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ORIGINAL STUDY

Analysis of morphological parameters in pelvic radiography and hip MRI : a practical reporting recommendation

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Although numerous criteria have been proposed to define abnormal hip morphology, mostly used in the diagnosis of femoroacetabular impingement, it is not a practical approach to measure all of these parameters in all cases without clinical suspicion.

In this study, our aim was to develop an evaluating and reporting standardization for routine hip examinations to define both hip morphology and impingement.

A total of 108 patients with routine hip magnetic resonance imaging (MRI) and antero-posterior pelvic radiograph (PR) were included in this retrospective study. Alpha angle (AA), acetabular depth (AD), acetabular protrusion, acetabular anteversion, collo-diaphyseal angle (CDA), lateral center-edge angle (LCEA) and Tönnis angle (TA) were measured. The differences and associations between these parameters were evaluated according to imaging modality or plane, and sex.

Although a significant difference has been found between the axial AA and the coronal AA mean values measured on MRI, there was also a strong correlation. Coronal measurements were significantly higher. AA values measured in PR and coronal MRI were comparable. Males had higher AA in both planes as compared to females. There were no significant differences between CDA values in MRI and PR. There was a significant difference and a moderate correlation between AD values in MRI and PR.

We suggest that routine reports should include a measurement of AA in two planes, and measurement of CDA in PR or MRI. Due to the difference in AD between MRI and radiography, LCEA or TA may represent better alternatives. Checking for a negative Tönnis sign would represent a practical approach.

Keywords : hip morphology ; magnetic resonance imaging (MRI) ; pelvic radiography (PR) ; femoroacetabular impingement ; Tönnis sign ; reporting.

INTRODUCTION

Abnormal hip morphology is an important cause of premature hip osteoarthritis *(1)*. A relationship between abnormal proximal hip morphology and idiopathic degenerative arthritis of the hip was first proposed by Stulberg et al. *(2)*, and this relationship was later supported by the observations of Harris,

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who reported the presence of subclinical childhood disease and abnormal bone morphology in 90% of patients with primary hip osteoarthritis *(3)*. Certain morphological abnormalities of the hip appear to increase the risk of femoroacetabular impingement (FAI), which in turn increases the future risk of osteoarthritis *(4-6)*.

Femoroacetabular impingement is a pathological abutment between the femoral head and acetabular rim *(7)* that is widely believed to lead to development of premature coxarthrosis *(4,8,9)*. Early diagnosis of abnormal hip morphology may allow interventions to alter the natural course of the disease, in an effort to prevent the development of osteoarthritis *(10)*. For establishing a diagnosis of FAI, in conjunction with clinical history and physical examination, radiological studies confirming the presence of morphologic abnormalities are required *(11)*. The most common imaging modalities used for diagnostic purposes include anterior-posterior (AP) pelvic radiography (PR) and magnetic resonance imaging (MRI).

Although numerous criteria have been proposed to define hip morphology and predisposition to degenerative changes, most of them lack practicability for routine use. Furthermore, critical radiological parameters that should be assessed for detecting morphological predisposition as well as for diagnosing early impingement have not been clearly defined. Determining the minimum parameters that will not aggravate the reporting process is important for sustainability, especially in centers with a high number of patients. In this study, our aim was to develop an evaluative and reporting standardization for routine hip examinations to define both hip morphology and impingement.

MATERIALS AND METHODS

In total, 193 patients who attended our hospital between January 2016 and January 2017 for routine hip MRI and AP pelvis radiography were considered as candidates for this study. No additional investigations were carried out in study subjects. All data, i.e. clinical and radiological findings, were obtained through the hospital automation system after the study protocol was approved by the *Institutional Scientific Committee (17073117-050.99)*. Patients who attended the Orthopedics, and Physical Medicine and Rehabilitation outpatient clinics due to hip or groin pain and who underwent radiography and MRI to investigate the etiology of pain were included. In these patients, there was no suspicion of impingement based on clinical records. Patients with osteoarthritis (grade 2 or higher as per Tonnis classification) *(6)*, history of hip surgery, or pathologies such as avascular necrosis or tumors associated with morphologic alterations were excluded. Pediatric patients were also excluded. Patients with scoliosis were not included due to the potential effect of hip rotation on measurements. Since this study, by design, involved a comparison between MRI and radiography images, only patients who underwent pelvic radiography in the supine position were included. Subjects with radiologic examinations that were technically inappropriate or not compatible with our procedural standards were excluded. Thus, the remaining 108 adult hip joints were retrospectively evaluated.

Imaging procedures

Pelvic AP radiographs were acquired in the supine position with feet at approximately 15°-20° internal rotation and legs parallel. The tube was centralized between the line connecting both anterior superior iliac spines and superior rami of the pubic bones. The X-ray tube was positioned approximately 120 cm distant from the table. To evaluate the presence of rotation, symmetry of the iliac wings, obturator foramen, and tear figures as well as the alignment of the coccyx with the symphysis pubis were checked.

All patients were scanned using a 1.5 Tesla MRI device (GE, USA) and an anterior array coil. Patients were placed in a supine position, with feet having sufficient internal rotation and legs being parallel. Anterior superior iliac crest, proximal metaphysis, and proximal diaphysis of femur were included in the imaging plane. Only images acquired in the coronal and axial planes were evaluated.

The routine hip MRI protocol in our clinic is as follows : axial T1-weighted (TR : 740 ms, TE : 8.6-25.7 ms), coronal T1-weighted (TR : 401 ms, TE : 8.6-25.7 ms), coronal short tau inversion recovery (TR : 4765 ms, TE : 42 ms, TI : 150 ms), and axial T2 Fatsat (TR : 4564 ms, TE : 85 ms). For all sequences, slice thickness = 4 mm, spacing = 1 mm, and number of excitations = 2. If deemed necessary in some patients, sagittal PD-weighted MRI (TR : 2000 ms, TE : 30 ms, slice thickness : 4 mm, spacing : 0.5 mm, FOV : 28 cm) was added. Coronal sequences were bilaterally acquired. The axial sequences were acquired parallel to the femoral neck.

The parameters measured by routine MRI included coronal alpha angle (MRC-AA) and axial alpha angle (MRA-AA), acetabular depth in the coronal plane (MRC-AD), acetabular depth in the axial plane (MRA-AD), collodiaphyseal angle (MRI-CDA), acetabular anteversion angle (MRI-AntA), and acetabular protrusion in the axial plane (MRA-PA). Measurements in pelvic radiography (PR) were alpha angle (PR-AA), collodiaphyseal angle (PR-CDA), acetabular depth (PR-AD), lateral center-edge angle (PR-LCEA), and Tönnis angle (PR-TA). The alpha angle (AA) is defined as that between the line passing through the center of the femoral head and neck and the line extending from the center of the femoral head to the head-neck junction (Figs. 1a and b). The collodiaphyseal angle (CDA) is the angle between the line connecting the femoral head center to the femoral neck mid-point and the anatomical axis of the femoral diaphysis. The lateral center-edge angle (LCEA) is the angle between the perpendicular line to the pelvis emerging from the mid-point of the femoral head and the line drawn to the superolateral aspect of the sourcil (Fig. 2a). The Tönnis angle (TA) is the acetabular index angle. The most medial (inferior) and the most lateral corner of the sclerotic portion (sourcil) of the acetabulum are marked and a line joining these two points is drawn. A second line is drawn parallel to the line joining the tear figures and passing through the inferior end of the sourcil. The angle obtained from the intersections is the Tönnis angle (Fig. 2b). The acetabular anteversion angle (AntA) is that between a line perpendicular to the trans-ischial line (connecting the posterior ischia) and a line across the lateral margin of the acetabulum from its anterior to posterior edge (Fig. 3). The vertical line from the most medial point of the acetabulum to the line from the most lateral point of the acetabulum to the most inferior point yields the acetabular depth (AD). For AD measures

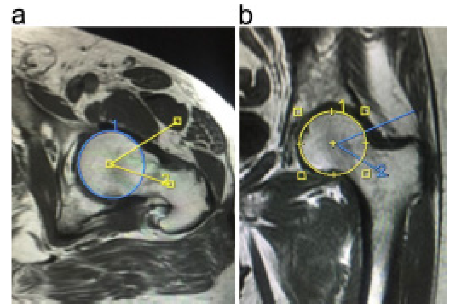

Fig. 1. — Measurement of alpha angle by magnetic resonance imaging. Axial T1-weighted (a) and coronal T1-weighted (b) images showing alpha angle measurements. A best-fit circle is drawn over the femoral head ; the center of the circle is automatically marked. The angle between the femoral neck axis and the point at which the femoral head crosses this circle was measured.

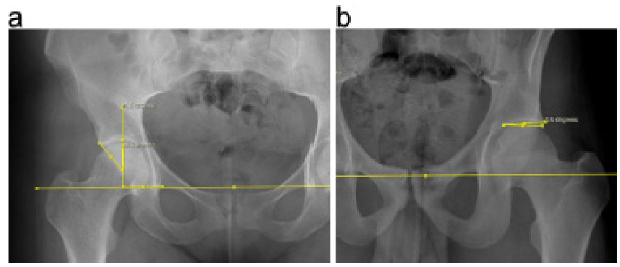

Fig. 2. — Measurement of lateral center-edge angle and Tönnis angle by pelvis anterior–posterior radiography. Lateral center-edge angle measurement in the right coxofemoral joint (a) and Tönnis angle measurement in the left acetabulum (b) showing the roof slope.

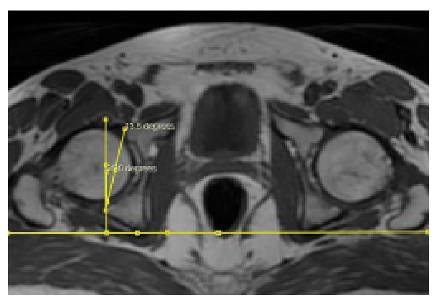

Fig. 3. — Acetabular anteversion measurement in the axial plane by magnetic resonance imaging at the level of the centre of the hip joint. The acetabular anteversion angle is formed between the line perpendicular to a line connecting the posterior ischia and a line connecting the posterior and anterior margins of the acetabulum.

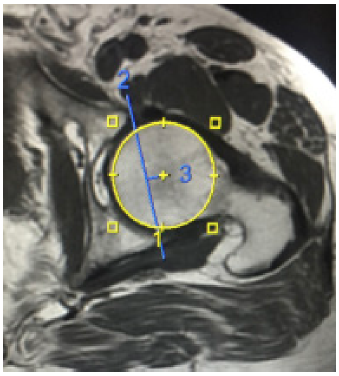

Fig. 4. — Measurement of acetabular protrusion on axial T1-weighted MRI images. The distance from the femoral head center to the line connecting the acetabulum anterior and posterior margins was measured.

on MRI, the axial slice with the widest femoral head diameter and the coronal slice passing through the superior and inferior margins of the acetabulum were used. Finally, protrusion acetabuli (PA) is the displacement of the femoral head so that the femoral head bulges medial to the ischial line. In the axial MRI, the distance between two parallel lines, one passing through the center of the femoral head and the other passing through the anterior and posterior acetabular rims, is measured as the PA (Fig. 4).

Femoral version angle and anterior center-edge angle are additional parameters used in FAI diagnosis. However, we did not include femoral version angle as it cannot be evaluated by hip MRI or radiography. Routine AP radiography is also not suitable for measuring anterior center-edge angle (rather, false profile radiography is required); therefore, it was also excluded**.** Pelvic AP radiographs and MRI scans were evaluated by two radiologists with at least 10 years of experience in musculoskeletal radiology who were blinded to patients' clinical information.

The average values of all the parameters were calculated. The AA values measured by MRI in the axial and coronal planes were compared. AD, coronal AA, and collodiaphyseal angle were measured by both MRI and radiography and compared between modalities. All the parameter values were also compared between males and females.

The Statistical Package for the Social Sciences 16.0 was used for all statistical analyses. Normality was examined using hypothesis tests and graphical methods. Continuous variables were compared by independent or paired sample t-test as appropriate. Finally, Pearson correlation coefficients were calculated to assess the association strengths between

Table I. — Morphological parameters

	Min–Max	Mean ± SD	Female	Male	p
			Mean ± SD	**Mean ± SD**	
MRC-AA	41-88	52.77 ± 7.71	51.61 ± 7.17	54.89 ± 8.31	**0.034***
MRA-AA	40-74	51.56 ± 6.67	50.53 ± 5.97	53.47 ± 7.51	**0.028***
MR-CDA	120-139.5	131.54 ± 4.07	131.05 ± 4.34	132.44 ± 3.42	**0.092**
MRC-AD	13.7-26	20.69 ± 2.58	20.51 ± 2.2	21.03 ± 3.16	**0.325**
MRA-AD	12.8-29.4	20.95 ± 3.04	20.5 ± 2.56	21.76 ± 3.66	**0.040***
MRA-AntA	8.4-26.6	17.72 ± 3.66	18.6 ± 3.61	16.09 ± 3.19	**0.001***
MRA-PA	-12.8-1	-4.57 ± 3	−4.87 ± 2.91	−4.02 ± 3.13	**0.163**
PR-AA	40-85	52.56 ± 7.34	51.57 ± 6.84	54.39 ± 7.94	**0.056**
PR-CDA	117.9-142.4	131.63 ± 4.36	130.76 ± 4.6	133.25 ± 3.38	**0.076**
PR-AD	17.9-37.8	27.53 ± 4.39	26.67 ± 3.64	29.13 ± 5.21	**0.005***
PR-LCEA	23-54.3	36.33 ± 6.11	34.72 ± 5.98	39.3 ± 5.21	**0.000***
PR-TA	4-16.9	7.29 ± 2.2	6.83 ± 1.51	8.13 ± 2.92	**0.003***

*p < 0.05 by independent sample t-test. MRC : coronal plane magnetic resonans imaging (MRI) ; MRA : axial plane MRI ; PR : pelvic radiography ; AA : alpha angle ; CDA : collodiaphyseal angle ; AD : acetabular depth ; AntA : acetabular anteversion angle ; PA : protrusio acetabuli ; LCEA : lateral center-edge angle ; TA : Tönnis angle.

variables measured by different modalities. A p-value of <0.05 was considered statistically significant.

RESULTS

The study group consisted of 70 females and 38 males (average age: 51 years, range: 18 to 77 years). The maximum, minimum and mean values of all measured hip morphological parameters are shown in Table 1 and the measurement techniques in Figures 1-4. There were significant sex differences in PR-TA, MRC-AD, MRA-AD, MRA-AntA, PR-AD PR-LCEA, MRC-AA, and MRA-AA but not in MRI-CDA, PR-AA, PR-CDA, or MRA-PA (Table 1). Although none of these patients were previously diagnosed with FAI, radiological measurements indicated Pincer-type FAI in five subjects and Cam-type FAI in four subjects.

A strong correlation (r=0.782) was found between AA as measured by axial and coronal MRI, and a significant difference in the mean values (51.6° vs. 52.8°) (p<0.05). In addition, mean AA as measured by radiography differed significantly from that measured by coronal MRI, although the magnitude of the difference was small. There was a strong correlation between MRI-CDA and PR-CDA (r=0.602, p<0.01) and no significant differences in mean values (p>0.05). On the other hand, MRC-AD and PR-AD mean values differed significantly and there was a moderate correlation (r=0.414) between these two measurements. There was also a moderate correlation between MRA-AD and MRA-PA and PR-LCEA and PR-AD (p<0.01, r=0.466, r=486, respectively). No correlation was found between PR-LCEA and MRC-PA (r=0.140).

There were significant gender differences in PR-TA (p<0,01), PR-AD (p<0,01), PR-LCEA (p<0.01), MRA-AD (p<0.05), MRA-AntA (p<0,01), MRC-AA (p<0.05) and MRA-AA (p<0.05) (Table 1). On the other hand, PR-AA, PR-CDA, MR-CDA, MRC-AD, and MRA-PA did not differ significantly between genders (Table 1).

DISCUSSION

Different morphological parameters have been proposed for determining the susceptibility to degenerative hip disease. Despite their general usefulness, most lack the practicability in terms of routine measurements, particularly in clinics with high patient turnover such as ours. Thus, in this study we aimed to propose a practical set of morphological parameters to be used for the evaluation of hip abnormalities, which may aid clinicians in identifying patients with such abnormalities, particularly FAI.

Two distinct forms of FAI have been identified based on the underlying pathogenic mechanisms, i.e., the “cam-type” and the “pincer-type”, although mixed cases are frequently encountered. This study included parameters used in the diagnosis of both types. Cam-type FAI is characterized by an aspheric femoral head and/or insufficient femoral head-neck offset *(4,8)*. The main objective of cam-type FAI correction surgery is to restore the natural morphology of the femoral head *(12)*. In these patients, it is important to determine the degree of femoral head asphericity, which can be assessed by AA. Although the AA is usually measured from MRI axial images, measurement is also possible using pelvic AP, cross-table lateral, frog-leg, or modified Dunn radiographs *(13)*. Pelvic AP radiography clearly reveals acetabular and femoral morphology. Standard radiographs such as AP pelvic and cross-table views represent the gold standard technique as an initial diagnostic work-up for cam-type FAI *(14)*. Siebenrock et al. defined standardized radiographic criteria to obtain adequate AP views in patients with suspected FAI *(15)*. In our study, AA measurements on radiographs and MRI images were performed in two planes. Although there was a strong correlation between AA as measured by axial MRI (Fig. 1a) and coronal MRI (Fig. 1b), absolute values differed significantly, with greater values obtained by coronal measurements. In addition, AA as measured by radiographs did not differ significantly from that measured by coronal MRI.

Some studies reported a higher frequency of cam-type deformities in the femoral head-neck junction (termed as pistol knuckles) in male patients than in females *(12,16)*. The results of our study are consistent with this finding, as mean AA was higher in males, regardless of the measurement performed, i.e. in the coronal or axial plane.

In several previous studies, AA was measured by MRI arthrography and CT in various plans *(17,18)*. In the current study, radial assessments were not performed, as our aim was to evaluate the diagnostic efficacy of morphological parameters obtained using routine imaging modalities.

In the study by Chakraverty et al., FAI-like features were also observed at high frequency in a young asymptomatic population and it was concluded that the traditional cut-off values for identifying morphologic abnormalities associated with FAI may be too low *(18)*. Similarly, Sutter et al. found substantial overlap in AA between healthy volunteers and patients with cam-type deformities, and suggested raising the AA threshold to 55°-60° for decreased false-positive results while maintaining reasonable specificity *(19)*. In our study population, mean AA ranged between 50°and 55°, and although the mean values did not exceed the 55° threshold value, the range among patients was relatively wide.

Acetabular deformities (coxa profunda, acetabular protrusion, retroversion) are easily recognized on standard radiographs of the hip *(7)*. Coxa profunda and acetabular protrusion are usually confused, although they are actually different entities. In both conditions, AD is larger than normal. In our study, PA and AD measurements exhibited an expected level of correlation. In this regard, axial MRI sequences of the hip provide a valuable means for the assessment of acetabular protrusion (Fig. 4).

The acetabulum is deeper in patients with pincer-type FAI, in contrast with normal acetabular depth in cam-type FAI. AD can be quantified using the same oblique axial MRI images as those used to calculate the AA *(17)*. A cut-off value for acetabulum depth that places a patient at risk of developing pincer FAI is yet to be defined *(20)*. Among such cases in our study, although AD values measured on coronal MRI images and radiographs were correlated, there was a statistically significant difference between the mean values. On the other hand, there was no statistically significant difference between axial and coronal MRI measurements.

The two radiographic markers commonly used to evaluate acetabulum over-coverage include LCEA and acetabular index angle of Tönnis (Fig. 2). TA and LCEA show acceptable intra-and inter-observer reproducibility *(21,22)* ; therefore, both are dependable measurements for medical evaluation. The LCEA is between 25° and 35° in a normal acetabulum, while a value below 25º is considered an indication of under-coverage. Alternatively, a high LCEA is associated with pincer-type FAI *(23,24)*. For diagnosis of acetabular over-coverage, the cut-off value is between 35° and 40° *(25)*. The TA ranges from 0° to 10° in the normal population *(26)* ; thus, the average value (7.3°) in our study was within normal limits. TA is known to be reduced in pincer-type FAI *(26)*. In the present study, values were lower in females, supporting the notion that susceptibility to pincer-type FAI is higher in females.

Acetabular retroversion (posteriorly oriented acetabulum), which is a risk factor for pincer-type FAI, can also be evaluated by axial MRI sequences. Normally, the acetabulum is anteriorly torsioned, and the AntA in a normal adult is 17° ± 6° *(27)*. In our study, the mean AntA was 18° for females and 16° for males. AntA has been proposed to increase with hip dysplasia, and undiagnosed acetabular shallowness accompanying developmental hip dysplasia (and sequela) is more common in females *(28,29)*. In line with these findings, AD was lower and AntA was higher in females when compared to males in our patient group.

In routine MRI axial examinations, only acetabular anteversion can be measured, while measurement of femoral anteversion requires sequences through the femoral condyles. Buller et al. *(30)* suggested that acetabular and femoral torsions reciprocally compensate. Indeed, the sum of the two values is known as the instability index. If this is the case, measurement of acetabular torsion alone would be insufficient. However, it should also be noted that other authors such as Reikeras et al. refuted the concept of compensation *(27)*. Detection of retroversion is important for the evaluation of over-coverage *(12,26)*, and the crossover sign is a radiographic finding associated with acetabular retroversion. On the other hand, Zaltz et al. showed the frequent occurrence of the crossover sign in well-positioned AP pelvic radiographs in the absence of acetabular retroversion *(31)*. Based on these controversial reports, the crossover sign was not evaluated in our study. Physiological pelvic tilt changes significantly according to body position (upright or supine) during AP pelvic radiography *(32,33)*. A recent study comparing standing and supine AP radiographs *(34)* found that standing radiographs were more valuable for pincer-type FAI diagnosis; therefore, the use of supine radiographs may be considered a limitation in our study. However, we also believe that the pelvic tilt due to position was minimal in our study, since all radiographs and MRI images were acquired in the supine position.

A normal CDA (the angle between the femur neck and shaft) is 130°. Coxa vara is defined by a CDA lower than 124° and coxa valga by an angle over 136° *(35)*. Proximal femoral abnormalities can contribute to secondary impingement *(36)*, as evidenced by the fact that both coxa valga and coxa vara represent risk factors for the development of coxarthrosis *(35,36)*. In our study, the mean CDA value from radiography (131.6°) and MRI (131.5°) were within normal limits. There was no significant difference between MRI and radiographic measurements of the CDA, indicating that both techniques can be used for evaluation. In patients with a high CDA, routine axial AA measurements are associated with the challenge of measuring both the neck and the head in the same section, which can be overcome by the use of more advanced workstation and PACS systems. CDA may be misdiagnosed due to distortion of the femoral shaft in the lower part of the image in routine coronal MRI sequences. However, our findings suggest that images obtained at this level will not be associated with a significant difference.

The utility of a very comprehensive set of morphological measurements is limited, both in routine clinical practice and for the assessment of patients with non-specific complaints such as hip pain. Since axial and coronal plane AA measurements are significantly different, AA should be measured in two planes before FAI is suspected and additional examinations are conducted, as an initial assessment of femoral head asphericity in routine hip radiological examinations. However, AA measurements with coronal MRI can be replaced with radiographic AA measurements, since the difference between these two techniques is negligible. The lateral margin of the sclerotic roof is normally superior to the medial margin, and an inclination angle below zero in the acetabular roof forming the TA suggests acetabular over-coverage. We termed this finding as the “negative Tönnis sign”, and we propose that the level control of the acetabular roof edges may be used a criterion for FAI risk. Further studies are required to better define the relationship between this sign and clinical findings.

CONCLUSIONS

As a result of our observations, we recommend routine reporting of AA, as measured on PR and axial plane MRI. CDA can be measured either by PR or MRI, since these measurements are in good agreement. On the other hand, due to the difference in AD between MRI and radiography, LCEA or TA may represent better alternatives for the assessment of the acetabular over-coverage. The presence of a negative Tönnis sign should also be examined. Furthermore, the value of measuring only AAnt in routine hip MRI (which cannot measure femoral anteversion) may be considered controversial, and in our view, it may be excluded from the routine reporting of the results. In addition, one should also consider the gender differences in certain parameters while establishing a diagnosis. The use of such a limited number of criteria for the evaluation of radiographs and MRI scans may facilitate the identification of abnormal hip morphology and clinically overlooked FAI patients or individuals with predisposition to FAI.

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