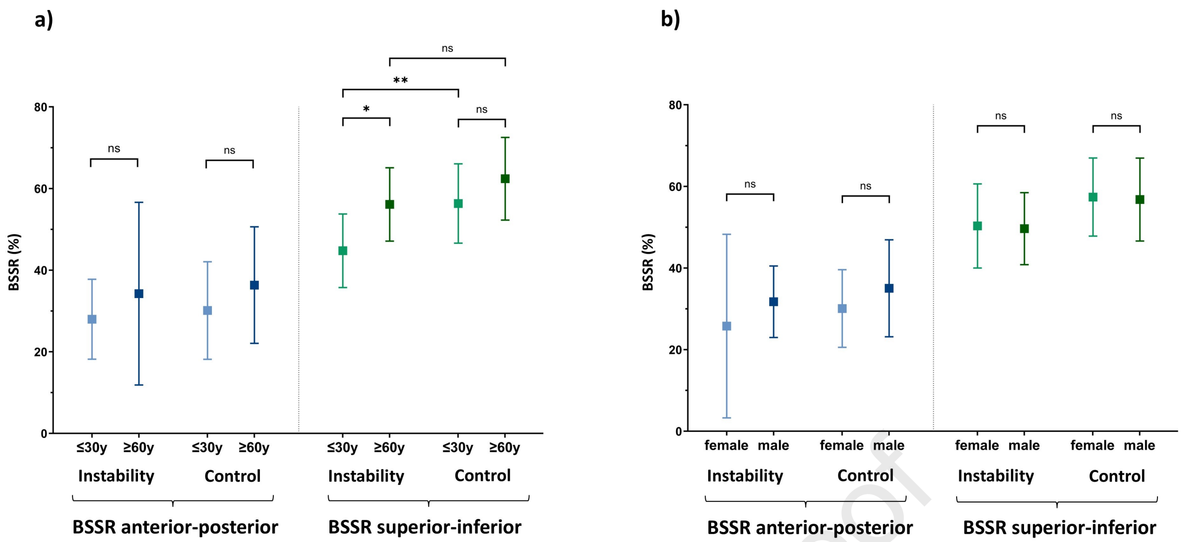
	Instability cohort	Control cohort	p-value
Glenoid radius (coronal)	36.54 (±7.8; 22.8 – 64)	32.59 (±4,91; 23,4 – 50.5)	**0.0048**[(b)]
Glenoid radius (axial)	43.72 (±14.81; 19.25 – 81)	36.58 (±8.2; 22.65 – 61)	**0.0241**[(b)]
Glenoid depth (coronal)	3.72 (±0,79; 1.9 – 5.36)	4.18 (±0.88; 2.03 – 6.2)	**0.0115**[(a)]
Glenoid depth (axial)	1.73 (±0.85; 0 – 3.42)	1.89 (±0.89; 0.01 – 4.95)	0.5974[(b)]
BSSR (s.i./coronal)	49.82 (±9.09; 31.95 – 66.42)	56.93 (±9.94; 29.62 – 81.28)	**0.0007**[(a)]
BSSR (a.p./axial)	30.15 (±13.63; 0 – 69.19)	33.72 (±11.44; 1.81 – 68.57)	0.1634[(b)]
Glenoid version	-13.14 (±4.38; -22.6 – -5)	-11.44 (±3.66; -18.7 – -3.3)	**0.0407**[(a)]

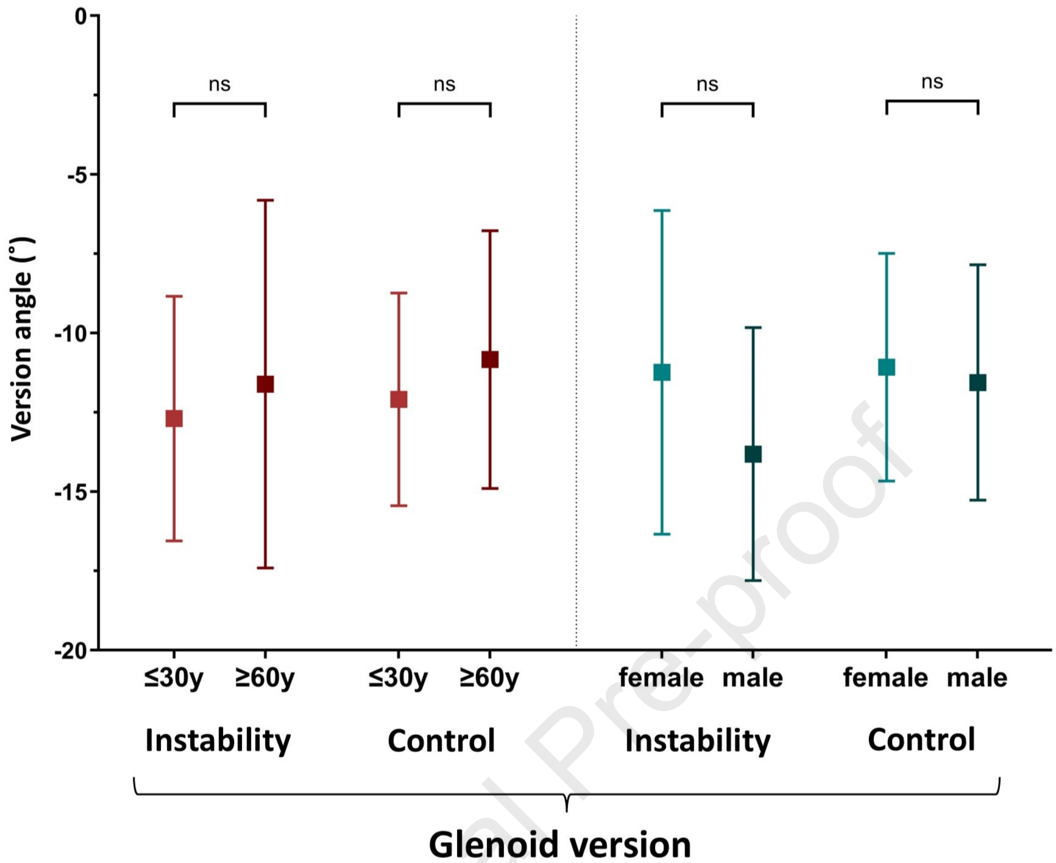

Patients in hospital's data base
between 2015 and 2021
with acute shoulder joint dislocation
n = 363
Glenohumeral CT scan performed
n = 123
Patients meeting exclusion criteria:
• Glenoid fracture
• No/incomplete CT imaging
• Posterior or multidirectional shoulder instability
• Recurrent shoulder instability
• Preexisting glenohumeral pathologies
n = 89
Patients eligible and included
n = 34


a)
b)
0,22 cm
c)
0,62 cm
d)


-8,8°


a) Glenoid concavity
(***)
(ns)
80
70
60
50
40
30
20
10
0
BSSR (%)
Instability
Control
Instability
Control
BSSR superior-inferior
BSSR anterior-posterior
b) Glenoid version
(*)
0
-5
-10
-15
-20
-25
Grad (°)
Instability
Control


a)
ns
**
*
ns
80
60
40
20
0
BSSR (%)
ns
ns
≤30y ≥60y ≤30y ≥60y ≤30y ≥60y ≤30y ≥60y
Instability
Control
Instability
Control
BSSR anterior-posterior
BSSR superior-inferior
b)
80
60
40
20
0
BSSR (%)
ns
ns
ns
ns
female male female male female male female male
Instability
Control
Instability
Control
BSSR anterior-posterior
BSSR superior-inferior



0
-5
-10
-15
-20
Version angle (°)
ns
ns
ns
ns
≤30y
≥60y
≤30y
≥60y
female
male
female
male
Instability
Control
Instability
Control
Glenoid version