ORIGINAL ARTICLE

# Is three-dimensional reconstruction really necessary for glenoid version measurement on magnetic resonance imaging in patients with glenohumeral instability?

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## ABSTRACT

**BACKGROUND:** The importance of glenoid version in glenohumeral instability (GHI) has become increasingly recognized. However, it remains unclear whether three-dimensional (3-D) correction of magnetic resonance imaging (MRI) scans provides more accurate glenoid version measurement in patients with GHI. The primary hypothesis of this study was that a statistically significant difference would exist between glenoid version values measured on standard two-dimensional (2-D) axial slices and those measured on 3-D–corrected axial slices.

**METHODS:** A retrospective analysis of glenoid version measurements was performed in 54 patients (22 females, 32 males) with glenohumeral instability. Measurements were obtained using the Friedman method on standard 2-D axial MRI slices and 3-D–corrected axial MRI slices. Two observers performed each measurement twice. Measurements obtained by each observer were compared using paired t-tests. Measurement reliability was evaluated using intraclass correlation coefficients (ICC).

**RESULTS:** For observer 1, mean glenoid version values were −0.69°±3.95° and −1.24°±3.94° on standard and 3-D–corrected axial MRI slices, respectively (p=0.16). For observer 2, corresponding values were −2.97°±4.48° and −2.81°±4.92°, respectively (p=0.66). Interobserver reliability was good for both techniques (ICC=0.87 for 2-D and 0.83 for 3-D measurements). Intraobserver reliability was excellent for measurements performed on 2-D slices (ICC=0.95 and 0.97) and ranged from good to excellent for measurements performed on 3-D–corrected slices (ICC=0.86 and 0.98).

**CONCLUSION:** The findings of this study suggest that 3-D correction may not be necessary for glenoid version measurements performed on MRI in patients with glenohumeral instability. Multicenter studies with larger patient populations should be conducted to enhance the clinical relevance of these findings.

**Keywords:** Glenohumeral instability; magnetic resonance imaging (MRI); three-dimensional correction.

## INTRODUCTION

The importance of glenoid version in patients with glenohumeral arthritis (GHA) is well established;[1-3] however, its relationship with glenohumeral instability (GHI) and labral injuries (LI) has only recently gained attention.[4-6] Several studies have reported that increased retroversion may be an important risk factor for posterior GHI.[4-8] In a study by Privitera et al.,[6] patients with posterior labral tears demonstrated 5° greater retroversion compared with controls. In

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contrast, the role of glenoid version in anterior GHI remains controversial.[6-9] Some studies have reported that decreased retroversion is associated with anterior GHI,[9-10] whereas others have found no association.[6-11] Accurate measurement of glenoid version may play an essential role in treatment selection for these conditions.[4] If excessive glenoid anteversion is accurately identified, procedures such as remplissage in combination with arthroscopic Bankart repair or the Latarjet procedure may be considered in cases of anterior glenohumeral instability with subcritical bone loss. Likewise, identifying excessive retroversion is clinically important, as it may predispose patients to recurrence following isolated soft-tissue repair and indicate the need for bony realignment procedures, such as osteotomy or bone block procedures.

Magnetic resonance imaging (MRI) is frequently used to evaluate patients with GHI and LI.[14,15] MRI also offers the advantage of avoiding ionizing radiation exposure. Owing to its widespread use and favorable safety profile, this study focused on MRI-based assessment. To date, the agreement and intraobserver/interobserver reliability of glenoid version measurements obtained from standard axial MRI slices and 3-D–corrected axial MRI slices have not been investigated. Therefore, the aims of this study were: (1) to compare glenoid version measurements obtained from standard 2-D axial slices and 3-D–corrected axial slices, and (2) to compare the intraobserver and interobserver reliability of these measurement techniques. The primary hypothesis was that a statistically significant difference would exist between glenoid version values measured on standard 2-D axial slices and 3-D–corrected axial slices. The secondary hypothesis was that intraobserver and interobserver reliability would differ significantly between the two techniques, indicating whether one method provides greater repeatability and consistency than the other.

## MATERIALS AND METHODS

### Patients

This study received approval from the Acıbadem University Institutional Ethics Committee (Date: 29.07.2022, Decision no: 2022-12/19) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. Shoulder MRI examinations from 62 patients diagnosed with glenohumeral instability at a single institution over a two-year period were retrospectively reviewed. Written informed consent had been obtained from all patients prior to inclusion. Inclusion criteria consisted of a diagnosis of anterior or posterior GHI. GHI was defined based on patient history, clinical examination findings, and confirmatory MRI findings. Exclusion criteria included previous instability surgery, neurological conditions associated with shoulder abnormalities, significant glenohumeral arthritis, a history of glenoid or scapular fracture, presence of a glenoid bone defect, and MRI studies in which the medial border of the scapula was not adequately visualized for accurate evaluation (Table 1). A sample size analysis was performed assuming detection of a minimum difference of 1.5° between the two methods, with a standard deviation of 4° based on clinical experience. With a significance level ($\alpha$) of 0.05 and statistical power ($1-\beta$) of 0.8, the required sample size was calculated as 54 patients. An additional sample size analysis for comparison of reliability using a point-biserial correlation model t-test, with $\alpha$=0.05 and power=0.8, indicated a minimum requirement of 37 patients. Therefore, inclusion of 54 patients was considered sufficient for analysis. The final study cohort consisted of 22 females and 32 males with a mean age of 44.96±13.46 years (range, 16–63 years) (Table 2). Of these, 48 patients had anterior GHI and six had posterior GHI (Table 2).

All images were acquired at the same institution using the same MRI system and a standardized shoulder imaging protocol. MRI examinations were performed using a Siemens Magnetom Vida 3T system running syngo MR XA60 software (Siemens Healthcare, Erlangen, Germany). Images were obtained with a 3-mm slice thickness and no interslice gap. This slice thickness represents a standard musculoskeletal shoulder imaging parameter that provides an optimal balance between high resolution and signal-to-noise ratio.[14] This configuration is important for minimizing partial volume averaging effects, thereby improving visualization of the glenoid rim and increasing measurement accuracy. Measurements were performed on axial PD FAT-SAT (proton density fat-saturated) sequences.

**Table 1.** Inclusion and exclusion criteria for study participation

| Inclusion criteria | Exclusion criteria |
|---|---|
| Diagnosis of anterior GHI | Previous surgery for GHI |
| Diagnosis of posterior GHI | Significant glenohumeral arthritis |
| Clinical history consistent with instability (recurrent dislocation, subluxation, or apprehension) | History of glenoid or scapular fracture |
| Positive physical examination findings for instability (e.g., apprehension test) | Presence of glenoid bone defect |
| MRI confirmation of labral, capsular, or bony injury | |

GHI: Glenohumeral instability.

**Table 2.** Characteristics of the study population

| | Data |
|---|---|
| Patients, n | 54 |
| Age, (range), years | 44.96 (16–62) |
| Sex, n | |
| Female | 22 |
| Male | 32 |
| Side, n | |
| Left | 24 |
| Right | 30 |
| GHI, n | |
| Anterior | 48 |
| Posterior | 6 |

n: Number; SD: Standard deviation.

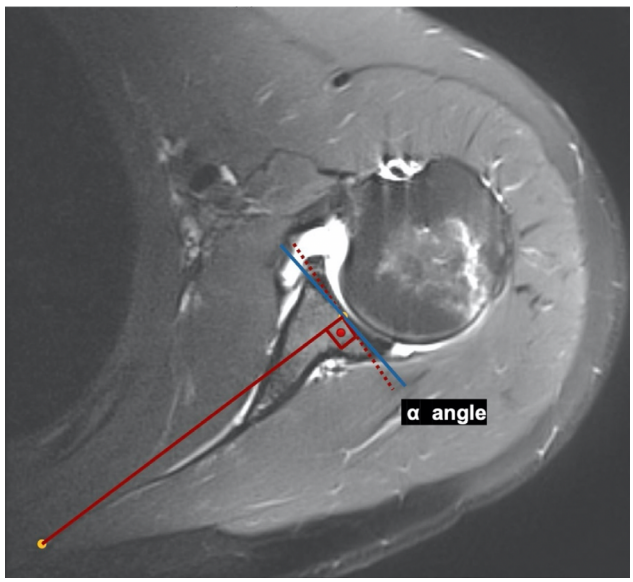



**Figure 1.** Measurement of glenoid version on an axial magnetic resonance imaging (MRI) slice using the Friedman method. The blue solid line represents the glenoid articular line, connecting the most prominent points of the anterior and posterior glenoid rims. The red solid line represents the scapular axis line, drawn from the midpoint of the glenoid articular line toward the medial border of the scapula. The glenoid version is measured as the angle between the glenoid articular line and a line perpendicular to the scapular axis line at the glenoid midpoint (red dotted line).

## Assessment

Measurements were performed on standard 2-D and 3-D corrected axial slices by two surgeons with six and nine years of experience in shoulder surgery, respectively, using standard angle measurement tools and the Friedman method[16] in Horos v4.0.0 RC4, an open-source medical image viewer (The Horos Project; horosproject.org). The glenoid version was measured as the posterior angle between the Friedman line and a line parallel to the glenoid fossa joint surface, minus 90° (Fig. 1). Standard 2-D axial slices were selected immediately inferior to the coracoid process, as originally described by Friedman et al.[16] The 3-D corrected axial slices were generated through multiplanar reconstruction (MPR), with the measurement plane defined as perpendicular to the scapular plane and passing through both the center of the glenoid fossa surface and the medial pole of the scapular spine, based on adjustments in coronal and sagittal views (Fig. 2).[17] To clarify the generation of the 3-D corrected axial slice used for measurement (Fig. 3), a standardized MPR protocol was applied using RadiAnt DICOM Viewer (Version 2021.1; Medixant, Poznań, Poland). The procedure began in the coronal plane (Panel 3, Fig. 3), where a reference slice demonstrating both the glenoid articular surface and the acromion was selected. In this plane (Fig. 3), one axis (blue) was aligned parallel to the glenoid surface, while the second axis (yellow) was positioned perpendicular to it. Next, adjustments were performed in Panel 2 (Fig. 3). The primary axis (pink) was carefully aligned to bisect the pear-shaped glenoid surface. The yellow axis was then positioned slightly inferior to

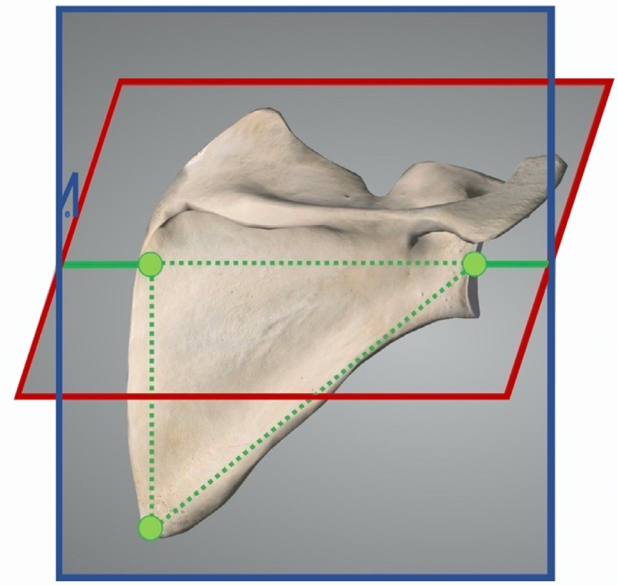


**Figure 2.** Principles of reconstruction of 3-D corrected slices. The scapular plane is defined using three reference points (green): the center of the glenoid, the inferomedial pole of the scapula, and the medial end of the scapular spine (forming the triangle indicated by the green dotted lines). The plane defined by these landmarks is shown within the blue frame. A second plane, including the scapular axis and perpendicular to the scapular plane, is reconstructed as the 3-D corrected slice (plane outlined by the red frame). The scapular axis is defined by lines connecting the center of the glenoid surface, the medial end of the scapular spine, and the inferior end of the scapular body (green solid lines).

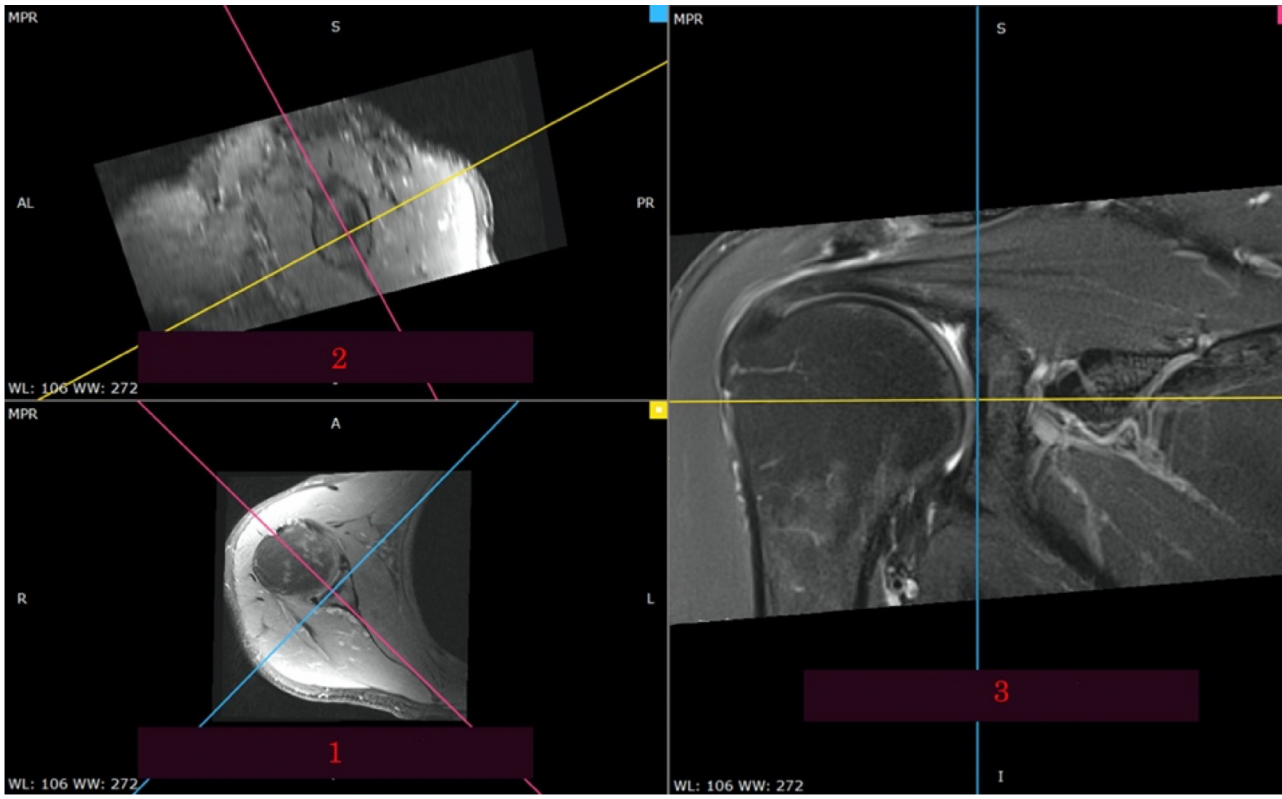



**Figure 3.** Generation of the standardized 3-D corrected axial slice using the multiplanar reconstruction (MPR) technique for glenoid version measurement. First, a reference section is selected in the coronal plane (Panel 3), where both the glenoid surface and acromion are clearly visualized, and the axes are aligned. Next, in the second plane (Panel 2), the axes are adjusted to align with the center of the glenoid. Through systematic fine-tuning across these planes, the final 3-D corrected axial plane (Panel 1) is generated, and all subsequent glenoid version measurements are performed on this plane.

the midpoint. This step ensured that the resulting axial slice passed through the true center of the glenoid and prevented superior or inferior tilt (Fig. 3). The combined adjustments made in Panels 2 and 3 produced the final 3-D corrected axial measurement plane (Panel 1, Fig. 3). In this reconstructed plane, the blue axis was expected to run parallel to the anterior glenoid rim, while the pink axis remained perpendicular to it. Additional iterative adjustments between Panels 2 and 3 (Fig. 3) were performed as needed to optimize alignment. All glenoid version measurements were ultimately obtained from this standardized reconstructed slice (Panel 1, Fig. 3).

To evaluate intraobserver reliability, each observer repeated all measurements after a two-month interval. Negative glenoid version values indicated retroversion, whereas positive values indicated anteversion.

### Statistical Analysis

Statistical analysis was performed using SPSS (version 26.0; IBM Corp., Armonk, NY, USA). Statistical significance was defined as $p<0.05$. Paired t-tests were used to determine differences in glenoid version values measured on standard 2-D and 3-D corrected slices. For reliability analysis, intraobserver and interobserver agreement were quantified using intraclass correlation coefficients (ICC) based on a two-way random-effects model.[18] ICC values were interpreted as follows: ≥0.90 indicated excellent agreement; 0.75–0.9 indicated good agreement; 0.50–0.75 indicated moderate agreement; and <0.50 indicated poor reliability.[19] Interobserver reliability was assessed by comparing measurements between the two observers. Intraobserver reliability was assessed by comparing repeated measurements obtained by each observer at the two-month interval.

Furthermore, distinct from the reliability analyses, agreement between measurements obtained from standard 2-D MRI slices and 3-D corrected MRI slices was assessed using the Intraclass Correlation Coefficient (ICC) based on a two-way mixed-effects model with absolute agreement for single measurements. This analysis complemented the paired t-test results, which indicated no statistically significant difference between measurements. ICC was calculated separately for each observer's first set of measurements. The same reference intervals were used for interpretation.

## RESULTS

For observer 1, the mean glenoid version was −0.69°±3.95°

**Table 3.** Glenoid versions measurements obtained from 2-D and 3-D corrected slices by each observer

| | 2-D slices | 3-D slices |
|---|---|---|
| Observer 1 | | |
| First measurement | | |
| Mean (°)† | -0.69 | -1.24 |
| Min–Max (°) | -12.8–5.5 | -9.9–6.10 |
| SD (°) | 3.95 | 3.94 |
| Second measurement | | |
| Mean (°) | -0.68 | -1.32 |
| Min–Max (°) | -17.8–6.5 | -17.6–8.9 |
| SD (°) | 3.73 | 4.43 |
| Observer 2 | | |
| First measurement | | |
| Mean (°) | -2.97 | -2.81 |
| Min–Max (°) | -15.99–8.69 | -23.55–7.54 |
| SD (°) | 4.48 | 4.92 |
| Second measurement | | |
| Mean (°) | -2.94 | -2.39 |
| Min–Max (°) | -17.52–5 | -20.58–8.27 |
| SD (°) | 4.28 | 5.09 |

2-D: Two-dimensional; 3-D: Three-dimensional; Min: Minimum; Max: Maximum; SD: Standard deviation. †Negative values indicate glenoid retroversion; positive values indicate glenoid anteversion.

**Table 4.** Interobserver and intraobserver reliability of glenoid version measurements (ICC)†

| | 2-D slices (95% CI) | 3-D slices (95% CI) |
|---|---|---|
| Interobserver reliability | 0.87 (good) | (0.78–0.92) |
| | 0.83 (good) | (0.70–0.91) |
| Intraobserver reliability | | |
| Observer 1 | 0.95 (excellent) | 0.86 (good) |
| Observer 2 | 0.97 (excellent) | 0.98 (excellent) |

ICC: Intraclass correlation coefficient. †ICC values were interpreted as follows: ≥0.90=excellent agreement; 0.75–0.9=good agreement; 0.50–0.75=moderate agreement; and <0.50=poor reliability.

on standard 2-D axial MRI slices and −1.24°±3.94° on 3-D corrected axial MRI slices (Table 3). This difference was not statistically significant (p=0.16). For observer 2, the corresponding values were −2.97°±4.48° and −2.81°±4.92°, respectively (Table 4). Likewise, no statistically significant difference was observed (p=0.66).

Interobserver reliability was good for both standard 2-D measurements (ICC=0.87) and 3-D corrected measurements (ICC=0.83) (Table 4). Intraobserver reliability for standard 2-D measurements was excellent for both observers (ICC=0.95 and 0.97, respectively) (Table 4). For 3-D corrected measurements, intraobserver reliability was good for observer 1 (ICC=0.86) and excellent for observer 2 (ICC=0.98) (Table 4).

Additionally, ICC analysis using a two-way mixed-effects model with absolute agreement demonstrated moderate agreement between the 2-D and 3-D methods for observer 1 (ICC=0.734, 95% CI: 0.583–0.836) and good agreement for observer 2 (ICC=0.826, 95% CI: 0.719–0.895).

## DISCUSSION

Glenoid version plays an important role in treatment selection and preoperative planning for patients with GHA, and previous studies suggest that 3-D corrected slices may improve measurement accuracy. However, generation of 3-D corrected slices is time-consuming and may require additional software and technical expertise.[2,21] To emphasize the uniqueness of the present study, it is important to compare our GHI cohort with previously studied GHA populations. Patients with GHI differ fundamentally from those with GHA in terms of mean age, glenoid morphology, and preferred imaging modalities. Previous studies advocating 3-D correction, including those by Scalise et al.[12] and Ganapathi et al.,[13] were conducted primarily in patients with GHA, in whom substantial bony deformity may compromise the reliability of 2-D measurements. In contrast, patients in our GHI cohort generally demonstrated preserved glenoid anatomy relative to GHA populations, which may explain why the additional complexity of 3-D correction did not provide meaningful benefit.

Retroversion of the glenoid due to glenoid erosion is commonly observed in patients with GHA.[22] Previous studies have reported mean glenoid version values ranging from -14.3 to -3.98 (range: -52.1 to 8.6) in patients with GHA.[2,16,20] In comparison, reported mean glenoid version values range from -1.6 to -5 (range: -19 to 7) in patients with anterior GHI.[6,9,23] and from -9.5 to -5 (range: -20 to 2) in patients with posterior GHI.[6] In patients with GHA, computed tomography (CT) imaging is commonly performed following X-ray radiographs, and glenoid version measurements are typically obtained from CT images.[24] In contrast, MRI is more frequently used for measurement in patients with GHI.[14,15] Slice thickness in CT imaging generally ranges from 1.25 to 2 mm, whereas MRI protocols for shoulder imaging typically use slice thicknesses of 3–5 mm.[1,25] This difference in slice thickness may influence measurement precision because of partial volume averaging and therefore represents an important limitation when comparing findings across imaging modalities. One possible explanation for the superiority of 3-D

correction reported in previous studies is that 2-D measurements are highly dependent on slice orientation and patient positioning. Additionally, the use of dedicated shoulder coils during MRI acquisition may help maintain a more standardized scapular position, which could partly explain why our findings differ from previous CT-based studies.

In the present study, glenoid version measurements in patients with GHI were compared between standard 2-D axial MRI slices and 3-D corrected axial MRI slices. Contrary to findings from previous CT-based studies in patients with GHA,[12,13] no statistically significant difference was observed between the two measurement methods for either observer. Our findings are consistent with those reported by Eisenhart-Rothe et al.,[23] the only previous study demonstrating that glenoid version measurements obtained using 3-D models were not significantly superior to standard 2-D measurements in patients with GHI. This agreement suggests that, unlike arthritic shoulders where substantial morphologic alteration may justify 3-D correction and result in clinically meaningful differences, the relatively preserved glenoid anatomy in GHI may allow standard 2-D measurements to provide sufficient accuracy for routine evaluation. Accordingly, our original hypothesis was rejected. Eisenhart-Rothe et al.[23] reported mean glenoid version values of 4.2°±2.4° using standard 2-D measurements and 4.4°±2.1° using 3-D models in patients with traumatic GHI. However, an important methodological difference should be noted. In the present study, measurements obtained from standard 2-D MRI slices were directly compared with measurements obtained from 3-D corrected MRI slices, whereas Eisenhart-Rothe et al.[23] compared 2-D measurements with measurements generated from virtual 3-D models. Furthermore, similar intraobserver and interobserver reliability values were observed for measurements performed on both standard 2-D and 3-D corrected slices (Table 3). Agreement analysis also demonstrated sufficient concordance to suggest that measurements obtained from 2-D axial slices and 3-D corrected axial slices may be used interchangeably.

This study has several limitations. First, its retrospective design introduces the possibility of selection bias. Because all data were obtained from a single medical center, referral bias may also be present, potentially resulting in overrepresentation of specific subsets of patients with GHI and limiting the generalizability of the findings. Second, only two observers participated in the measurements, and both were shoulder and elbow surgeons rather than musculoskeletal radiologists. Nevertheless, these measurements are frequently performed by orthopedic surgeons in routine clinical practice. One strength of this study is that it includes the largest patient cohort evaluated for this topic to date. In addition, sample size analysis was performed before study initiation to minimize issues related to insufficient statistical power. Future studies with larger populations are needed to validate these findings and further explore potential subgroup differences within patients with GHI. It should also be emphasized that the present study was conducted exclusively in patients with GHI. Significant differences between measurements obtained using 3-D correction and standard 2-D slices may be more likely in patients with GHA, in whom glenoid erosion and retroversion are typically more pronounced. Further investigation in this population is therefore required. As one of the initial MRI-based studies addressing this question, the findings should be confirmed by future studies.

## CONCLUSION

This study demonstrates that glenoid version measurements obtained from standard 2-D MRI slices and 3-D corrected MRI slices yield comparable results. Neither method demonstrated superior reliability. Therefore, 3-D correction may not be necessary for obtaining accurate and reliable glenoid version measurements on MRI in patients with glenohumeral instability.

**Ethics Committee Approval:** This study was approved by the Acıbadem University Institutional Ethics Committee (Date: 29.07.2022, Decision No: 2022-12/19).

**Peer-review:** Externally peer-reviewed.

**Informed Consent:** Written informed consent was obtained.

**Authorship Contributions:** Concept: G.K., O.T., S.K.D., M.Ç., A.C.A.; Design: G.K., O.T., S.K.D., M.Ç., A.C.A.; Supervision: G.K., O.T., S.K.D., M.Ç., A.C.A.; Resource: G.K., A.C.A.; Materials: O.T., S.K.D., M.Ç.; Data collection and/or processing: O.T., S.K.D., M.Ç.; Analysis and/or interpretation: G.K., A.C.A.; Literature review: O.T. , S.K.D , M.Ç.; Writing: G.K. , O.T.; Critical review: G.K., A.C.A.

**Conflict of Interest:** None declared.

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ORİJİNAL ÇALIŞMA - *ÖZ*

## Glenohumeral instabilitesi olan hastalarda manyetik rezonans görüntülemede glenoid versiyon ölçümü için 3-boyutlu rekonstrüksiyon gerçekten gerekli mi?

AMAÇ: Glenohumeral instabilitede (GHİ) glenoid versiyonun önemi giderek daha iyi anlaşılmaktadır. Ancak, manyetik rezonans görüntüleme (MRG) görüntülerinde yapılan üç boyutlu (3-B) düzeltmenin GHİ hastalarında daha doğru bir glenoid versiyon ölçümü sağlayıp sağlamadığı bilinmemektedir. Bu çalışmanın temel hipotezi, standart 2 boyutlu aksiyel kesitlerde ve 3 boyutlu düzeltilmiş aksiyel kesitlerde ölçülen glenoid versiyon değerleri arasında istatistiksel olarak anlamlı bir fark olacağıdır.

GEREÇ VE YÖNTEM: Glenohumeral instabilitesi olan 54 hastanın (22 kadın, 32 erkek) glenoid versiyon ölçümleri retrospektif olarak incelendi. Ölçümler, iki gözlemci tarafından, standart 2-B aksiyel MRG kesitleri ve 3-B düzeltilmiş aksiyel MRG kesitleri üzerinde Friedman metodu kullanılarak ikişer kez yapıldı. Her gözlemcinin ölçtüğü değerler eşleştirilmiş t-testi ile karşılaştırıldı. Ölçümlerin güvenilirliği sınıf içi korelasyon katsayısı (SKK) testi ile değerlendirildi.

BULGULAR: Birinci gözlemci için standart ve 3-B düzeltilmiş aksiyel MRG kesitlerinde ölçülen ortalama glenoid versiyon değerleri sırasıyla −0.69°±3.95° ve −1.24°±3.94° idi (p=0.16). İkinci gözlemci için bu değerler sırasıyla −2.97°±4.48° ve −2.81°±4.92° idi (p=0.66). Gözlemciler arası güvenilirlik her iki yöntem için de iyi düzeydeydi (2-B için SKK= 0.87 ve 3-B için SKK=0.83). Gözlemci içi güvenilirlik, 2-B kesitlerde yapılan ölçümler için mükemmel (SKK=0.95 ve 0.97), 3-B düzeltilmiş kesitlerde yapılan ölçümler için ise iyi-mükemmel düzeydeydi (SKK=0.86 ve 0.98).

SONUÇ: Bu çalışmada elde edilen bulgular, glenohumeral instabilitesi olan hastalarda MRG ile yapılan glenoid versiyon ölçümlerinde 3-B düzeltmenin gerekli olmayabileceğini düşündürmektedir. Daha güçlü bir klinik geçerlilik sağlamak için daha geniş hasta örneklemleri içeren çok merkezli çalışmalar planlanmalıdır.

Anahtar sözcükler: Glenohumeral instabilite; manyetik rezonans görüntüleme; üç boyutlu düzeltme.

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