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Ultrasound for the evaluation of femoroacetabular impingement of the cam type. Diagnostic performance of qualitative criteria and alpha angle measurements

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Abstract *Objective* To develop and assess a technique to evaluate cam type femoroacetabular impingement (FAI) using ultrasound (US). *Methods* Fifty patients (24 women, 26 men) were included (mean age: 39.1years; age range: 16–59). US images of the anterior and anterosuperior contour of the femoral neck were obtained and analysed in 50 patients. Non-spherical shape of the head-neck junction (cam deformity), bony protuberances at the femoral neck, shape of the femoral neck (waist deficiency) and alpha angle were assessed. Magnetic resonance (MR) arthrography served as the standard of reference. Diagnostic performance and receiver operating characteristics (ROC) curves were calculated. *Results* Based on MR arthrography 28 patients had cam-type FAI. On US, an anterosuperior cam deformity was seen in 40/44 patients (Reader 1/Reader 2; sensitiv-

ity 93%/89%, specificity 36%/14%). A bony protuberance anterosuperiorly in 23/13 patients (sensitivity 71%/32%, specificity 86%/82%) and an anterosuperior waist deficiency in 19/35 patients (sensitivity 25%/54%, specificity 100%/54%). Sensitivity and specificity of the other criteria were lower than 70% (average of Reader 1 & 2). *Conclusion* A technique to evaluate cam type FAI using US is presented. The detection of an anterosuperior cam deformity is sensitive, and presence of an anterosuperior bony protuberance is specific for cam FAI. Alpha angle measurements are not helpful in establishing the diagnosis.

Keywords Femoroacetabular impingement · Cam deformity · Ultrasound · Alpha angle · Magnetic resonance imaging

Introduction

Femoroacetabular impingement is a known aetiology of premature osteoarthritis of the non-dysplastic hip [1–5]. Cam and pincer types of FAI have been proposed [1, 6]. In young athletic individuals FAI of the cam type is predominant. A prevalence of 17% in men and 4% in women has been reported [7]. The cam type is characterised by a non-spherical shape of the femoral head at the junction to the femoral neck (cam deformity), reduced waist of the femoral neck, and bony protuberances generally at the anterior and anterosuperior aspect of the femoral neck [4, 8–11]. This deformity leads to jamming of the femoral head into the anterior and anterosuperior

acetabulum resulting in early chondral and labral damage due to recurrent microtrauma [12–14].

Cam impingement may be treated by open or arthroscopic restoration of a physiological waist and removal of bony protuberances [5, 15, 16] at a low rate of complications [2, 16, 17]. These procedures aim to prevent or delay additional degeneration of the hip joint. Patients with no or mild osteoarthritis have a substantially better outcome than patients with advanced cartilage damage [15].

Groin pain is a very early complaint of patients suffering from FAI but its differential diagnosis is very wide: stress fractures of the femoral neck, iliopsoas tendonitis, tears of the adductor tendons, nerve entrapment

syndromes and inguinal hernia are only a few of the possible underlying conditions leading to groin pain, especially in athletes [18]. Therefore, a history of groin pain is an early, but non-specific finding of FAI. Diagnosis is additionally suspected based on clinical examination (impaired internal rotation and flexion of the hip joint) [1, 19, 20]. Plain radiography and magnetic resonance (MR) imaging are used to confirm the diagnosis, to exclude some of the differential diagnostic possibilities, and to assess the degree of joint damage for treatment planning.

Early recognition of FAI is important because patients with osteoarthritic changes do substantially worse post-operatively [5, 15, 16, 21, 22]. Delay in diagnosing the underlying condition or misdiagnosis may be associated with prolonged training interruptions, unnecessary medical and surgical treatments, and last but not least potentially more pronounced cartilage damage [1, 5, 23]. Therefore, a cost-effective, fast and widely available technique for early detection of patients with FAI is of interest. An examination technique based on ultrasound (US) would meet these criteria. Thus, the purpose of our study was to develop and assess a technique to evaluate femoroacetabular cam deformity using US.

Materials and methods

The institutional review board approved the study. Written informed consent was obtained from all patients.

Patients

Patients with suspected FAI of the cam-type based on clinical examination were included in the study. Clinical examination was performed by the referring orthopaedists and included tests for the evaluation of internal rotation and flexion of the hip joint [14, 24–26]. Patients with inflammatory diseases, tumours, previous hip surgery, developmental hip dysplasia, and vascular necrosis of the femoral head were excluded from the study. In total, 50 patients (mean age: 39.1 years; age range: 16–59) out of 68 consecutive patients referred for MR arthrography from the orthopaedic outpatient clinic were included in the study. There were 24 women (mean age: 40.1 years; age range: 18–58) and 26 men (mean age: 32.6; age range: 16–59).

Eighteen patients (mean age: 35.2 years; age range: 16–59) had to be excluded because of previous surgery to the hip joint ($n=8$), developmental dysplasia of the hip ($n=6$), and avascular necrosis of the femoral head ($n=2$).

Clinical information about the patients was gathered from the referring orthopaedists. In particular, the presence or absence of groin pain, increase of groin pain upon physical exercise, pain at night, and impaired internal rotation and flexion of the hip was documented in each patient.

Ultrasound

Ultrasound was performed before MR arthrography using a curved array transducer with 2–5 MHz frequency range (iU22 Ultrasonography System, C5-2 curved array transducer, Philips Medical Systems, DA Best, The Netherlands). US was performed by a radiologist with 4 years of experience in US who was blinded as to the MR findings (BFM). The examination was performed with the patient in a supine position and neutral position of the hip joint and leg.

Longitudinal images of the anterior and anterosuperior head-neck contour were obtained in a transverse oblique plane parallel to the axis of the femoral neck (Fig. 1) and labelled “anterior contour” or “anterosuperior contour” for the reviewers. The anterior contour was evaluated with the transducer perpendicular to the skin surface. The anterosuperior contour was evaluated in almost the same position, but with the transducer slightly more cranial and angled 45° caudally. All US images were saved in the picture archiving and communication system (PACS).

Analysis of ultrasound

Two musculoskeletal radiologists with 14 years (ZM) and 18 years (HJ) of experience in musculoskeletal radiology analysed all US images independently and were blinded to the results of MR imaging. Three qualitative criteria were evaluated at the anterior and anterosuperior head-neck contour: Presence or absence of a non-spherical head-neck junction (cam deformity) (Fig. 2), presence or absence of focal bony protuberances at the femoral neck (Fig. 3), and shape of the osseous contour of the femoral waist (concave, flat, convex) (Fig. 4). In the qualitative evaluation, a cam deformity was defined as the presence of a non-spherical head-neck junction (Fig. 2) evaluated by visual judgement before measurement of the alpha angle. The labrum was not assessed.

Quantification of the cam deformity (alpha angle measurement) was performed in a five-step procedure (Fig. 1): First, a tangent line from the distal insertion of the joint capsule (point A in Fig. 1e) to the femoral head contour was drawn (Fig. 1e). This line served as an approximation for the femoral neck axis. Then, a circle was defined by three points (Points B, C, D in Fig. 1f) on the contour of the femoral head. To prevent measurement errors due to a femoroacetabular cam deformity, all three points were placed on the spherical portion of the proximal femoral head contour. The first point (Point B in Fig. 1f) was placed where the tangent line drawn in step 1 touched the femoral head contour. The second point (Point D in Fig. 1f) was placed on the most proximal femoral head contour that was visible. The third point (Point C in Fig. 1f) was placed in the middle between the first two points.

In a third step, the centre axis of the femoral neck was drawn as a parallel line to the first tangent line and

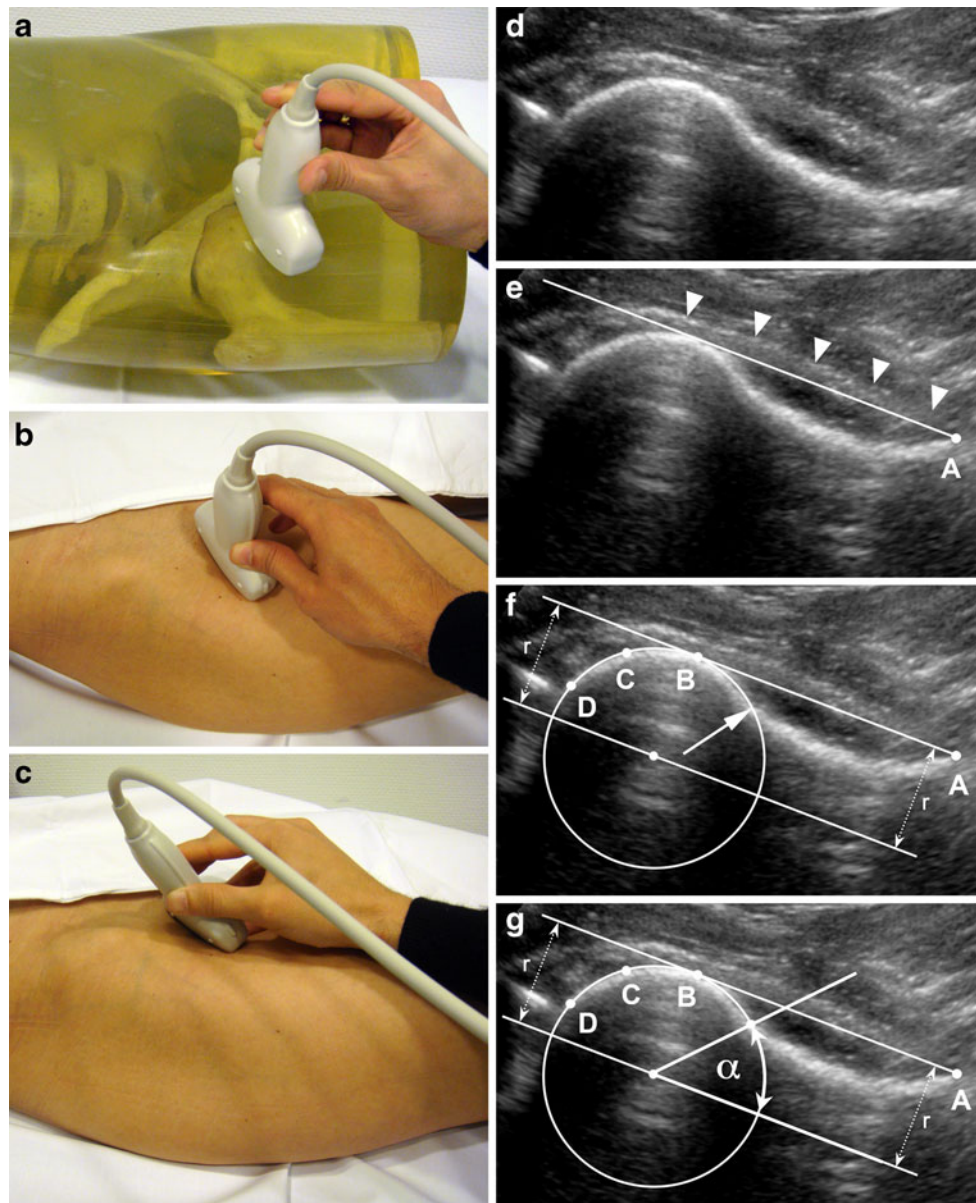


Fig. 1 Photograph illustrating the US probe position to evaluate the anterior (a, b) and anterosuperior (c) femoral neck contour in a hip phantom consisting of a human hip skeleton embedded in anatomically shaped acrylic glass (a) and a patient (b, c) and the corresponding US image of the anterior osseous contour as evaluated in b (d). Measurement of the alpha angle was performed in a five-step procedure: First, a tangent line from the distal insertion (a) of the joint capsule (arrowheads) to the femoral head contour was drawn (e). This line served as an approximation for the femoral neck axis. Then, a circle was defined by three points (b–d) on the contour of the femoral head (f). The first point (Point B in f) was placed where the tangent line drawn in step 1 touched the

the centre of the femoral head (Fig. 1f). Then, the point where the femoral head contour crossed the circle defined in step 2 was identified (white arrow, Fig. 1f). Finally, the alpha angle was measured (Fig. 1g) in accordance with the method described by Nötzli and co-workers [25].

femoral head contour. The second point (Point D in f) was placed on the most proximal femoral head contour that was visible. The third point (Point C in f) was placed in the middle between the first two points. To prevent measurement errors due to a femoroacetabular cam deformity, all three points were placed on the concentric portion of the proximal femoral head contour. In a third step, the centre axis of the femoral neck was drawn as a parallel line to the first tangent line and the centre of the femoral head (f). Then, the point (arrow) where the femoral head contour crossed the circle defined in step 2 was identified (f). Finally, the alpha angle was measured (g) in accordance with the method described by Nötzli and co-workers [25].

MR arthrography

Intra-articular contrast media were injected in a standardised fashion by a musculoskeletal radiologist. After fluoroscopic confirmation of the intra-articular position of the tip of the needle with 1 mL of an iodinated contrast agent (iopamidol

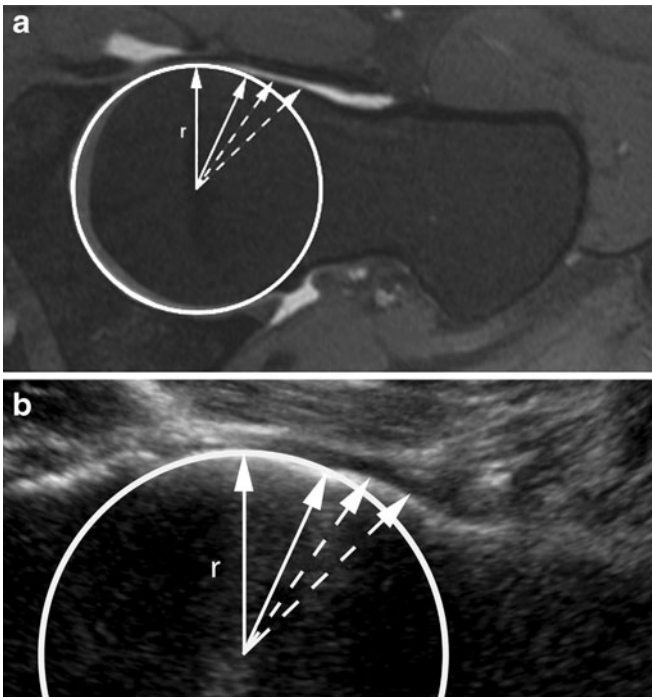


Fig. 2 A 34-year-old man with a laterally increasing radius of the femoral head at the anterior contour consistent with cam impingement (*arrows*, normal radius; *dashed arrows*, increased radius). Comparison of the imaging techniques. **a** MRI. **b** US

200 mg/mL, Iopamiro 200, Bracco, Milan, Italy), 8 mL of a diluted MR contrast agent (gadopentetate dimeglumine, Magnevist, Bayer Pharma, Berlin, Germany) at a concentration of 2 mmol/L were injected.

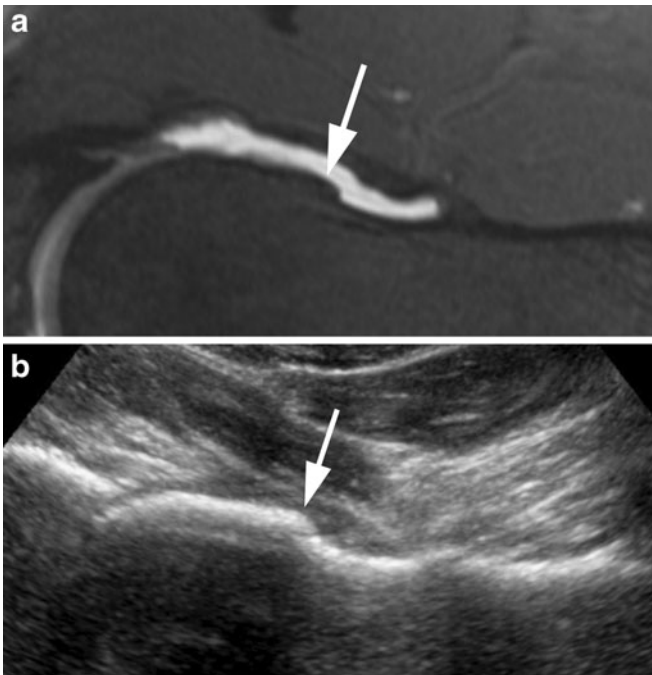


Fig. 3 A 36-year-old woman with a bony protuberance at the anterosuperior head-neck junction (*arrow*) consistent with cam impingement. Comparison of the imaging techniques. **a** MRI. **b** US

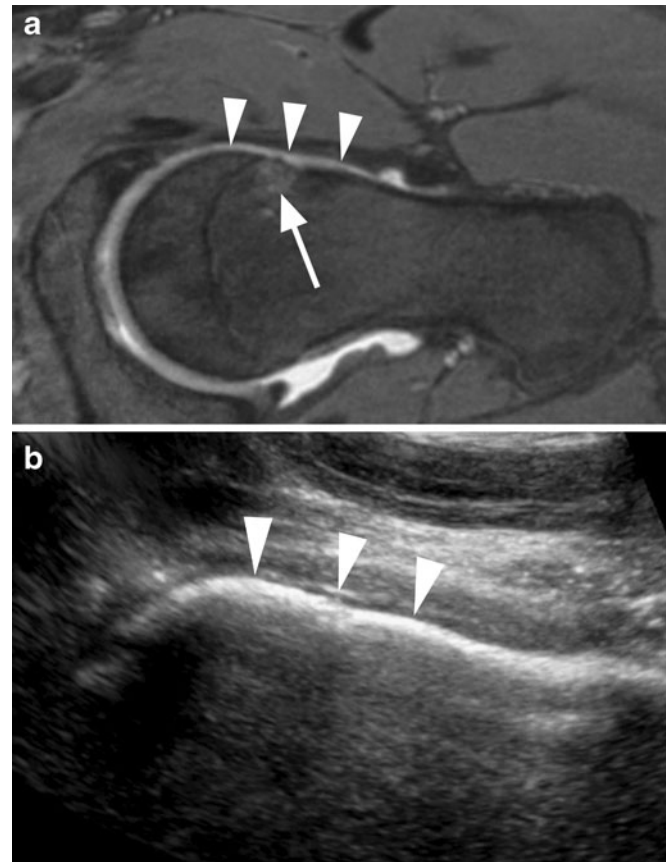


Fig. 4 A 40-year-old man with considerable waist deficiency consistent with cam impingement (*arrowheads*). Comparison of the anterior contour of the femoral head-neck junction using MRI (**a**) and US (**b**). Bone marrow edema pattern is seen at the typical location of the anterior aspect of the femoral neck (*arrow* in **a**)

MR imaging was performed with one of two 1.5-T systems (Avanto or Espree; Siemens Medical Solutions, Erlangen, Germany). The examination was performed in the supine position with the hip joint in a neutral position. The following sequences were acquired: coronal T1-weighted spin-echo sequence (section thickness, 3 mm; repetition time, 604 ms; echo time, 13 ms; field of view, 16 cm; matrix, 512×512), coronal intermediate-weighted fast spin-echo sequence with fat saturation (section thickness, 3 mm; repetition time, 3520 ms; echo time, 39 ms; field of view, 16 cm; matrix, 512×512; turbo factor, 7), sagittal water excitation three-dimensional double-echo steady-state sequence (section thickness, 1.7 mm; repetition time, 25 ms; echo time, 9 ms; field of view, 15 cm; matrix, 512×512), sagittal T1-weighted spin-echo sequence (section thickness, 4 mm; repetition time, 550 ms; echo time, 13 ms; field of view, 16 cm; matrix, 512×512), transverse oblique (parallel to the long axis of the femoral neck) water-excitation true fast imaging with steady-state precession sequence (section thickness, 1.25 mm; repetition time, 8.9 msec; echo time, 3.3 msec; flip angle, 28°; intersection gap, none; field of view, 17 cm; matrix, 512×512). The transverse oblique three-

dimensional data set was used for radial reformations by using the long axis of the femoral neck as a rotation axis [8].

Standard of reference

Two musculoskeletal radiologists with 2 years (BFM) and 10 years (PCWA) of experience in musculoskeletal radiology analysed all MR arthrographic images in consensus. The radiologists were not involved in the US evaluation and were blinded to its results. In the presence of a cam deformity and/or femoral waist deficiency the diagnosis of FAI of the cam type was established, disregarding the alpha angle measurement. The result of the MR evaluation served as a standard of reference.

Statistical analysis

Diagnostic performance of the qualitative criteria (sensitivity, specificity, positive and negative predictive value, and accuracy) was calculated. Receiver operating characteristics (ROC) curve analysis for alpha angles measured on ultrasound was performed. Interobserver agreement was evaluated using kappa statistics for qualitative criteria and intraclass correlation coefficient (ICC) for quantitative criteria. The results of the evaluation on the US and MR images were compared using descriptive statistics (qualitative criteria) and Pearson correlation coefficient (PCC; alpha angle measurements). SPSS (version, 16.0 mac; SPSS, Chicago, IL, USA) software was used for statistical analysis.

Results

Forty-seven patients suffered from groin pain, whereas the pain increased in 36 patients upon physical exercise (Table 1). Three patients had pain at night and 41 patients had impaired internal rotation and flexion of the hip.

The results of the analysis of the ultrasound examinations are presented in Table 2. Interobserver agreement was slight to moderate according to Landis and Koch [27] (Table 3). The calculated diagnostic performances of all the items evaluated are shown in Table 4.

Table 1 Symptoms of included patients

Symptom	Number of patients	FAI	No FAI
Groin pain	47	28	19
Increase of groin pain upon physical exercise	36	22	14
Pain at night	3	1	2
Impaired internal rotation and flexion of the hip	41	25	16

Abbreviations: *FAI* Patients with FAI; *No FAI* Patients without FAI.

Table 2 Sonographic findings

Finding	Reader 1	Reader 2
Non-Spherical Head-Neck Junction (Cam Deformity)		
Anterior	29	18
Anterosuperior	40	44
Focal Bony Protuberances at the Femoral Neck (Osseous Bump)		
Anterior	17	8
Anterosuperior	23	13
Flat or Convex Osseous Contour of the Femoral Neck (Waist Deficiency)		
Anterior	19	7
Anterosuperior	35	24

Mean anterior and anterosuperior alpha angle measured by reader 1 was 64.8° (range, 31°–89°; standard deviation, 12.5°) and, 69.5° (range, 43°–94°; standard deviation, 11.7°), respectively. Reader 2 measured a mean anterior and anterosuperior alpha angle of 57.1° (range, 34°–83°; standard deviation, 15.0°) and 72.7° (range, 38°–90°; standard deviation, 11.2°), respectively. The ICC for the quantitative interreader agreement was moderate for both anterior and anterosuperior alpha angle measurements (Table 3).

The results of the evaluations on the US and MR images matched as follows: The presence of a cam deformity at the anterior contour matched in 48% ($n=24$) for Reader 1 and in 66% ($n=33$) for Reader 2; at the anterosuperior contour in 64% ($n=32$) for Reader 1 and 56% ($n=28$) for Reader 2. Bony protuberances at the anterior contour matched in 48% ($n=24$) for Reader 1 and in 60% ($n=30$) for Reader 2. Corresponding values for bony protuberances anterosuperiorly were 78% ($n=39$) for Reader 1 and 50% ($n=25$) for Reader 2. Concerning the presence of an anterior waist deficiency, Reader 1 agreed with the evaluation on MR images in 66% ($n=33$) and Reader 2 in 78% ($n=39$); anterosuperiorly 50% ($n=25$) and 32% ($n=16$), respectively.

The alpha angle measurements of reader 1 showed a strong, significant relationship with the measurements on MR images (anterior measurements: PCC 0.891, $p<0.001$;

Table 3 Interobserver agreement

Ultrasound qualitative evaluation		Kappa	P
Presence of a cam deformity			
Anterior		0.196	0.126
Anterosuperior		0.265	0.050
Presence of a bony protuberance at the femoral neck			
Anterior		0.335	0.008
Anterosuperior		0.168	0.191
Waist deficiency			
Anterior		0.420	0.000
Anterosuperior		0.252	0.048
Alpha angle measurements			
		ICC	P
Alpha angle	Anterior	0.515	0.006
	Anterosuperior	0.509	0.007

Abbreviations: *ICC* Intraclass correlation coefficient.

Table 4 Diagnostic performance of qualitative read-out criteria

	TP	TN	FP	FN	Sens	Spec	PPV	NPV	Acc
Presence of a cam deformity									
Anterior									
R1	19	12	10	9	68%	55%	66%	57%	62%
R2	14	18	4	14	50%	82%	78%	56%	64%
Anterosuperior									
R1	26	8	14	2	93%	36%	65%	80%	68%
R2	25	3	19	3	89%	14%	57%	50%	56%
Presence of a bony protuberance									
Anterior									
R1	11	16	6	17	39%	73%	65%	48%	54%
R2	6	20	2	22	21%	91%	75%	48%	52%
Anterosuperior									
R1	20	19	3	8	71%	86%	87%	70%	78%
R2	9	18	4	19	32%	82%	69%	49%	54%
Waist deficiency									
Anterior									
R1	14	17	5	14	50%	77%	74%	55%	62%
R2	25	12	10	3	89%	55%	71%	80%	74%
Anterosuperior									
R1	7	22	0	21	25%	100%	100%	51%	58%
R2	15	13	9	13	54%	59%	63%	50%	56%

Abbreviations: *TP* true-positive. *TN* true-negative. *FP* false-positive. *FN* false-negative. *Sens* sensitivity. *Spec* specificity. *PPV* positive predictive value. *NPV* negative predictive value. *Acc* accuracy. *R1* reader 1. *R2* reader 2.

anterosuperior: PCC 0.889, $p < 0.001$). The measurements of reader 2, however, showed only a poor to moderate relationship (anterior measurements: PCC 0.425, $p = 0.002$; anterosuperior: PCC 0.199, $p = 0.165$).

ROC curves (Fig. 5) were plotted for the alpha angle measurements. The results are provided in Table 5. ROC analysis for anterior alpha angle measurements demonstrated areas under the curve of 0.581 ($p = 0.328$) for

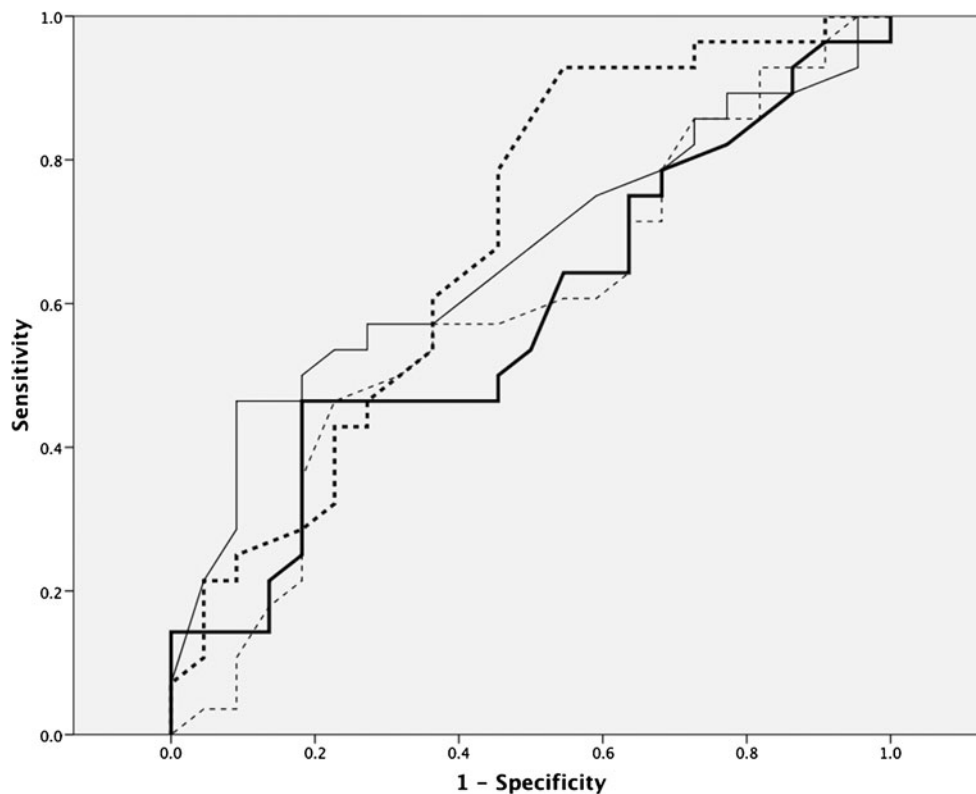


Fig. 5 Receiver operating characteristics (ROC) curves for ultrasound alpha angle measurements. *Solid lines* show the results of the anterior measurements (Reader 1, *thick line*; Reader 2, *thin line*). *Dashed lines*

show the results of the anterosuperior measurements (Reader 1, *thick line*; Reader 2, *thin line*)

Table 5 Receiver operating characteristics (ROC) curve analysis: area under the curve of the alpha angle measurements using US

Measurement		Area	SD	P	95% confidence interval	
					Lower bound	Upper bound
Anterior	R1	0.581	0.082	0.328	0.412	0.741
	R2	0.665	0.077	0.047	0.514	0.815
Anterosuperior	R1	0.688	0.078	0.023	0.536	0.841
	R2	0.588	0.082	0.291	0.426	0.749

Abbreviations: *Area* area under curve in ROC. *SD* standard deviation. *R1* reader 1. *R2* reader 2.

Reader 1 and 0.665 ($p=0.047$) for Reader 2. Anterosuperiorly, the areas under the curve were 0.688 ($p=0.023$) for Reader 1, and 0.588 ($p=0.291$) for Reader 2.

Discussion

It is possible to visualise the anterior and anterosuperior osseous contour of the femoral neck and, in the opinion of the authors, look for the typical osseous configuration causing FAI of the cam type using US. However, no criterion with equally high specificity and sensitivity was found. Based on the osseous contour of the femoral neck, we defined and evaluated three qualitative criteria (cam deformity, waist deficiency and bony protuberances) and proposed a technique to measure the alpha angle. To the best of our knowledge, this is the first time evaluation of FAI of the cam type was attempted using US.

Ultrasound is widely available, inexpensive, and does not involve radiation exposure to the patient examined. These attributes are important for the examination of young patients. In particular, young men dedicated to high performance sports could benefit when cam FAI is diagnosed before damage of the joint occurs. In the country where the authors' institution is located screening for FAI of young men during army recruitment is currently evaluated. Standardised clinical measurement of the internal rotation of the hip joint is performed. Individuals with FAI of the cam type could be advised to change their type of sport (for example no martial arts, no ice hockey) or surgical treatment at an early stage may be initiated [28–30].

Detection of an anterosuperior cam deformity was a sensitive finding for FAI. The presence of an anterosuperior bony protuberance and a femoral waist deficiency were specific findings. However, looking at Table 4 the negative predictive value (NPV) for the presence of a cam deformity at the anterosuperior osseous contour was between 50% and 80%.

Likewise, the positive predictive values (PPV) for the presence of an anterosuperior bony protuberance and a femoral waist deficiency and interreader agreement were not high enough for the recommendation of US as a screening tool for FAI.

In the clinical situation, this makes additional imaging such as plain radiographs and MRI necessary in these patients. From a patients perspective one-stop-shop imag-

ing is to be preferred and this would certainly hamper the implementation of US.

The anterosuperior osseous contour seems to be more useful for the assessment of cam FAI than the anterior contour. This finding is in line with an article by Pfirrmann and co-workers [8] evaluating the specific location of cam deformities at the femoral head-neck junction. The authors demonstrated a predominance of the cam deformity at the anterosuperior aspect compared with the anterior aspect of the femoral neck.

In our study, the measurement of alpha angles did not prove to be helpful. There may be two possible reasons for this. First, US and the measurement technique we have developed may have some limitations: We made the assumption that the femoral neck axis is parallel to, or at least in a constant relationship with, a line drawn from the insertion of the joint capsule at the femoral neck to the femoral head. Additionally, any malalignment of the US transducer to the femoral neck could have led to distortion of the osseous contour of the femoral neck and consecutively to measurement errors.

Second, the alpha angle itself could be an unreliable criterion for diagnosing FAI. Several recent articles support the thesis that alpha angle measurements are not very helpful in the evaluation of FAI. Lohan et al. [31] found a considerable variability of alpha angle measurements performed on MR images. Statistically they found no value of alpha angle measurements in suggesting the presence or absence of cam FAI. Nohu and co-workers [32] assessed the value of a subjective assessment of the alpha angle on MR images. Measurement of the alpha angle served as the standard of reference. Because of the quite low areas under the curve (≤ 0.606) of the ROC analysis they concluded that subjective assessment of alpha angles is not optimal unless one is quite confident about a bony abnormality.

Because many intra-articular abnormalities, like labral tears and chondral lesions are not accessible to US, US has limitations in the evaluation of patients with groin pain. Because up to 76% of cases of FAI are of a mixed type (cam FAI and pincer FAI combination) and because it is not possible to address the pincer component with US, additional imaging may be needed for a comprehensive evaluation of FAI [33, 34]. In our study, there were no patients with a pincer FAI only. However, in the hands of an experienced ultrasonographer the presented qualitative criteria can be useful in suggesting the diagnosis of a FAI as the cause of the patients' complaints and a cam FAI component can be assessed.

Contrary to the US evaluation of hips in newborns, the mature skeleton is fully mineralised and therefore not all parts of the hip joint may be visualised. This renders US evaluation of the hip in adults considerably more difficult. In our study, US evaluation of alpha angles is characterised by a moderate interreader agreement (ICC 0.509–0.515) only. Falliner et al. [35] and Simon et al. [36] reported a superior interreader agreement in ultrasound angle measurements at DDH (developmental dysplasia of the hip) screening in newborns (ICC 0.72–0.74) compared with the ultrasound angle measurements in our study. This superior interreader agreement can be partly explained by the new measurement techniques in our study and the mineralised skeleton in adults.

An alternative to MR imaging and US for visualising cam deformities is CT with 3D reconstruction [24]. 3D CT-based hip models may be used for kinematic hip analysis. However for CT of the pelvis radiation exposure is necessary which may be a problem because typically young patients suffer from cam impingement.

Limitations of our study include the selected group of patients from an orthopaedic clinic. The lack of a true gold standard, such as surgery, to prove cam-type impingement was another limitation. Because the use of US in the evaluation of FAI has not been presented before, data on

the interobserver variation with respect to repeated measurements would be beneficial. Concerning the alpha angle measurements, angulation of the US probe with respect to the femoral neck could potentially lead to different measurements because the measurement technique strongly relies on the tangent line from the distal insertion of the joint capsule to the femoral head contour. Finally, during the US examination, the observer may have lost his “blindness” to the presence of FAI based on symptoms that the patient had.

Ultrasound examination should preferably be performed in combination with standardised physical examinations and in collaboration with experienced orthopaedic surgeons. Based on the described qualitative criteria, it is possible to evaluate cam FAI using US and decide whether an additional plain radiograph or MR examination is required to substantiate the diagnosis of FAI and to demonstrate secondary damage of the cartilage and the labrum.

In conclusion, a technique to evaluate cam type FAI using US is presented. The detection of an anterosuperior cam deformity is a sensitive, and the presence of an anterosuperior bony protuberance is a specific finding for a cam FAI. Alpha angle measurements are not helpful in establishing the diagnosis.

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