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Objective Criteria for Diagnosis of Articular Cartilage Loss Using the Glenohumeral Weighted Abduction Radiograph

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Abstract: Glenohumeral cartilage space (GCS) loss may be difficult to assess accurately due to overlapping shadows on radiographs taken in the anteroposterior (AP) plane of the chest. In addition, shoulder radiographs are usually taken with the arm passively at the side (i.e., without application of joint load). The purpose of this study was to assess the utility of the weighted abduction radiograph (WAR) for diagnosis of decreased GCS and for diagnosis of rotator cuff tendinopathy. True AP radiographs of the glenohumeral joint were obtained without weight (standard view) and with the arm abducted holding a one pound weight (WAR) for 87 patients with shoulder pain. There were significant effects of clinical degenerative joint disease (DJD) ratings upon GCS measurements using the standard view and the WAR (ANOVA). Although there were significant effects of rotator cuff tendinopathy rating upon the acromiohumeral interval and the acromiotuberosity interval (ANOVA), these parameters were not useful for setting diagnostic clinical criteria due to data variability within the groups. The following objective criteria were established for diagnosis of decreased GCS based upon the distribution of radiographic measurements in 61 patients without evidence of DJD: GCS < 2.0 mm on the standard view and/or GCS < 2.0 mm on the WAR and/or ΔGCS > 1.25 mm on the standard view minus the weighted view. The WAR may be particularly useful for objective demonstration of decreased GCS when classic radiographic signs of DJD are subtle or absent.

Introduction

Articular cartilage loss of the shoulder may be difficult to diagnose secondary to the complex geometry of glenohumeral joint and absence of forces across the joint during routine radiographs. Standard anteroposterior radiographs may produce overlapping shadows that may interfere with accurate assessment of the glenohumeral cartilage space (GCS). Oblique radiographs, which are taken in the plane of the scapula, facilitate better assessment of the GCS. These radiographs are generally taken with the arm in a relaxed position at the side. Relatively little axial load is applied across the glenohumeral joint in this position.

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Cartilage space loss may also be difficult to assess in other joints. Rosenberg and coworkers [7] described the 45° of postero-anterior flexion weight bearing radiograph of the knee for evaluation of articular cartilage loss. These authors [7] found that the normal tibiofemoral cartilage space was 4 mm or greater medially and 5 mm or greater laterally, and reported that narrowing of the joint space by 2 mm or more was an indicator of cartilage degeneration. This weighted view increased sensitivity and specificity compared to standard non-weight-bearing radiographs. The technique was recommended for patients who were suspected of having cartilage degeneration, but did not have overt signs of degenerative arthritis (DJD) on plain radiography. Messieh and co-workers [5] also noted increased sensitivity for articular cartilage loss using a standing 30° postero-anterior view of the knee.

Unfortunately, current advanced imaging modalities do not facilitate direct assessment of articular cartilage status. Magnetic resonance imaging (MRI) has not been demonstrated to be useful for clinical assessment of cartliage loss. Speer and co-workers [8] reported that MRI was 31% sensitive for diagnosis of articular cartilage defects in the knee. Other studies also demonstrate variable sensitivity and inadequate positive predictive value for assessment of articular cartilage defects when correlated with arthroscopic findings in human knees (see Manaster and Tyson [4] for a recent review). Advances in MRI technology may eventually provide accurate clinical information about the status of articular cartilage. However, plain radiography will probably continue to be the primary orthopaedic imaging modality due to its high reliability for assessment of osseous structures and relative cost-effectiveness.

Recent studies [1,2] described an active abduction radiograph of the shoulder to facilitate diagnosis of rotator cuff tears. These studies noted a decrease of the acromiohumeral interval (AHI) during active abduction; loss of AHI was greater in patients with rotator cuff tears. Others report that decreased AHI may be apparent on standard anteroposterior radiographs in patients with massive rotator cuff tears [3]. The weighted abduction radiograph (WAR) was utilized at Duke University (by K.P.S.) following adaptation of this technique for assessment of cartilage loss by Russell Warren, M.D. at the Hospital for Special Surgery, New York.

The purpose of the present study was to assess the utility of the WAR for diagnosis of GCS loss. We hypothesized that application of joint load should facilitate demonstration of GCS loss in patients with degenerative arthritis. We also wished to assess the utility of the WAR for diagnosis of rotator cuff pathology.

Methods

A standard series of shoulder radiographs were obtained by a single radiographer (A.A.) for 87 patients with a chief complaint of shoulder pain (mean age 45.3 years, range 18–75 years). Patients with shoulder fractures or a clinical history of shoulder instability were excluded from the study. A true AP radiograph of the glenohumeral joint was obtained while the patient was standing with the arm relaxed at the side (the standard view). For this film, the unaffected shoulder was turned approximately 45° away from the cassette and the beam was directed parallel to the joint surface. The WAR was obtained with the patient standing in the same position relative to the plate, with the arm abducted approximately 60° while the patient held a one pound dumbbell in the hand. This position was calculated to induce approximately a one body weight glenohumeral joint reaction force in an average person [6]. Some patients were unable to abduct the arm to 60°; these individuals were asked to make a maximal effort for purposes of obtaining a WAR. Axillary lateral radiographs were obtained for all patients. Routine clinical history and physical examination data were recorded for all patients. Additional studies were obtained as indicated by the treating physician (K.S.). Magnetic resonance imaging was obtained in 30 patients. Eleven patients had direct surgical confirmation of pathology.

All of the radiographic assessments were made by a single observer (R.P.) who was blinded to the clinical and surgical findings. Radiographic measurements were made from the original radiographs using digital calipers with an accuracy of ±0.02 mm (Model 599-571-3, Browne and Sharpe, North Kinstown, Rhode Island). In pilot experiments, the coefficient of variation for repeated measures using this device was less then ten percent for the present radiographic parameters.

Radiographic measurements were made from the standard and weighted radiographs in random order. The specific measurements are demonstrated in Figure 1. The radiographic center of the humeral head was determined using concentric circles, referencing the superior and medial aspects of the humeral head. The superior and inferior margins of the glenoid were identified and a line was drawn connecting the two points (the glenoid face). The mid-position between the superior and inferior glenoid margins was determined, and a line perpendicular to the glenoid face was constructed at this position. This was defined as the glenoid equator line. The GCS was defined as the distance between the subchondral bone margins of the humerus and glenoid along the glenoid equator line. Two perpendicular lines were then drawn from the glenoid equator line. One line extended through the radiographic center of the humeral head to the acromion. The other line extended superiorly from the glenoid equator line through the tip of the greater tuberosity to the acromion. The vertical to the center of the head was defined as the superior (positive) or inferior (negative) distance from the glenoid equator line. The acromiohumeral interval was defined as the distance between the undersurface of the acromion and the superior surface of the humerus along the vertical line through the center of the head. The acromion tuberosity interval was defined as the vertical distance between the undersurface of the acromion and the greater tuberosity. Acromiohumeral interval was well assessed with the arm at the side, while acromion tuberosity interval was measured best with the arm abducted. All objective radiographic measurements were entered into a computer database.

A subjective grading scheme was used to record the presence and degree of glenohumeral sclerosis, osteophytosis, and cyst formation on both radiographs. A normal grade was defined as absence of a specific finding. A severe grade was assigned to changes that would typically be considered diagnostic for advanced degenerative joint disease. A mild grade was assigned if findings were intermediate in severity.

Clinical diagnoses were identified after completion of all radiographic assessments. Deference was given to surgical findings when they were available. The objective radiographic measurements were not used to define the presence or degree of degenerative joint disease (DJD). DJD was graded as either none, mild or severe based upon the clinical, surgical, and subjective radiographic findings. A normal DJD rating required normal subjective radiographic findings, and absence of clinical or surgical evidence of cartilage abnormality. A severe grade for DJD was assigned if the subjective radiographic findings indicated severe scle-

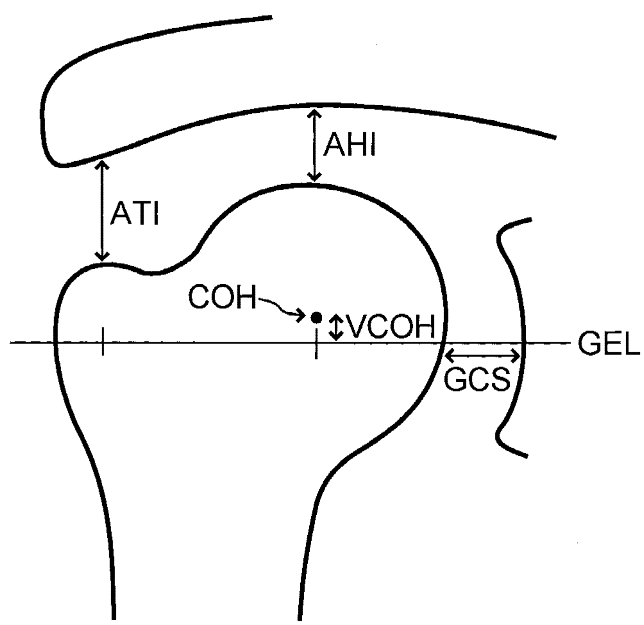

Fig. 1. Schematic representation of radiographic measurements. The center of the head was determined using an overlay of concentric circles, referencing the superomedial aspect of the proximal humerus. (GEL—Glenoid Equator Line; GCS—Glenohumeral Cartilage Space; COH—Center of Head; VCOH—Vertical to Center of Head; AHI—Acromiohumeral Interval; ATI—Acromiotuberosity Interval).

rosis, osteophytosis and/or cyst formation, or if the clinical diagnosis and/or surgical findings suggested severe cartilage loss.

In a similar, subjective manner, rotator cuff tendinopathy was graded as absent, mild or severe. Mild cuff tendinopathy was defined by clinical findings consistent with subacromial impingement, without significant weakness. Severe tendinopathy was defined as a rotator cuff tear that was diagnosed by MRI or at surgery; deference was given to the surgical findings when available.

Radiographic measurements are presented as mean ± standard deviation. Statistical analysis included analysis of variance (ANOVA) and unpaired t test. Statistical significance was considered at p < than .05.

Results

Sixty-one of the patients had no evidence of DJD, 16 patients had mild DJD, and 10 patients had severe DJD based upon clinical, surgical, and subjective radiographic findings. Twenty-eight patients had no tendinopathy, 43 patients had mild tendinopathy, and 15 patients had severe tendinopathy (cuff tear). Standard radiographs and WARs were well tolerated in all patients.

GCS according to DJD ratings are presented in Table 1 and Figure 2. With the standard projection, mean GCS was 3.96 ± 0.97 mm in patients without DJD. In these patients, mean GCS was 3.85 ± 0.94 with the WAR. Using the standard AP view, there was no statistically significant difference between the no DJD and the mild DJD groups. However, using the WAR, GCS was significantly decreased in the mild DJD group compared to the no DJD group (p = .024). GCS was significantly decreased in the severe DJD group compared to the no DJD or mild DJD groups using the standard AP radiograph and the WAR. The difference in GCS (ΔGCS) between the non-weighted and weighted views averaged 0.11 mm in patients without DJD; this difference increased significantly in patients with mild DJD (1.01 mm) and severe DJD (1.87 mm).

Table 1. Radiographic measurements according to DJD rating (mm, mean ± S.D.)

	Degenerative Joint Disease Rating		
	None [D1] (n = 61)	Mild [D2] (n = 16)	Severe [D3] (n = 10)
GHJS-S[a]	3.96 ± 0.97	4.28 ± 0.76	2.86 ± 0.43
GHJS-W[b]	3.85 ± 0.94	3.27 ± 0.69	0.99 ± 1.05
Δ GHJS[c]	0.11 ± 0.57	1.01 ± 0.71	1.87 ± 0.86

[a]Glenohumeral Joint Space, Standard View: One-way ANOVA, p = .002. Unpaired t-tests: D1 vs D2, p = .26; D1 vs D3, p = .003; D2 vs D3, p < .002.

[b]Glenohumeral Joint Space, Weighted View: One-way AVOVA, p < .001. Unpaired t-tests: D1 vs. D2, p = .024; D1 vs D3, p < .001; D2 vs D3, p < .001.

[c]Difference, Standard minus Weighted View: One-way ANOVA, p < .001. Unpaired t-tests: D1 vs D2, p < .001; D1 vs D3, p < .001; D2 vs D3, p < .001.

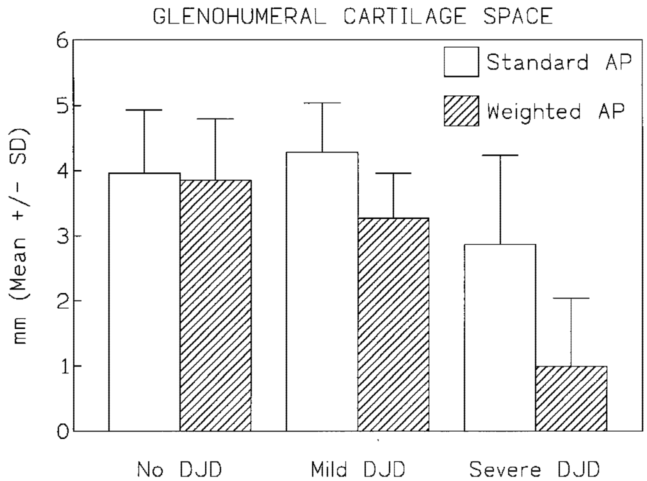

Fig. 2. There were significant effects of DJD rating on glenohumeral cartilage space using either the standard AP view or the weighted abduction view (ANOVA).

The distributions of GCS values in patients without evidence of DJD were used to establish reference data for the standard AP view (Figure 3) and WAR (Figure 4). Decreased GCS was defined as the mean minus two standard deviations of GCS based upon this population (95% interval). Using this method, the lower limits of GCS was 2.04 mm on the standard view and 1.97 mm on the WAR. A similar approach was used to define diagnostic criteria for the ΔGCS. In the non-DJD group, the mean plus two standard deviations of the ΔGCS was 1.25 mm. Therefore, objective criteria for diagnosis of decreased GCS were established as GCS < 2.0 mm on the standard view and/or GCS < 2.0 mm on the WAR and/or ΔGCS > 1.25 mm.

These diagnostic criteria were then assessed retrospectively to get an estimate of their potential clinical utility. None of the no-DJD patients had a GCS < 2.0 mm on the standard view. One of no-DJD patients fell below the criterion on the WAR (false positive rate less than 2%). Four of the no-DJD patients had a ΔGCS > 1.25 mm (7% false

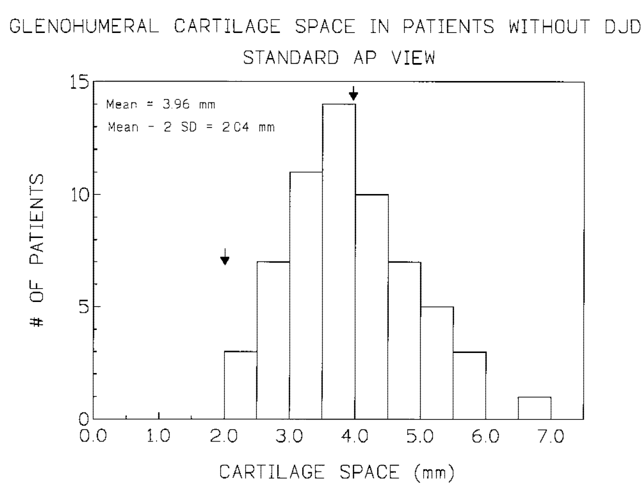

Fig. 3. Distribution of glenohumeral cartilage space measurements on the standard AP view in patients without DJD. The mean minus two standard deviations defines a criterion for diagnosis of decreased glenohumeral cartilage space.

postive). None of the mild-DJD group had GCS < 2.0 mm on the standard view; only one of these sixteen patients fell below the criterion on the WAR. However, 38 percent of this group had a ΔGCS > 1.25 mm. Forty percent of the severe-DJD patients had GCS < 2.0 mm on the standard view, while sensitivity doubled to 80% using the WAR. Eighty percent of the severe DJD patients had ΔGCS > 1.25 mm. All of the severe DJD patients met at least one of the criteria for decreased GCS.

Table 2 presents the radiographic data for acromiohumeral interval, acromion tuberosity interval, and the change in position of the center of the head from the standard view to the weighted view according to tendinopathy ratings. There were significant effects of tendinopathy rating upon acromiohumeral interval and acromion tuberosity interval (ANOVA p = .01 and p = .03, respectively). There was no significant effect of tendinopathy rating on the change in position of the center of the head (ANOVA, p = .89). Although there were statistically significant decreases in acromiohumeral interval and acromion tuberosity interval with greater severity of tendinopathy, there was considerable overlap between the normal and abnormal groups for these variables (Figure 5). Therefore, clinically useful diagnostic criteria could not be developed for acromiohumeral interval and acromion tuberosity interval based upon our findings in the no-tendinopathy group. It should be noted that acromiohumeral interval was greater than 7 mm in all patients without tendinopathy and in all patients with mild tendinopathy. Only three of the severe tendinopathy patients had acromiohumeral interval less than 7 mm. Therefore, acromiohumeral interval < 7 mm was a highly specific but relatively insensitive parameter in patients with a rotator cuff tear.

Discussion

The weighted abduction radiograph was well tolerated by the patients in the present study. This radiograph involves application of joint load through muscle forces acting across the glenohumeral joint. Load application may highlight GCS loss due to improved apposition of the articulating surfaces. This mechanism would eliminate apparent widening of the joint space due to distraction of the humerus due to gravity. Abduction of the outstretched arm holding a one-pound weight produces an estimated glenohumeral joint reaction force of approximately one body weight [6]. It is not known whether similar objective measurements would be obtained with lower weights (or no weight) in the hand. Larger weights would probably be impractical, since this may be difficult and painful in symptomatic patients.

Table 2. Radiographic measurements according to tendinopathy rating (mm, mean ± S.D.)

	Tendinopathy Rating		
	None [T1] (n = 28)	Mild [T2] (n = 43)	Severe [T3] (n = 15)
AHI-S[a]	11.37 ± 2.43	10.46 ± 1.83	9.12 ± 2.75
ATI-W[b]	5.85 ± 3.12	4.51 ± 1.59	3.65 ± 2.09
VCOH-S[c]	−0.57 ± 1.61	0.03 ± 2.20	−0.619 ± 1.56
VCOH-W[d]	0.16 ± 2.07	0.97 ± 1.16	0.41 ± 1.69
Δ COH[e]	−0.73 ± 2.47	−0.94 ± 2.10	−1.03 ± 1.96

[a]Acromiohumeral Interval, Standard View: One-way ANOVA, p = .01. Un-paired t-tests: T1 vs T2, p = .09; T1 vs T3, p = .01; T2 vs T3, p = .04.
[b]Acromiotuberosity Interval, Weighted View: One-way ANOVA, p = .03. Un-paired t-tests: T1 vs T2, p = .04; T1 vs T3, p = .05; T2 vs T3, p = .17.
[c]Vertical to Center of Head, Standard View: One-way ANOVA, p = .34.
[d]Vertical to Center of Head, Weighted View: One-way ANOVA, p = .11.
[e]Δ Center of Head, Standard minus Weighted: One-way ANOVA, p = .89.
(Negative sign indicates superior migration.)

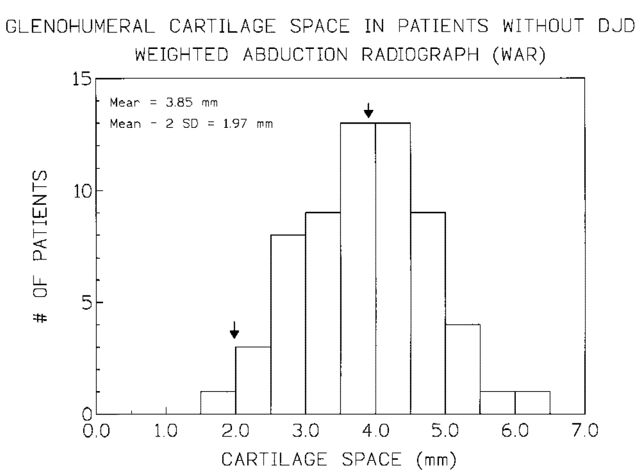

Fig. 4. Distribution of glenohumeral cartilage space measurements on the weighted view in patients without DJD. The mean minus two standard deviations defines a criterion for diagnosis of decreased glenohumeral cartilage space.

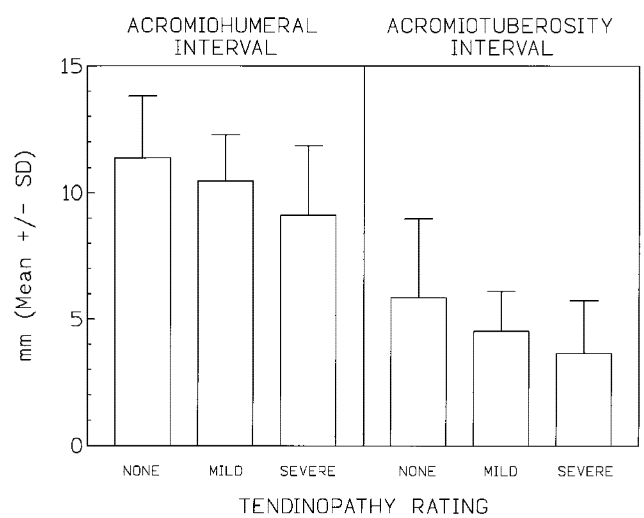

Fig. 5. There were significant effects of tendinopathy rating on acromiohumeral interval and acromio tuberosity interval (ANOVA). However, these parameters could not be used to set clinically useful diagnostic criteria due to data variability within the tendinopathy groups.

Another possible mechanism for decreased GCS with the WAR is articulation of different, relatively thin cartilage regions with shoulder abduction, with subsequent decrease of GCS. Similar limitations in data interpretation were noted by Rosenberg and co-workers [7] in an analogous study of the knee. Our data do not allow for absolute differentiation of these mechanisms. This issue could be addressed by measurement of GCS with and without isometric contraction of the abductors in patients with DJD (i.e., load application without a change in joint position).

The present study is limited by lack of surgical confirmation of cartilage status in all of the patients. However, it is valid and reasonable to base objective criteria for diagnosis of GCS loss upon data from patients who did not have any evidence of DJD. These measurements provide normally distributed reference data (Figures 3 and 4) for patients with complaints of shoulder pain who had no clinical or radiographic evidence of DJD. If these data can be applied to the general population, 95% of patients would be expected to have a GCS greater than 2 mm using either the weighted or non-weighted views, and a ΔGCS less than 1.25 mm between the non-weighted and weighted views.

Prospective studies are needed to assess the clinical accuracy of the proposed diagnostic criteria. However, retrospective analysis of our data demonstrated greater sensitivity with the WAR than with the standard AP radiograph for diagnosis of DJD (80% versus 40% sensitivity), with an acceptably low false positive rate. Rosenberg and coworkers [7] observed similar improvement of diagnostic sensitivity for cartilage space loss using the weight bearing PA oblique radiograph of the knee.

Several investigators described decreased acromiohumeral interval in some patients with rotator cuff tears. Bloom [1] reported that seven of sixteen patients with arthrographic evidence of rotator cuff tear had acromiohumeral interval less than 2 mm in an abducted position, while all the patients had acromiohumeral interval greater than 5 mm in the standard AP view. Thus, the weighted view had a 43% sensitivity and 100% specificity using these criteria [1]. These findings were thought to reflect insufficiency of the supraspinatus tendon, which allowed close opposition of the humerus with the acromion. Lack of close opposition in some patients was believed to be secondary to incomplete tearing. However, this observation may also be explained by varying degrees of dysfunction of the inferiorly directed force couple in patients with rotator cuff tears, with superior migration of the humeral head due to unopposed deltoid contraction. These force couples may be deranged due to frank tendon tear or secondary to decreased function of the neuromuscular unit.

It is interesting to note that active abduction produced very small changes in the position of the center of the humeral head relative to the glenoid (Δ less than 1 mm for all patients). This observation confirms previous observations that the radiographically-determined center of the head corresponds roughly with the physiologic center of rotation in the coronal plane [6]. However, due to significant variation of changes in the position of the center of the humeral heads within the no-tendinopathy group, this parameter was not useful for developing diagnostic criteria. Although there were statistically significant effects of tendinopathy rating on both acromiohumeral interval and acromion tuberosity interval by ANOVA, between-group variability suggests that these measures can not be used to rule out rotator cuff disease. It should be noted, however, that acromiohumeral interval less than 7 mm was noted only in patients with a rotator cuff tear, making it a highly specific but relatively insensitive parameter of rotator cuff tear.

Conclusion

The WAR may not affect clinical diagnosis or treatment when overt signs of DJD are present (i.e., osteophyte formation, sclerosis, cyst formation). However, this radiograph may be particularly useful when subtle forms of cartilage space loss are suspected. Our data do not support use of the WAR for definitive diagnosis of rotator cuff pathology. Limited data suggest that acromiohumeral interval less than 7 mm is highly specific for rotator cuff tear, but this parameter has low diagnostic sensitivity. Based upon the findings in our patients who did not have any clinical or radiographic evidence of DJD, objective criteria were established for diagnosis of GCS loss: (1) GCS < 2.0 mm on the weighted or non-weighted view and/or (2) ΔGCS > 1.25 mm between the weighted and non-weighted views.

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