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Diagnosis of acetabular retroversion: Three signs positive and increased retroversion index have higher specificity and higher diagnostic accuracy compared to isolated positive cross over sign[☆]

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ABSTRACT

Objectives: The crossover-sign (COS) is a radiographic sign for diagnosis of acetabular-retroversion(AR) in patients with femoroacetabular-impingement (FAI) but overestimates AR. Three signs combined with retroversion-index (RI) could potentially improve diagnostic-accuracy.

Aims:

(1) To calculate central acetabular-version (AV, CT/MRI) in patients with isolated positive COS and in patients with three radiographic signs for AR on radiographs (AP).
(2) To calculate diagnostic performance of positive COS and of three signs combined with retroversion-index (RI) > 30% on radiographs (AP) to detect global AR (AV < 10°, CT/MRI).

Methods: A retrospective, IRB-approved, controlled diagnostic study comparing radiographic signs for AR (AP radiographs) with MRI/CT-based measurement of central AV was performed. 462 symptomatic patients (538 hips) with FAI or hip-dysplasia were compared to control-group (48 hips). Three signs for AR(on radiographs) were analyzed: COS, posterior-wall-sign and ischial-spine-sign. RI (synonym cross-over-index) quantifies overlap of anterior and posterior wall in case of positive COS. Diagnostic performance for COS and for three signs combined with RI > 30% to detect central AV < 10° (global AR) was calculated.

Results:

(1) Central AV was significantly (p < 0.001) decreased (13 ± 6°, CT/MRI) in patients with three signs for AR and RI > 30% on radiographs compared to patients with positive COS (18 ± 7°).
(2) Sensitivity and specificity of three signs combined with RI > 30% on radiographs was 85% and 63% (87% and 23% for COS). Negative-predictive-value (NPV) was 94% (93% for COS) to rule out global AR (AV < 10°, CT/MRI). Diagnostic accuracy increased significantly (p < 0.001) from 31% (COS) to 68% using three signs.

Abbreviations: AR, acetabular retroversion; COS, cross over sign; FAI, Femoroacetabular impingement; AV, acetabular version; RI, retroversion-index.

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Conclusion: Improved specificity and diagnostic accuracy for diagnosis of global AR can help to avoid misdiagnosis. Global AR can be ruled out with a probability of 94% (NPV) in the absence of three radiographic signs combined with retroversion-index < 30% (e.g. isolated COS positive).

1. Introduction

Acetabular retroversion (AR) was associated with hip pain [1], femoroacetabular impingement [2] (FAI) and the development of hip osteoarthritis [3,4] in young patients. AR is associated with decreased internal rotation and flexion [5] and was described in patients with FAI and slipped capital femoral epiphysis (SCFE) [6,7]. But this deformity remains poorly understood and different definitions of AR [8] add confusion. In addition, a high prevalence of the crossover sign [9] (COS) raised concerns of overestimation of AR.

Surgical treatment with hip arthroscopy for patients with AR is controversial [10,11]. Some described good clinical short-term followup [11] after treatment with hip arthroscopy but female patients with FAI due to AR are at risk for poor outcomes after hip arthroscopy [12] and exhibited a high rate of conversion to THA. In a recent systematic review [10] both arthroscopic and open treatment for FAI caused by AR resulted in satisfactory postoperative patient reported outcome. But different definitions and radiographic signs exist for AR. The COS is a common radiographic sign associated with AR. Unfortunately, signs for AR are affected by small changes in pelvic tilt and rotation [13,14] on pelvic radiographs. Due to the limitations of radiographs, the differentiation in cranial (focal) and central (global) AR was proposed based on CT scans [8]. Global AR was associated with a deformity of the iliac wing [51] and the hemipelvis [15]. Pelvic CT scans allow the exact measurement of acetabular version (AV) and diagnosis of AR. Exact diagnosis of AV is very important for planning of surgical treatment (e.g. open or arthroscopic).

Overestimation of AR can lead to unnecessary diagnostic workup with CT/MRI and it could be dangerous because surgical treatment with acetabular rim trimming [16] has been found to decrease the size of the lunate surface [17] with the risk of iatrogenic hip dysplasia and instability. Therefore, the potentially high false-positive rate of (focal) cranial AR indicated by the presence of a COS may errantly lead to surgical overcorrection of young FAI patients. Diagnosis of global AR is important, because some hip surgeons consider this an indication for anteverting periacetabular osteotomy [18], an open and demanding procedure [19].

Initially, a prevalence of 17–18% of AR was reported using radiographs for patients with hip dysplasia [20,21]. Prevalence of AR has been quite variable in the literature. A prevalence of AR up to 43% was described using CT scans [22,23]. A recent prevalence study showed a high prevalence of combined abnormalities of AV and femoral version in patients with hip disease [24]. But CT has considerable radiation exposure and MRI is expensive. Therefore, the retroversion-index (RI) was introduced for quantification of the overlap of anterior and posterior wall in case of positive COS, and this could help radiologists to detect central (global) AR on radiographs. The purpose was to investigate diagnostic performance of radiographic signs to detect global AR (defined with AV measurement on CT scans/MRI).

1.1. Aims

(1) To calculate central acetabular-version (AV, CT/MRI) in patients with single COS and in patients with three radiographic signs for AR on AP radiographs.
(2) To calculate diagnostic performance of single COS and of three signs combined with retroversion-index (RI) > 30% on AP radiographs to detect global AR (AV < 10°, CT/MRI).

2. Methods

A retrospective, IRB-approved, controlled diagnostic study comparing radiographic signs for acetabular retroversion on conventional radiographs with MRI/CT-based measurement of AV was performed. A total of 462 symptomatic patients (538 hips) were consecutively evaluated who had hip pain attributed to FAI or hip dysplasia and who presented to our university center for hip preservation surgery in a 5-year period (2011–2015). We evaluated all symptomatic patients between January 2011 and December 2015. All patients presented with hip pain at the time of image acquisition. Inclusion criteria included the presence of hip pain, radiographic signs of skeletal maturity, standard plain radiographs, and the availability of either CT or MRI of the pelvis/hip. Central AV was measured on CT or MRI on the level of the femoral head center, the so called 3 o'clock version (equator level) as described by Hetsroni [25]. RI was measured [18] on AP radiographs (Fig. 1A).

During routine clinical examination, all patients were clinically evaluated by one of our attending hip surgeons (KAS,MT) with 10 years of experience in open and arthroscopic hip preserving surgery. This included acquisition of the patient history, measurement of the hip range of motion and the evaluation of the anterior and posterior impingement tests [26].

We excluded 372 patients (385 hips) out of a total of 824 patients (912 hips, Fig. 2). The reasons for exclusion were the following reasons: incomplete radiographic documentation (190 patients [198 hips]), previous surgery of hip joint altering acetabular and/or femoral version (72 patients [74 hips]), patients with skeletally immature hips (stage 4 or less according to Risser et al. [27], 25 patients [26 hips]), posttraumatic conditions (70 patients [71 hips]), increased acetabular anteversion (10 patients [11 hips]) and avascular necrosis of the femoral head (5 patients [5 hips]). This resulted in a total of 538 hips in 462 patients Table 1 for inclusion in this study (Fig. 2). All patients were part of a previous study [24]

Radiographic evaluation generally consisted of an anteroposterior (AP) pelvic radiograph taken in supine position with a standardized technique [26] and a cross-table lateral radiograph of the hip, while additional projections or functional views were added if needed for diagnosis or surgical planning. Center of the beam is directed to the midpoint between a line connecting both anterosuperior iliac spines and the superior border of the symphysis [26]. Measurement of the COS and of the RI was performed manually on AP pelvic radiographs [18]. The AP pelvic radiograph was evaluated with a previously validated computer software (Hip^{2}Norm, University of Bern, Bern, Switzerland) [13,28,29]. This software allowed reliable measurement of eight radiographic parameters of the hip and the calculation of femoral head coverage (total coverage, anterior coverage and posterior coverage). The alpha-angle served as a measure of femoral asphericity and was measured manually on axial cross table radiograph. All radiographic measurements were performed by two independent observers, two radiology residents with minimal 5 years of experience in musculoskeletal radiology, that were not involved in treatment of the patients.

As a control group, we used the whole body computed tomography (CT) scans of asymptomatic patients with cancer diagnosis (mostly multiple myeloma patients). The control hips were selected in the PACS (Picture archiving System) of our hospital from 44 patients (88 hips) undergoing bilateral CT for diagnostic staging between 2011 and 2015. All patients with a whole body CT scan in this period were included for radiographic analysis. Of these, 40 hips were excluded from the control group for the following reasons: Total hip or knee arthroplasty (9 patients [15 hips]), hip pain (3 patients [5 hips]), previous hip surgery (1 patient [1 hip]), osteoarthritis Grade 1 or higher according to Tönnis (3 patients [5 hips]), lateral center-edge (LCE) angle of less than 25° or more than 39° (3 patients [3 hips]), neck-shaft angle of less than 120° or more than 139° (1 patient [1 hip]), diagnosis of poliomyelitis as child and paraparesis (1 patient [2 hips]), alpha-angle [13] of more than 55° (4 patients [8 hips]). This resulted in 48 hips (27 patients) serving as the control group. The demographic (Tables 1 and 2) and radiographic parameters (Table 3) and the surgical treatment (Table 2) differ between the study and control group.

Based on the analysis of the conventional radiographs, our patient cohort included hips with the following diagnosis (Table 1): 1) hip dysplasia (LCE angle < 22° [30]), 2) pincer-type FAI due to overcoverage (LCE-angle of 35–39° [30]), 3) pincer-type FAI due to severe overcoverage (LCE-angle > 39°), 4) pincer FAI due to acetabular retroversion, 5) cam-type FAI (alpha angle > 50°), 6) mixed-type FAI, 7) varus, 8) valgus, 9) post-Perthes, and 10) no obvious hip pathomorphology (Fig. 2). The diagnosis of each group was based on published acetabular and femoral reference values on radiographs (Table 1) [4,30, 31]. One hip could be allocated to multiple study groups, e.g. 'dysplasia' and 'valgus' group.

For calculation of AV, all symptomatic patients either underwent standardized magnetic resonance imaging and/or computed tomography of the hip. The use of each of these imaging modalities has been validated for this purpose by previous studies that compared the measurement of AV [32] on MRI and on CT. CT and MRI was performed in supine position. This is in contrast to a previous large study that evaluated CT in prone position [4]. Recent validation studies showed comparable results for AV measurements between CT and MRI [32,33]. Previous studies used advanced methods for calculation of AV [34] or evaluated the influence of pelvic tilt [35]. Direct MR arthrography [36] was obtained according to a protocol-specific standardized technique. In brief, after fluoroscopic-guided intraarticular injection of 10–15 ml (Artirem 0.0025 mmol/ml, Guerbet, Paris, France), the scans were performed with a flexible surface coil using a Siemens TRIO 3.0-T high field scanner (Erlangen, Germany). To prevent motion during scanning, the patients were positioned supine, and the feet were fixed in neutral position. A radial proton density sequence was acquired for evaluation of lesions of the labrum and cartilage. Sagittal and coronal proton density-weighted and axial T1-weighted and FLASH sequences were acquired of which the axial slices were used for measurements of acetabular version. An additional axial T1-weighted sequence of the femoral condyles was used for measurements of femoral torsion [24,37]. These sequences were taken immediately after the original axial T1-weighted sequences and the patient was instructed not to move the leg to ensure accurate measurement. If needed, CT was acquired according to a previously validated protocol [38,39] including the entire pelvis and the knee joint,which was used for measurement of AV and femoral torsion and three-dimensional virtual impingement simulation [39]. A slice thickness of 2 mm and an interval of reconstruction of 1.7 mm were chosen for CT scans.

Central AV was measured on the level of the femoral head center, the so called 3 o'clock version (equator level) according to Hetsroni [25] and was defined with a line connecting the anterior and posterior acetabular rim (Fig. 3A). A normal central AV was defined from 10 to 25° [4]. Acetabular retroversion was defined in previous studies as central AV < 15° [40,41], while other studies used a lower threshold for acetabular retroversion, they defined it as central AV < 10° [4,8,24]. Other reported normal values for AV ranged from 17° [35] to 26° [42] using various measurement methods. Reported thresholds for categorizing AV in low and high were < 10° and > 25° [4], < 15° and > 20° [41], < 0° and > 20° [22].

Two different and independent observers manually measured central AV of 538 hips. On a random sample of 50 hips taken from our patient cohort, the two observers measured independently central AV at two different time points. A substantial agreement (defined as interclass correlation coefficient [ICC] of > 0.6 [43]) was found for reproducibility of central AV (ICC of observer 1 was 0.80, [range, 0.65–0.97] and of observer 2 was 0.78 [range 0.61–0.87]). A substantial agreement (defined as ICC > 0.6 [43]) was found for reliability of central AV (ICC Interobserver was 0.75, ranging from 0.62 to 0.83).

We retrospectively measured AV among 10 subgroups with predefined hip morphologies and compared them. Three signs for acetabular retroversion on radiographs were analyzed: COS, posterior wall sign

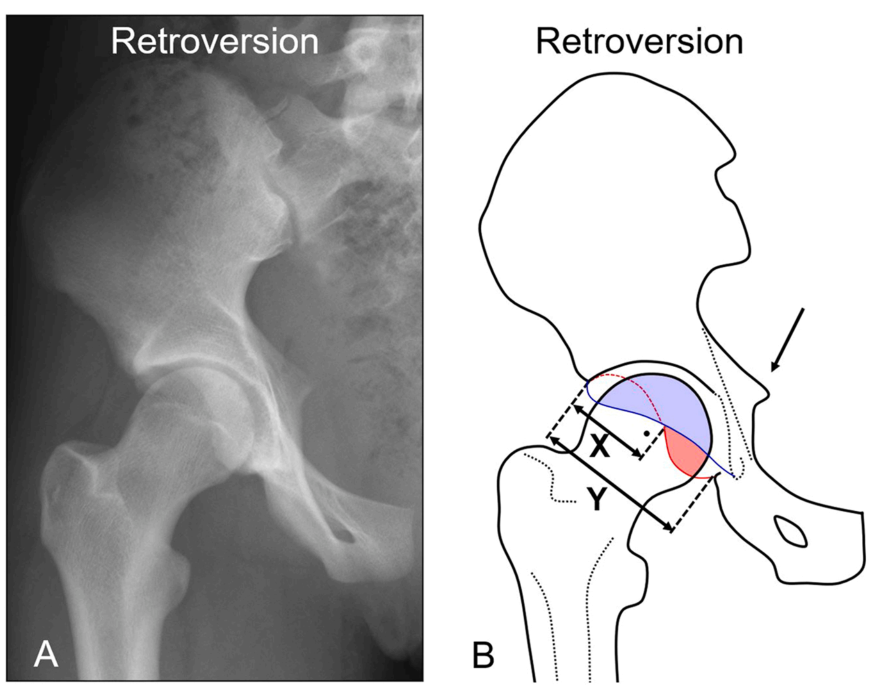

Fig. 1. A and B. A pelvic radiograph of a patient with acetabular retroversion is shown (A) with positive cross over sign, positive ischial spine sign and positive posterior wall sign. Measurement of the cross over sign (intersection of blue and red line) and of the retroversion index (X divided by Y) on schematic view is shown (B). Figures reprinted with permission from [51]

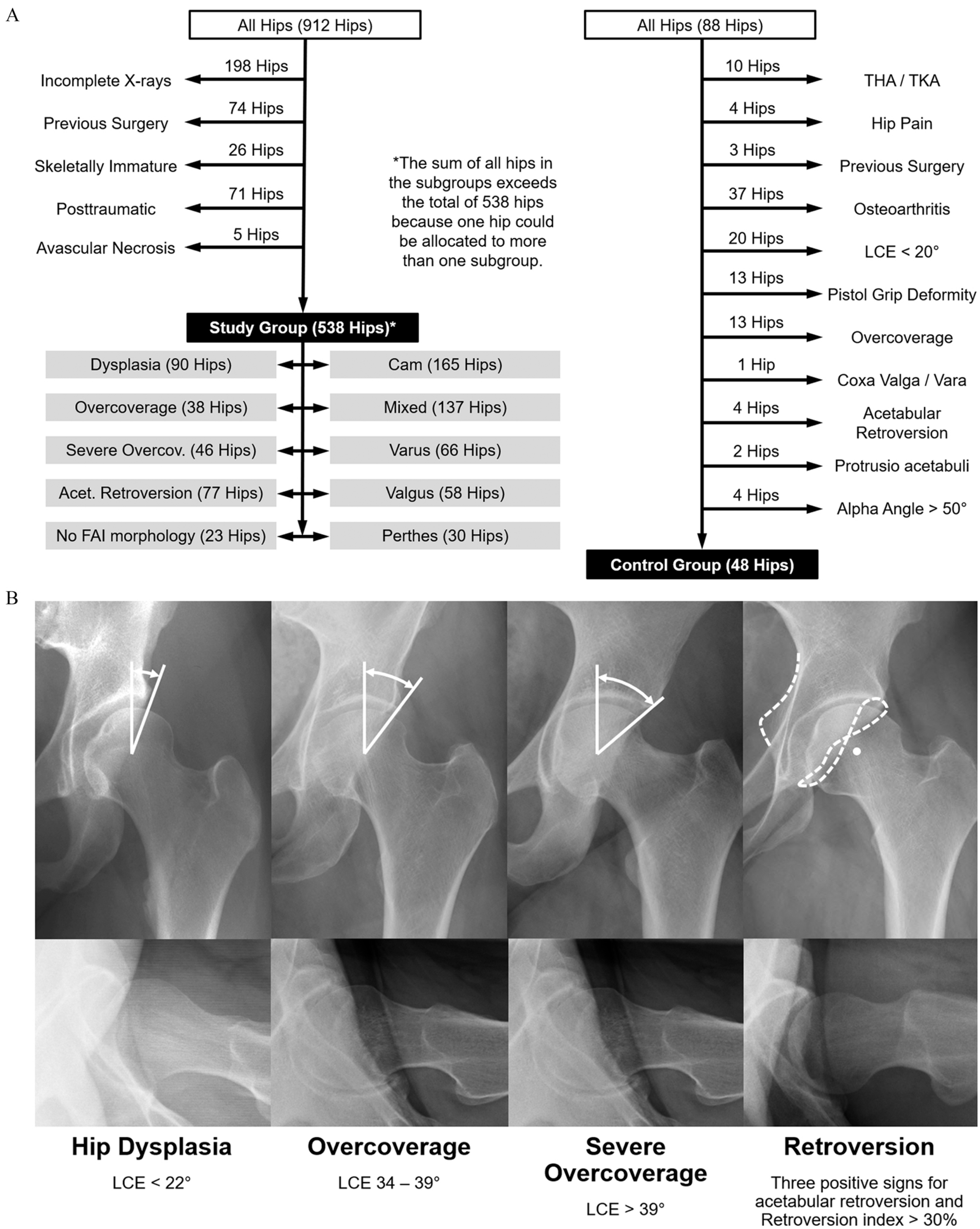

Fig. 2. A–C. Inclusion and exclusion criteria for the study groups and for the control group (A) are shown. The study group was then further subdivided into ten subgroups based on the definitions given in Table 1. *The sum of all hips in the subgroups exceeds the total of 538 hips since one hip could be allocated to several subgroups. Radiographic definitions (B and C) are shown for the subgroups. Figures reprinted with permission from [24]

C

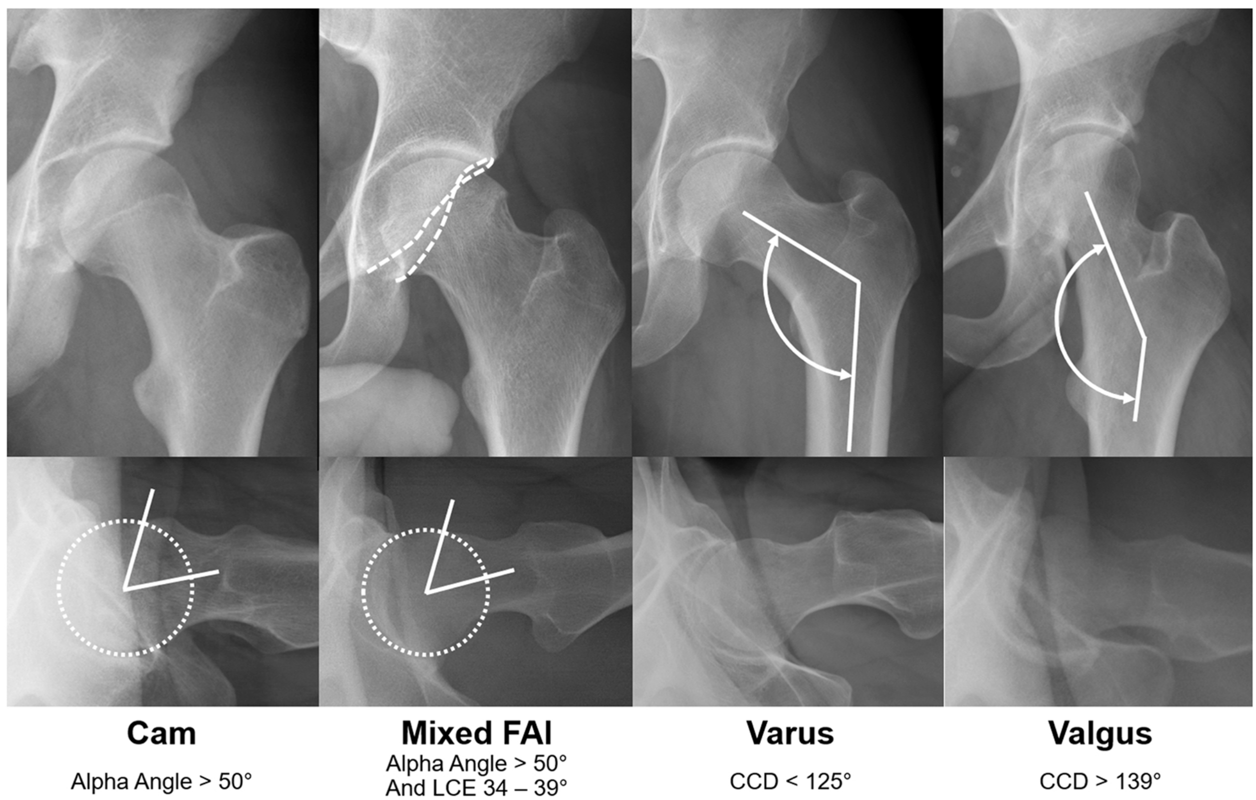

Fig. 2. (*continued*).

and ischial spine sign. RI allows quantification of the crossover sign. Diagnostic performance for RI > 30% to detect central AV < 10° was calculated. We performed a power analysis for central AV in a fixed-effect 1-way analysis of variance design with a level of significance of 1% and beta error of 5%, given previously reported mean values of AV of 17° in 27 normal hips [35], 22° in 12 patients with a cam-deformity [44], 19° in 27 patients with hip dysplasia [35] and a published standard deviation of 8° [35]. This resulted in a total number of 91 patients.

2.1. Statistical analysis

A normal distribution was present for all continuous parameters, which were confirmed using the Kolmogorov-Smirnov test. Continuous variables among the study groups were compared using the univariate analysis of variance (ANOVA). Adjustment for multiple comparisons was done with the Bonferroni correction for 10 groups. The level of significance was adjusted to 0.05/10 = 0.005. A p-value < 0.005 was considered significant.

Continuous values for each study group were compared using the unpaired Student's t-test. Categorical variables were compared among the study groups using the Chi square test. Statistical analysis was performed using the Winstat software (R Fitch Software). Diagnostic performance was calculated using Medcalc software.

3. Results

(1) Central AV was significantly ($p < 0.001$) decreased ($13 \pm 6°$) in patients with three signs for acetabular retroversion combined with RI > 30% compared to all patients ($19 \pm 7°$) and compared to patients with positive crossover-sign ($18 \pm 7°$, Fig. 3B). Central AV of patients with hip dysplasia was higher (22°) compared to all patients, while patients with mixed-type FAI had 16° of central AV.

Of the 538 hips, 164 hips (30%) had three signs for AR and 15% had three signs combined with RI > 30%. Of the 538 hips, 12% had central AV <10°. Of the patients with hip dysplasia, 68% had a positive crossover sign, while 83% of the patients with LCPD had a positive crossover sign. Of the patients with cam-type FAI, 78% had a positive crossover sign. On the other hand, only 2% of the patients with hip dysplasia had three signs combined with RI > 30%.

(2) Sensitivity of three signs combined with RI > 30% was 85% and negative predictive value (NPV) was 94% to detect acetabular retroversion (AV < 10°, Table 4A). Specificity was 63% and PPV 38% (Table 4A). Diagnostic performance for patients with a positive COS (to detect AV < 10°) showed a NPV of 93%, Sensitivity of 87%, Specificity of 23% and PPV of 13% (Table 4B). False-positive rate was reduced from 77% (positive COS, Table 4B) to 37% using three signs combined with RI > 30% (Table 4A).

4. Discussion

We performed a retrospective controlled diagnostic study with 538 hips comparing a single and three radiographic signs for acetabular retroversion on radiographs with MRI/CT-based measurement of central AV. Most importantly, we found that three signs combined with RI (> 30%) have a high NPV and high Sensitivity to detect AV < 10° (Table 4A) and can reduce false positive results. Therefore, due to the high NPV, the three signs combined with RI (< 30%) can be used to rule out AV < 10° with a probability of 94% (NPV). The high Sensitivity allows to use this definition (three signs for acetabular retroversion and retroversion index > 30%) for diagnosis of global acetabular retroversion on AP radiographs.

In addition, we found that central AV was significantly ($p < 0.001$) decreased ($13 \pm 6°$) in patients with three signs for acetabular retroversion combined with RI > 30% compared to patients with a positive

Table 1
Definition of study groups. The allocation to a specific group was performed based on the morphological analysis of the conventional anteroposterior pelvic radiograph and the cross-table lateral radiographs of the hip.

Group	Definition	Number of hips (patients)
Hip Dysplasia	LCE-angle < 22° [30], and/or anterior coverage < 14% [30]	90 (78)
Overcoverage	LCE-angle 34–39° [30] with alpha angle < 50°, not all retroversion signs positive	38 (33)
Severe overcoverage	LCE-angle > 39° [4], and/or protrusio acetabuli (defined as femoral head touching or crossing the ilioischial line), and/or total femoral coverage > 93% [30]	46 (41)
Acetabular Retroversion	Positive cross-over sign [1], positive ischial spine sign [49], positive posterior wall sign [1], and retroversion index > 30% [18], independent from alpha angle	77 (65)
Cam- type FAI	Alpha angle > 50° [31] with neck-shaft angle of 125–140° and with normal acetabulum (LCE-angle 23–33°) [30], not all retroversion signs positive	165 (142)
Mixed-type FAI[a]	Alpha angle > 50° [31] and LCE-angle 34–39°, not all retroversion signs positive	137 (118)
Varus[a]	Neck-shaft angle ≤ 125° [4] independent from acetabular morphology and alpha angle, without Perthes disease	66 (58)
Valgus[a]	Neck-shaft angle ≥ 140° [4] independent from acetabular morphology and alpha angle, without Perthes disease	58 (49)
Perthes (LCPD)	Documented avascular necrosis of femoral head in childhood [50]	30 (25)
No obvious pathomorphology	No obvious acetabular and femoral pathology, normal LCE-angle (22–34°), normal alpha angle (< 50°) [39], normal femoral head coverage [30], symptomatic hip	23 (19)
Overall study group		538 (462)[a]

FAI = Femoroacetabular Impingement; LCE = lateral center edge angle, Perthes = Legg-Calvé-Perthes disease.
[a] The hips in the mixed, varus and valgus group can overlap with other pathomorphological subgroups.

Table 2
Demographic information and surgical treatment of the study groups are shown.

Parameter	Overall study group	Control group	p value
Number of hips (patients)	538 (462)	48 (27)	
Age at imaging (years)	32 ± 12 (14–71)[a]	63 ± 11 (36–79)	p < 0.001
Side (% [hips] left of all hips per group)	252 (47%)	25 (52%)	0.284
Sex (% [hips] men of all hips group)	257 (48%)[a]	39 (81%)	p < 0.001
Height (cm)	171 ± 8 (154–197)	173 ± 8 (161–188)	0.075
Weight (kg)	73 ± 15 (44–138)	80 ± 8 (61–92)	0.102
BMI (kg/cm^2)	25 ± 4 (16–43)	26 ± 2 (24–30)	0.225
Surgical treatment	53%	n/a	

BMI = Body mass index, FAI = Femoroacetabular Impingement; continuous values are expressed as mean ± SD and range in parentheses.
[a] Significant difference of the mean compared to the control group (Chi-square test).

Table 3
Radiographic parameters of the study group are shown.

Parameter	Overall study group
Number of hips (patients)	538 (462)
LCE-angle (°)	29 ± 10 (– 10 to 63)
Acetabular index (%)	4 ± 8 (– 14 to 34)
Extrusion index (%)	21 ± 9 (– 3 to 63)
Retroversion index (%)	13 ± 16 (0–100)
Neck-shaft angle (°)	131 ± 7 (107–161)
Alpha angle (°) [31]	61 ± 16 (30–162)
Anterior coverage (%)	24 ± 9 (3–58)
Posterior coverage (%)	42 ± 10 (11–74)
Total coverage (%)	77 ± 13 (24–100)
Cross over sign pos. (%)	78%
Posterior wall sign pos. (%)	58%
Ischial spine sign pos. (%)	57%
COS, PWS and ISS and RI > 30%	15%
Retroversion index (%)	13 ± 16 (0–100)
Central Acetabular version (°)	19 ± 7 (– 1 to 38)

Continuous values are expressed as mean ± SD with range in parentheses; LCE = lateral center edge angle, FAI = Femoroacetabular Impingement; COS = Cross over sign; ISS = Ischial spine sign; PWS = Posterior wall sign; RI = Retroversion index.

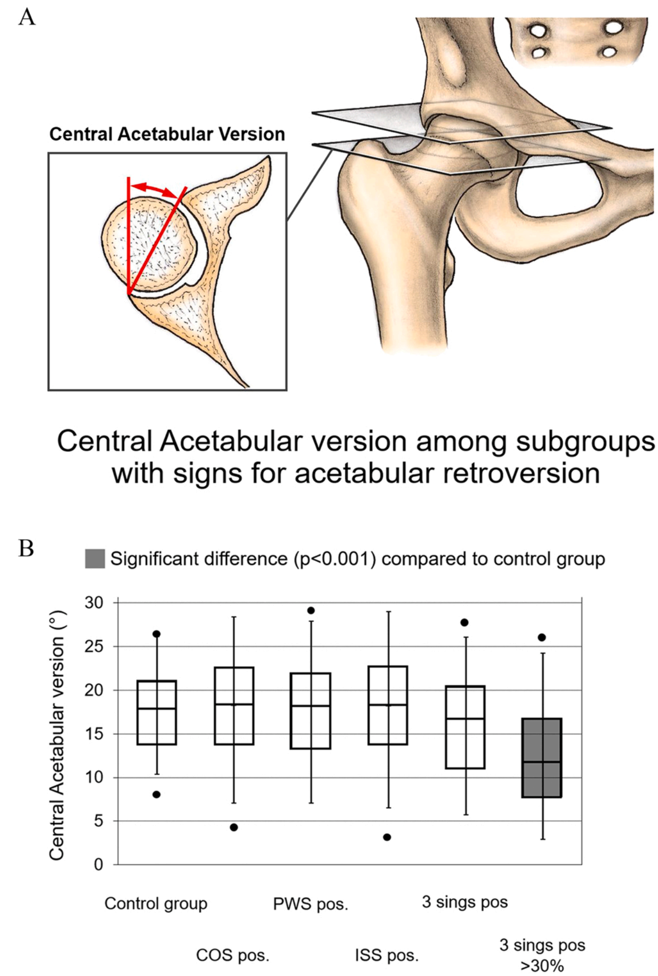

Fig. 3. A. Measurement of central acetabular version is shown. Central acetabular version was measured according to Hetsroni [25] with the angle constructed by the sagittal line and a line connecting the anterior and posterior acetabular rim at the center of the femoral head (3 o'clock version). Figure reprinted with permission from [24]. **B.** Boxplots for central acetabular version for five subgroups with radiographic signs for acetabular retroversion.

Table 4A
This 2 × 2 table shows the diagnostic performance for three signs positive with Retroversion index > 30% (all patients have a positive COS, PWS and ISS) to detect acetabular retroversion (defined as AV < 10°). Numbers are given as numbers of hips. Total of 164 hips had a positive COS, PWS and ISS.

	Decreased AV (AV < 10°)	Not decreased AV (AV > 10°)		Total
Three signs positive combined with Retroversion index > 30%	29	48	Positive predictive value 38% (32–44%)	77
Three signs negative and No Retroversion index > 30% (RI < 30%)	5	82	Negative predictive value 94% (88–97%)	87
	Sensitivity 85% (69–95%) False-negative Rate 15% (0–25)	Specificity 63% (54–71%) False-positive Rate 37% (28–45%)	Accuracy 68% (60–75%)	164

AV = acetabular version; calculation were performed with Medcalc software. COS = Cross over sign. PWS = posterior wall sign. ISS = ischial spine sign.

Table 4B
This 2 × 2 table shows the diagnostic performance for patients with a positive COS, to detect acetabular retroversion (defined as AV < 10°). Numbers are given as numbers of hips. Total number of hips with a positive COS are 420 hips.

	Decreased AV (AV < 10°)	Not decreased AV (AV > 10°)		Total
Isolated COS positive	55	365	Positive predictive value 13% (12–14%)	420
No COS positive	8	110	Negative predictive value 93% (88–96%)	118
	Sensitivity 87% (77–94%) False-negative Rate 13% (6–23)	Specificity 23% (19–27%) False-positive Rate 77% (73–81%)	Accuracy 31% (27–35%)	538

AV = acetabular version; calculation were performed with Medcalc software. COS = Cross over sign.

crossover-sign (18 ± 7°). This is important because this confirms the previously proposed differentiation of global and focal acetabular retroversion.

In a previous study, the prevalence of positive COS was 38% and the prevalence of global AR was 14% [45]. This is consistent with our results because 14% of the 538 hips had three signs combined with RI> 30% (Table 3). Interestingly, we found a high prevalence of a positive COS (78%, Table 3) in the study group. Compared to a previous study [9] reporting a prevalence of the COS of 50%, we found an increased prevalence of the COS (Table 3). A lower prevalence of positive COS was described for patient with hip dysplasia [20] (18%) and for patients with LCPD (42%) in a previous study, compared to our study (68% for hip dysplasia, and 83% of the patients with LCPD, Table 3). The higher prevalence of a positive COS in our study could be caused by the use of the software Hip2Norm. This software is sensitive for detection of an overlap of anterior and posterior wall.

Comparing the results of central AV, we found comparable values for patients with hip dysplasia. Nepple et al. [46] reported mean central AV of 22° for patients with hip dysplasia, this is in line with our results. Dandachli et al. reported a mean central AV of 19° for patients with hip dysplasia and 17° for control group, that is slightly lower compared to the current study (22° for hip dysplasia and 20° for the control group). In a previous study investigating 135 patients [22] with labral tears, 43% had acetabular retroversion and they reported mean central AV of 13.7° ± 7.6. This is lower compared to our results for the overall study group (19° for central AV, Tables 4A and 4B), but similar compared to our results for patients with acetabular retroversion (mean central AV of 13°). For patients with unilateral FAI, mean central AV of 16° was described [47] and that is in line with our results for patients with mixed-type FAI (mean central AV of 16°).

Comparing the results of diagnostic performance, others found a 50% false-positive rate for the COS [9]. The authors of this study described, that only 50% of the patients with a COS had focal or true central acetabular retroversion. Interestingly, in our study the high false-positive rate of 77% of the COS was reduced to 37% using three signs combined with RI > 30% Table 4A and 4B. We found a high sensitivity of 87% for the COS and this is consistent with the results found in the literature. Previously, Jamali et al. [8] reported a high sensitivity of 96% of the COS to detect a cranial AV of less than 4°. While Dandachli et al. [48] reported a sensitivity of 92% and a NPV of 91%. For RI > 30%, we found a slightly higher NPV of 94% Table 4A and 4B.

This study has limitations. First, we did measure AV manually on 2D axial CT/MRI images, there was no 3D model available [34]. However, by using the same method of previous studies [25], this allows for a direct comparison with the reported values from previous studies. Second, the mean age of the patients was 32 years and the mean age of the control was 63 years (Table 2). We included patients with age of 14 years (Table 2), but since all our hips from the study group had closed physes, this should not have jeopardized our results. Third, despite the large number of patients, our study group does not represent a cross-sectional analysis. Although collected consecutively, it rather should be considered a selective patient group from a tertiary referral center, which may contain a higher percentage of abnormal values of AV when compared with the general population. Fourth, the mean age of the control group was higher compared to patients (Table 2). Theoretically, in this age group, degenerative changes of the acetabulum could be present. But we excluded patients with degenerative changes for the control group, therefore we believe that there should be no relevant bias. Another limitation is, that we did not evaluate the influence of pelvic tilt [51] on AV measurement. Previous studies using 3D models evaluated standardized measurements of AV while normalizing pelvic tilt [34].

One of the strengths of this study is the large sample size. This allowed the calculation of subgroups and analysis of prevalence. Another strength is used software Hip2Norm, that allowed standardized evaluation of AP radiograph and also standardized calculation of retroversion index. This study has clinical implications. Due to the known limitations and the unreliability of pelvic radiographs, it is challenging to distinguish focal from central (global) acetabular retroversion. Therefore, we propose to use three signs combined with RI > 30% for diagnosis of global AR. This could help to reduce overestimation of AR. The potentially high false-positive rate of focal cranial retroversion of the acetabulum indicated by the presence of a crossover sign has diagnostic and surgical consequences. First, this could potentially lead to unnecessary diagnostic workup with CT/MRI. Second, overestimation of AR can be avoided. This is important for the surgical resection of the acetabular rim. Decreasing the acetabular rim could theoretically lead to iatrogenic dysplasia and structural instability. This is even worse for patients with hip dysplasia or borderline hip dysplasia with posterior wall deficiency.

5. Conclusion

To use isolated positive COS on conventional radiographs overestimates AR. Using three radiographic signs combined with RI > 30% for the diagnosis of global acetabular retroversion improves specificity and improves diagnostic accuracy and reduces overestimation. Global acetabular retroversion can be ruled out with a probability of 94% (NPV) in the absence of three radiographic signs combined with RI < 30%. Using three radiographic signs combined with RI > 30% can help to improve diagnosis and surgical planning of young patients with FAI or hip dysplasia that are eligible for hip preservation surgery.

CRediT authorship contribution statement

Till D. Lerch: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. **Malin Meier:** Data curation, Formal analysis. **Adam Boschung:** Data curation, Formal analysis. **Simon D. Steppacher:** Conceptualization, Supervision, Validation, Visualization. **Klaus A. Siebenrock:** Conceptualization, Supervision, Validation, Visualization. **Moritz Tannast:** Conceptualization, Supervision, Validation, Visualization, Funding acquisition. **Florian Schmaranzer:** Conceptualization, Supervision, Validation, Visualization, Writing – review & editing, Funding acquisition.

Ethical statement

IRB approval was obtained for this study. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

Author contribution

All authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

Conflict of interest

None of the authors have competing interests to declare.

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