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SCIENTIFIC ARTICLE

Utility of radial reformation of three-dimensional fat-suppressed multi-echo gradient-recalled-echo images for the evaluation of acetabular labral injuries and femoroacetabular impingement

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Abstract

Objectives To assess the utility of the radial reformation of three-dimensional fat-suppressed multi-echo gradient-recalled-echo (3D FS me-GRE) for evaluating acetabular labral injuries and femoroacetabular impingement (FAI).

Materials and methods A total of 25 patients with suspected acetabular labral injuries were examined using 3D FS me-GRE and radial 2D T2*-weighted imaging (T2*WI) on a 3-T magnetic resonance imaging (MRI) scanner. The range of acetabular labral injuries was evaluated by radial reformation through the center of the acetabulum perpendicular to the plane across the entire acetabular rim (type 1 radial reformation) of 3D FS me-GRE and radial 2D T2*WI. To evaluate the FAI morphology, we performed radial reformation perpendicular to the central axis of the femoral head and neck (type 2 radial reformation) of 3D FS me-GRE.

Results Acetabular labral injuries were identified in 23 patients, and no acetabular labral injury was seen in two patients on type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI. The diagnostic concordance rate for the range of acetabular labral injuries between the two imaging methods was 76.0%, and there was excellent agreement for the injured angles ($r = 0.977$, $p < 0.001$). FAI morphology could be evaluated in all patients (no FAI, $n = 8$; cam, $n = 10$; pincer, $n = 4$; combined cam and pincer, $n = 3$) using type 2 radial reformation of 3D FS me-GRE.

Conclusions Type 1 and type 2 radial reformations of 3D FS me-GRE imaging were useful for evaluating acetabular labral injuries and determining whether patients with acetabular labral injuries have FAI, respectively.

Keywords Radial reformation · 3D fat-suppressed multi-echo GRE · Acetabular labral injury · Femoroacetabular impingement

Introduction

Hip joint abnormalities are generally evaluated on magnetic resonance imaging (MRI) in axial, coronal, sagittal, or occasionally oblique axial (parallel to the long axis of femoral neck) planes [1, 2]. However, evaluation of the ranges of acetabular labral injuries is difficult using standard two-dimensional (2D) MRI due to the ball-and-socket anatomy of the hip joint. Radial 2D MRI is reported to be useful to show the acetabular labrum and evaluate the range of acetabular labral injuries [3]; nonetheless, the number of slices obtained within reasonable scan times is limited.

Direct magnetic resonance arthrography (d-MRA) after the intra-articular injection of gadolinium (Gd) contrast agent [4–6] and indirect MRA (i-MRA) after venous injection of

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Gd contrast agent [7–9] of the hip joint have been reported to be much more sensitive for detecting lesions of the acetabular labrum and cartilage than conventional MRI. However, these imaging techniques are invasive and have the potential risks of Gd contrast agent. Three-T MR scanners provide a higher signal-to-noise ratio (SNR) and higher spatial resolution without increasing imaging times using multi-receiver coils, and Sunberg et al. reported that noncontrast 3-T MRI could detect acetabular labral defects as well as 1.5-T d-MRA [10].

Advantages of three-dimensional (3D) isotropic acquisitions of MRI include a high SNR, high spatial resolution, and the ability to yield high-quality multiplanar reconstruction (MPR) images with reduced partial volume effects [11, 12], and 3D MRI sequences are being used for hip joint evaluation [13–16]. The first purpose of this study was to assess the utility of radial reformation through the center of the acetabulum perpendicular to the plane across the entire acetabular rim (type 1 radial reformation) of 3D fat-suppressed multi-echo gradient-recalled-echo (3D FS me-GRE) images in the evaluation of acetabular labral injuries.

Femoroacetabular impingement (FAI) has recently been recognized as a cause of groin pain in active young adults, and this condition has been proposed as the leading cause of labral tears and the subsequent development of hip osteoarthritis (OA) [17–19]. The second purpose of this study was to confirm the utility of radial reformation perpendicular to the central axis of the femoral head and neck (type 2 radial reformation) of 3D FS me-GRE imaging for evaluating FAI morphology in patients with suspected acetabular labral injuries.

Materials and methods

Patients

The present study was approved by the Hiroshima University Hospital review board, and informed consent was obtained from each patient. A total of 25 non-developmental dislocation of the hip (DDH) patients with suspected acetabular labral injuries (11 men, 14 women; mean age, 45 ± 16 years) were recruited during the period from July 2015 to July 2017.

MRI

All images were obtained on a 3-T MR scanner (Philips INGENIA 3.0 T, Best, The Netherlands; gradient strength = 40 mT/m, slew rate = 150 T/m/s) using a dS anterior coil and a dS posterior coil. The 3D FS me-GRE sequence (repetition time (TR) 32 ms, echo time (TE) 2.3/5.6/8.9/12.2/15.5 ms (five echoes), flip angle (FA) 7°, field of view (FOV) 350 × 280 mm, matrix 352 × 282, voxel size 1 × 1 × 1 (zero-fill interpolation 0.5 × 0.5 × 0.5) mm, number of signals averaged (NSA) 1, SPIR (fat suppression, FS) +, scan time 5 m 30 s) and the radial scan 2D T2*-weighted imaging (T2*WI) sequence (TR 400 ms, TE 18.4 ms, FA 30°, FOV 160 × 160 mm, matrix 320 × 320, slice thickness 4 mm, pixel size 0.5 × 0.5 mm, NSA 2, slice numbers 12, scan time 5 m, 25 s) were optimized. Axial 3D FS me-GRE imaging and radial 2D T2*WI through the center of the acetabulum perpendicular to the plane across the entire acetabular rim of the right hip joints in 15 patients and the left hip joints in ten patients with suspected acetabular labral injuries was acquired.

Two radial reformation methods of FS multi-echo GRE for evaluating acetabular labral injuries and FAI

OsiriX v3.0.2 imaging software (Pixmeo, Geneva, Switzerland) was used, and type 1 radial reformatted images at 15° slice intervals were reconstructed to evaluate acetabular labral injuries (Fig. 1a), and type 2 radial reformatted images at 15° slice intervals were reconstructed to evaluate FAI (Fig. 1b). These two types of radial reformations were performed for the right hip joints of 15 patients and the left hip joints of ten patients with suspected acetabular labral injuries.

Evaluation of acetabular labral injuries using type 1 radial reformation

Image data were randomized by a radiologist (T.S.), and the range of acetabular labral injury of each patient was evaluated blindly by another radiologist (K.T. with 22 years of experience of musculoskeletal radiology). Two weeks after interpreting the radial 2D T2*WI, the 25 affected hip joints of the patients were evaluated on type 1 radial reformation of 3D FS me-GRE. In this study, complete tear, incomplete tear, detachment, and degeneration of the acetabular labrum were included as acetabular labral injuries. The diagnostic accuracy of type 1 radial reformation was assessed in comparison with radial 2D T2*WI (Fig. 2). Acetabular labral injuries were localized using a clock-face localization image across the entire acetabular labrum, and the locations were classified as eight zones (anterosuperior, anterior, anteroinferior, inferior, posteroinferior, posterior, posterosuperior, and superior zones).

Evaluation of FAI using type 2 radial reformation

FAI is classified into three morphologic types: insufficient offset or pistol grip deformities of the femoral head-neck junction are referred to as cam-type; acetabular overcoverage of the femoral head is classified as pincer-type; and a hip joint contour with both of these characteristics is classified as combined cam- and pincer-type. These different types of FAI

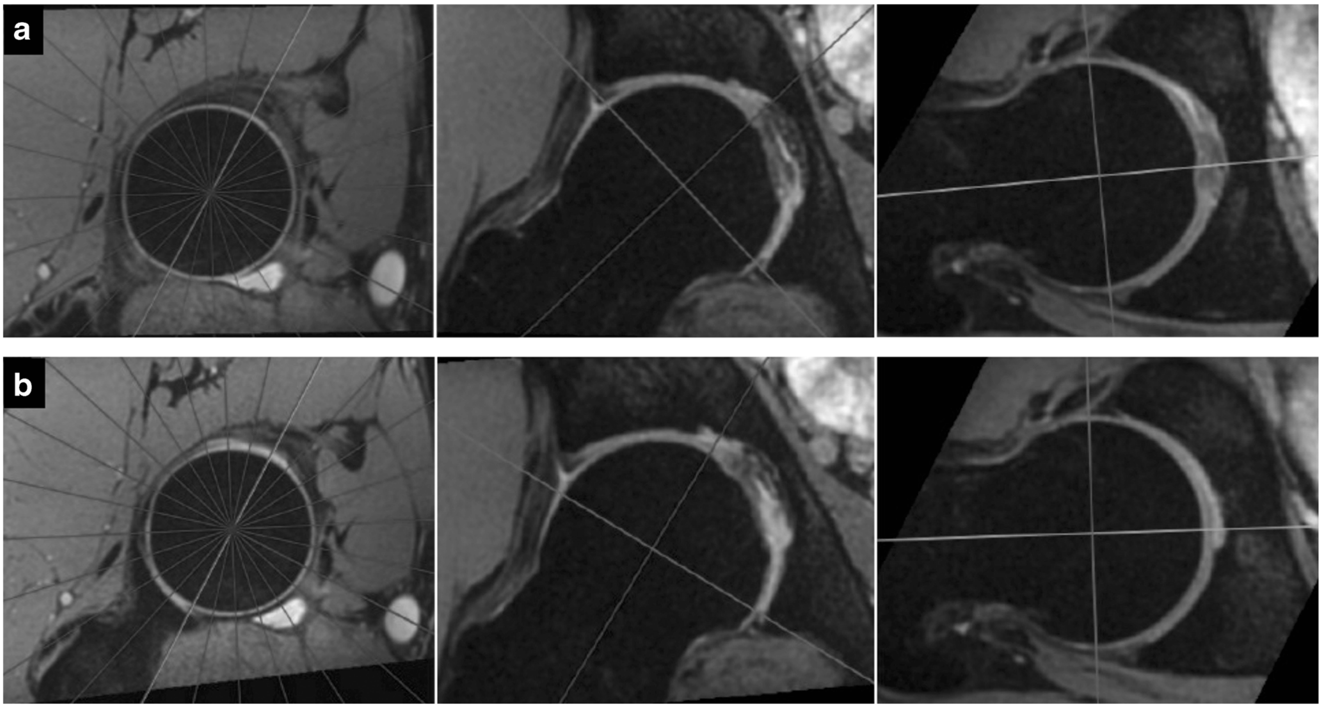

Fig. 1 **a** Type 1 radial reformation of 3D FS me-GRE for evaluating acetabular labral injuries. Twelve radial reformatted slices at 15° intervals through the center of the acetabulum perpendicular to the plane across the entire acetabular rim were produced. **b** Type 2 radial reformation of 3D FS me-GRE for evaluating FAI. Twelve radial reformatted slices at 15° intervals perpendicular to the center of the femoral head through the central axis of the femoral neck were produced

morphology were evaluated based on previously published methods using type 2 radial reformation of 3D FS me-GRE.

The α angle is defined as the angle between a line from the center of the femoral head through the middle of the femoral neck and a line through a point where the contour of the femoral head–neck junction exceeds the radius of the femoral head. An alpha (α) angle over 55° was considered indicative of cam-type FAI [20, 21] (Fig. 3a).

Acetabular depth (AC depth) is defined as the distance between the center of the femoral head and the line connecting the anterior acetabular rim to the posterior acetabular rim, and the AC depth value is positive if the center of the femoral head is lateral to the line. Negative values of AC depth were considered as indicative of pincer-type FAI [22] (Fig. 3b).

Statistical analysis

Statistical analysis was performed using IBM SPSS (version 22). We used the Pearson correlation coefficient to assess the agreement of type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI for the angles with acetabular labral injury.

Results

The comparison of type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI in the evaluation of acetabular labral injury is shown in Table 1. Acetabular labral injuries were identified in 23 patients, and no acetabular labral injury was seen in two patients with type 1 radial reformation and radial 2D T2*WI. Labral injuries from 1 to 14 angles were identified on both imaging techniques, and they were visualized in a total of 52 zones (anterosuperior zone, $n = 17$; anterior zone, $n = 12$, superior zone, $n = 10$; posterosuperior zone, $n = 8$; posterior zone, $n = 3$; posteroinferior zone, $n = 2$). The rate of diagnostic concordance for the range of acetabular labral injuries on type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI was 76.0%. There was excellent agreement between the two imaging methods for the angles with acetabular labral injury ($r = 0.977$, $p < 0.001$). In four patients, the number of angles with acetabular labral injury on type 1 radial reformation was one more than on radial 2D T2*WI. In two patients, the number of angles with acetabular labral injury was two more on type 1 radial reformation than on radial 2D T2*WI. In all patients, the injured angles demonstrated on type 1 radial reformation included those on radial 2D T2*WI.

Arthroscopic evaluations and treatments of the hip joints were performed in nine of the 25 patients after MRI. Acetabular labral injuries were confirmed in all patients underwent arthroscopic examination. The concordance rate for the zones of acetabular labral injury between MRI and arthroscopy was 100%.

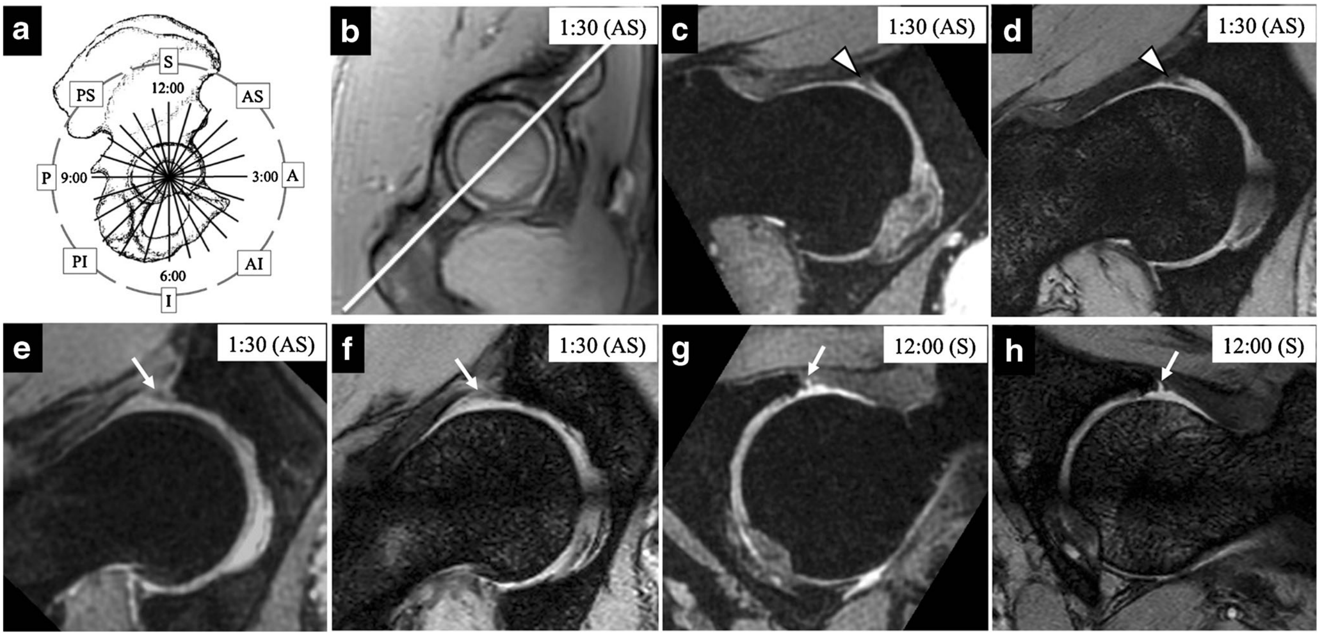

Fig. 2 Comparison of type 1 radial reformation of 3D FS me-GRE images and radial 2D T2*WI. **a** Schema of radial reformation for evaluating acetabular labral injuries. Clockface nomenclature was adopted for localization, and the anterior and superior locations were designated 3 o'clock and 12 o'clock, respectively. AS, A, AI, I, PI, P, PS, and S indicate anterosuperior, anterior, anteroinferior, inferior, posteroinferior, posterior, posterosuperior, and superior zones, respectively. **b** The reference image for comparing type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI. **c, d** Normal acetabular labrum at the 1:30 clock position in a 30-year-old man. Type 1 radial reformation of 3D FS me-GRE (**c**) and radial 2D T2*-WI (**d**) show normal acetabular labrum as a low signal intensity triangular structure with a smooth margin (*arrowheads*) **e, f** Acetabular labral injury at the 1:30 clock position in a 37-year-old woman. Type 1 radial reformation of 3D FS me-GRE (**e**) and radial 2D T2*WI (**f**) show injured acetabular labrum as a high signal intensity triangular structure with an irregular margin (*arrows*). **g, h** Acetabular labral defect at the 12:00 clock position in a 52-year-old man. Acetabular labral defect is shown on type 1 radial reformation of 3D FS me-GRE (**g**) and radial 2D T2*WI (**h**) (*arrows*)

FAI could be evaluated in all patients (no FAI, $n = 8$; cam, $n = 10$; pincer, $n = 4$; combined cam and pincer, $n = 3$) using type 2 radial reformation of 3D FS me-GRE (Fig. 4).

Discussion

The present study demonstrated that two radial reformations of 3D FS me-GRE using a 3-T MR unit and open-source software can be used to evaluate acetabular labral injuries and FAI. To the best of our knowledge, there have been no previous studies demonstrating that two radial reformations of 3D MRI sequences can be used for evaluating acetabular labral injuries and FAI.

Images with a high SNR and high spatial resolution can be achieved by using 3-T MRI scanners and multi-receiver coils in reasonable scan times, and some recent reports of conventional 3-T MRI have shown diagnostic performance similar to that of 1.5-T or 3-T MRA in the detection of acetabular labral tears [10, 23]. We think that fine-tuned non-contrast 3-T MRI is safe and patient friendly for evaluating acetabular labral injuries.

In addition, 3D FS me-GRE produces increasingly T2*-weighted images by combining the signal from the individual echoes: early echoes provide increased SNR, and later echoes improve contrast [24, 25]. The parameters of the 3D FS me-GRE sequence were optimized for evaluating hip joints; the shortest five TEs were chosen to increase the SNR and reduce susceptibility artifact, and small iso-voxel resolution images were acquired to obtain enough volume data to reconstruct images in arbitrary radial planes [25, 26]. Although the weakness of 3D sequences of MRI is degraded imaging quality with patients' motion artifact, hip joints show less motion than shoulder joints. Furthermore, as we applied fat-saturation prepulse to suppress possible artifacts from fat, high spatial resolution images of 3D FS me-GRE were obtained in all patients.

On 3D FS me-GRE images with short echo times, the "magic angle effect" can contribute to increased signal intensity in the acetabular labrum when the collagen fibers are orientated at 55° to B_0 [27, 28]. We could recognize slightly increased signal intensity of the acetabular labrum in the AS, AI, PI, and PS zones in healthy volunteers and clinical patients on the 3D FS me-GRE images. We think that this effect needs to be considered when evaluating acetabular labral injuries.

Radial reformatted images through the center of the acetabulum perpendicular to the plane across the entire acetabular rim, which we call "type 1," can show the entire acetabular labrum [3, 29]. On the other hand, type 2 radial reformatted

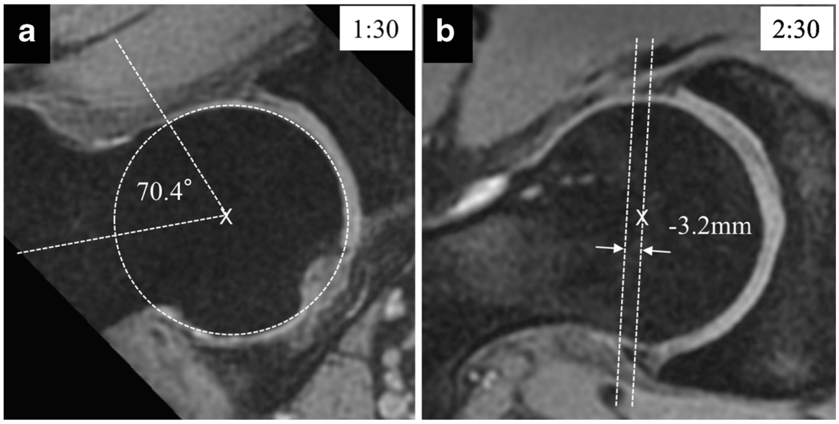

Fig. 3 The degree of FAI is estimated using type 2 radial reformation of 3D FS me-GRE. **a** An α angle over 55° is considered indicative of cam-type FAI. The α angle measured at the 1:30 clock position in a 48-year-old man with cam-type deformity is 70.4°. **b** Pincer-type FAI is diagnosed if the center of the femoral head is medial to the line connecting the anterior acetabular rim to the posterior acetabular rim. The AC depth measured at the 2:30 clock position in a 25-year-old man with pincer-type deformity is −3.2 mm

images are used for evaluating FAI [22, 30–32]. The weak point of the radial reformation method is the post-processing time; 10 min are usually spent in reconstructing these two types of radial reformation on the OsiriX 3D workstation.

Table 1 Acetabular labral injuries on radial 2D T2*WI and type 1 radial reformation of 3D FS me-GRE

Patient	Age (years)	Sex	Hip side	Injured angles of acetabular labral injury		Injured zone
				Radial 2D T2*WI	Radial reformat of 3D FS me-GRE	
1	42	M	R	3:00–3:30 (2)	3:00–3:30 (2)	A
2	37	F	L	1:00–2:30, 9:30–10:30 (7)	1:00–2:30, 9:30–10:30 (7)	AS, A, P, PS
3	52	M	L	1:00–1:30, 10:30–11:30 (5)	1:00–1:30, 10:30–12:00 (6)	AS, PS, S
4	41	F	R	11:30–2:00 (6)	11:30–3:00 (8)	AS, S
5	19	M	R	3:00–3:30 (2)	3:00–3:30 (2)	A
6	54	F	L	1:00–2:30 (4)	1:00–2:30 (4)	AS, A
7	51	F	R	1:00 (1)	1:00 (1)	AS
8	36	F	R	2:30–3:00 (2)	2:30–3:00 (2)	A
9	20	M	R	None	None	None
10	38	M	R	12:30–2:00 (4)	12:30–2:00 (4)	AS, S
11	52	F	L	11:00 (1)	1:30, 2:30, 11:00 (3)	PS
12	48	M	L	2:00–3:00 (3)	2:00–3:00 (3)	AS, A
13	46	F	R	12:30–1:00 (2)	12:30–1:30 (3)	AS, S
14	25	M	R	1:30–3:00 (4)	1:30–3:00 (4)	AS, A
15	68	M	R	12:30–2:30, 7:30–11:30 (14)	12:30–2:30, 7:30–11:30 (14)	AS, A, PI, P, PS, S
16	51	F	L	1:30, 11:00–11:30 (3)	1:30, 11:00–11:30 (3)	AS, PS, S
17	65	F	R	12:00–2:00 (5)	12:00–2:00 (5)	AS, S
18	30	M	R	None	None	None
19	44	F	R	2:00–2:30 (2)	2:00–2:30 (2)	AS, A
20	56	F	R	1:00–1:30, 10:30–11:30 (5)	12:30–1:30, 10:30–11:30 (6)	AS, PS, S
21	69	F	L	2:00–3:30 (4)	2:00–3:30 (4)	AS, A
22	45	M	L	12:00–2:30 (6)	12:00–2:30 (6)	AS, A, S
23	83	F	L	1:00–3:00 (5)	1:00–3:00 (5)	AS, A
24	15	M	L	9:00–11:30 (6)	8:30–11:30 (7)	P, PS, S
25	35	F	R	7:00–7:30, 10:00–10:30 (4)	7:00–7:30, 10:00–10:30 (4)	PI, PS

Injured zone Zone of acetabular labral injury demonstrated on both images, *M* male, *F* female, *R* right, *L* left, *AS* anterosuperior, *A* anterior, *PI* posteroinferior, *P* posterior; *PS* posterosuperior, *S* superior

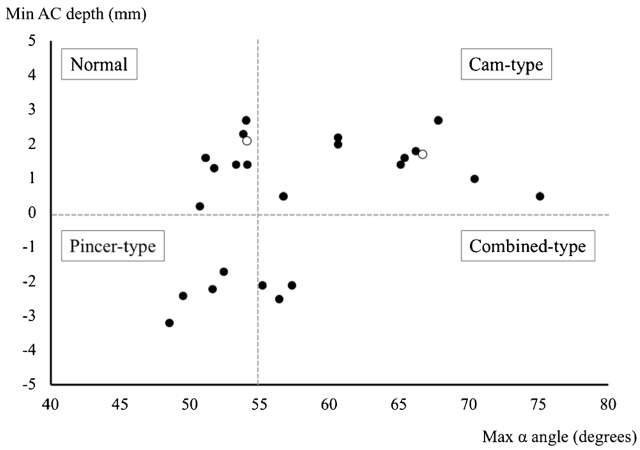

Fig. 4 FAI features on type 2 radial reformation of 3D FS me-GRE. The max α angle is the maximum value of the α angles, and the Min AC depth is the minimum value of the acetabular depths among all angles. Sixteen of 23 patients (69.6%) with acetabular labral injury have FAI features (seen as a *solid circle* in the figure), whereas one of two patients without findings of acetabular labral injury has a cam-type FAI feature (seen as an *open circle*)

The diagnostic concordance of acetabular labral injuries between type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI was excellent. Based on this result, it appears that type 1 radial reformation of 3D FS me-GRE tends to overestimate slightly or radial 2D T2*WI may underestimate slightly in the evaluation of acetabular labral injuries; and there is no way to know which is true because arthroscopic examinations were not performed in all patients, and even in the patients examined with arthroscopy, the range of acetabular labral injury could not be determined correctly. However, if type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI show a acetabular labral injury together at the same angle, the diagnosis of acetabular labral injury can probably be made with confidence.

In the evaluation of FAI, we generally use oblique axial or radial reformatted images from CT volume data [31–34]. However, the radiation exposure to pelvic organs is problematic. The α angle as for cam-type FAI and the acetabular depth as for pincer-type FAI could be evaluated on type 2 radial reformation of 3D FS me-GRE satisfactorily. The scan times of 3D FS me-GRE are approximately the same as for radial 2D T2*WI, and 3D FS me-GRE is the one-stop-shop imaging technique in the evaluation of acetabular labral injuries and FAI morphology.

This study was performed in Asian subjects. Hips of Asian persons are shallower than of Caucasian persons, and it has been considered that FAI is less common and DDH is the major cause of hip OA in Asian populations [35–37]. However, FAI features were detected in 69.6% (16/23) of patients with an acetabular labral injury in the present study. FAI may be the main leading cause of acetabular labral injury in Asians, as well as Caucasians.

The present study has several limitations. First, the study population was relatively small with 25 patients. However, based on the results, it appears that type 1 radial reformation of 3D FS me-GRE has at least similar diagnostic performance to radial 2D T2*WI for evaluating acetabular labral injuries, and type 2 radial reformation obtained from the same volume data is useful for evaluating FAI. Second, all the results of type 1 radial reformation and radial 2D T2*WI were not compared with the findings of arthroscopy, considered the diagnostic gold standard. Arthroscopy can identify acetabular labral lesions easily, but it is invasive. In present clinical practice, 3-T MRI can depict acetabular labral injuries sufficiently well to satisfy orthopedic surgeons, and arthroscopy is used not as a diagnostic tool but as the arthroscopic surgery to repair or remove the torn portion of the labrum at our institution. Third, in our view, it is difficult to differentiate between a small tear and degeneration in the labrum with a slightly increased signal intensity on type 1 radial reformation of 3D FS me-GRE and radial 2D T2*WI, and which is dependent on the radiologist's experience and knowledge; this is a weak point of the noncontrast MRI protocol when compared with Gd contrast-enhanced MRA [4–6].

In conclusion, type 1 radial reformations of 3D FS me-GRE imaging can be applied to the evaluation of the range of acetabular labral injuries and can be regarded as a complementary technique to radial 2D MRI. Furthermore, type 2 radial reformation of 3D FS me-GRE can determine whether patients with acetabular labral injuries have FAI.

Compliance with ethical standards

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Conflicts of interest Kazuo Awai has received research grants from Toshiba Medical Systems Co., Ltd.

The other authors declare that they have no conflicts of interest.

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