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SCIENTIFIC ARTICLE

MRI morphometric hip comparison analysis of anterior acetabular labral tears

Abdel Rahman Aly · Sathish Rajasekaran · Haron Obaid

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Abstract
Objective Anterior (3 o'clock) acetabular labral tears (AALTs) have been reported to be associated with iliopsoas impingement (IPI). However, no study has examined the association between anatomical bony variables of the hip joint and AALTs. The purpose of this study was to evaluate the association between AALTs, femoroacetabular impingement (FAI) and other bony variables of the hip.
Material and methods Seventy-six out of 274 hip MRI records met the inclusion criteria. Two independent blinded investigators evaluated the location of acetabular labral tears (ALTs), edema at the musculotendinous junction of the iliopsoas insertion, femoral neck anteversion angle, femoral neck shaft angle, acetabular anteversion angle, alpha angle, lateral central edge angle (LCEA), acetabular index, and acetabular depth. Comparison analyses between groups were performed.
Results Twenty-two patients had no ALTs (controls), 19 patients had AALTs, and 35 patients had ALTs not isolated at the 3 o'clock position (25 with cam-bony deformities [FAI-cam] and 10 with pincer-bony deformities [FAI-pincer]). The alpha angle mean was significantly higher ($p<0.001$) in the FAI-cam group (62.7º, 95 % confidence interval [CI]: 56.2–69.2º) compared with the AALTs group (46.9º, 95 % CI: 40.1–53.7º). The LCEA mean was significantly higher ($p<0.001$) in FAI-pincer group (41.9º, 95 % CI: 39.3º–44.5º) compared to AALTs group (29.4º, 95 % CI: 24.2º–34.6º). There was no statistically significant difference in any of the bony variables between the controls and the AALTs group.
Conclusion Our study demonstrated that AALTs are pathologically distinct and not associated with FAI or other bony abnormalities. This supports the previous studies, which proposed that AALTs are associated with IPI.

Keywords Magnetic resonance imaging · Magnetic resonance arthrography · Iliopsoas tendon · Femoroacetabular · Impingement

A. R. Aly
Department of Physical Medicine and Rehabilitation, University of Saskatchewan, Saskatoon, SK, Canada

A. R. Aly (✉)
Saskatoon City Hospital, 7th Floor, 701 Queen Street, Saskatoon, SK, Canada S7K 0M7
e-mail: dr.a.n.aly@gmail.com

S. Rajasekaran
Pain, Spine & Sport Medicine, HealthPointe, Edmonton, Alberta, Canada

H. Obaid
Department of Medical Imaging, Royal University Hospital, University of Saskatchewan, Saskatoon, SK, Canada

Introduction

Acetabular labral tears (ALTs) are frequently associated with a history of trauma or bony abnormalities such as femoroacetabular impingement (FAI) [1–3]. ALTs are commonly located in the anterosuperior region in patients with cam-type bony deformities (FAI-cam) or the posteroinferior region in patients with pincer-type bony deformities (FAI-pincer) [1, 4]. Recent studies have shown that isolated anterior (3 o'clock) acetabular labral tears (AALTs) are commonly seen in patients with central iliopsoas impingement (IPI) without any anterosuperior extension [2, 5, 6]. It has been proposed that the mechanism of injury in these AALTs is related to a compression or traction injury caused by the iliopsoas tendon (IPT) as it crosses over the acetabular rim [2, 5].

Central IPI represents a novel diagnostic entity that differs from internal coxa saltans and iliopsoas impingement after total hip arthroplasty (THA) [5, 6]. Patients with central IPI present with anterior hip pain and physical examination reveals: pain with passive flexion–adduction–internal rotation (FADIR) and with resisted straight leg raise; focal tenderness over the IPT; and lack of an audible hip snapping [5, 6]. The diagnosis is confirmed on arthroscopy by the presence of inflammation or tearing of the labrum at the iliopsoas notch directly underneath the IPT [5, 6]. In contrast, internal coxa saltans is a well-established hip pathology secondary to extra-articular IPT snapping that tends to affect young athletes such as ballet dancers [7, 8]. Patients characteristically present with a painful anterior hip clicking/popping sensation that is reproducible on examination by extending and internally rotating the hip from a flexion–abduction–external rotation (FABER) position [7, 8]. This condition has been traditionally diagnosed with iliopsoas bursography, psoas bursa injections, and more recently with dynamic ultrasound [7–9]. Iliopsoas impingement after THA is another hip disorder involving the IPT and is most commonly due to friction against a malaligned or oversized prosthetic acetabular component [10, 11]. Patients usually present with postoperative anterior hip pain and the diagnosis is confirmed by CT imaging or dynamic ultrasound [11, 12].

The diagnosis of IPI remains arthroscopic with no established preoperative imaging criteria [5, 6]. Although Domb et al. and Blankenbaker et al. reported that AALTs on preoperative MRI are suggestive of IPI, none of the previous studies established that AALTs are not associated with other bony abnormalities or FAI [5, 6]. The main objective of this study was to evaluate the association between AALTs and FAI on MRI and to identify any other bony abnormalities that might predispose to this disorder.

Materials and methods

The study was approved by our University Biomedical Research Ethics Board and in compliance with our national Health Information Protection Act.

Selection

We retrospectively reviewed 274 hip MRI records that were performed for assessment of ALTs between 1 January 2008 and 7 January 2013. Seventy-six hip MRI records (57 MR arthrography [MRA] records on a 1.5-Tesla [T] scanner and 19 MRI records on a 3-T scanner) met the inclusion criteria:

1. Patient's age at the time of the examination was between 20 and 45 years
2. Patient presented with hip pain and referred for ALTs assessment
3. An MR arthrogram of the hip on a 1.5-T scanner or an MRI of the hip on a 3-T scanner (acetabular labral evaluation protocol)

The exclusion criteria were:

1. Trauma
2. Hip surgery
3. Hip dislocation
4. Hip infection
5. Hip degenerative arthritis
6. Femoral head avascular necrosis
7. Femoral neck fracture
8. Developmental dysplastic hip

MRI protocol

The MRI examination without contrast medium was performed on a 3-T scanner (Siemens Magnetom® Skyra). The standard FAI/ALTs imaging protocol included: axial T2 fat-suppressed (FS; TR/TE 6060/78, slice thickness [ST] 3 mm and field of vision [FoV] 37 cm); axial oblique T2 (TR/TE 3,200/83, ST 3 mm and FoV 25 cm); coronal T1 (TR/TE 668/9.4, ST 3 mm and FoV 40 cm); coronal short T1 inversion recovery (STIR; TR/TE 3,000/33, ST 3 mm and FoV 40 cm); coronal and sagittal proton density (PD) FS (TR/TE 3,100/30, ST 3.5 mm and FoV 23 cm); sagittal oblique PD (TR/TE 3,000/28, ST 3 mm and FoV 22 cm); and radial PD (TR/TE 1,800/13, ST 4 mm and FoV 16 cm) sequences. Patients who had an MRA underwent anterolateral fluoroscopically guided hip injections using a 22-gauge spinal needle and under standard sterile precautions. The intra-articular placement of the needle tip was confirmed by injecting 2–4 ml of iodinated contrast material (Isovue). A total of 10–15 ml of 1 % gadolinium mixture was injected intra-articularly and the MRA was obtained within 30 min of the injection. The MRA was performed on a 1.5-T scanner (Siemens Magnetom® Avanto). The standard imaging protocol included: axial T1 (TR/TE 775/12, ST 3 mm and FoV 22 cm); axial T2 FS (TR/TE 6,500/78, ST 3 mm and FoV 43 cm); axial oblique T2 (TR/TE 3,200/83, ST 3 mm and FoV 25 cm); coronal STIR (TR/TE 3,000/33, ST 3 mm and FoV 40 cm); coronal T1 FS (TR/TE 786/22, ST 3 mm and FoV 22 cm); and sagittal T1 FS (TR/TE 786/22, ST 3 mm and FoV 22 cm) sequences.

Image analysis

All the MRI records were assigned serial codes and independently reviewed by two blinded investigators. The first investigator is a fellowship trained musculoskeletal radiologist with 11 years of clinical experience and the second investigator is a senior resident with 5 years of clinical experience. The first investigator identified the following:

1. The presence and location of ALTs
2. The presence of edema at the musculotendinous junction (MTJ) of the IPT insertion
3. Diagnostic group

The second investigator measured the following morphometric hip parameters:

1. Femoral neck anteversion angle (FNAA)
2. Femoral neck shaft angle (NSA)
3. Acetabular anteversion angle (AAA)
4. Alpha angle
5. Lateral central edge angle (LCEA)
6. Acetabular index
7. Acetabular depth

The MRI record analysis and the morphometric hip measurements were performed on the picture archiving and communications system (PACS).

Acetabular labral tears were diagnosed when the contrast material or joint fluid was identified within the labrum or between the labrum and acetabulum on the sagittal T1 FS and axial T2 FS sequences on 1.5-T MRA or on the radial PD, sagittal PD FS, and axial T2 FS sequences on 3-T hip MRI (Fig. 1) [13–15]. ALTs were classified by location on the clock face (12 o'clock superior and 3 o'clock anterior) using the scout localizer on the sagittal, coronal, and axial planes to triangulate the location of the labral tear [4]. Edema at the MTJ of the IPT was identified by an increased signal intensity on the T2 FS or the STIR sequences (Fig. 1d) [16].

The femoral head center for all the measurements was identified as the center of a best fit circle outlining the femoral head [17]. The femoral neck axis line was identified as a line passing through the center of the femoral neck and the center of the femoral head [1, 18, 19]. FNAA represented the angle difference between two measured angles: the femoral neck axis angle minus the posterior lesser trochanter line angle (Fig. 2) [18, 20]. The femoral neck axis angle was measured on the axial plane and represented the angle between a horizontal line and the femoral neck axis line [18]. The posterior lesser trochanter line angle was measured on the same axial plane sequence and represented the angle between a horizontal line and a line passing through the posterior cortex of the femur and the posterior lesser trochanter at the level of the largest width of the lesser trochanter [18]. In adults, the normal FNAA is 8–11º, but has been reported to be as high as 30º [19]. The AAA was measured on the axial plane and represented the angle between a line perpendicular to the trans-ischial line and a line passing through the anterior and posterior bony edges of the acetabular rims (Fig. 3a) [21]. The reported normal AAA is 19.9º±6.6 º [19]. NSA (caput–collum–diaphysis angle) was measured on the coronal plane and represented the angle of intersection between the femoral neck axis line and a line passing through the femoral diaphysis (Fig. 3b) [19]. In adults, a NSA<120º identifies coxa vara, while an angle>135º identifies coxa valga [19].

The alpha angle was measured on the axial oblique plane and represented the angle of intersection between the femoral neck axis line and a line connecting the center of the femoral head to the point where the peripheral contour of the femoral head exceeded the radius (femoral head–neck offset; Fig. 3c) [1]. An alpha angle>55º is diagnostic of FAI-cam [1]. The acetabular depth was measured on the oblique axial image (at the level of the femoral neck center) and represented the distance in millimeters between a line connecting the anterior acetabular rim to the posterior acetabular rim and a second parallel line passing through the center of the femoral neck (Fig. 3c) [1]. The lower value for the acetabular depth, which may be negative, corresponds to FAI-pincer [1]. LCEA (center edge of Wiberg) was measured on the coronal plane (at the level of the femoral neck center) and represented the angle between a vertical line and a line connecting the femoral head center with the superior edge of the acetabulum (Fig. 3d) [17, 22]. An LCEA>39º identifies FAI-pincer, while an angle<25º indicates acetabular dysplasia [22, 23]. The acetabular index (Tönnis angle) was measured on the coronal plane (at the level of the femoral neck center) and represented the angle between a horizontal line and a line connecting the medial point of the sclerotic zone with the superior edge of the acetabulum (Fig. 3d) [17, 22]. Acetabular index values near to 0º or even negative are typically seen in cases of FAI-pincer [23].

Statistical analysis

All data analysis was completed using SPSS® 20 for Windows software (IBM Inc., Armonk, New York, USA). Statistical analysis was performed using the one-way ANOVA analysis of variance for numerical (interval and ratio) data and Fisher's exact test for categorical data. Confidence intervals (CI) for means were calculated using the one-sample t test. Statistical significance was set at $p<0.05$.

Results

Twenty-two patients (14 women and 8 men) had no ALTs (controls), 19 (10 women and 9 men) had AALTs, 25 (8 women and 17 men) had non-AALTs associated with FAI-cam, and 10 (8 women and 2 men) had non-AALTs associated with FAI-pincer. There was no statistically significant difference in patient demographics between the groups except for the FAI-cam group, which had a higher proportion of male patients compared with controls ($p=0.042$) and the FAI-pincer group ($p=0.022$; Table 1).

The mean morphometric hip measurements with 95 % CI are graphically represented in Fig. 4. The FAI-cam group had

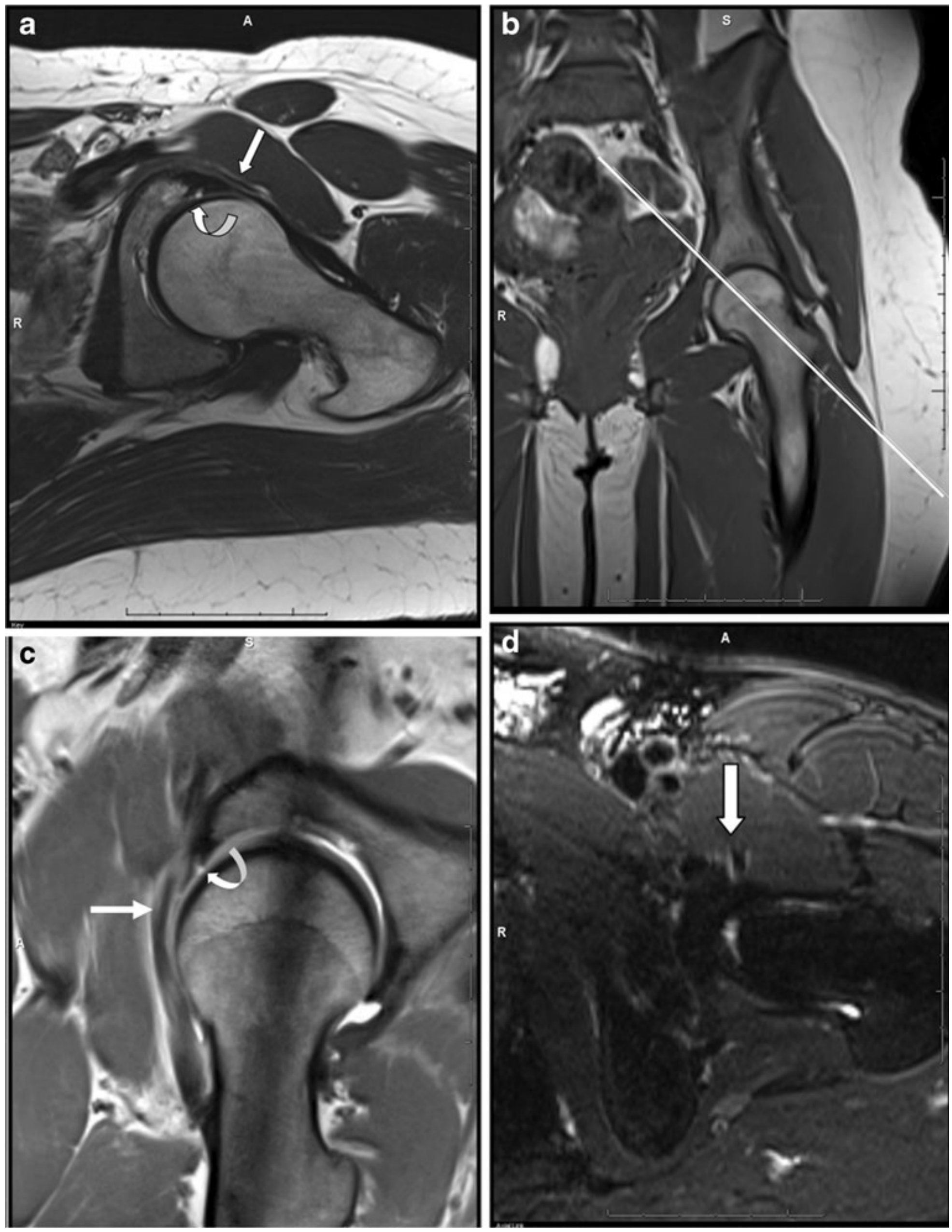

Fig. 1 Anterior (3 o'clock) acetabular labral tears (AALTs). **a** Axial oblique T2-weighted 3-T MRI scanner of the left hip at the level of the anterior acetabulum using the scout localizer, **b** on the coronal sequence demonstrating an isolated AALTs (*curved arrow*) directly underneath the iliopsoas tendon (*straight arrow*). **c** Radial proton density 3-T MRI of the left hip demonstrating an isolated AALT (*curved arrow*) directly underneath the iliopsoas tendon (*straight arrow*). **d** Axial T2-weighted fat-suppressed 3-T MRI of the left hip demonstrating edema at the musculotendinous junction of the iliopsoas tendon (*straight arrow*)

a significantly higher alpha angle (62.7º, 95 % CI: 60.0–65.4º) than the controls (48.7º, 95 % CI: 44.8–52.7º, $p<0.001$), the AALTs group (46.9º, 95 % CI: 43.7–50.2º, $p<0.001$), and the FAI-pincer group (51.4º, 95 % CI: 40.7º62.1º, $p=0.005$). All the patients in the FAI-cam group had alpha angle >55º (diagnostic for a cam lesion) while only 3 patients in the controls, 2 patients in the AALTs group, and 3 patients in the FAI-pincer group had alpha angle >55º. LCEA was significantly higher ($p<0.001$) in the FAI-pincer group (41.9º, 95 % CI: 401–43.4º) compared with controls (31.1º, 95 % CI: 28.8–33.4º), AALTs (29.4º, 95 % CI: 26.9–31.9 º), and FAI-cam (27.9º, 95 % CI: 25.4–30.6º) groups. All the patients in the FAI-pincer group had LCEA >39º (diagnostic for a pincer lesion) while only 2 patients in the controls and 1 patient in the AALTs group had LCEA >39º. The FNSA was significantly higher in the AALTs group (130.5º, 95 % CI: 127.5–133.5º) compared with the FAI-cam group (125.0º, 95 % CI: 122.6–127.5º, $p=0.045$), but there was no statistically significant difference compared with controls (128.5º, 95 % CI: 125.3–131.8º) or the FAI-pincer group (129.4º, 95 % CI: 123.8–135.1º). There was no statistically significant difference in the other bony variables between the groups. There was a significant difference in the presence of edema at the MTJ of the IPT insertion for the AALTs group (7 out of 19) compared with controls (0 out of 22, $p=0.002$). However, there was no significant difference compared with the FAI-cam (3 out of 25, $p=0.074$) or the FAI-pincer group (0 out of 10, $p=0.063$).

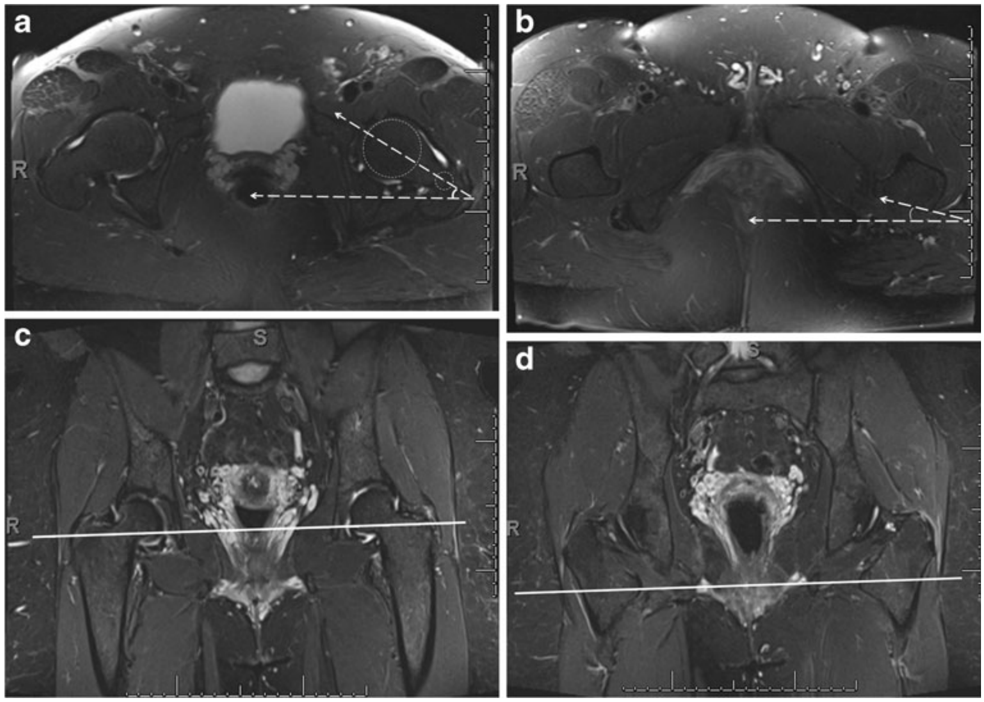

Fig. 2 Femoral neck anteversion angle (FNAA) on MRI. **a**, **b** Axial T2-weighted fat-suppressed and **c**, **d** coronal short T1 inversion recovery images of both hips. The left femoral neck axis angle (**a**) measured at the inferior level of the neck that had a head portion using the scout localizer (**c**). The left posterior lesser trochanter angle (**b**) measured at the level of the largest width of the lesser trochanter using the scout localizer (**d**)

Discussion

To the best of our knowledge, our study was the first to evaluate the association of AALTs with the different morphometric hip parameters (FNAA, NSA, AAA, alpha angle, LCEA, acetabular index, and acetabular depth). This study showed that AALTs were not associated with FAI-cam or FAI-pincer deformities, which supports the pervious findings that AALT is a distinct pathological diagnosis and should raise the possibility of underlying IPI [5, 6]. There was an association between AALTs and edema at the MTJ of IPT that was significant compared with controls, but was not significant compared with the FAI groups. This finding suggests that the presence of edema at the MTJ of the IPT on MRI is associated with IPI. However, this was only variably present in the MRI records with AALTs (7 out of 19). FNSA was also significantly higher in the AALTs group than in the FAI-cam group, but was not significantly higher than the

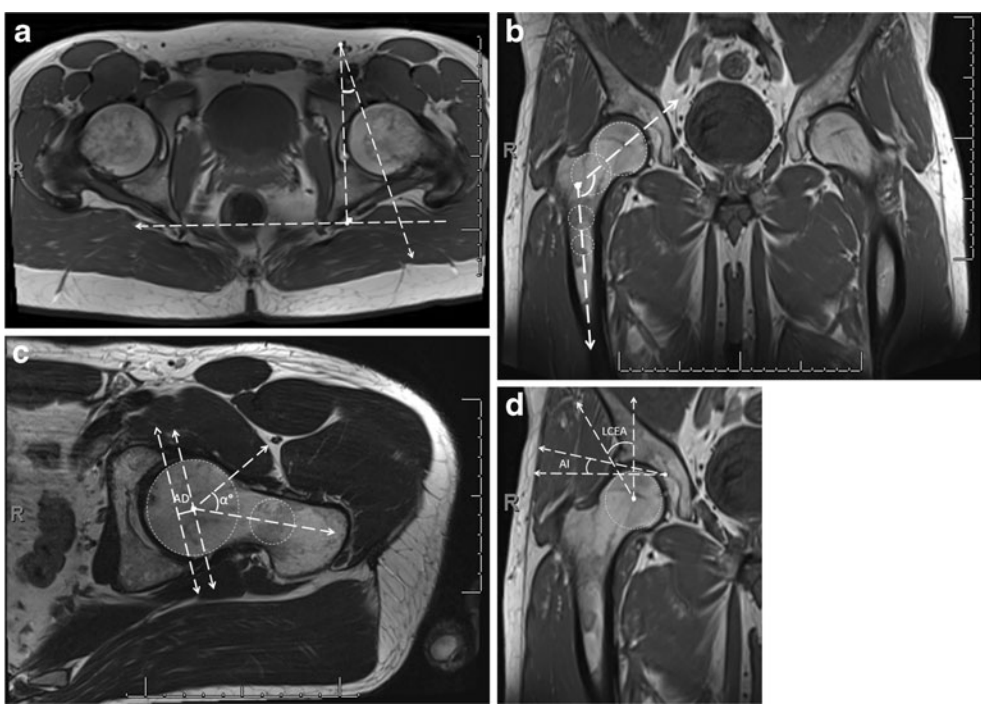

Fig. 3 Morphometric hip measurement on MRI. **a** The left acetabular anteversion angle measured on the axial T1-weighted image. **b** The right femoral neck shaft angle measured on the coronal T1 image. **c** The left alpha angle ($\alpha°$) and acetabular depth (*AD*) measured on the axial oblique T2-weighted image. **d** The right lateral central edge angle (*LCEA*) and the acetabular index (*AI*) measured on the coronal T1 image

Table 1 Patient demographics and side involved

	Controls (*n*=22)	AALTs (*n*=19)	FAI-cam (*n*=25)	FAI-pincer (*n*=10)
Age (mean±SD)	30.23±7.303	34.63±7.065	31.32±6.434	34.00±5.735
Women:men	14:8	10:9	8:17[a]	8:2
Right:left hip	14:8	12:7	14:11	5:5

AALTs anterior acetabular labral tears, *FAI-cam* femoroacetabular impingement with cam-bony deformities, *FAI-pincer* femoroacetabular impingement with pincer-bony deformities

[a] The FAI-cam group women:men ratio was significantly lower than that of the controls (p=0.042) and the FAI-pincer group (p=0.022)

controls or the FAI-pincer group. This finding may represent an association between FAI-cam and coxa vara (decreased NSA), which has been previously reported in the literature [24]. We did not identify any other bony variables associated with AALTs.

Central IPI is an arthroscopic diagnosis that refers to inflammation, tearing, or mucoid degeneration of the labrum directly underneath the IPT at the 3 o'clock position [2, 5, 6]. Domb et al. proposed three theories for the underlying mechanism of AALTs:

1. A tight or inflamed IPT that impinges over the anterior labrum
2. A traction injury secondary to a scarred or adherent IPT
3. A traction injury secondary to a hyperactive iliocapsularis muscle [5]

The authors retrospectively identified 36 out of 640 hip arthroscopic records with IPI and isolated AALTs [5]. Twenty-five out of the 36 patients underwent iliopsoas tenotomy plus labral debridement/repair and were followed up for 1 year, while 11 patients were lost to follow-up. There were significant differences in the postoperative modified Harris hip scores and hip outcome scores at 1-year follow up. These findings proposed that AALTs are associated with IPI. However, there were various limitations to the study. First, the authors had identified that the results of the study would have been changed if those patients who had been

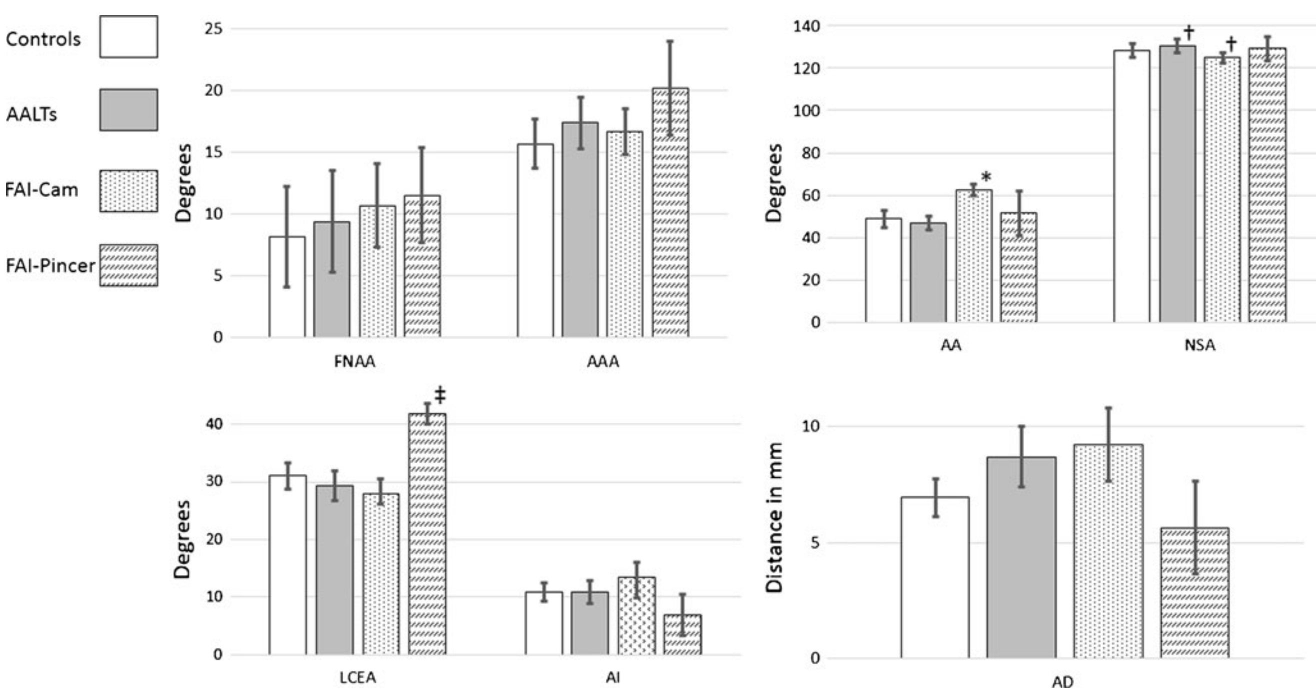

Fig. 4 Morphometric hip measurement mean values with 95 % confidence interval graph. *AALTs* anterior acetabular labral tears, *FAI-cam* femoroacetabular impingement with cam-bony deformities, *FAI-pincer* femoroacetabular impingement with pincer-bony deformities, *FNAA* femoral neck anteversion angle, *AAA* acetabular anteversion angle, *AA* alpha angle, *NSA* femoral neck shaft angle, *LCEA* lateral central edge angle, *AI* acetabular index, *AD* acetabular depth. * Mean value of AA was significantly higher in the FAI-cam group than in the controls (p<0.001), the AALTs group (p<0.001), and the FAI-pincer group (p=0.005). † Mean value of the NSA was significantly higher (p=0.045) in the AALTs group than in the FAI-cam group. ‡ Mean value of the LCEA was significantly higher (p<0.001) in the FAI-pincer group than in the controls, the AALTs group, and the FAI-cam group

lost to follow-up had had poor outcomes. Second, it was not clear if the postoperative improvement was due to the labral repair or iliopsoas tenotomy as there was only one group, and thus no comparison with patients who underwent labral repair without an iliopsoas tenotomy. Third, although the patients with isolated AALTs in the study had no evidence of FAI, there was no clear explanation about the location of the ALTs and the association with FAI in the excluded records.

Blankenbaker et al. retrospectively evaluated the MRA records of 23 patients who had IPI diagnosed with hip arthroscopy and compared them with 24 age and sex-matched controls who underwent arthroscopy, but did not have IPI [6]. In the IPI group, all the patients had labral injuries at the 3 o'clock position adjacent to the IPT on arthroscopy. In contrast, the controls had ALTs not isolated to the 3 o'clock position on arthroscopy. Two independent radiologists evaluated six different characteristics of the IPT at the level of labrum and the presence of ALTs at the 3 o'clock position on MRA records. The authors reported a statistical association in the IPI group with AALTs compared with controls. There was no statistical difference between the IPI group and controls regarding the characteristic of the IPT, except that in the IPI group, women had a narrower IPT than men within the same group. This study proposed that AALTs on MRA might indicate IPI. However, the authors identified some limitations to this study, including the small sample size, and low inter-reader agreement. Additionally, they did not evaluate any of the bony variables or the presence of FAI in the IPI group or the controls. Furthermore, there was no comparison with patients without ALTs or a clear explanation of the underlying etiology of ALTs in the controls.

Although there were several limitations to the previous two studies, the data they presented proposed that AALTs were associated with IPI [5, 6]. Our study further supports their findings as there was no significant association between AALTs and FAI or any of the other bony variables of the hip that were measured. Several study limitations are noteworthy. First, we did not correlate the MRI findings with the arthroscopic findings, clinical examination findings or the postoperative course. However the main purpose of the study was to assess the association of AALTs with bony abnormalities and our study was not designed to assess the correlation between AALTs and arthroscopic findings or clinical presentation of IPI. Second, we did not assess the interrater and intrarater reliability of diagnosing and locating ALTs and measuring the other morphometric features of the hip. However, all the measurements and evaluations of the MRI were based on the recent literature, which demonstrated an established validated technique and/or accuracy [1, 13–15, 17–22]. Third, although radial cuts provide higher accuracy in measuring the alpha angle, we measured the alpha angle on the axial oblique plane to conserve the consistency of the measurement protocol as the radial cuts were only available for the 3-T MRI records [1, 25]. Fourth, there were 3 patients in the FAI-pincer group with mixed FAI (LCEA >39° and alpha angle >55°), which might have lowered the significant difference in the alpha angle measurement between the FAI-pincer and FAI-cam. Fifth, the sample size for our study was small and thus our results would have to be further validated in a larger cross-sectional study.

Conclusion

Our study demonstrated that anterior acetabular labral tears are not associated with femoroacetabular impingement or any other bony abnormalities. This supports previous studies, which proposed that anterior acetabular labral tears on preoperative imaging constitute a distinct pathological diagnosis and raise the possibility of underlying iliopsoas impingement.

Conflict of interest None.

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