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SCIENTIFIC ARTICLE

MRI morphometry, cartilage damage and impaired function in the follow-up after slipped capital femoral epiphysis

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Abstract
Objective To assess rotation deficits, asphericity of the femoral head and localisation of cartilage damage in the follow-up after slipped capital femoral epiphysis (SCFE).
Materials and Methods Magnetic resonance imaging studies were obtained in adult patients with a history of SCFE. A total of 35 hips after SCFE in 26 patients (mean age 24.1±6.5, mean follow-up 11.9±6.1 years) were evaluated. The control group comprised 20 healthy hips from 10 young adults with an average age of 23.9±3.7 years. The MR protocol included a T1-weighted sequence with a 3D volumetric interpolated breath-hold sequence and a radial 2D proton density-weighted sequence around the femoral neck. Images were evaluated for alpha angle and cartilage damage in five positions around the femoral head. Hip function was evaluated at the time of MRI and correlated with MRI results. Mann–Whitney *U* test and Spearman's correlation coefficient were used for statistical analysis.
Results In the hips after SCFE alpha angles were significantly increased in the anterosuperior (74.1°±18.8°) and superior (72.5°±21.5°) positions and decreased in the posterior position (25.0°±7.2°). Cartilage damage was dominant in the anterosuperior and superior positions. Impaired rotation significantly correlated with increased anterosuperior, superior and posterosuperior alpha angles.
Conclusion The data support an anterosuperior and superior cam-type deformity of the femoral head–neck junction in the follow-up after SCFE. MRI after SCFE can be used to assess anterosuperior and superior alpha angles, since the anterior alpha angle by itself may underestimate asphericity and is not associated with rotation deficits.

Keywords Slipped capital femoral epiphysis · Femoroacetabular impingement · Alpha angle · Acetabular depth · Cartilage · MRI

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Introduction

With the advent of surgical treatments that potentially decrease the risk of secondary osteoarthritis after slipped capital femoral epiphysis (SCFE), information on the localisation of femoral asphericity and cartilage damage in these patients has become even more relevant.

The purpose of this study is to provide a localised assessment of the asphericity of the femoral head–neck junction and cartilage damage in follow-up examinations of patients after slipped capital femoral epiphysis and to correlate MR morphometry with physical examination results.

The abnormal morphology of the femoral head–neck offset in hips after clinically overt or silent SCFE has been associated with early cartilage damage due to cam-type femoroacetabular impingement (FAI) [1–8].

In situ pinning or fixation of the epiphysis by screws is recommended for acute cases of SCFE with mild and moderate slips [9–11]. In acute slips MRI has been used to demonstrate the degree of slip, synovitis, periphyseal oedema and joint effusion [12]. For chronic cases with severe slips, corrective femoral osteotomies restoring hip function have been applied with long-term success [13–16]. Recent reports identified labral and cartilage lesions caused by prominent femoral metaphysis in SCFE as a sequelae of cam-type impingement after SCFE [1, 4]. Consequently, osteochondroplasty of the femoral head–neck junction has been proposed in an attempt to restore sphericity and to prevent secondary osteoarthritis in the intermediate term [1, 4, 17].

Indication for osteochondroplasty in patients with impingement depends on the asphericity of the femoral head–neck junction, which has long been recognised as tilt [18] or pistol grip deformity [19] on conventional radiographs. Recent studies suggest that conventional radiographs may underestimate the extent of asphericity in FAI [20]. In magnetic resonance imaging, the amount of asphericity of the femoral head–neck junction can be quantified using the alpha angle [21], which has been determined on oblique transversal images in an anterior position [21, 22] or radial, around the femoral neck [23]. For the radial imaging the anterosuperior position is the dominant location of deformity of the head–neck junction in cam-type FAI [23]. These findings correlate with an assessment on femoral head specimens of SCFE patients after total hip arthroplasty that reported cartilage damage in the superior, weight-bearing portion of the hip joint and loss of the head–neck offset of the anterior and superior portions of the femur [24].

In clinical examinations, reduced internal rotation in 90° flexion of the hip has been proposed to be suggestive of FAI [25] and has been associated with the forcing of the aspheric femoral head–neck junction into the acetabulum.

Materials and methods

Patient population and examination

Institutional review board approval was obtained for this study and all patients and volunteers provided written consent. Inclusion criteria were a history of SCFE in childhood and a minimum age of 18 years or older at the time of inclusion.

In a retrospective assessment of two orthopaedic hospitals, patients treated for mild or moderate SCFE in childhood were identified. A total of 33 patients with a history of SCFE could be recruited to the study. The average age was 24.2±5.9 years, ranging from 18 to 51 years. The mean age at diagnosis was 12.6±2.9 years, ranging from 9.4 to 15.3 years. There were 14 female patients and 19 male patients. Hips treated with an acetabular or intertrochanteric osteotomy were excluded (n=9). Claustrophobia, pace makers, pregnancy and large metallic implants constituted exclusion criteria. Therefore in total, 35 hips after SCFE in 26 patients (mean age 24.1±6.5 years, ranging from 18 to 51 years) were analysed. Ten were female and 16 were male. The follow-up period was an average of 11.9±6.1 years, ranging from 3.6 to 39.0 years.

The control group involved 10 asymptomatic young adult volunteers under 30 years of age (average age 23.9±3.7 years, ranging from 19 to 29 years, 3 female and 7 male). None reported past hip problems. Age and gender distribution were not significantly different, compared with the patient group.

Hip internal rotation at 90° flexion was assessed by a single clinical assistant that was blinded to imaging results.

MRI

Imaging was performed using a body matrix and spine coil wrapped around the hip with a 1.5 T clinical scanner (Avanto®, Siemens Healthcare AG, Erlangen, Germany). The MR protocol was:

1. T2-weighted 3D true fast imaging with steady precession sequence (FOV: 160 mm, slices: 60, slice thickness: 1.3 mm, matrix: 128 × 128, TR: 2.43 ms, TE: 4.19 ms, bandwidth: 230 Hz/pixel, flip angle: 30°). Acquisition time was 0.48 min per hip. Images were reformatted in three planes along and perpendicular to the axis of the femoral neck and served as scouts for
2. A radial 2D proton density (PD)-weighted sequence obtained around the femoral neck (FOV: 160 mm, slices: 12, slice thickness: 4 mm, matrix: 448 × 448, TR: 2,590 ms, TE: 13 ms, three averages, bandwidth: 190 Hz/pixel, flip angle: 150°). Acquisition time was 5.23 min per hip
3. A sagittal 3D T1-weighted sequence with a 3D volumetric interpolated breath-hold sequence (VIBE; FOV: 200 mm, slices: 64, slice thickness: 1.1 mm, matrix: 256 × 256, TR: 6.7 ms, TE: 2.45 ms, two averages, bandwidth: 190 Hz/pixel, flip angle: 8°). Acquisition time was 3.14 min per hip

MRI analyses

Alpha angle

Two musculoskeletal radiologists (F.R.M., A.H.) analysed all MR images in consensus. The MRI images were evaluated in a random order. The non-spherical shape of the head–neck junction was assessed in five positions around the femoral head and neck using reformatted images of the 3D T1-weighted VIBE (position 1: anterior; position 2: anterosuperior; position 3: superior; position 4: posterosuperior; position

5: posterior). The alpha angle (°) was calculated using the method described by Nötzli et al. [21]. The first line defining the alpha angle was positioned between the centre of the femoral head and the centre of the femoral neck at its narrowest point. The second line was drawn from the centre of the femoral head to the point where the contour of the femur exceeded the radius of the femoral head (Fig. 1).

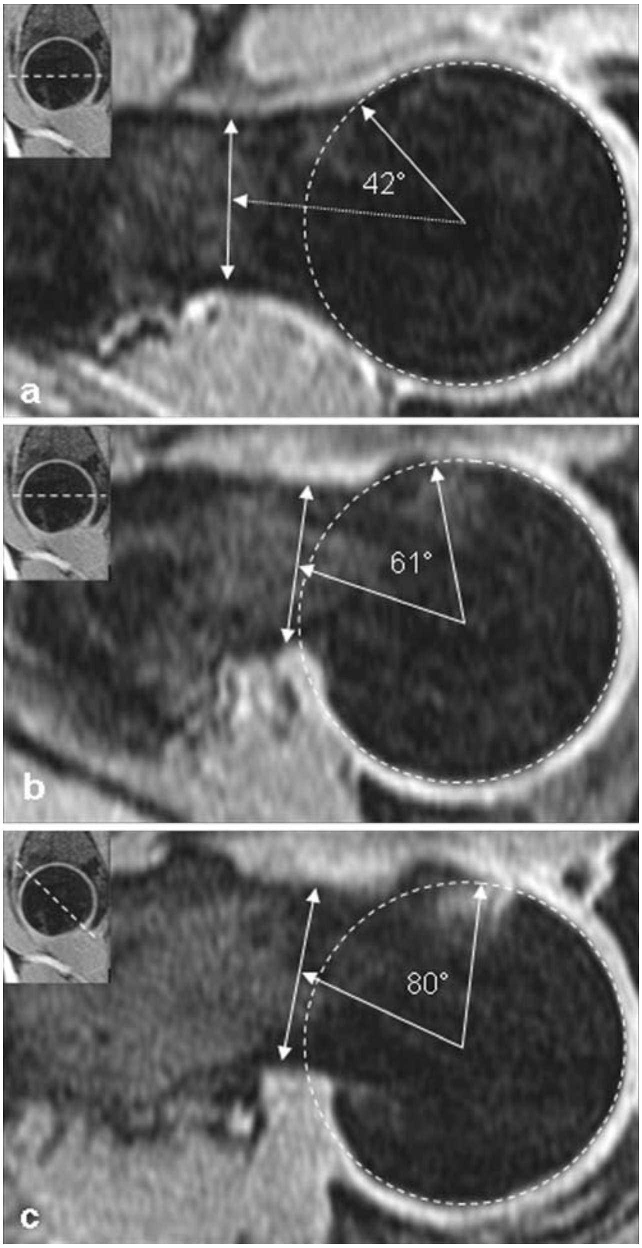

Fig. 1 Measurement of alpha angles on radial reformatted images. Each alpha angle was defined by the line between the centre of the femoral head and the centre of the femoral neck and by the line from the centre of the femoral head to the point where the contour of the femur exceeded the radius of the femoral head. **a** Control subject, measurement of the anterior alpha angle. **b** Affected hip after slipped capital femoral epiphysis (SCFE) with disturbed sphericity of the femoral head, anterior alpha angle. **c** Affected hip after SCFE with disturbed sphericity of the femoral head, anterosuperior alpha angle

Acetabular depth

The acetabular depth (mm) was measured on transverse oblique images positioned along the axis of the femoral neck as the distance between the line connecting the anterior and the posterior acetabular rim and the centre of the femoral head as described by Pfirrmann et al. [23]. Negative values represented a femoral head centre medial of the line connecting the acetabular rim (Fig. 2).

Cartilage damage

Acetabular cartilage was evaluated from radial 2D TSE PD-weighted MR images at five positions around the hip joint (position 1: anterior, position 2: anterosuperior, position 3: superior, position 4: posterosuperior, position 5: posterior). Cartilage damage was assessed using a modified graduation developed by Outerbridge et al. [26–28]: Grade 1 was defined as an inhomogeneous cartilage signal; Grade 2 was irregularity of the cartilage surface or thinning of less than 50%; Grade 3 indicated damage above 50%; and Grade 4 was defined as denudation of the subchondral bone (Fig. 3).

Statistical analyses

The Mann–Whitney U test was used to determine statistically significant differences in alpha angles and acetabular depths between the patient and the control group. Spearman's correlation coefficient was used to calculate the correlation of the alpha angle with cartilage damage and internal rotation. P values below 0.05 were considered significant. SPSS software (SPSS statistics, version 17.0.0; SPSS, Chicago, IL, USA) was used for all statistical calculations.

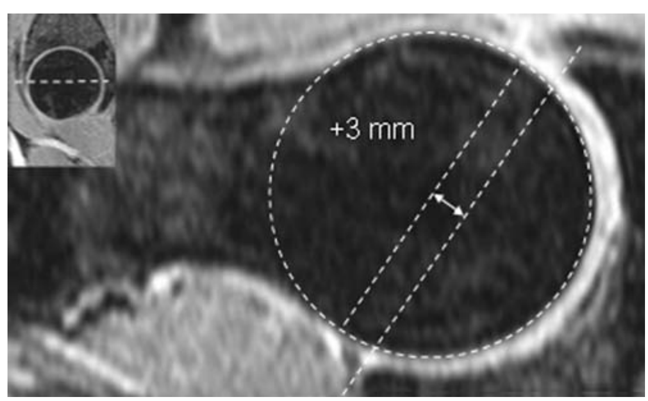

Fig. 2 Measurement of the acetabular depth. The acetabular depth was defined on transverse oblique images as the distance between the line connecting the anterior and the posterior acetabular rim and the centre of the femoral head. Control subject

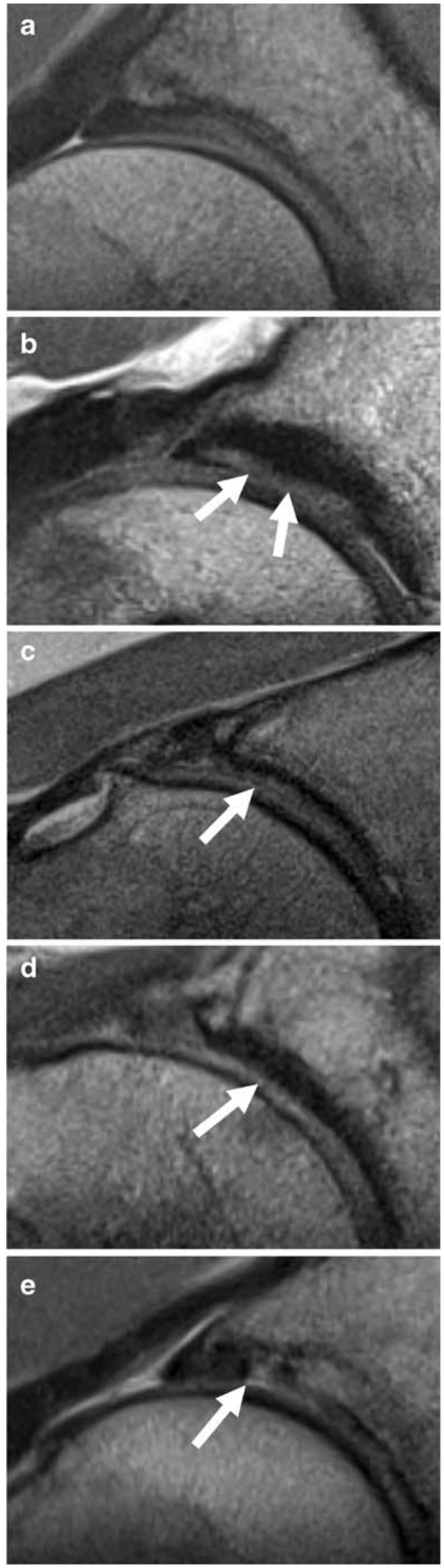

Fig. 3 Cartilage lesions in PD-weighted images. Acetabular cartilage was evaluated from radial 2D TSE PD-weighted MR images at five positions around the hip joint. **a** Grade 0 with smooth cartilage surface and no thinning in a control subject. **b** Grade 1 cartilage damage with heterogeneous cartilage signal (*arrows*). **c** Grade 2 with irregular cartilage surface. **d** Grade 3 with thinning of more than 50%. **e** Grade 4 with denudation of the subchondral bone

Table 1 Alpha angles in five positions around the femoral head. Data are mean values ± standard deviation

	Control group		Hips with slipped capital femoral epiphysis		
	Alpha angle (°)	SD	Alpha angle (°)	SD	*P* value*
Anterior	41.9	4.8	53.0	21.4	0.060
Anterosuperior	46.6	6.3	74.1	18.8	0.000
Superior	42.5	4.0	72.5	21.5	0.000
Posterosuperior	40.9	5.4	47.3	22.3	0.707
Posterior	39.4	4.0	25.0	7.2	0.002

**P* values were calculated using the Mann–Whitney *U* test

Results

Alpha angle

In both groups, the largest alpha angle was observed in the anterosuperior position of the femoral head and neck. In the SCFE group significantly increased alpha angles in the anterosuperior and superior positions were noted. The posterior angle was significantly decreased. The results are summarised in Table 1 and Fig. 4.

Acetabular depth

The acetabular depth was positive for both groups (Table 2). There was no significant difference in the acetabular depth of the affected hips of SCFE patients, compared with the control group (p=0.779). No significant correlation of acetabular depth and cartilage damage was noted (anterior: r=−0.061, p=0.727; anterosuperior: r=0.138, p=0.429; superior: r=0.160, p=0.359; posterosuperior: r=0.000, p=0.998; posterior: r=0.083, p=0.639).

Cartilage damage

No cartilage damage was observed in the control group.

In the affected hips, cartilage damage was most frequent and most severe in the superior position. A significant correlation between alpha angles and cartilage damage severity was noted in both the anterior and anterosuperior positions (Fig. 5, Table 3). In one affected hip, posterosuperior and posterior cartilage could not be assessed due to imaging artefacts.

Clinical function

In hips after SCFE internal rotation 90° flexion was 26°± 11°. Limited rotation correlated significantly with increased anterosuperior (r=−0.427, p=0.011), superior (r=−0.511,

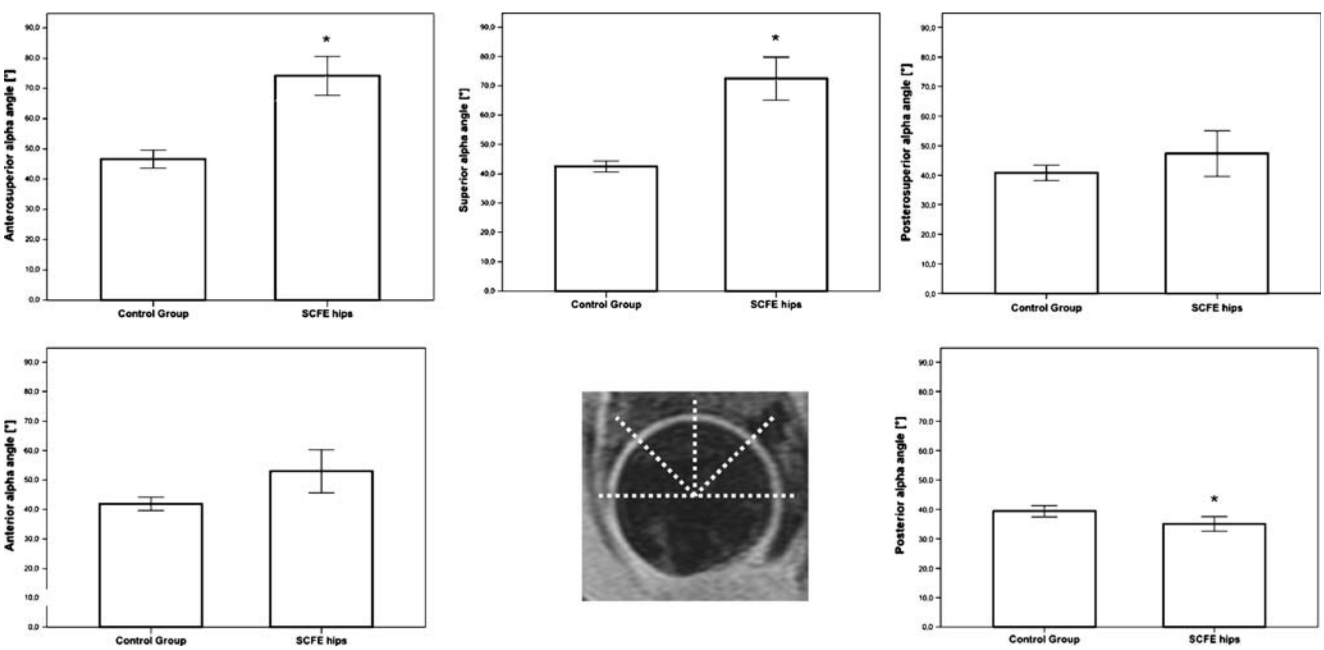

Fig. 4 Alpha angles in five positions around the femoral neck. Graphs show mean alpha angles, whiskers represent 95% confidence interval. *Significant difference from the control group (Mann–Whitney *U* test)

Table 2 Acetabular depth in patients with slipped capital femoral epiphysis and controls. Data are mean values ± standard deviation

	Control group		Hips with slipped capital femoral epiphysis		
	mm	SD	mm	SD	*P* value*
Acetabular depth	4.6	1.7	4.4	2.3	0.779

*Significant difference, compared with controls. *P* values were calculated using the Mann–Whitney *U* test

p=0.002) and posterosuperior (r=−0.471, p=0.004) alpha angles.

Discussion

Cam-type femoroacetabular impingement has been described as a possible mechanism for early cartilage damage and osteoarthritis of the hip [5, 6, 8, 29]. Clinically manifest SCFE, subclinical or missed SCFE and growth abnormalities of the capital femoral epiphysis [30] have been discussed as potential causes of a reduced femoral head–neck offset [1–5]. New surgical options aiming to restore femoral sphericity in order to prevent or delay early secondary osteoarthritis have recently been developed [4, 31], but widely discussed for their potential use in patients after SCFE. We found an increased alpha angle in affected hips after SCFE in the anterosuperior position (74.1°± 18.8°) and a correlation with cartilage damage in the anterosuperior and superior positions. The data point towards a similar localisation of asphericity and cartilage damage described in FAI and in patients after SCFE [2, 32–36].

In 6 hips with cam-type FAI, Bittersohl et al. found cartilage degeneration on delayed Gd-enhanced MRI of the cartilage (dGEMRIC) in anterior and superior positions [37]. In an MR arthrography study with 33 patients with cam-type FAI, Pfirrmann et al. report a dominance of cartilage lesions in the anterosuperior and superior positions [23]. Abraham et al. noted loss of superior articular cartilage in 16 head–neck specimens from SCFE patients [24]. Our findings are consistent with these reports. The presence of cartilage damage in the anterosuperior and superior positions after SCFE points towards a potential impingement mechanism, where the aspherical anterosuperior head–neck junction is forced into the acetabulum. The

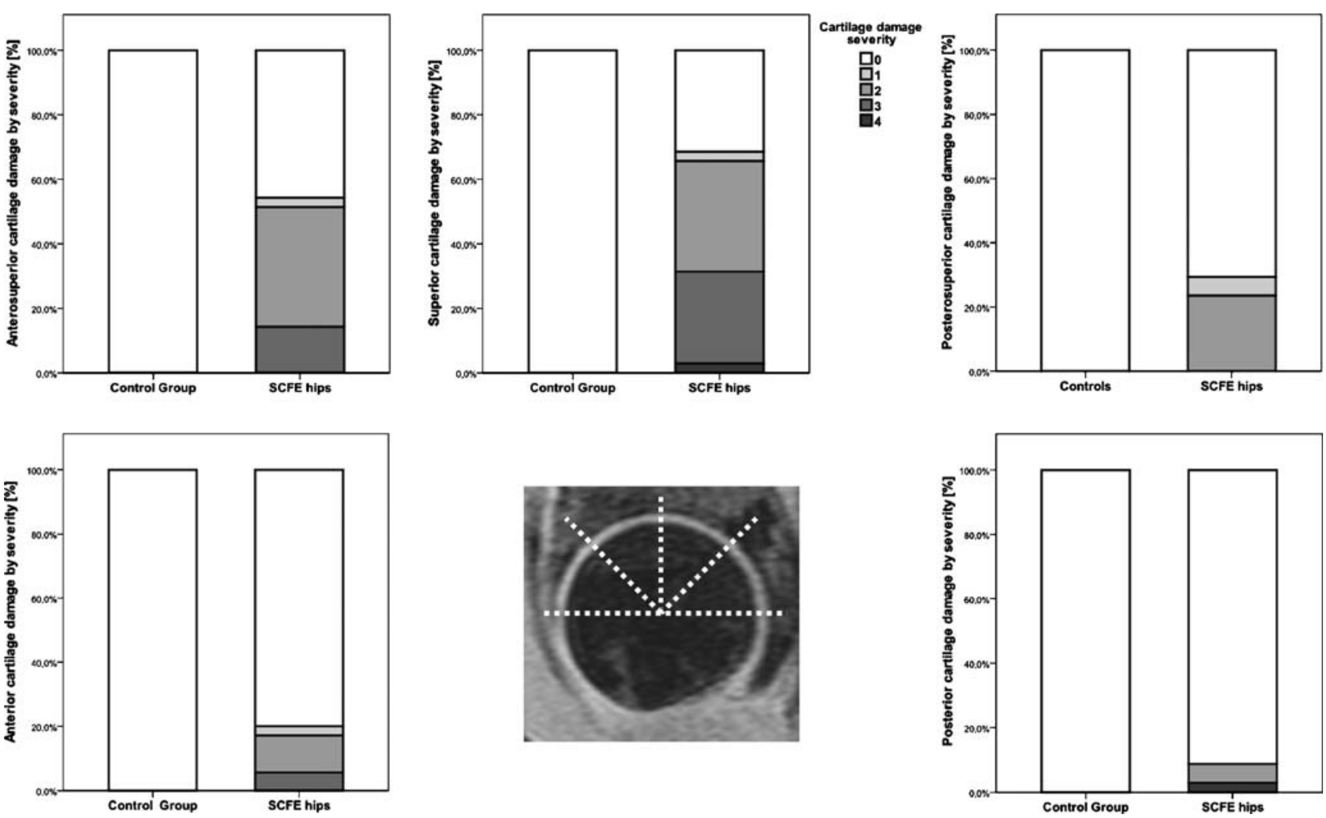

Fig. 5 Cartilage lesions in five positions around the femoral neck. Graphs show the percentages of valid cases

Table 3 Cartilage damage severity in five positions around the femoral head in patients with slipped capital femoral epiphysis. Data are absolute numbers and percentages of included hips

Position		Hips with slipped capital femoral epiphysis			
		n	Percentage	Spearman rho[a]	*P*
Anterior	Grade	0 28	80	0.399	0.018
	Grade 1	1	2.9		
	Grade 2	4	11.4		
	Grade 3	2	5.7		
	Grade 4	0	0		
Anterosuperior	Grade 0	16	45.7	0.355	0.036
	Grade 1	1	2.9		
	Grade 2	13	37.1		
	Grade 3	5	14.3		
	Grade 4	0	0		
Superior	Grade 0	11	31.4	0.180	0.302
	Grade 1	1	2.9		
	Grade 2	12	34.3		
	Grade 3	10	28.6		
	Grade 4	1	2.9		
Posterosuperior	Grade 0	24	68.6	0.084	0.638
	Grade 1	2	5.7		
	Grade 2	8	22.9		
	Grade 3	0	0		
	Grade 4	0	0		
Posterior	Grade 0	31	88.6	−0.089	0.619
	Grade 1	0	0		
	Grade 2	2	5.7		
	Grade 3	0	0		
	Grade 4	1	2.9		

[a] Correlations with the alpha angles in corresponding positions were determined using Spearman's correlation coefficient

result of this cam deformity is repeated microtrauma to the anterosuperior and superior hip cartilage during flexion and internal rotation leading to cartilage damage [38, 39].

Radiographs have been reported to be unreliable in the detection and localisation of femoral asphericity [20]. Conversely, measurements of the alpha angles on MRI scans of the hip assessing asphericity have reportedly shown high inter- and intraobserver agreement [21].

The predictive value of anterior alpha angles in FAI has been reported to be relatively low [22] and anatomical considerations indicate that deformities of the anterosuperior and superior aspects of the femoral head–neck junction produce significant effects [24]. In a study evaluating alpha angles at eight positions around the femoral neck in 33 patients with cam-type FAI, the highest alpha angle was found in the anterosuperior position (81°±15°) [23].

Nötzli et al. report alpha angles in the anterior position of 42.0°±2.2° in a healthy control group [21]. Beaulé's study group published alpha angles of 43.8°±3.9° for the anterior and of 43.8 °±4.5° for the posterior position for a healthy control group [40]. Our data for the normal cohort (anterior alpha angle 41.9°±4.8°, posterior alpha angle 39.4°±4.0°) are in accordance with these reports. There is no consensus on cut-off values for definite pathology [36], although alpha angles above 55° are considered pathological by some study groups [21, 41]. In our control group alpha angles ranged from 39.4°±4.0° in the posterior to 46.62°±6.3° in the anterosuperior position. Three control hips (15%) exceeded an anterosuperior alpha angle of 55°.

The lowest anterosuperior alpha angle in our SCFE group was 44.7°. There were 6 hips (17%) with anterosuperior alpha angles lower than 55°, which are possible due to successful metaphyseal remodelling after in situ pinning. A metaphyseal remodelling mechanism has been proposed as a process leading to good long-term results after in situ pinning in SCFE [42, 43]. In our SCFE group we noted a significantly decreased posterior alpha angle. This might represent an increased femoral head–neck offset due to the anterior and superior displacement of the femoral metaphysis in relation to the capital epiphysis commonly found in SCFE [44, 45].

Increased anterosuperior, superior and posterosuperior alpha angles were associated with limited internal rotation in flexion. These data support the proposal that this clinical test is suggestive of FAI [25]. The absence of a significantly increased anterior alpha angle and the lack of a significant correlation between the anterior alpha angle and limited hip rotation are constituent with the report of Lohan et al., who found a low predictive value for the anterior alpha angle in patients imaged for FAI [22].

In the majority of FAI cases, a combination of cam and pincer-type FAI mechanisms has been reported [7]. Pincer-type FAI is characterised by acetabular over-coverage with direct contact between the acetabular rim and the femoral head–neck junction. Recurrent abutment against the acetabular rim and the labrum causes labral degeneration, ossification and cartilage lesions [46]. The pincer-type abnormality of the hip is associated with an increased acetabular depth, which can be directly measured on paraxial MRI scans of the hip [23]. No decreased acetabular depth in the patients after SCFE and no significant difference compared with the normal cohort were noted within our study. These data do not support a pincer-type acetabular morphology mechanism in the follow-up after SCFE.

This study has several limitations. No true gold standard such as surgical or histological data for the quality of the hip cartilage of our patients was available and the sensitivity of MRI is still limited. However, because the observed degree and location of asphericity and cartilage damage are in accordance with the literature, we believe they may constitute a representative group. Femoral cartilage could not be evaluated separately because of limited resolution; therefore, irregularities in the cartilage surface cannot be reliably attributed to the acetabular cartilage alone. In addition, an intra-articular contrast agent was not used in this study for reasons of patient safety. It is proposed to have achieve sensitivity and specificity in the detection of cartilage damage [47], which may have resulted in underdiagnosis of cartilage lesion severity in some cases. However, good agreement between the grading of hip articular cartilage damage on non-contrast MRI with arthroscopic grading has been reported [48]. A further limitation to the study is the lack of a second follow-up; this way, no data can be presented on the predictive value of femoral head asphericity in the development of FAI after SCFE or on the benefit of surgical femoral head remodelling.

In conclusion, the anterior alpha angle alone may not be the optimal measure of the femoral head–neck junction in patients after SCFE and may underestimate the amount of asphericity in the follow-up assessment. Anterosuperior and superior asphericity are the dominant findings in the follow-up after SCFE and are associated with impaired hip rotation and cartilage degeneration. Imaging protocols should be designed to allow assessment of the contour of the femoral head–neck offset in these positions. Further studies are needed to address the value of alpha angle measurement and cartilage assessment in the follow-up after SCFE in correlation with clinical outcome.

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