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The Cartilage Wear Index: a new evaluation method to improve patient selection in surgical treatment of recurrent posterior glenohumeral instability

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Background: The purpose of this study was to validate glenoid cartilage lesions as a negative prognostic factor and to define a new image-based preoperative evaluation method to identify surgical candidates for arthroscopic labral refixation with suture anchors in posterior shoulder instability.

Methods: Twenty-six patients who underwent arthroscopic posterior labral repair for shoulder instability were evaluated. Only patients with structural dynamic posterior instability were included. We evaluated on preoperative magnetic resonance arthrogram: glenoid version, humeral head subluxation, type of capsular insertion, and the cartilage lesions using the new Cartilage Wear Index (CWI). Two subgroups were analyzed with regard to the preoperative CWI and shoulder outcome scores: Single Assessment Numerical Evaluation (SANE) and Western Ontario Shoulder Instability Index (WOSI).

Results: The median age at operation was 28 (interquartile range = 21-33) years. Median overall postoperative outcome assessment demonstrated a SANE of 90 and a WOSI of 385. The median CWI was 1.02. Subgroup analysis revealed worse median WOSI and SANE scores in patients with a CWI >1.02 and a strong correlation between a high preoperative CWI and a higher postoperative WOSI score ($R = 0.58$; $P = .038$).

Conclusion: The CWI can be useful to identify patients who might obtain better outcomes when treated with arthroscopic labral repair in posterior shoulder instability.

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Posterior glenohumeral instability (PGHI) is less common than anterior instability, and the diagnosis can be missed or delayed in many cases owing to its nonspecific symptoms.[18] One must have a high index of suspicion to diagnose this entity and obtain appropriate imaging studies, especially in young competitive athletes or patients with repetitive overhead activities, as the incidence of this pathology has been shown to be higher in this specific population.[6]

In addition, the wide spectrum of pathology that PGHI encompasses has led to different classification systems that recommend grouping patients in distinctive categories that can be treated through different modalities. In the case of recurrent, unidirectional, posterior shoulder instability, with image findings supporting the diagnosis, operative treatment has shown to be successful, with a return-to-sport rate of 86.9%,[25] and superior over nonoperative treatment in terms of pain relief.[22] Arthroscopic posterior labral repair with suture anchors has been described as an adequate technique for repair. However, little is known about outcome predictors regarding arthroscopic PGHI treatment. Smaller glenoid bone width and greater percentage of glenoid bone loss,[3] as well as the presence of glenoid cartilage lesions, have been recently described as a poor functional outcome prognostic factor.[28] We hypothesize that patients with posterior chondral defects will tend to do worse after surgery. Therefore, the aim of this study is to describe a new image-based method, the Cartilage Wear Index (CWI), that consists in a relation between the anterior and posterior cartilage thickness. Our hypothesis is that the CWI could be used as a preoperative prognostic factor, as patients with a higher CWI will obtain worse postoperative outcomes.

This study was approved by the Institutional Review Board of Hospital Universitario Fundación Jimenez Diaz (approval number EO158-18).
Informed consent was obtained from all patients who participated in this study.

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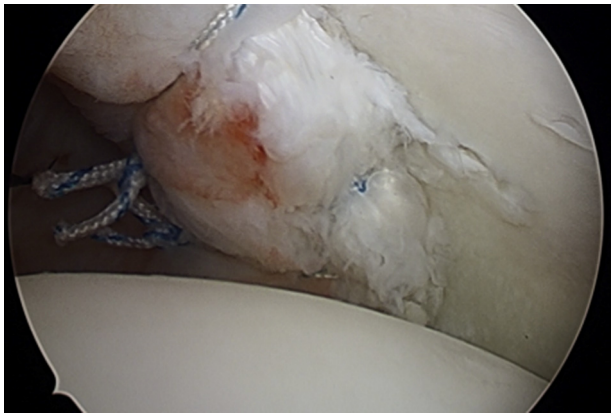

Figure 1 View of a right shoulder from the anterosuperior portal in the beach chair position. One can appreciate the posterior labral tear that was fixed from the 6 ó clock to the 10 ó clock with suture anchors.

Materials and methods

This is a retrospective analysis of patients with PGHI who underwent arthroscopic posterior labral repair after a 2-year minimum follow-up. Posterior instability was defined as patients with B2 structural dynamic posterior instability as described in the ABC classification,[27] and available preoperative magnetic resonance arthrograms (MRAs) were included. Patients with an acute first-time posterior instability event, functional dynamic posterior instability, chronic static posterior instability, voluntary instability, concomitant anterior or inferior instability, diagnosed connective tissue disorders, posterior glenoid bone loss, signs of osteoarthritis in conventional radiographs or magnetic resonance imaging (MRI) different to cartilage wear, and reverse Hill-Sachs lesions were excluded. For each patient, we reviewed the operative reports and arthroscopic video-recorded files, to confirm diagnosis and the type of procedure performed. Indications for surgery were patients with history, with physical examination and preoperative MRA findings consistent with posterior shoulder instability, and who had failed at least 3 months of conservative treatment of physical therapy. All procedures consisted of an arthroscopic posterior suture-anchor capsulolabral repair, performed by a single surgeon in the beach chair position (Fig. 1). The study was approved by the institutional review board under act EO158-18.

The following parameters related to patient demographics were recorded: age, gender, laterality, degree of laxity registered by the Beighton score, history of a traumatic event, number of dislocation or subluxation events referred by the patient before surgery, contact or overhead sports before and after surgery, and occupation before and after surgery. A subluxation event of the shoulder was defined as a specific short-time event that consisted of the humeral head locking into the glenoid rim during forward elevation, adduction, and internal rotation but that could be reduced by the own patient without the need of reduction maneuvers by an orthopedic surgeon.

Postoperatively, the result of surgery was assessed objectively as per the number of postoperative recurrences. Recurrence was defined as a postoperative subluxation or dislocation, whereas a positive apprehension sign did not indicate a clinical failure if the shoulder was otherwise subjectively stable and shoulder function had been restored.[9] Patient-reported outcomes were measured following the Single Assessment Numerical Evaluation (SANE) and Western Ontario Shoulder Instability Index (WOSI). We also registered the need and type of revision surgeries.

The MRA protocol performed consisted of a 20-mL ultrasound-guided injection of the following premixed solution: 1-mL gadoteric acid (Dotarem, Guerbet, Solohill, UK), 8-mL 1% mepivacaine, and 100-mL of saline solution. MRA data were acquired on a 1.5T (Siemens MAGNETOM Sempra, Siemens Healthineers, Getafe, Madrid, Spain) or 3T magnet (Siemens MAGNETOM Verio, Siemens Healthineers, Getafe, Madrid, Spain) with a 512 x 512 or 384 x 384 matrix. The magnetic resonance sequences used included axial T1-weighted, axial and coronal T2 spectral attenuated inversion recovery–weighted, and coronal and sagittal T1 fat suppressed–weighted, with a 3-mm section thickness. The CWI was calculated in the preoperative axial plane MRA on the specific view corresponding to the mid-inferior-glenoid level (glenoid "perfect circle" diameter). The Friedman line was used to divide the glenoid cartilage in anterior and posterior areas.[13] Regions of interest corresponding to the anterior and posterior cartilage thickness areas were defined and measured in in mm^2 to calculate the CWI using Carestream Radiology Imaging Systems, software V 12.1.5.5151 (Carestream Health Inc., Rochester, NY, USA) (Fig. 2).

Additional image data collected included the following: glenoid version using the vault method[17,33] and Friedman angle[11], humeral head subluxation as per the glenohumeral index,[11] and type of capsular insertion as described by Park et al.[32] Interobserver reliability was calculated using the Kappa coefficient (k) by introducing all the CWI measurements performed by two independent observers: a shoulder and elbow fellowship-trained orthopedic surgeon and a musculoskeletal radiologist. Based on anatomical studies, we assumed that normality is a CWI 1, indicating that thickness of anterior and posterior glenoid cartilage in healthy individuals is equal.[37]

Continuous data are presented as median and interquartile range (IQR). Categorical variables are represented by frequencies. Differences in continuous variables between categories of patients were studied by the Mann-Whitney U test. Differences in proportions were analyzed by the Fisher exact test. Number of subluxation events and outcome scores were analyzed through one-way analysis of variance. The Spearman coefficient of correlation was used to estimate an association between the CWI and the WOSI score. All statistical tests were performed with SPSS software, version 20.0 (IBM, Armonk, NY, USA). A 2-tailed P value $< .05$ was considered statistically significant.

Results

A total of 26 patients who underwent arthroscopic posterior stabilization were followed up for a mean of 24 months (IQR, 24-29) (Table I). There were 25 men and 1 woman, and the median age at operation was 28 (IQR, 21-33) years. Fourteen patients recalled having a traumatic incident in the past which they associated with the onset of symptoms. None of them consisted of a frank posterior dislocation that required reduction in the emergency department. Sixteen patients (62%) sustained fewer than 10 subluxation events, and 4 patients (15%) had more than 20 episodes. Ten patients participated in overhead or contact sports before surgery, and 4 of them were employed in heavy duty work.

At surgery, all patients presented a posteroinferior capsulolabral tear that was repaired using the Lupine Loop Anchor (DePuy Synthes West Chester, PA, USA) in 12 cases and 1.4-mm Iconix all-suture anchors (Stryker, Kalamazoo, MI, USA) in 14 cases. The mean number of suture anchors implanted was 3.

The overall median CWI obtained from the preoperative MRA was 1.02 (IQR, 0.76-1.3). Interobserver reliability of the CWI was moderate ($k = 0.43$). The mean glenoid retroversion was 14.8° (IQR, 11.1-18.4) as per the vault method and 13.4° (IQR, 7.4-16.3) following the Friedman method. The median glenohumeral index

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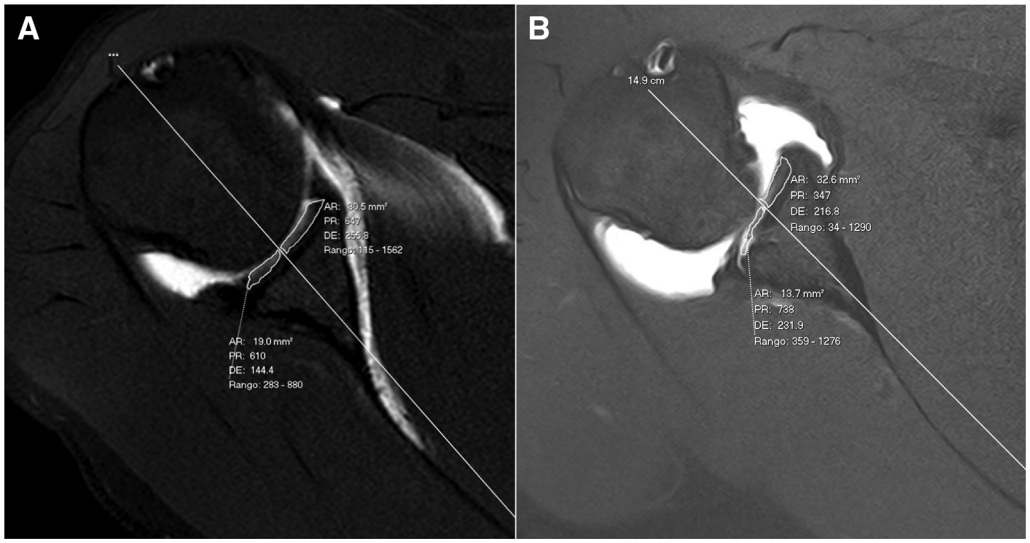

Figure 2 Preoperative magnetic resonance arthrogram (MRA) showing CWI measurements in two different cases. (**A**) Right shoulder. Anterior glenoid cartilage measures 30.5 mm^2, and the posterior glenoid cartilage measures 19.0 mm^2, which provides a CW index of 1.6. (**B**) Right shoulder. Anterior and posterior glenoid cartilage measures 32.6 mm^2 and 13.7 mm^2, respectively, resulting in a CW index of 2.4. *CWI*, Cartilage Wear Index.

Table I
Patient characteristics.

	All patients (n = 26)	CWI <1.02 (n = 15)	CWI >1.02 (n = 11)	*P* value
Age (yr)	28 (21-33)	26 (21.5-33)	29.5 (26.5-47.75)	.21
Sex, male:female	25:1	14:1	11:0	.50
Affected side, right:left	14:12	4:11	10:1	.16
Traumatic:atraumatic	14:12	8:7	6:5	.70
Number of subluxation events (<10:10-20:>20)	16:6:4	10:3:2	6:3:2	.34
Location of pain (posterior:internal: lateral:anterior)	15:8:2:1	8:5:2:0	7:3:0:1	.45
Beighton score, mean	0 (0-0.5)	0 (0-4.25)	0 (0-0)	.06
Overhead/contact sports before surgery(yes:no)	10:16	5:10	5:6	.18
Occupation before surgery (manual labor; yes:no)	4:22	2:13	2:9	.30
Follow-up (mo), range	24 (24-29)	24 (24-29)	24 (24-33)	.48

CWI, Cartilage Wear Index.
Data are expressed as median and interquartile range.

was 52% (IQR, 48-55). Fifty-four percent of cases had a type I capsular insertion with the posterior capsule completely inserted in the labrum, whereas 46% had a type II capsular insertion. No cases with type III capsular insertion were observed.

CWI subgroup analysis between group 1, defined as no posterior glenoid cartilage wear (CWI <1), and group 2 or increased posterior glenoid cartilage wear (CWI >1) showed that there were no differences between groups with regard to age, history of trauma, number of subluxation events before surgery, type of sport practiced before surgery, and occupation (Table I). Subgroup analysis revealed also no differences concerning glenoid retroversion, posterior humeral head subluxation, and type of posterior capsular insertion (Table II).

Postoperative overall outcome assessment after arthroscopic labral refixation demonstrated a median SANE of 90 (IQR, 50-90) and median WOSI of 385 (IQR, 162-531). Table III shows clinical outcomes of each subgroup analysis. Patients with a high CWI (group 2) revealed worse median scores in both WOSI (Fig. 3) and SANE scores. A correlation analysis between the preoperative CWI and the postoperative outcome questionnaires showed a positive correlation between the preoperative CWI and the postoperative WOSI score. More specifically, an increased preoperative CWI had a statistically significant worse WOSI score (R = 0.58 P = .038). Among the remaining preoperative variables evaluated, only the number of preoperative shoulder subluxation events (>20 events) was associated with a statistically significant worse postoperative WOSI score (P = .015) (Fig. 4).

Three patients (11.5%) required revision surgery. The first patient had a preoperative CWI of 1.73. He had a new dislocation 12 months postoperatively. A postoperative posterior labral tear was identified on MRI, and revision surgery with a new arthroscopic labral repair was carried out, obtaining a significant clinical improvement in terms of shoulder stability, although symptoms of mild residual shoulder pain. The second patient had a preoperative CWI of 3.09. At one year postoperatively, the patient referred persistent pain, and revision surgery showed a healed labrum but did not seem to produce an adequate bumper. The labrum was detached, and a new refixation with 3 anchors was performed. Three years later, the patient continued with pain, weakness, and looseness in forward flexion. The patient now refers similar symptoms in his contralateral shoulder.

Finally, the third patient had a preoperative CWI of 2.03. The patient continued with the same symptoms one year after the surgery, and an arthroscopic revision surgery with 3 suture anchors was performed. Two years after the surgery, the patient continued with symptoms of pain and weakness. However, the patient did not consider these symptoms severe enough to undergo further revision surgery.

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Table II
Preoperative MRA measurements.

	All patients (n = 26)	CWI <1.02 (n = 15)	CWI >1.02 (n = 11)	*P* value
Glenoid version (°, vault method)	14.8 (11.1-18.4)	14.8 (8.8-18.6)	16.1 (14.2-18.4)	.46
Glenoid version (°, Friedman)	13.4 (7.4-16.3)	15 (6.8-17)	11 (7.4-15.9)	.46
Glenohumeral index (%)	52 (48-55)	51 (46-55)	54 (50.5-55)	.19
Type of capsular insertion (I-IV)	14:12:0:0	10:5:0:0	4:7:0:0	.86
CW index (median, range)	1.02 (0.76-1.3)			

CWI, Cartilage Wear Index.
Data are expressed as median and interquartile range.

Table III
Postoperative measurements.

	All patients (n = 26)	CWI <1.02 (n = 15)	CWI >1.02 (n = 11)	*P* value
SANE (mean)	90 (50-90)	90 (70-95)	65 (38-90)	.30
WOSI (mean)	385 (162-531)	268 (48-469)	525 (290-1500)	.09
Overhead/contact sports after surgery (yes:no)	7:19	3:12	4:7	.16
Occupation after surgery (manual labor yes:no)	3:23	2:13	1:10	.87

CWI, Cartilage Wear Index; *WOSI*, Western Ontario Shoulder Instability Index.
Data are expressed as median and interquartile range.

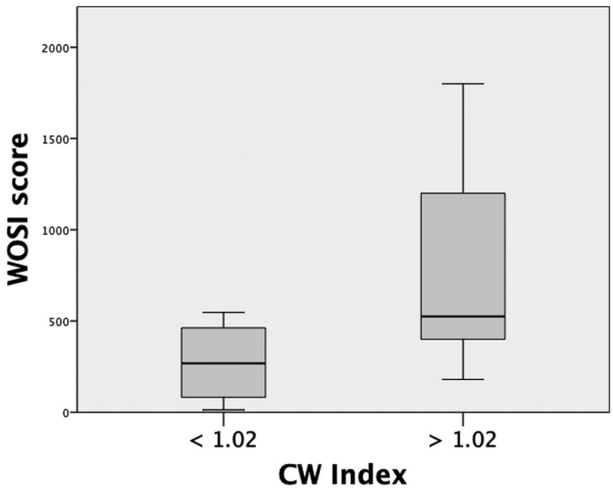

Figure 3 WOSI score and number of preoperative shoulder subluxation events. *WOSI*, Western Ontario Shoulder Instability Index.

The three patients who had revision surgery had a mean preoperative CWI of 2.28 which was more than double the mean CWI of 0.878 in the no-recurrence group ($P = .063$).

Discussion

Posterior shoulder instability is poorly understood and can be challenging to diagnose as symptoms are subtler than in anterior instability.[10,21] Moreover, grouping patients in a specific treatment modality can be cumbersome owing to the wide spectrum of pathology of posterior shoulder instability, as evidenced by the different classification systems that have been developed in the last years.[27,29] Therefore, in this article, we provide insight into patients who were grouped as per the ABC classification system, describing the CWI as a preoperative predictor of poor outcomes.

More specifically, we included B2 patients with structural dynamic posterior instability who were treated with soft tissue stabilization. The emphasis on patient selection is crucial as one must rule out patients with B1 with functional dynamic posterior, C constitutional static, and C2 acquired static posterior shoulder instability, as for in those cases, an isolated arthroscopic procedure will probably not suffice.[27] Previous studies have grouped patients with posterior instability erroneously with other subtypes of posterior instability or other types of instability such as anterior, multidirectional, or even nonsurgical candidates, that is, voluntary instability, and this may alter the evaluation of the surgical techniques.[2,34] Therefore, we reinforce the importance of adequate patient selection for treatment and study analysis.

In this study, satisfactory outcomes were achieved in most patients with arthroscopic posterior capsulolabral repair. Only three patients (11.5%) of 26 required revision surgery. With regard to the number of subluxation events reported by the patient before surgery, there was a statistically significant difference between a higher number of shoulder subluxation events (>20 events) and a worse WOSI score. Lansdown et al also found a similar finding in which they described a positive correlation between cartilage lesions and the number of instability events.[21] It may be possible that patients with multiple subluxation events present to surgery with greater cartilage damage and a higher CWI. Thus, it is a noteworthy aspect to take in consideration during clinic as it is a simple question to ask while at the same time helps predict results.

Analogous to other studies, we also found an increased incidence of glenoid retroversion in the patients with B2 instability.[5,15,17,19,31] The median glenoid version of all patients measured with the vault method was 14.8°. Meanwhile, the glenohumeral index was normal being 52% (Table II). These findings reinforce that increased glenoid retroversion is related with symptomatic PGHI, whereas posterior humeral subluxation is not a reliable indicator of symptomatic PGHI.[31] Other authors have recently proposed different shoulder anatomical features that we did not include in this study and that could be associated with PGHI, such as glenoid convexity[38] and posterior acromion morphology.[26] Nevertheless, the underlying cause of PGHI is likely multifactorial to a combination of both bone and soft tissue pathology such as muscle imbalance and capsular stiffness and may not be attributed exclusively to one factor.[11]

To further understand the causes of poor outcomes, we devised the CWI.

Our hypothesis was that patients with increased posterior cartilage wear and thus a preoperative CWI >1 would do worse after surgery. Unlike other studies that used the International Cartilage Repair Society[8] and Outerbridge[30] classifications or

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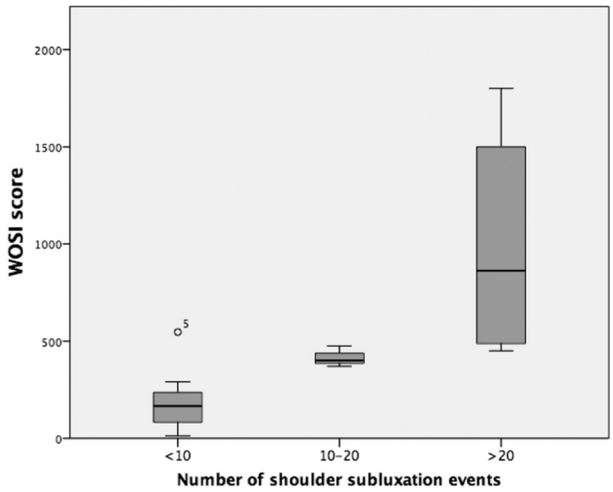

Figure 4 Preoperative CW index and postoperative WOSI. *WOSI*, Western Ontario Shoulder Instability Index; *CW*, Cartilage Wear.

simply classified the patients dicotomically as with or without cartilage damage, this is the first time that a specific index for measurement of glenoid cartilage wear is used in patients with PGHI.[4,16,28]

In our series, despite the small sample size, there was a trend toward a greater CWI associated with need for further surgery. In addition, a high preoperative CWI had a strong correlation with a higher postoperative WOSI score (R = 0.58; $P = .038$). Thus, the CWI could be considered as an indirect method of identifying and quantifying cartilage damage in PGHI.

It may well be that patients with a high CWI are likely in the initial stages before an acquired static posterior instability.[11,27,36] Nonetheless, if labral tissue is of adequate quality and bone loss is not significant, despite a high CWI, one should still focus on labral refixation although pain elimination will not be as reliable owing to the underlying cartilage damage.

At this stage, we do not fully understand the relationship between glenoid version and posterior humeral head subluxation or the reason of the three failed cases. Before surgery, the failed cases had no posterior humeral head subluxation, and all had in common an increased glenoid retroversion, a posterior labral tear, and an increased CWI. After surgery and in the subsequent visits, the imaging studies have demonstrated a progression of osteoarthritis with worsening of the posterior subluxation index and increased posterior glenoid cartilage wear. One of the explanations may be that these patients had an underlying aberrant shoulder muscle activation pattern and should have been classified as both B2 and B1, that is, functional dynamic posterior shoulder instability, in which a specific rehabilitation scheme should have been implemented in addition to the surgical repair. The coexistence of these two subtypes is suggested by Moroder et al, and we believe that it is precisely in this population in which patient selection is difficult but at the same time essential to explain to the patient that surgical results might not be as promising.[27]

There are several limitations to this study. The sample size is small, with the consequent limitation in drawing strong conclusions. However, we think that this sample is very valuable as there are limited single-center studies with these strict inclusion criteria and precise patient selection.[7,12,14,19,20,23,24,28,31,34] Other limitations are related to the method of image measurements. Although most MRAs were obtained in a 3T magnetic resonance scanner, some of them were obtained in a 2T scanner, but both scanners are sensitive enough to calculate the cartilage thickness. In addition, our parameters were obtained from MRA instead of computed tomography arthrography that could seem more adequate to measure certain bony parameters such as glenoid version; however, several studies have demonstrated the reliability and validity of MRI measurements for these purposes.[1,14,17,35] In addition, it is important to note that the CWI only assesses cartilage thinning or disappearance at the axial view in which the Friedman line is drawn to obtain the ratio. Although this system might not detect cartilage lesions localized superior or inferior to that plane, it has been demonstrated that cartilage lesions in posterior instability are more commonly located at that level.[16,28] In addition, it could be argued that the preoperative CWI is challenging to measure for the average orthopedic surgeon in the day-to-day practice, especially because the method requires removing the anterior and posterior labrum to outline the cartilage area which might make measurements variable. For this reason, measurements were performed by two independent observers as a reliability test that showed encouraging results. Finally, we did not evaluate the CWI with computed tomographic arthrography but believe that it could be an interesting imaging system to be evaluated in future studies.

Conclusion

Although arthroscopic posterior labral refixation is successful in most patients with B2 structural dynamic posterior instability, results may be worse in patients with cartilage lesions. This subgroup of patients presents a high CWI and can be preoperatively identified to improve patient selection.

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