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Magnetic Resonance Imaging Staging to Evaluate the Stability of Capitellar Osteochondritis Dissecans Lesions

Toshiro Itsubo,*† MD, PhD, Narumichi Murakami,‡ MD, PhD, Kazutaka Uemura,† MD, Koichi Nakamura,† MD, PhD, Masanori Hayashi,† MD, PhD, Shigeharu Uchiyama,† MD, PhD, and Hiroyuki Kato,† MD, PhD

Investigation performed at Shinshu University, Matsumoto, Japan

Background: Treatment for capitellar osteochondritis dissecans (COCD) lesions is usually based on their stability from the bony floor after arthroscopic or open direct observation. Thus, a noninvasive means of lesion stability assessment by use of imaging is desirable to preoperatively determine treatment strategy.

Purpose: To evaluate our modified MRI staging system for COCD, we compared the results of MRI staging with the International Cartilage Repair Society (ICRS) classification for lesion stability. Intra- and interrater reliability for MRI staging was examined as well.

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

Methods: Fifty-two COCD lesions were preoperatively evaluated by T2-weighted MRI and classified into 5 stages: stage 1 = normally shaped capitellum with several spotted areas of high signal intensity that is lower than that of cartilage; stage 2 = as with stage 1 but with several spotted areas of higher intensity than that of cartilage; stage 3 = as with stage 2 but with both discontinuity and noncircularity of the chondral surface signal of the capitellum and no high signal interface apparent between the lesion and the floor; stage 4 = lesion separated by a high intensity line in comparison with cartilage; and stage 5 = capitellar lesion displaced from the floor or defect of the capitellar lesion noted. The MRI staging results were compared with the intraoperative ICRS classification for lesion stability of each patient. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were all determined for fragment instability. Intra- and interrater correlations for our MRI staging were calculated among 3 examiners.

Results: Preoperative MRI grading correctly matched ICRS classification in 49 of 52 patients (94%), with a sensitivity of 100% and a specificity of 80%. The PPV and NPV were 93% and 100%, respectively, for diagnosing lesion instability. Intrarater reliability (intraclass correlation coefficient [ICC]) for MRI staging was high at ICC(1, 1) = 0.86 and ICC(1, 2) = 0.90, as was interrater reliability at ICC(2, 1) = 0.82 and ICC(2, 3) = 0.88.

Conclusion: The MRI staging system provides accurate and reliable evidence for estimating ICRS classification and instability of COCD and is useful to decide appropriate treatment.

Keywords: osteochondritis dissecans; humeral capitellum; magnetic resonance imaging; International Cartilage Repair Society classification

Capitellar osteochondritis dissecans (COCD) is a localized injury of the articular cartilage and subchondral bone at the humeral capitellum that is commonly seen in young athletes of overhead-throwing sports, such as baseball.[2,4,5,16,17,24,26] This lesion often occurs when the epiphyseal growth plate is open, during which repetitive valgus strain causes damage to the poorly vascularized capitellum.[2,16,19,23] The COCD lesion advances from reversible to irreversible stages. If the lesion is stable to the bony floor, it will likely heal naturally with the rest of the elbow. After the lesion becomes unstable or detaches from the floor, however, surgery provides significantly better results.[21,24]

Plain anteroposterior (AP) radiographic findings are useful to determine the basic grading of COCD lesions,[17] while tangential AP radiography perpendicular to the forearm with the elbow at 45° of flexion[13,21] and tangential oblique radiography perpendicular to the forearm with

*Address correspondence to Toshiro Itsubo, MD, Department of Orthopaedic Surgery, Shinshu University School of Medicine, 3-1-1 Asahi, Matsumoto, Nagano 390-8621, Japan (e-mail: itsubo@shinshu-u.ac.jp).

†Department of Orthopaedic Surgery, Shinshu University School of Medicine, Matsumoto, Japan.

‡Sports Medicine Center, Aizawa Hospital, Matsumoto, Japan.

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the elbow at 45° of flexion and 30° of external rotation[13] are helpful to assess the COCD lesion during treatment and follow-up. However, preoperative radiographic grading does not correlate well with the International Cartilage Repair Society (ICRS) classification.[20] The ICRS classification system of osteochondritis dissecans lesions[3,10] by arthroscopic or direct visual findings is conventionally used as a precise, albeit invasive, method to determine the progression and stability of COCD lesions.

Magnetic resonance imaging (MRI) may be useful for evaluating patients with COCD because it can identify lesions in their early stage, even when radiographs show a nearly normal appearance of the capitellum. Magnetic resonance imaging also provides information about the size, location, presence of joint effusion, bone marrow change, and loss of continuity of surface cartilage over the osteochondritis dissecans lesion.[15] Several MRI staging methods are widely used for OCD of the knee and ankle,[6,15] while others can indicate to some extent the stability of COCD lesions.[15,20] To our knowledge, no MRI staging system is specific for COCD lesions to indicate the ICRS classification. In 2004, Denno et al[7] proposed MRI staging criteria for COCD, which we have modified and used since 2006. The purpose of this study was to (1) present our novel MRI staging for COCD, (2) demonstrate its agreement with the intraoperative ICRS classification, (3) analyze the relationship between our MRI staging and lesion instability, and (4) verify our system's reliability.

MATERIALS AND METHODS

Patient Characteristics

Fifty-two patients with COCD who were treated by direct open surgery between 2006 and 2013 were enrolled in this study. All patients had symptoms of dominant hand–sided elbow pain from athletic activity and were first monitored radiographically during abstinence of throwing sports for a minimum of 6 months. After lesions and symptoms persisted, all patients agreed to surgical treatment. Patient age at the time of surgery ranged from 10 to 18 years (mean age, 14.2 years). We enrolled 51 male patients and 1 female patient. The right elbow was affected in 43 patients and the left in 9, and all patients had injury of their dominant side. The sport related to the onset of symptoms was baseball for 42 patients (26 pitchers, 8 infielders, 6 outfielders, and 2 catchers), tennis for 3, dodge ball for 3, basketball for 2, gymnastics for 1, and badminton for 1. The mean period between onset of symptoms and clinical presentation was 5.4 months (range, 2 months to 3 years). The mean range of elbow motion was –14.2° (range, –30° to 0°) of extension and 128.2° (range, 105° to 140°) of flexion. At the time of surgery, the growth plate of the capitellum was open in 15 patients and closed in 37 (Table 1).

TABLE 1
Patient Characteristics (N = 52)

Characteristic	Value[a]
Age, range (mean), y	10-18 (14.2)
Sex	
Male	51
Female	1
Related sports	
Baseball (26 pitchers, 8 infielders, 6 outfielders, and 2 catchers)	42
Tennis	3
Dodge ball	3
Basketball	2
Gymnastics	1
Badminton	1
Capitellar growth plate	
Open	15
Closed	37

[a]Values are presented as numbers unless otherwise indicated.

Preoperative Radiographic Grading

All lesions were classified by a single orthopaedic specialist (T.I.) into 3 grades according to AP radiographs taken at a tangential view within 1 month before surgery. Grade I lesions included elbows in which a translucent cystic shadow was seen in the lateral or middle parts of the capitellum. Grade II lesions were split-type, whereby a clear zone or split line was seen between the lesion and the adjacent subchondral bone. Grade III lesions included elbows with a loose body after a split fragment had become completely separated from its bony floor.[17]

Preoperative MRI Technique and Staging

Preoperative magnetic resonance (MR) images were obtained for all patients. The interval between MRI and surgery ranged from 3 days to 8 weeks (mean, 4 weeks). Patients were placed in a supine position with their elbow at full extension and forearms kept at neutral rotation. We used a 1.5-T MR unit (Signa Horizon LX 1.5T; GE Medical Systems, Milwaukee, Wisconsin, USA) with a 20-cm circular surface coil. We acquired unenhanced oblique-sagittal T1-weighted spin-echo images (repetition time/echo time, 580 ms/16 ms) and oblique-coronal and oblique-sagittal T2-weighted fast spin-echo images (2000/14) with a section thickness of 2 mm, intersection gap of 0.5 mm, matrix of 320 × (202-256), and field of view of 120 mm.

Using the T2-weighted MR images in coronal or sagittal sections, we classified the lesions into one of the following 5 stages: stage 1 = normally shaped capitellum with several spotted areas of high signal intensity that is lower than that of the cartilage; stage 2 = as with stage 1 but with several spotted areas of higher intensity than that of the cartilage; stage 3 = as with stage 2 but with both discontinuity and noncircularity of the chondral surface signal of the capitellum and no high signal interface apparent between the lesion and the floor; stage 4 = lesion separated by a high intensity line in comparison with cartilage; and stage 5 = capitellar lesion displaced from the floor or defect of the capitellar lesion noted (Table 2 and Figure 1). All lesions were staged by a single orthopaedic specialist (T.I.) using MR images displayed on a monitor.

TABLE 2
Magnetic Resonance Imaging (MRI) Staging for Capitellar Osteochondritis Dissecans

MRI Stage	Signal Intensity of the Subchondral Bone of the Lesion	Existence of High Signal Interface Line Between Capitellar Lesion and Subchondral Bone	Contour of the Capitellum in Coronal and Sagittal Sections	Continuity of the Cartilage Surface
Stage 1	Low	No	Circular	Complete
Stage 2	Low to high	No	Circular	Complete
Stage 3	Low to high	No	Noncircular	Incomplete
Stage 4	Low to high	Yes	Circular or noncircular	Incomplete
Stage 5	Free or obviously displaced fragment			

Intraoperative ICRS Classification

Twenty-eight of 52 lesions were classified by arthroscopic observation alone and the remaining 24 lesions were evaluated by both arthroscopic and direct visual findings. All patients were given general anesthesia and placed in a supine position. An elbow arthroscopic procedure was performed using a 2.9-mm diameter, 30° arthroscope through the proximal anteromedial portal to explore the capitellar lesion between the extensor carpi ulnaris and the anconeus muscles. The ICRS classification was carried out intraoperatively by a single author (H.K.) who was unaware of the preoperative MRI staging results. Lesion stability was also evaluated by palpation using an arthroscopic probe as well as by direct vision in some patients to determine ICRS classification. Stable lesions with a continuous but softened area covered by visually and elastically normal cartilage were classified as ICRS I, lesions with partial discontinuity that were stable when probed were classified as ICRS II, lesions with a complete discontinuity that was not yet dislocated ("dead in situ") were classified as ICRS III, and empty defects as well as defects with a dislocated or loose fragment within the bed were classified as ICRS IV. We considered ICRS III and IV lesions to be unstable. We deemed lesions as being ICRS III if we could confirm instability during surgery, even if they appeared to be ICRS II with an arthroscope. We performed drilling for 2 lesions of ICRS I; bone peg grafting[18] for 3 lesions of ICRS I, 10 of ICRS II, and 1 of ICRS III; mosaicplasty[11,21] for 10 lesions of ICRS III and 7 for ICRS IV; and removal of the lesion with drilling for 19 lesions of ICRS IV.

Correlation of Radiographic Grading and MRI Staging With Operative ICRS Classification

The correlation between MRI staging and intraoperative ICRS classification was investigated. When lesions classified as MRI stage 3, 4, or 5 were considered unstable, the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were determined for fragment instability as assessed by the ICRS classification.

Investigation of MRI Staging Reliability

We evaluated the reliability of our MRI staging method using an intraclass correlation coefficient (ICC). One orthopaedic specialist (K.U.) who was not involved in the treatment of our patients staged the 52 COCD lesions using MRI 2 times, 2 weeks apart, to calculate intrarater reliability. To assess interrater reliability, 3 orthopaedic specialists not involved in this study's treatments (K.N., M.H., and K.U.) evaluated the 52 COCD lesions with our MRI staging system. The interpretation of ICC values was based on criteria proposed by an earlier report,[1] whereby an ICC value of 0.00 to 0.20 represented slight agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.80 substantial agreement, and >0.81 almost perfect agreement.

This study was carried out in accordance with the World Medical Association Declaration of Helsinki. The review board of our institution approved this study.

RESULTS

Grading of all 52 COCD lesions by radiography, MRI staging, and ICRS classification is presented in Table 3. The relationships between radiographic grading and ICRS classification and MRI stage and ICRS classification were analyzed. In 21 lesions judged as grade 2 by radiographs, 10 were stable ICRS I or II lesions and 11 were unstable ICRS III lesions. Radiographic grading did not correspond well to ICRS classification (Table 4). On the contrary, MRI staging and ICRS classification showed a high rate of agreement. In 5 lesions classified as MRI stage 1, 4 were ICRS I and 1 was ICRS II. In 7 lesions classified as MRI stage 2, 1 was ICRS I and 6 were ICRS II. In 4 lesions judged as MRI stage 3, 2 were ICRS II and 2 were ICRS III. In 10 lesions judged as MRI stage 4, 1 was ICRS II and 9 were ICRS III. In these 9 lesions, MRI showed the outer contour of the capitellum to be circular in 3 lesions and noncircular in 6 lesions. All 26 lesions classified as MRI stage 5 were ICRS IV. When MRI stage 1 and 2 lesions were considered to identify stable ICRS I and II, respectively, MRI stage 3 and 4 lesions were considered to correspond to unstable ICRS III, and MRI stage 5 lesions were deemed to reflect unstable ICRS IV. Preoperative MRI staging matched the ICRS classification for 49 of 52 cases (94%) (Table 4). When lesions classified by MRI as stage 3, 4, or 5 were considered unstable, our system yielded a sensitivity of 100% and a specificity of 80% for diagnosing lesion instability, with PPV and NPV values of 93% and 100%, respectively, of stability of the lesion (Table 4).

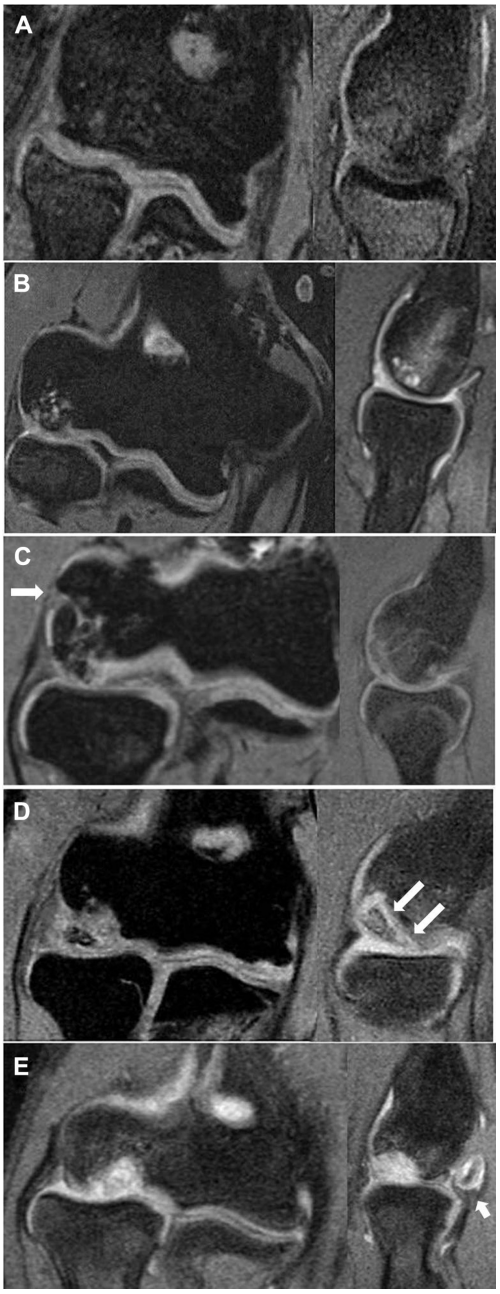

Figure 1. Magnetic resonance imaging staging. (A) Stage 1: normally shaped capitellum has several spotted areas with high signal intensity that is lower than that of cartilage. (B) Stage 2: as with stage 1 but with several spotted areas of higher intensity than that of cartilage. (C) Stage 3: as with stage 2 but with discontinuity of the chondral surface signal and noncircular outer contour of the capitellum in coronal and sagittal sections (white arrow). No high signal interface is apparent between the lesion and the floor. (D) Stage 4: the capitellar lesion is separated by a high intensity line in comparison with the cartilage (white arrow), regardless of whether the outer contour of the capitellum is circular or not. (E) Stage 5: capitellar lesion is displaced from the floor of the bone marrow or defect of the capitellar lesion is noted (white arrow).

TABLE 3
Radiographic, MRI, and ICRS Classifications of the 52 Lesions[a]

	No. of Lesions
Preoperative anteroposterior radiography grade	
I	5
II	21
III	26
Preoperative MRI stage	
1	5
2	7
3	4
4	10
5	26
Intraoperative ICRS classification	
I	5
II	10
III	11
IV	26

[a]ICRS, International Cartilage Repair Society; MRI, magnetic resonance imaging.

TABLE 4
Relationship of ICRS Classification to Radiographic Grade and MRI Stage[a]

	ICRS Classification			
	Stable		Unstable	
	I	II	III	IV
Radiographic grade				
I	3	2	0	0
II	2	8	11	0
III	0	0	0	26
MRI stage				
1 (stable)	4	1	0	0
2 (stable)	1	6	0	0
3 (unstable)	0	2	2	0
4 (unstable)	0	1	9	0
5 (unstable)	0	0	0	26

[a]Values are expressed as the number of lesions. ICRS, International Cartilage Repair Society; MRI, magnetic resonanc imaging.

The intrarater reliability of MRI staging was ICC(1, 1) = 0.86 and ICC(1, 2) = 0.90. Interrater reliability was ICC(2, 1) = 0.82 and ICC(2, 3) = 0.88. These values indicated almost perfect agreement of intra- and interrater reliability.

DISCUSSION

Recent clinical series have demonstrated that surgeries preserving the COCD lesion are preferable when the lesion is ICRS grade I or II and therefore stable. However, when the lesion is ICRS III or IV and unstable, reconstructive

surgery that abandons the idea of lesion preservation is indicated.[21,23,24] This determination of surgical strategy needs precise judgment as to whether the lesion is stable before treatment. In the present study, all 12 lesions classified as MRI stage 1 or 2 were equivalent to ICRS I or II, 11 of 14 lesions classified as MRI stage 3 or 4 were equivalent to ICRS III, and all 26 lesions judged as MRI stage 5 corresponded with ICRS V. Thus, our noninvasive MRI staging system demonstrated strong agreement with the ICRS classification and appeared able to identify unstable COCD lesions with high accuracy without the preoperative ICRS classification.

The basic method to estimate the stability of a COCD lesion is with an AP radiograph, for which Minami et al[17] defined grade I, II, and III lesions. Iwase and Ikata[13] modified the Minami classification and developed a tangential AP radiograph method that was taken with the elbow bent at 45° of flexion. Takahara et al[22] also recommended an oblique image of the elbow bent at 30° of flexion. As these latter 2 radiographic assessments are simple, reproducible, low cost, and readily available, they are used in both routine preoperative care and postoperative follow-up. However, these images provide only single-plane information. Among the 17 cases with radiographic grade II staging, 6 were ICRS I or II and 11 were ICRS III; radiographic grading could not accurately assess the stability of lesions. Meanwhile, computed tomography (CT) scanning can produce 3-dimensional information, and thus it is more sensitive in detecting intra-articular loose bodies and can identify subchondral bone configuration at the capitellum.[25] However, CT cannot detect cartilaginous change at the lesion. Ultrasound has the ability to evaluate the subchondral bone and overlying cartilage, identify nondisplaced and slightly displaced fragments, and diagnose cartilaginous loose bodies.[9] Dipaola et al[8] reported a staging system for osteochondral lesions of the knee and talus that accurately correlated MRI with arthroscopic findings, although ultrasound was affected by echogenic reflection and could not reveal interior pathology at the capitellum.

Several studies have attempted to predict the instability of COCD lesions by MRI. Jans et al[14] compared the preoperative MRI and arthroscopic findings of 11 cases and concluded that multiple underlying cysts or a large underlying cyst, the peripheral rim of high T2 signal intensity having the same intensity as that of joint fluid or breaks in the subchondral bone plate, or a linear high T2 signal osteochondral fracture line or fluid-filled osteochondral defect indicated an unstable lesion. Iwasaki et al[12] performed MRI on 27 patients who had undergone surgery for COCD, using the De Smet et al[6] and Dipaola et al[8] staging systems that were not disease specific; they reported a sensitivity of 89% and a specificity of 44% for diagnosing fragment instability using the De Smet criteria and a sensitivity of 83% and a specificity of 44% using the Dipaola staging system. The PPV and NPV for fragment instability were 76% and 67%, respectively, using the De Smet criteria and 75% and 57% according to the Dipaola system. Iwasaki et al[12] concluded that these criteria could not precisely diagnose fragment instability. Satake et al[20] analyzed the relationship between criteria in preoperative MRI and intraoperative observations in 47 elbows. They found that the predictive value of irregular contours of the articular surface or a high signal interface in T2-weighted preoperative MR images provided more than 90% positive predictive value for instability of COCD lesions. Although informative, these studies did not describe MRI staging or assess intra- and interrater reproducibility.[6,8,20] To our knowledge, no previous English-language reports have established a staging method of COCD lesions by MR images.

Our MRI staging system achieved superior sensitivity, specificity, PPV, and NPV compared with both the De Smet and Dipaola values in the Iwasaki et al[12] study. Here, lesions with evidence of incomplete continuity of the cartilage surface and a noncircular contour of the capitellum without a high signal interface line beneath the lesion were considered stage 3, which preceded stage 4, whereby the lesion was separated from the bony floor by a high intensity line. This is the key difference between our MRI staging and the earlier MRI grading concepts of Denno et al.[7] From our results, the MRI findings of incomplete continuity of the cartilage, noncircular contour of the capitellum, and high signal interface line were found in all ICRS III cases.

We encountered 3 false-positive and no false-negative cases of lesion instability in our study. In 2 false-positive cases, the existence of incomplete continuity of the capitellar cartilage surface and a noncircular contour of the capitellum in the coronal plane was interpreted as MRI stage 3. However, direct open observation revealed a small linear fissure over the cartilage of the lesion, and thus it was deemed to be stable. This case was reclassified as ICRS II. In the other false-positive case, MRI demonstrated marked marrow edema at the subchondral bone that was interpreted as a high signal interface line beneath the lesion with a circular contour of the capitellum, and thus this case was interpreted as MRI stage 4. However, the lesion was stable at surgery and therefore classified as ICRS II.

There are several limitations to this study. First, the number of patients with mild stage COCD lesions in our cohort was small; several such patients were excluded from this series because their symptoms had disappeared during 6 months of abstinence from throwing. Second, our patients' backgrounds were not standardized in terms of age, time from symptoms to MRI, or elapsed time from MRI staging to ICRS classification. Third, the MRI resolution power used was 1.5-T, which may not have been sufficient to detect minute signal changes. Although most T2 images were adequate for interpretation, some cases could not be clearly evaluated for cartilage surface detail. There may also have been some patients with compromised MRI results due to body movement.

CONCLUSION

Preoperative MRI grading correctly matched ICRS classification in 49 of 52 patients (94%) with a sensitivity of 100% and a specificity of 80%. The PPV and NPV were 93% and

100%, respectively, for diagnosing lesion instability with very high inter- and intrarater reproducibility. Our MRI staging provides accurate and reliable evidence regarding the instability of COCD and is useful to decide appropriate treatment.

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