

Optimization of the Grashey View Radiograph for Critical Shoulder Angle Measurement

A Reliability Assessment With Zero Echo Time MRI

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Background: Suboptimal positioning on Grashey view radiographs may limit the prognosticating potential of the critical shoulder angle (CSA) for shoulder disorders.

Purpose: To investigate whether radiography optimized according to the latest research is reliable for measuring CSA in comparison with magnetic resonance imaging (MRI) featuring 3-dimensional (3D) zero echo time (ZTE) sequencing, which accentuates the contrast between cortical bone and surrounding soft tissue with high fidelity.

Study Design: Cohort study (diagnosis); Level of evidence, 2.

Methods: Patients with shoulder pain were prospectively and consecutively enrolled. All patients had Grashey view radiographs as well as 3.0-T MRI scans with isotropic 3D ZTE sequencing. Acceptable positioning on the radiographs was determined using the ratio of the transverse to longitudinal (RTL) diameter of the lateral glenoid outline; radiographs with an RTL ≥ 0.25 were repeated. Two observers independently measured the CSA on the radiographs and the coronal oblique reformatted ZTE images, the latter including verification of measurement points by cross-referencing against images from other planes. Reliability of measurements between observers and modalities was analyzed with the intraclass correlation coefficient (ICC). The paired-samples *t* test was used to compare the differences between imaging modalities.

Results: Enrolled were 65 patients (35 female and 30 male; mean age, 40.2 years; range, 25-49 years). Radiographs with optimal positioning (RTL < 0.25) were attained after a mean of 1.6 exposures (range, 1-4); the mean RTL was 0.09 (range, 0-0.20). Interobserver agreement of CSA was excellent for radiographs (ICC = 0.91; 95% CI, 0.84-0.94) and good for ZTE MRI scans (ICC = 0.85; 95% CI, 0.71-0.92). Intermodality agreement of CSA between radiographs and ZTE MRI scans was moderate (ICC = 0.66; 95% CI, 0.48-0.73). The CSA was significantly different between an optimal radiograph ($30.7^\circ \pm 4.3^\circ$) and ZTE MRI scan ($31.8^\circ \pm 3.8^\circ$) ($P = .005$). Subgroup analysis revealed no significant differences in CSA measurement between ZTE MRI scans and Grashey view radiographs with an RTL of <0.1 ($P = .08$).

Conclusion: CSA measurement on ZTE MRI scans with anatomic point cross-referencing was significantly different from that on Grashey view radiographs, even with optimal positioning, and radiography may necessitate more than 1 exposure. An RTL of <0.1 ensured reliability of radiographs when other standards of sufficient x-ray exposure were met.

Keywords: Grashey view; critical shoulder angle; zero echo time imaging; magnetic resonance imaging

The critical shoulder angle (CSA) was first described in 2013 by Moor et al²³ as a potential prognosticator for shoulder disorders. According to Moor et al, a CSA between 30° and 35° is normal, a CSA $>35^\circ$ is associated with increased superior shear forces on the rotator cuff muscles and a high prevalence of rotator cuff tears (RCTs), and a CSA $<30^\circ$ is associated with increased compressive forces across the glenohumeral joint, which is likely to lead to osteoarthritis (OA).

Since the first description of the CSA, studies supporting or refuting the association between CSA, shoulder disease, and

clinical treatment outcomes have been published.[§] This controversy surrounding the CSA may be attributable to incorrect positioning on Grashey view (true anteroposterior) radiographs, leading to measurement error. Although Moor et al²³ defined $>20^\circ$ of glenoid rotation as the cutoff for an optimal Grashey view, Suter et al³¹ later found that deviations as little as 5° in anteversion could result in a CSA difference of $>2^\circ$. These authors proposed a system (the Suter-Henninger classification [SHC]) for categorizing the extent of rotation of the lateral glenoid joint face on Grashey view radiographs. A study on the effect of scapular rotation found that a high degree of

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variability in the 3-dimensional (3D) morphology of the scapula makes it difficult to obtain reproducible Grashey view radiographs, which is crucial to accurately measure the CSA.¹⁹

To overcome the limitations of incorrect (ie, suboptimal) positioning on Grashey view, several studies have used computed tomography (CT) or magnetic resonance imaging (MRI), with mixed results.^{5,12,16,17,30} Using digitally reconstructed radiographs from CT scans, Hou et al¹⁵ recently found that for a reliable CSA measurement, the maximum ratio of the transverse to longitudinal (RTL) diameter of the lateral glenoid outline on Grashey view was 0.25.

During the past decade, a novel MRI sequence called *zero echo time* (ZTE) has been developed that provides enhanced contrast between the cortical bone and the surrounding soft tissue and shows osseous morphology with CT-like images.³⁵ ZTE MRI accomplishes this by virtue of eliminating low signal from other (but noncalcified) soft tissue structures adjacent to the bone cortex, which itself has a low signal. When the resultant images are inverted (ie, black and white are reversed), high-fidelity renditions are produced. Moreover, ZTE features near-isotropic or isotropic voxels, meaning that high-resolution 2-dimensional (2D) reformats and 3D reconstructions are possible.⁷ Studies comparing CT versus ZTE MRI (mostly at 3.0 T) in osseous pathologies of the shoulder, hip, skull, and cervical spine have shown strong intermodality agreement between measurements (excluding CSA) and gradings.^{1,6,7,11} CT with multiplanar reformatting ensures accurate CSA measurement as long as anatomic point cross-referencing is performed.¹⁷ This entails the acquisition of a separate CT scan, and the attendant ionizing radiation, for patients with shoulder problems. However, many such patients are already scheduled for shoulder MRI. Thus, ZTE MRI, with its already proven high fidelity for showing cortical bone detail, may well replace Grashey view radiography or obviate the need for multiplanar CT in patients with shoulder disorders.

The purpose of this study was to measure and compare the CSA on optimal Grashey view radiographs and CT-like reformatted images from ZTE MRI scans. Our hypothesis was that what is currently described as optimal Grashey view radiography would correlate favorably with ZTE imaging for the measurement of CSA.

METHODS

Patient Selection

The reporting of this study conforms to the Standards for Reporting Diagnostic Accuracy and the Strengthening the Reporting of Observational Studies in Epidemiology

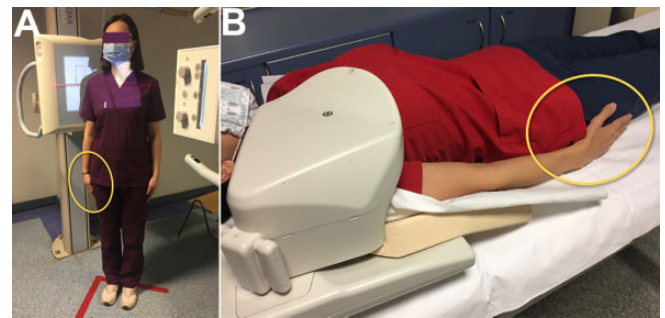


Figure 1. Patient positioning for (A) Grashey view radiography and (B) shoulder magnetic resonance imaging. The red lines on the floor in (A) show the 45° angulation with respect to the x-ray detector. Patients put their arm by their side with the palm facing the body (yellow circles).

statement guidelines,^{4,34} and the study protocol was approved by our institutional review board. This prospective observational cohort study included patients ≥ 25 and < 50 years of age with shoulder pain who were referred to the radiology department of our institution for shoulder radiography and MRI over a 5-month period (September 2020–February 2021) by a single orthopaedic surgeon (G.H.). Exclusion criteria were a history of acromioclavicular joint dislocation; surgery for subacromial impingement (ie, acromioplasty) or fracture of the scapula, clavicle, or humerus; and/or the presence of soft tissue or bone abnormalities (eg, tumors, infection) that could have disrupted shoulder alignment, potentially altering the CSA measurement between standing and supine positions. Patients with a history of shoulder dislocation were also excluded from the study if ZTE MRI scans showed an osseous Bankart lesion.⁷

Imaging Technique and Assessment

All patients underwent both Grashey view shoulder radiography and shoulder MRI. Grashey view radiographs profiling the glenohumeral joint were obtained by standard positioning of the patients, whereby their heels were placed on a floor line that ensured 45° of angulation with respect to the x-ray detector (Figure 1A).²⁸ Per Hou et al,¹⁵ we established the criterion for reliability of CSA measurement on radiographs as an RTL of < 0.25 (Figure 2). Upon immediate review by a musculoskeletal radiologist (A.E.Y. or Ü.A.), radiographs that were unacceptable according to this criterion were repeated. The extent of radiographic rotation of the lateral glenoid joint face was then categorized according to the SHC,³¹ which entails 2 parts: (1) determination of

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Ethical approval for this study was obtained from Hacettepe University (protocol No. GO 20/1117).

a glenoid rim double contour (types A-D) and (2) assessment of coracoglenoid overlap and projection of the coracoid process (types 1-3).³¹

Shoulder MRI examinations were performed on a 3.0-T MRI scanner (Signa Architect; GE Healthcare) with a dedicated surface coil, with the patient's arms placed on the

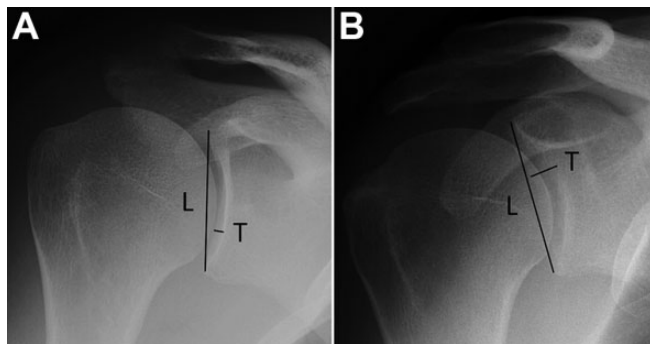


Figure 2. The ratio of the transverse (T) and longitudinal (L) diameter measurements of the lateral glenoid outline (ie, the ratio of the transverse to longitudinal [RTL] diameter of the lateral glenoid outline) on Grashey view radiographs was calculated in all patients. The RTLs in these 2 study patients were (A) 0.05 and (B) 0.16.

side with palms facing the torso (Figure 1B). Shoulder MRI sequences included an isotropic (ie, $1 \times 1 \times 1$ -mm voxel size) 3D ZTE imaging sequence in addition to our standard protocol, which featured T1-weighted and fat-saturated T2-weighted sagittal oblique sequences, fat-saturated T2-weighted coronal oblique and axial sequences, and proton density-weighted axial sequences. The ZTE sequence parameters were as follows: repetition time, 414 milliseconds; echo time, 0 milliseconds; flip angle, 1° ; field of view, 18 cm; matrix, 180×180 ; number of signal acquisitions, 4; bandwidth, 31.3 kHz; scan time, 4 minutes 18 seconds.

Two observers (a third-year radiology resident and a radiologist with 3 years of dedicated musculoskeletal imaging experience after the residency (Y.Y. and A.E.Y. respectively) independently measured the CSA on both the Grashey view radiographs (Figure 3A) and the ZTE images that entailed 20 mm-thick, coronal oblique reformatted, inverted minimum intensity projection (Figure 3B); for the latter, the measurement points were verified by cross-referencing on images from other planes (Figure 3, C-F). The obliquity of coronal ZTE reformats was determined on a virtual workstation such that the resultant images were perpendicular to the glenohumeral joint face of the scapula on the axial plane and parallel to the longitudinal axis of the lateral glenoid joint face on the sagittal plane (Figure 3, B, E, and F). We decided to use the 20 mm

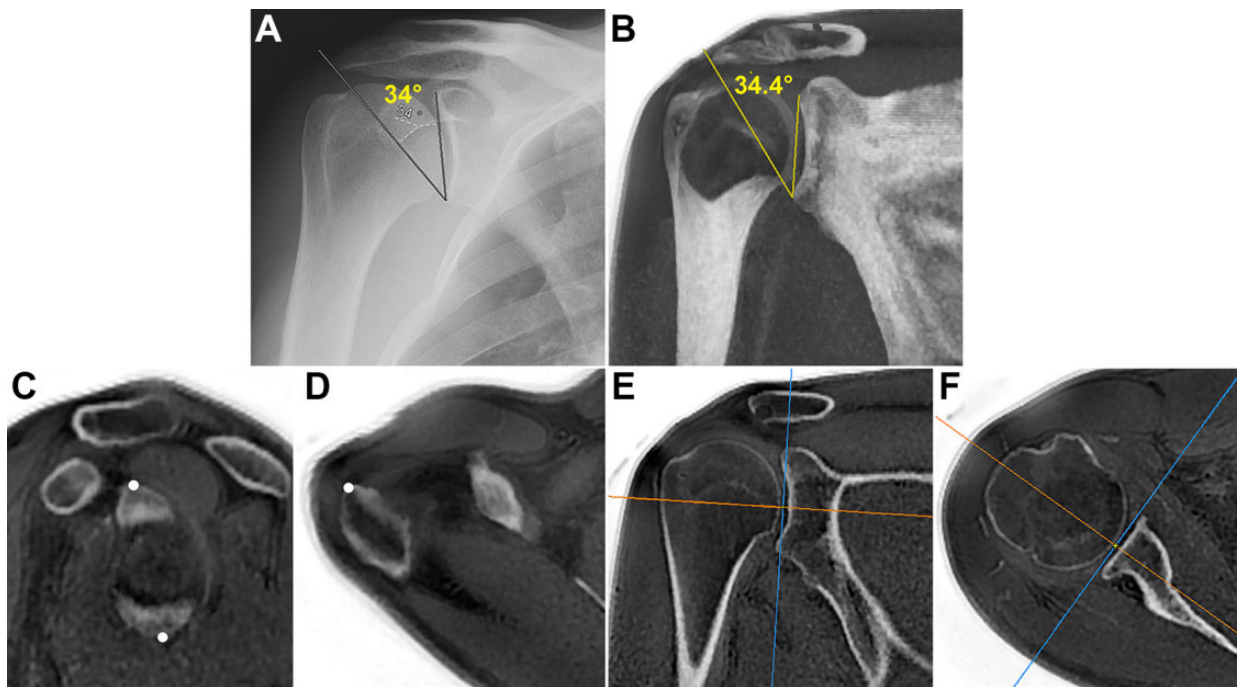


Figure 3. The critical shoulder angle (CSA) was measured by identifying the superior and inferior corners of the lateral glenoid joint face and the lateral edge of the acromion on (A) Grashey view radiographs and (B) 3-dimensional, zero echo time (ZTE), magnetic resonance image (MRI) scans with 20 mm-thick, coronal oblique reformatted, inverted minimum intensity projection. Note that both measurements are similar (34.0° vs 34.4°) in this patient (the ratio of the transverse to longitudinal diameter of the lateral glenoid outline was 0.06). During measurement, the anatomic landmarks of the CSA were cross-referenced on ZTE MRI scans: (C) sagittal oblique (white dots mark superior and inferior glenoid corners) and (D) transverse (white dot marks lateral edge of the acromion). The sagittal oblique ZTE image in (C) was derived from reformatting according to (E) coronal and (F) axial ZTE images, which ensures the most accurate depiction of the lateral glenoid joint face. The blue lines in (E) and (F) show the orientation of (C).

thickness on coronal oblique ZTE reformats after measuring the projectional distance between the lateral rim of the acromion and the superior corner of the glenoid cavity on 10 patients (outside the study group with similar demographic and clinical characteristics).

The CSA was measured according to its original description by Moor et al.²³ All CSA measurements on the radiographs and MRI scans were made at least 7 days apart, and the observers were blinded to each other's and their own measurements on both imaging modalities. To ensure measurement standardization, we measured the CSA angle using a $\times 2$ zoom setting for radiographs on our picture archiving and communication system and a $\times 1.5$ zoom setting for MRI using a special software program (AW Server; GE Healthcare). Measurements were performed after a training session on 10 patients (outside the study group with similar demographic and clinical characteristics), whereby the musculoskeletal radiologist showed the measurement method to the radiology resident and checked the measurements.

Statistical Analysis

Data analysis was performed using SPSS Statistics Version 23.0 (IBM). Mean values and their deviations, as well as maximum and minimum values, were calculated with descriptive statistics. Agreements between radiography- and ZTE-based CSA measurements were analyzed with the intraclass correlation coefficient (ICC). ICC estimates and their 95% CI were calculated based on a single-rating, absolute-agreement, 2-way mixed-effects model. The values were interpreted as ICC <0.50 indicating poor reliability, 0.50-0.75 moderate reliability, 0.76-0.90 good reliability, and >0.90 excellent reliability.²⁵ The paired-samples *t* test was used to compare the differences between means of groups (radiography vs ZTE) and subgroups (radiography with RTL <0.1 vs radiography with RTL ≥ 0.1 and ≤ 0.2). $P < .05$ was considered the threshold for statistical significance.

RESULTS

The study included 65 shoulders in 65 patients (35 female and 30 male; mean age, 40.2 years; range, 25-49 years; 29 right and 36 left shoulders) (Figure 4). Post hoc analysis yielded 64.6% power. Radiographs with acceptable positioning for CSA measurement (RTL < 0.25) were attained after a mean of 1.6 exposures (range, 1-4 exposures); the overall mean RTL was 0.09 (range, 0-0.20).

No repeat radiography was necessary in 35 (54%) patients; repeat radiography was needed due to excessive rotation in 22 (34%) patients and due to both excessive rotation and overexposure in 8 (12%) patients (over- or underexposure was never the sole reason for repeat radiography). The distribution of study patients according to RTL and SHC type is summarized in Table 1. The mean interval between radiography and MRI was 2.6 days (range, 0-11 days).

Interobserver agreement was excellent for radiography (ICC = 0.91; 95% CI, 0.84-0.94) and good for ZTE MRI

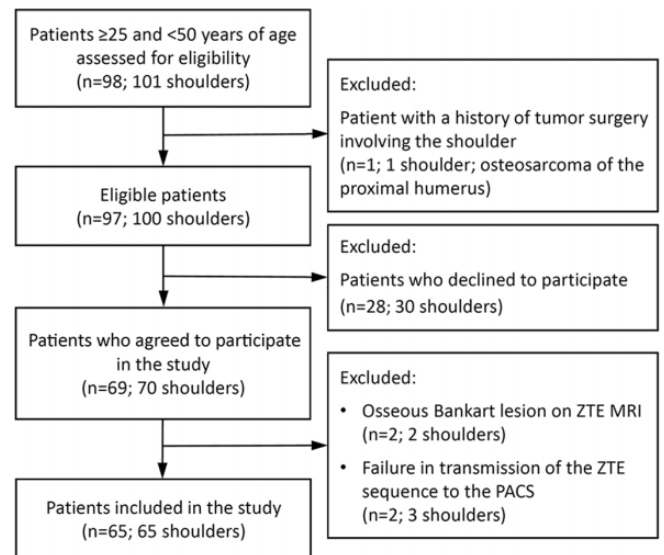


Figure 4. Flowchart of patient enrollment. MRI, magnetic resonance imaging; PACS, picture archiving and communication system; ZTE, zero echo time.

TABLE 1
Distribution of Patients (N = 65) According to RTL
and SHC Type on Grashey View Radiographs^a

	n (%)
RTL ^b	
≥ 0 and <0.1	37 (56.9)
≥ 0.1 and ≤ 0.2	28 (43.1)
SHC type ^c	
A1	9 (13.8)
B1	12 (18.5)
B2	1 (1.5)
C1	10 (15.4)
D1	33 (50.8)

^aRTL, ratio of the transverse to longitudinal (diameter of the lateral glenoid outline); SHC, Suter-Henninger classification.

^bRTL <0.25 is considered a prerequisite for reliability of Grashey view radiographs in the measurement of critical shoulder angle.¹⁵ RTL categories do not correspond to specific SHC types.

^cCombination of following types: type A, no double contour of glenoid rim; type B, inverted-teardrop double contour of glenoid rim initiated at the upper glenoid ($<50\%$ of glenoid height); type C, teardrop double-contour glenoid rim initiated at the lower glenoid ($<50\%$ of glenoid height); type D, double-contour glenoid rim $>50\%$ of glenoid height; type 1, overlap of the upper glenoid rim and the coracoid process (or its inferior edge aligned with the upper glenoid rim); type 2, no overlap of the upper glenoid rim and the coracoid process (coracoid process above the upper glenoid rim); type 3, no overlap of the upper glenoid rim and the coracoid process (coracoid process below the upper glenoid rim or its superior edge aligned with the upper glenoid rim).³¹

(ICC = 0.85; 95% CI, 0.71-0.92). Intermodality agreement of the musculoskeletal radiologist for radiography and ZTE MRI was moderate (ICC = 0.66; 95% CI, 0.48-0.73).

TABLE 2
Comparison of CSA Between Grashey View Radiographs and ZTE MRI Scans According to RTL and SHC Type^a

	CSA, deg, mean (range)		P
	Grashey View Radiographs	ZTE MRI Scans	
RTL			
≥0 and <0.1 (n = 37)	30.4 (23.0-37.0)	31.3 (24.4-39.1)	.080
≥0.1 and ≤0.2 (n = 28)	30.9 (24.0-41.0)	32.4 (27.5-40.7)	.036
SHC type			
A1 (n = 9)	30.9 (24.0-34.0)	31.7 (24.7-38.2)	.415
B1-D1 (n = 56)	30.6 (23.0-41.0)	31.8 (24.4-40.7)	.009

^aBoldface *P* values indicate statistically significant difference between imaging modalities ($P < .05$, paired-samples *t* test). CSA, critical shoulder angle; MRI, magnetic resonance imaging;

RTL, ratio of the transverse to longitudinal (diameter of the lateral glenoid outline); SHC, Suter-Henninger classification; ZTE, zero echo time.

The CSA measurements of the musculoskeletal radiologist were significantly different between an optimal radiograph ($30.7^\circ \pm 4.3^\circ$) and ZTE MRI ($31.8^\circ \pm 3.8^\circ$) ($P = .005$).

The CSA measurements on radiographs with an RTL of <0.1 (n = 37) were not significantly different from the ZTE-based measurements ($P = .08$). The CSA measurements on radiographs with an RTL of ≥0.1 (n = 28), however, were significantly different from the ZTE-based measurements ($P = .036$) (Table 2). Figure 2 shows patients from each of these 2 RTL subgroups. The CSA measurements on radiographs categorized as SHC type A (n = 9; all type 1) were not significantly different from the ZTE-based measurements ($P = .415$). However, the CSA measurements on all other radiographs (ie, SHC types B-D, regardless of types 1-3 according to coracoglenoid overlap and projection of the coracoid process; n = 56) were significantly different from the ZTE-based measurements ($P = .009$).

DISCUSSION

This study showed that CSA measurement on ZTE MRI with anatomic point cross-referencing was significantly different from that on Grashey view radiography that was optimized according to the RTL criterion, which ranged between 0 and 0.2 ($P = .005$). In subgroup analysis, however, we found no significant differences between the CSA measurements on ZTE and Grashey views with an RTL <0.1 ($P = .08$) or SHC type A1 ($P = .415$). Our subgroup results were compatible with the findings in studies comparing CSA measurements between SHC type A1 Grashey views and cross-sectional imaging on CT and MRI,^{12,16,17} highlighting the negative effect of even minimal rotation on Grashey views (ie, with an RTL ≥0.1 and ≤0.2) that were considered optimal in a recent study.¹⁵

Studies assessing CSA measurement on radiography and cross-sectional imaging are summarized in Table 3. Karns et al¹⁶ found that Grashey view radiographs corresponding to SHC type A1 on CT-reconstructed images overcame measurement errors, suggesting the reliability of Grashey views with no glenoid rim double contour in correctly measuring the CSA. The SHC stipulates that CSA in radiographs can be measured with <2° error compared with

the Grashey view, provided that there is no double contour of >50% of glenoid height or an inverted teardrop pattern at the upper glenoid rim.³¹ In contrast, Spiegl et al³⁰ and Garcia et al¹² measured the CSA on both radiographs and conventional MRI scans in small samples of patients (N = 10 and N = 15, respectively) and reported conflicting results on the reliability of using MRI for the measurement of CSA. Spiegl et al reported no significant difference between the Grashey view and MRI for measuring CSA in patients without OA but disclosed greater variability of and less correlation between the 2 modalities in patients with OA, likely “due to disadvantages of MRI in bone imaging of the glenoid compared to radiographs and CT.” However, Garcia et al found no significant difference between radiography and MRI for measuring the CSA.

In contradistinction to our study, Bouaicha et al,⁵ in a study comprising 60 patients and using coronal multiplanar reformatted CT images, found a high correlation of CSA measurements with conventional anteroposterior radiography. However, although those authors accepted “slight malrotation” on radiographs, no further details about the degree of rotation was reported, nor did the authors report whether their observers measured the CSA at separate radiography and CT evaluation sessions, thereby rendering it impossible to rule out confirmation bias. Kim et al¹⁷ (N = 238) and Karns et al¹⁶ (N = 88), using multiplanar reformatted and 3D volume-rendered reformatted CT images, both reported high agreement between CSA measured on SHC type A1 Grashey views and CT ($P = .905$ and $.296$, respectively). Kim et al also reported less agreement between the CSA measured on SHC type C1 Grashey views and CT scans ($P = .017$). Results from both of these studies, like ours, highlight the influence of rotation on the CSA measurement.

Spiegl et al,³⁰ using conventional MRI sequences (ie, no ZTE) and cross-referencing during MRI measurement, found that the correlation of CSA between radiography and MRI was higher in RCT patients and non-RCT/non-OA patients than in OA patients. The authors attributed the lower correlation in the OA patients with the difficulty posed by osteophytes in determining the upper and lower borders of the glenoid. In fact, the CSA can be reliably measured by examiners at varying levels of orthopaedic

TABLE 3
Published Studies Assessing CSA Measurement on Radiography and/or Cross-sectional Imaging^a

Lead Author (Year, Design)	Imaging Modality	No. of Scapulae	Age, y, mean (range)	Remarks
Bouaicha ⁵ (2014, retrospective) Suter ³¹ (2015, prospective)	XR, CT CT	60 68	60 (42-71) 60 (26-73)	No significant difference in CSA between XR and MPR CT Nonpathological cadaveric specimens (25 pairs, 18 individuals); a classification (SHC) was proposed for glenoid rotation and coracoid overlap on DRRs based on morphometric measurements on 3D reconstructions
Spiegl ³⁰ (2016, retrospective)	XR, MRI	30	41 (43-60)	CSA measurements significantly different between XR and MRI for the OA group; no significant difference for the RCT and non-RCT/non-OA groups
Karns ¹⁶ (2018, prospective)	XR, CT	88	62 (26-101)	Nonpathological cadaveric specimens (30 pairs, 28 individuals); 3D-CT and DRR (for all scapulae) and fluoroscopic XR positioned to correspond to SHC type A1 (limited to 20 scapulae) were used; no significant difference for CSA between 3D-CT, DRR, and fluoroscopic XR
Kim ¹⁷ (2019, retrospective)	XR, CT	238	57 in RCT group, 58 in normal cuff group (40-70)	CSA measurements from SHC types A1 and C1 XR and MPR CT images; XR SHC type A1 and CT were recommended for CSA measurement to reduce errors
Garcia ¹² (2021, prospective)	XR, MRI	15	>18 (NR)	No significant difference in CSA between XR and T1-weighted MRI with cross-referencing (no ZTE; no reformats from a 3D image set)
Hou ¹⁵ (2021, retrospective)	CT	86	41 (18-83)	SHC types A1 and D1 were compared on DRRs; RTL <0.25 found to be a prerequisite for XR for reliable CSA measurement
Current study (2022, prospective)	XR, MRI	65	40 (25-49)	Coronal reformats from ZTE MRI data set with anatomic point cross-referencing used as the gold standard; RTL <0.1 found to be a prerequisite for XR for reliable CSA measurement

^a3D, 3-dimensional; CSA, critical shoulder angle; CT, computed tomography; DRR, digitally reconstructed radiograph; MPR, multiplanar reformatted; MRI, magnetic resonance imaging; NR, not reported; OA, osteoarthritis; RCT, rotator cuff tear; RTL, ratio of the transverse to longitudinal (diameter of the lateral glenoid outline); SHC, Suter-Henninger classification; XR, true anteroposterior (Grashey view) radiography; ZTE, zero echo time imaging.

training, even in patients with more advanced radiographic glenohumeral OA.²⁹ Nevertheless, our study group did not include patients ≥ 50 years of age, at which point the prevalence of shoulder OA begins to increase.¹⁸ We used 25 years as the lower age limit to ensure complete fusion of the secondary ossification centers of the glenoid and distal acromion.³⁶

Despite having narrowed the age range of our study participants to avoid the confusing effects of OA (which would have nevertheless appeared on both radiography and ZTE MRI), we did not find a good correlation between radiography and MRI for CSA measurement. One of the drawbacks of the earlier study comparing MRI and radiography for CSA measurement is the lack of information about the extent of rotation in radiography.³⁰ In a recent study using conventional T1-weighted and fat-saturated T2-weighted images (but no ZTE) and cross-referencing technique, Garcia et al¹² found no statistically significant difference between radiographic and MRI-based CSA measurements, similar to our results. Although the Garcia study had a small sample size (N = 15 patients), radiographs were reportedly performed with x-rays penetrating the glenohumeral joint at 90°, suggesting SHC type A1.

In addition to strictly ensuring that Grashey radiography was optimal, another unique aspect of our study was

using CT-like images produced with ZTE MRI as well as anatomic point cross-referencing on MRI scans from other planes to overcome measurement errors. ZTE MRI has been shown to be a robust technique in producing CT-like images that accentuate the contrast between cortical bone and soft tissue,³⁵ and studies on osseous pathologies in various body parts including the shoulder have reported strong intermodality agreement between measurements and gradings made on ZTE images and CT scans.^{1,6,7} ZTE is a 4- to 5-minute sequence available from several MRI manufacturers that can be easily added to routine shoulder MRI in 3.0-T or 1.5-T systems, without necessarily incurring additional costs for patients (or their health insurance providers). Considering the possibility of accurately measuring the CSA as well as other potential applications of generating CT-like images from MRI scans, we believe that ZTE is well worth acquiring for MRI service providers.

Regarding Grashey view radiographs, the recommended body rotation from the posterior is between 35° and 45° depending on how flat- or round-shouldered the patient is as well as on scapular morphologic variability.^{19,21} Despite the given angular degree range for Grashey view, there is no study in the literature investigating its optimum angle. In our study, we used a standardized 45° angle, which might have resulted in a relatively small proportion of SHC

type A1 radiographs (13.8%) compared with rotated—but still optimal—radiographs with an overwhelming majority of SHC type D1 (50.8%). In 2 studies that investigated the relation between CSA and RCT,^{8,33} all but SHC type A1 or C1 Grashey radiographs were discarded (resulting in only 21% and 27%, respectively, of radiographs of the entire set of patients acceptable for further investigation). In our study, our optimization of all radiographs according to RTL by repeated exposures notwithstanding, subgroup analysis showed the importance of stricter (RTL <0.1) optimization of the Grashey view to provide accurate measurements.

Apart from rotation effects, the obliquity of the Grashey view results in a sudden change of overlying soft tissue density, which decreases the quality and visualization of the osseous detail.²⁸ This limitation of the Grashey view may obscure the superior glenoid under the coracoid process on SHC type 1 radiographs due to an insufficient radiation dose to depict the superior glenoid clearly without concealing the lateral acromion. All but 1 of our radiographs were SHC type 1, and our quality control ensured sufficient visualization of the lateral edge of the acromion; however, this measure might have resulted in increased fuzziness of the superior glenoid rim with the juxtaposition of the coracoid process in some of our patients. In fact, although identification of the lateral acromial point may be problematic on high-dose radiographs due to the steep gradient of overlying soft tissue in this area, a study comparing radiographs with 3D-reconstructed CT scans showed that this identification would not be a problem as long as the radiation dose was optimal.¹⁶ The effects of rotation and obscuration of the superior glenoid under the coracoid process due to imaging technique and radiation dose might lead to false CSA measurements on radiographs. Given that the normal CSA lies between a narrow range of 30° and 35°, erroneous measurements of CSA on Grashey views might have misleading consequences. Determination of the inferior glenoid rim is usually straightforward because there is no overlapping bone structure. Obviously, ZTE MRI is free from all such projectional and x-ray exposure-related issues.

A recent review evaluating the relationship between the CSA and shoulder diseases concluded that conflicting findings of studies in the literature may be attributable to the lack of standardized radiographic methods for measuring CSA and/or to measurement errors.¹⁹ The authors also emphasized the need for a standard and reproducible method of CSA measurement to elucidate the true relationship between the CSA and shoulder disease.¹⁹ For comparison of pre- and postoperative CSA, the exact orientation of the x-rays and the spatial orientation of the scapula should be as similar as possible.²² Given the difficulty of obtaining SHC type A1 radiographs in daily practice and the inherent problems of standardization of Grashey views that might result in repeated or substantial ionizing radiation exposures (in the form of radiography or CT), patients for whom shoulder MRI is considered part of the diagnostic workup would better have their CSAs measured by means of the ZTE MRI sequence with anatomic cross-referencing on images from other planes.

The CSA is not the only measurement that benefits from better identification of anatomic landmarks afforded by cross-sectional imaging, which eliminates perspective and malrotation issues that radiography entails. In fact, parallel to our findings, studies on the glenoid inclination and the glenopolar angle also suggested superiority of 3D over 2D measurements.^{9,32} Measurements of such parameters can also potentially benefit from anatomic point cross-referencing combined with ZTE MRI as described in this study.

Strengths and Limitations

The strengths of our study include its prospective design with immediate verification of an optimal Grashey view, standardization of measurement settings, and independence and blinding of the observers. Validating or discrediting Grashey view radiography as a prognosticator of RCTs or shoulder OA was not within the scope of our study. The relatively small sample size is a limitation of our study. However, the size of our cohort is comparable with previous studies (see Table 2). In fact, our sample size is remarkably larger than either of the 2 CSA reliability studies that entailed MRI,^{12,30} and ours is the only study that used CT-like images generated from MRI scans. Another limitation is that we did not generate 3D reconstructions and compare their utility to the coronal reformatted MRI scans that we used. However, our method was simple and facilitated on-the-fly, anatomic point cross-referencing that ensured exact measurement of the CSA. Volumetric reconstructions from the ZTE sequence would entail the lengthier procedure of removing the humerus from the images (because identification of the CSA measurement points might be hindered when the humeral head is not well-centered within the glenoid cavity). Finally, our study population excluded patients younger than 25 and older than 49 years. However, we deliberately limited our study population's age range to ensure that the age-dependent shoulder ossification process was completed and avoid any difficulty that glenohumeral joint osteoarthritis might have posed during the measurements.

CONCLUSION

Results of the current study indicated that CSA measurement on ZTE MRI scans with anatomic point cross-referencing was significantly different from CSA measurement on Grashey view radiographs, even with optimal positioning according to current criteria; in addition, optimal positioning may necessitate >1 exposure. An RTL of <0.1 ensured reliability of Grashey views when other standards of sufficient x-ray exposure were met. Given the extensive use of MRI for shoulder problems where the CSA might be a prognosticator, patients already scheduled for shoulder MRI would benefit from CSA measurement on ZTE MRI scans rather than on Grashey view radiographs.

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