Impingement by prominence at the femoral head-neck junction on the anterior acetabular rim may cause early osteoarthritis. Our aim was to develop a simple method to describe concavity at this junction, and then to test it by its ability to distinguish quantitatively a group of patients with clinical evidence of impingement from asymptomatic individuals who had normal hips on examination.

MR scans of 39 patients with groin pain, decreased internal rotation and a positive impingement test were compared with those of 35 asymptomatic control subjects. The waist of the femoral head-neck junction was identified on tilted axial MR scans passing through the centre of the head. The anterior margin of the waist of the femoral neck was defined and measured by an angle (α). In addition, the width of the femoral head-neck junction was measured at two sites.

Repeated measurements showed good reproducibility among four observers. The angle α averaged 74.0° for the patients and 42.0° for the control group (p < 0.001). Significant differences were also found between the patient and control groups for the scaled width of the femoral neck at both sites.

Using standardised MRI, the symptomatic hips of patients who have impingement have significantly less concavity at the femoral head-neck junction than do normal hips.

This test may be of value in patients with loss of internal rotation for which a cause is not found.

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Active young people occasionally present with groin pain which may be reproduced by internal rotation of the hip at 90° of flexion. If passive adduction increases the pain, the possibility of anterior impingement of the femoral neck on the acetabular rim or labrum should be considered. An abnormal anatomical relationship between the femoral head and neck acquired as a developmental deformity has been proposed as a cause of this impingement.2-9 The association, and subsequent damage to the joint, has been documented in subacute cases of slipped capital femoral epiphysis.4 Several studies suggest that milder deformities in patients without a history of developmental disease are a significant cause of osteoarthritis later in life.3,5,8 Stulberg et al10 assert that a so-called ‘pistol-grip deformity’ is present in 40% of patients who develop osteoarthritis of the hip. If there is such a relationship, early recognition and management of impingement are desirable.

Radiological criteria for anterior impingement are not well established. The term ‘pistol-grip’ describes a flattened head-neck junction seen on standard anteroposterior (AP) radiographs of the hip, but Goodman et al10 argue that the principal deformity in subclinical slipped epiphyses is in the sagittal plane and, as such, is not necessarily evident on AP views. Also, without a quantitative or objective definition, descriptions such as ‘pistol-grip’ and ‘post-slip’ cannot be used to determine the severity of the deformity or to distinguish normal from pathological shapes.

MRI is now commonly used in the evaluation of groin pain in the young athlete, because of its specificity and the broad range of conditions which can be detected when radiographs are negative.10 A recent study found evidence of reduced femoral neck anteversion and head-neck offset on standard MR scans of hips in patients with symptomatic impingement.11 Since there is no standardised, simple test for such abnormalities, we have developed a method for measurement of the head-neck relationship on MR scans. Our aim in this study was to confirm that young patients with clinical symptoms and signs of impingement also have abnormalities of the anterior femoral head-neck junction,
when compared with those who clearly do not have features of this syndrome, and to determine if the new test allows differentiation of normal from abnormal hips.

**Patients and Methods**

The series consisted of 39 consecutive patients, 26 men and 13 women, with groin pain, internal rotation less than 10° (+10 to -5) at 90° of flexion and a positive ‘impingement test’ with a radiologically normal acetabulum. A normal acetabulum was defined as having no protrusion, no retroversion, and a centre-edge (CE) angle of > 25° on standard radiographs. MRI of the pathological hips showed either a degenerate labrum or a labral tear and in 85% of all patients there was evidence of damage to acetabular cartilage, mainly anterolateral or, more rarely, in the area of the posterior rim. The mean age of the patients was 35 ± 9 years (18 to 57). The exclusion criteria were previous hip surgery or post-traumatic deformities, hip dysplasia, necrosis of the femoral head, septic or rheumatoid arthritis and advanced osteoarthritis (Tönnis grade ≥2).

For comparison, 40 volunteers with asymptomatic hips were examined and from these 35 with not less than 20° (20 to 40) of internal rotation at 90° of flexion and a negative impingement test were selected as a control group. Five were excluded because internal rotation was less than 20°, and two of these had, in addition, pain on forced adduction. The mean age of the remaining 17 men and 18 women was 30 ± 5 years (20 to 46). For ethical reasons, subjects who were excluded from the control group could not have radiographs to determine if there was an apparent cause for their restriction of movement. In both groups the range of movement was assessed by the same two orthopaedic surgeons (HPN, TFW). The hip was flexed to 90°, and during the rotational manoeuvres, rotation of the pelvis was minimised by using gentle movements and monitored by the position of the anterior iliac spine. The internal rotation in the two groups was different in accordance with the selection criteria. It averaged 30 ± 6° (20 to 40) for the control group and 4 ± 5° (+10 to -5) for the patient group.

In order to minimise exposure to radiation radiographs were only taken in the patients but MRI was carried out in all individuals as agreed by the Ethical Committee.

**MRI.** In the patients, MR arthrography was carried out using a 1T MR unit (Magnetom Expert; Siemens, Erlangen, Germany) and a flexible transmit/receive surface coil. All patients were examined in the supine position. Before MRI, 10 ml of MR contrast (4 mmol/l Gadoteridol; Bracco, Milano, Italy), 1 ml of a local anaesthetic agent (2%, Scandicain) and 1 ml of iodine contrast medium (200 mg Iopamiro; Bracco) were injected into the hip under fluoroscopic control. Following our standard MRI protocol, axial gradient-echo (FLASH) sequences (TR 400 ms, TE 11 ms, flip angle 60°, FOV 16 cm, matrix 256 × 256) were acquired parallel to the axis of the femoral neck and passing through the centre of the femoral head. This plane was defined individually on the basis of the coronal scout view (Fig. 1). It provides a view corresponding to a lateral radiograph with the plate parallel to the femoral neck.

In the control subjects, MR scans were acquired using a 0.5T MR system (Sigma Advantage SP; General Electric, Milwaukee, Wisconsin) and a flexible transmit/receive surface coil. There was no intra-articular injection of contrast medium because additional information on the quality of the cartilage was not thought to be important for this study, and also to minimise possible adverse effects on the volunteers. As in the patients, angled axial gradient-echo images (SPGR-Sequence) were obtained parallel to the axis of the femoral neck (TR 450 ms, TE 10 ms, flip angle 60°, FOV 16 cm, matrix 256 × 224).

**Evaluation.** Two different methods were used to quantify the concavity of the femoral head-neck junction.

**Method 1.** The anterior extent of the concavity of the femoral neck was defined as a point (A) where the distance from the bone to the centre of the head (hc) first exceeds the radius (r) of the cartilage-covered femoral head. The angle formed between the axis of the neck and a line connecting hc to point A was then measured. The axis of the neck was defined as a line passing through hc and the centre of the neck (nc) at its most narrow point (Fig. 2). Therefore a larger angle corresponds to diminished concavity or ‘waisting’ at the junction.

**Method 2.** The width of the femoral head-neck junction was measured at distances of r and r/2 (sites 1 and 2) from hc along the axis of the femoral neck. The perpendicular
distances to the anterior cortex (T1a and T2a) and posterior cortex (T1p and T2p) were recorded separately, and, to correct for individual size, expressed as ratios of r (Fig. 3).

Every measurement was done three times, and four examiners (two orthopaedic surgeons and two radiologists) measured the different variables independently. In order to determine the intraobserver reliability three measurements were taken at intervals of two weeks.

Statistical analysis. The intra- and interobserver measurements were made by analysis of a simple variable. Common QQ-plots showed that the distributions of the variables were approximately normal. Therefore Student’s t-distribution was used to test the hypothesis that normal hips can be distinguished from the pathological using the applied variables.

The association between variables was tested using the Pearson product moment correlation coefficient after a normal distribution was confirmed.

Results

Measuring technique. The measurements showed an intraobserver variation of ±2% for T1a/r and T2a/r anterior and for the angle α of ±3%. The interobserver value showed differences of ±5% for T1/r, ±3% for T2/r and ±7% for the angle α.

MRI. The mean angle α was 42.0 ± 2.2° (33 to 48) in the control group and 74.0 ± 5.4° (55 to 95) in the patients (p < 0.001). The relationship between the width of the femoral neck (T1a + T1p/2r; T2a + T2p/2r) and the diameter of the femoral head showed a significant difference between the two groups at both sites (p < 0.001). In the group with normal rotation of the hip, T1a/r was 0.61 ± 0.02, and in the pathological joints 0.73 ± 0.05 (p < 0.001). T2a/r was 0.85 ± 0.01 in the control group and 0.93 ± 0.03 in the pathological joints. On the basis of the MR scans, neither acetabular anteversion nor the CE angle differed significantly between the two groups. Normal and pathological α angles are shown in Figure 4. Whereas a good correlation was found between T1a/r and α for the normal hips (r = 0.75, p < 0.001) and between T2a/r and α (r = 0.82, p < 0.001) for the pathological hips, the correlation between internal rotation and α was relatively poor within both normal (r = 0.66, p < 0.001) and pathological hips (r = 0.51, p = 0.001).

Discussion

In a concentric joint, internal rotation of the hip can be limited by soft-tissue contractures or masses, and by structural abnormalities of the acetabulum or proximal femur. The measurements tested here were specifically intended to identify and to quantify an abnormal contour of the head-neck junction uninfluenced by the orientation of the neck or
acetabulum. Using these specific measurements, and especially angle $\alpha$, clear differences were observed between a group of patients with painfully limited rotation and asymptomatic individuals with normal rotation. This finding suggests a close correlation between symptomatic limitation of combined hip internal rotation/adduction and reduced concavity of the anterior femoral head-neck junction.

Structural abnormalities at the head-neck junction in skeletally mature individuals have been associated with osteoarthritis of the hip.\textsuperscript{2,3,5,7-9,13} Since most patients have no previous history of hip disease, the aetiology of the deformity is unproven, but several investigators have implicated subclinical displacement of the femoral epiphysis as a risk for osteoarthritis.\textsuperscript{3,5,8,11,13} The terms ‘head-tilt’ and ‘post-slip’ describe this mechanism. Stulberg et al\textsuperscript{8} introduced the term ‘pistol-grip deformity’ to describe the radiological appearance of an abnormal head-neck relationship on AP radiographs. While they noted that this deformity is found predominantly in active men and is present in many patients with so-called ‘idiopathic’ arthritis, they did not elucidate the pathological mechanism involved.

If head-neck deformities are a significant factor in the development of arthritis, efforts should be devoted to earlier detection, treatment or prevention. At present, there is no accepted method of identifying hips which are at risk and the criteria for an abnormal head-neck relationship are not defined. Murray\textsuperscript{5} used AP radiographs to characterise the tilt deformity of the femoral head. He constructed the axis of the femoral neck by using the midpoint between the trochanters and the narrowest portion of the femoral neck as landmarks and then calculated a ‘femoral head ratio’ by dividing the width of head above the axis by that below. Using skeletal preparations Goodman et al\textsuperscript{3} showed that, as in the slipped capital femoral epiphysis, the deformity of the neck is three-dimensional and predominantly anterior. They therefore advocated the use of a true lateral view to describe the deformity. The assessment of the deformity in the axial plane has become of interest because deformities at the anterior head-neck junction have been implicated as the mechanism of ‘anterior rim’\textsuperscript{14} or femoro-acetabular‘ impingement.\textsuperscript{11} The measurement techniques used are technically demanding and therefore not suitable for clinical application. Furthermore, they do not provide a quantitative standard by which a normal femoral head-neck junction can be distinguished from an abnormal junction. Our technique describes the anterior relationship of the femoral articular surface to the femoral neck and therefore identifies deformities not apparent on AP radiographs. Especially when used without contrast, MRI is straightforward, relatively inexpensive and, of course, does not involve exposure to radiation. Positioning is simple because as long as the thigh is horizontal the measurement is not affected by the alignments of the neck or joint contractures. The technique of measurement is also simple. It differs from that described by Murray\textsuperscript{5} and Goodman et al,\textsuperscript{3} because the ‘neck axis’ passes through the centre of the femoral head. This axis was chosen, in part, because identification of the lateral landmarks or the metaphysis used in other studies is more complex than finding the centres of the head and neck. The simplicity of our method is confirmed by the high degree of intra- and interobserver agreement. Observer agreement diverged only with those hips with the largest $\alpha$ angles, in a range that placed all of them well within the abnormal group.

As shown in Figures 1 and 2, the axis of the neck clearly indicates how changes in its contour affect the functional articular surface of the head. Widening of the neck anterior to this line reduces the concavity of the neck just as a thicker prosthetic neck reduces the potential movement of a hip replacement. Similarly, the point A where the distance between the centre of hip rotation (head centre) and the anterior cortex exceeds the radius of the joint represents the point at which no more of the femoral head can enter the concentric portion of the acetabulum. All causes of impingement due to the shape of the junction such as a wide neck, formation of osteophytes or displacement of the head posteriorly, will cause angle $\alpha$ to be high. Remote causes of impingement such as neck or acetabular retroversion or
acetabular osteophytes will not affect the measurements, but may explain the relatively poor correlation between angle $\alpha$ and internal rotation.

Given the specificity of the tests, the separation of the study groups reveals a close relationship between the absence of internal rotation and the contour of the femoral head-neck junction. The patients included in the pathological group were individuals who sought treatment for pain in the hip and who had a positive impingement test often without an obvious cause on radiographs. All showed some degree of articular damage on the MRI contrast study in the region of potential impingement, a finding which correlates with intraoperative findings in early degenerative arthritis. Therefore, it is likely that this relatively simple measurement could accurately detect clinically significant impingement of the rim in individuals with suspicious findings, but no obvious abnormality on conventional radiography.

It remains to be shown whether subjects with large $\alpha$ angles (>50$^\circ$) and a positive impingement test are limited by contact between the anterior neck and the acetabular rim. Demonstration of impingement will require use of open MRI not available when the symptomatic group was studied. Also, because the control group was selected to have >20$^\circ$ of internal rotation, it is not known whether asymptomatic hips with limited movement have abnormal $\alpha$ angles, or if they impinge, but in a way that is not painful or damaging. We chose 20$^\circ$ because the control group was intended to be normal, and without radiographs, ‘normal’ was defined as asymptomatic with normal movement. The five subjects examined for and excluded from the control group, had limited internal rotation between 10$^\circ$ and 15$^\circ$ and two of these experienced pain in the groin when examined. We believe that it was reasonable to assume that these individuals were abnormal and at risk for hip disease and thus to exclude them. Since these were volunteers recruited in a clinical study, documentation of this by radiography or MR arthrography was not permissible. The documented incidence of osteoarthritis of the hip in European populations may be as high as 10% and, if as Harris asserts, 95% of these can be traced to anatomical abnormalities, the fact that 12% of the potential control group were abnormal should be expected.

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References