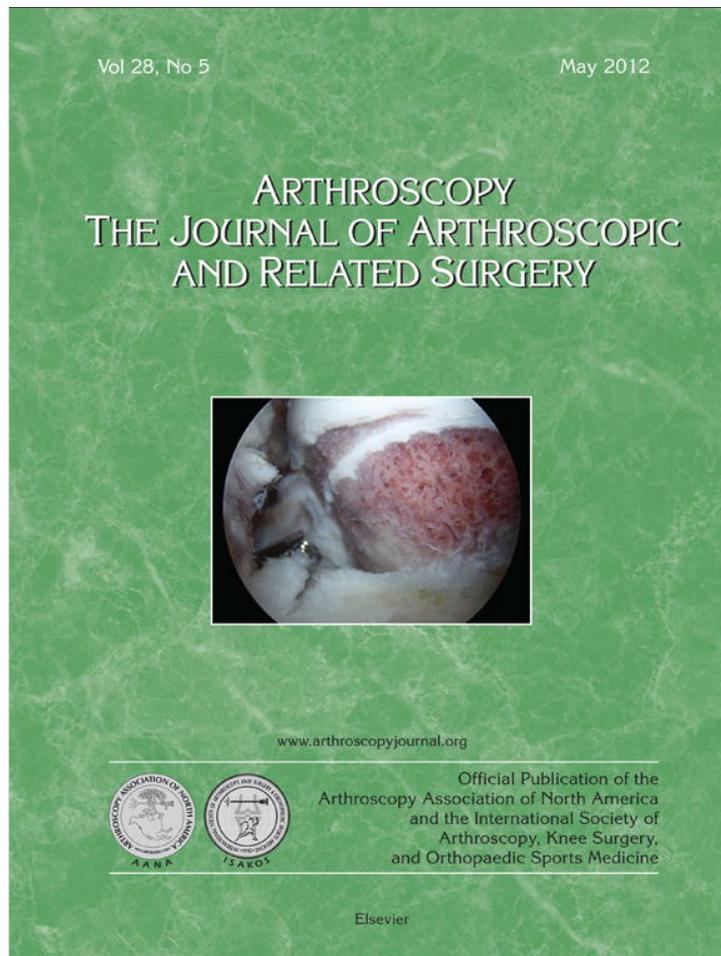


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Femoral Anteversion in the Hip: Comparison of Measurement by Computed Tomography, Magnetic Resonance Imaging, and Physical Examination

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Purpose: The purpose of this study was to evaluate the correlation between computed tomography (CT) and magnetic resonance imaging (MRI) measurements of femoral anteversion, as well as the relation of anteversion with physical examination and radiographic findings. **Methods:** Preoperative CT and MRI measurements of anteversion along with clinical examination were performed on 129 consecutive hips before hip arthroscopy for nonarthritic hip injuries. All anteversion measurements were performed by 2 musculoskeletal radiologists. The radiographic findings and physical examination findings were analyzed for statistically significant correlations. For statistical analysis purposes, the patients were divided into 3 groups according to the mean CT anteversion measurement: group I (low), less than 10°; group II (medium), 10° to 22°; and group III (high), greater than 22°. **Results:** High interobserver correlation was found for femoral anteversion measurement by CT and MRI ($r = 0.95$ and $r = 0.86$, respectively; $P < .0001$ for both). CT and MRI measurements showed high correlation with each other ($r = 0.80$, $P < .0001$). However, in 96% of the cases, the CT measurement was larger, with a mean difference of 8.9° (range, -37° to 1.5°). A significant correlation coefficient was found between internal rotation and anteversion angles as measured by CT ($r = 0.36$, $P < .0001$). However, no correlation was found with other hip movement measurements. Abnormal femoral acetabular bony architecture of the hip was found in 64% of the patients; isolated cam impingement was more prevalent in group I, whereas isolated pincer impingement was more prevalent in group III ($P = .01$). **Conclusions:** Although high correlation was found between anteversion angle measurements by CT and MRI, significant discrepancies in the absolute anteversion number between the 2 techniques suggest that they may not be interchangeable. Furthermore, CT was found to have higher interobserver reliability than MRI. There was a significant correlation between CT and examination of internal rotation of the hip. Clinically, the findings of the study show that the diagnosis of excessive femoral anteversion or retroversion should have different thresholds according to MRI and CT measurements; moreover, the diagnosis should not rely exclusively on either examination or radiologic criteria. **Level of Evidence:** Level III, retrospective comparative study.

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The authors report that they have no conflicts of interest in the authorship and publication of this article.

Received January 31, 2011; accepted October 14, 2011.

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0749-8063/1173/\$36.00

doi:10.1016/j.arthro.2011.10.021

It has been shown that abnormal anteversion of the femoral neck is related to several disease processes. Osteoarthritis of the hip and knee, slipped capital femoral epiphysis, knee and patella instability, and in- or out-toeing gait patterns have all been shown to be related to abnormal femoral neck version.¹⁻⁴ Accurate assessment of femoral neck version may be important for guiding diagnosis as well as treatment.^{2,5-10} Although computed tomography (CT) has been regarded by some investigators as the gold standard, no study has proven that CT measurement of anteversion is correlated with any other relevant variable. Furthermore, although multiple techniques for measurement of version have been described,^{9,11-13} currently, there

still remains no consensus on the imaging modality of choice.

In our clinical practice, the physical examination findings and injury patterns of patients with hip pathology have been inconsistent with the CT and magnetic resonance imaging (MRI) assessment of femoral neck version. These observations have led to the suspicion that these particular imaging modalities may provide an inaccurate description of true femoral rotational anatomy. The idea that CT and MRI are not adequate modalities has also been suggested in many other studies, with flaws of the different techniques having contributed to the controversy. The challenge of accurately summarizing the 3-dimensional rotational anatomy of the femur using a single number is reflected in the multiple existing methods used to measure anteversion on CT or MRI.^{9,11,13-19}

The purpose of this study was to evaluate the correlation between CT and MRI measurements of femoral anteversion, as well as to investigate the relation between anteversion and physical examination. We hypothesized that CT and MRI measurements of anteversion would be moderately correlated and that both measurements of anteversion would be related to rotational range of motion (ROM).

METHODS

Patient Inclusion and Data Collection

Data were prospectively collected between June 2009 and January 2010 from patients who underwent hip arthroscopic surgery. Patients were included in the study if they had both preoperative CT and MRI scans conducted at our institution with adequate knee and hip views for anteversion measurement. Patients with Tönnis arthritic grade 3 and those with any previous hip condition, such as Legg-Calve-Perthes disease or slipped capital femoral epiphysis, were excluded from the study. This study was approved by our institutional review board. Objective data were collected, including age, gender, body mass index, prior surgeries, and Workers' Compensation status.

Physical Examination

Each patient underwent preoperative physical examination, including passive ROM testing. Passive ROM for internal and external rotation was evaluated in a supine position with both the hip and knee joint flexed to 90°. All patients were examined by 2 examiners, an orthopaedic fellow or athletic trainer and the senior surgeon. If the results differed by less than 5°, the senior surgeon's

measurement was used. If they differed by more than 5°, a third examiner performed the measurement, and the values were averaged. Internal hip click for iliopsoas snapping was elicited by a circumduction motion of the hip. Impingements tests (anterior, lateral, and posterior) were recorded as well.²⁰ We must note that we believe that ROM examination of the hip with the patient under anesthesia is potentially dangerous to the patient, because it may cause further damage to the joint by taking the hip into positions that pain would have prevented if the patient were awake. To avoid inadvertent damage to intra-articular structures, we do not perform ROM testing with the patient under anesthesia. However, pain may influence the ROM, and ROM in symptomatic patients may not correlate strictly to bony alignment because of the contribution of pain generated by soft-tissue injury.

Radiographic Parameters

Radiographic views included an anteroposterior (AP) pelvic view, Dunn view, cross-table lateral view, and false-profile view.²¹ The radiographic evaluation of the hips included measurement of the joint space in the most narrow area, classification according to the Tönnis osteoarthritic grade, and measurement of the center-edge angle of Wiberg on the AP view.^{1,22} The alpha angle was measured on MRI and on the Dunn view in the same manner as described by Nötzli et al.²³ on MRI and modified by Meyer et al.²¹ for the Dunn view.²⁴ Because CT was not validated for alpha angle measurement and measuring the alpha angle on axial CT cuts would produce different results from the techniques mentioned earlier, we did not measure the alpha angle by CT. All radiographs were measured by the same orthopaedic surgeon. Hips classified as having cam impingement had an alpha angle greater than 55° on MRI examination. Hips classified as having pincer impingement had a positive crossover sign, coxa profunda, or protrusio acetabuli on AP pelvis radiographs.

Anteversion Measurement

All CT and MRI anteversion measurements were performed by 2 radiologists with formal musculoskeletal experience and training. The radiologists were blinded to each other's measurements and to the other study results. For both CT and MRI scans, the technique for determining the version of the femoral neck was carried out in a systematic fashion. First, a line parallel to the posterior femoral condyles was drawn. Next, a line was drawn through the center of the

femoral neck on the oblique axial images. These images and lines were then superimposed over one another. The angle between the drawn lines was reported as the anteversion measurement and was recorded in degrees.

CT imaging was obtained with 4 different scanners: GE VCT 64, GE LightSpeed 16, GE BrightSpeed 16, and GE Plus 8 (GE Healthcare Technologies, Waukesha, WI). Patients were placed in the supine position with their toes pointed up. Images were acquired axially through the hip and femoral neck (120 kV; automatic dose modulation; pitch, 1.375:1; 1.25-mm slice thickness; 1.25-mm reconstruction interval) and reconstructed in the coronal, sagittal, and oblique axial planes (1.25-mm slice thickness, 1.25-mm reconstruction interval). Images were also acquired axially just above the knee (120 kV; 100 mA; pitch, 1.375:1; 2.5-mm slice thickness, 2.5-mm reconstruction interval).

MRI was obtained with a GE 1.5-T EchoSpeed scanner with Excite HDx software, version 15.0 (GE Healthcare Technologies). The type of coil used was a GE Signa HD 1.5-T 12-channel body array (single and dual connector) (GE Healthcare Technologies). Patients were in the supine position and were allowed to assume the position of most comfort to limit motion artifact because of the long protocol (45 minutes). The position of the toes therefore was not controlled. Image sequences through the hips were obtained in the axial, coronal, sagittal, oblique axial, and radial planes. Axial and sagittal images of the hips were obtained with a 4-mm slice thickness with a 0.4-mm slice gap. Coronal and oblique axial images of the hips were obtained with a 4-mm slice thickness and no slice gap. Radial images were obtained with a 4-mm slice thickness, each spaced 20° apart, with a total of 10 images. Of note, oblique axial images were only “obliqued” in 1 plane. They maintained an orthogonal relation with the coronal plane. Magnetic resonance arthrography was performed after fluoroscopically guided gadolinium injection into the hip. T1, fat-saturated T1, and fat-saturated T2 sequences were used for the conventional 3 planes. For the oblique axial view and the radial view, fat-saturated proton density sequences were used. At the knee, axial T1 images were obtained with a 4-mm thickness with a 1-mm slice gap.

Statistical Analysis

For statistical analysis purposes, hips were divided into 3 groups according to the mean CT anteversion

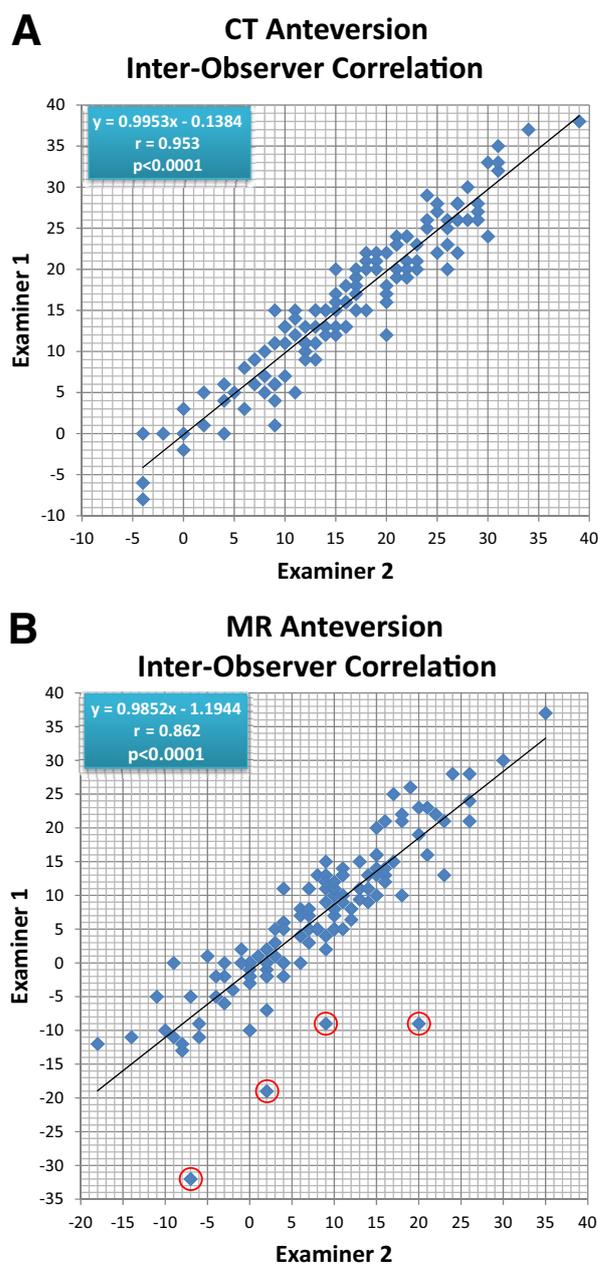


FIGURE 1. Interobserver correlation coefficients for anteversion measurement by CT (A) and MRI (B). Both modalities showed very high correlation, with a slope of almost 1 and r values of 95% and 86%, respectively. However, in the MRI scatter plot (B), the anteversion of 4 hips (red circles) were read with a difference of more than 20° between the examiners. For this reason, the anteversion groups were created according to the CT results only (Fig 2).

measurement. The CT measurement was chosen because of the higher reproducibility by the 2 examiners in comparison with MRI (Fig 1). A histogram of CT anteversion values was then created, and a normal

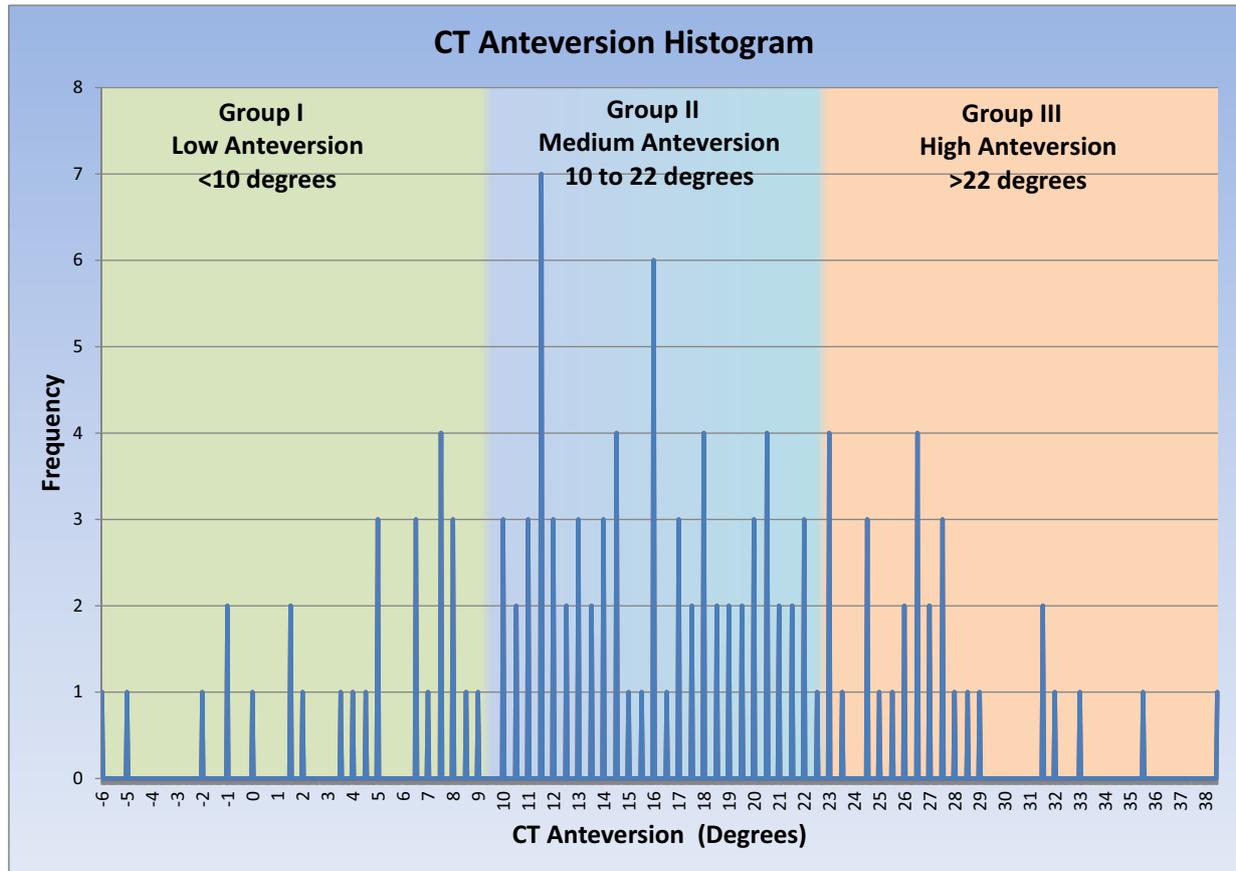


FIGURE 2. CT anteversion histogram of 129 hips included in study. Group I (low-anteversion group) contains the lower 25th percentile with anteversion measurement of less than 10°. Group II (medium-anteversion group) includes hips with anteversion between 10° and 22°. Group III (high-anteversion group) contains the upper 25th percentile with anteversion measurement of greater than 22°.

curve was assumed (Fig 2). CT anteversion values were classified as group I when they fell within the lower 25th percentile of the assumed normal curve ($n = 32$). Group II, or midrange CT anteversion values, were between the 25th and 75th percentiles ($n = 65$). Group III was defined as the upper 25th percentile of the normal curve ($n = 32$). On the basis of this normal distribution, CT group I contained hips with CT anteversion measurements that were less than 10°, CT group II contained hips with CT anteversion angles between 10° and 22°, and CT group III contained hips with CT anteversion angles greater than 22° (Fig 3).

Comparisons of 2 continuous variables were performed by use of the Pearson correlation coefficient test. Comparison of a continuous variable between categorical groups was performed with an unpaired 2-tailed Student t test (2 categorical variables) or 1-way analysis of variance (>2 categorical variables).

Comparison of categorical values was performed with the χ^2 test. Statistical analysis was performed with Microsoft Office Excel 2007 (Microsoft, Redmond, WA). We considered α values of $< .05$ statistically significant.

Finally, an a priori power analysis was performed to estimate the number of cases needed in each group. On the basis of previous study that found a correlation efficient of $r = 0.77$ between CT and MRI measurement of the anteversion angle,⁹ we have calculated a large effect size of 1.44; thus, to obtain a power of 80% or higher with $P < .05$, each group would need to include at least 8 hips.

RESULTS

A total of 129 hips (121 patients) fit our inclusion and exclusion criteria. The mean age of the patients was 36 years (range, 14 to 74 years), and there were

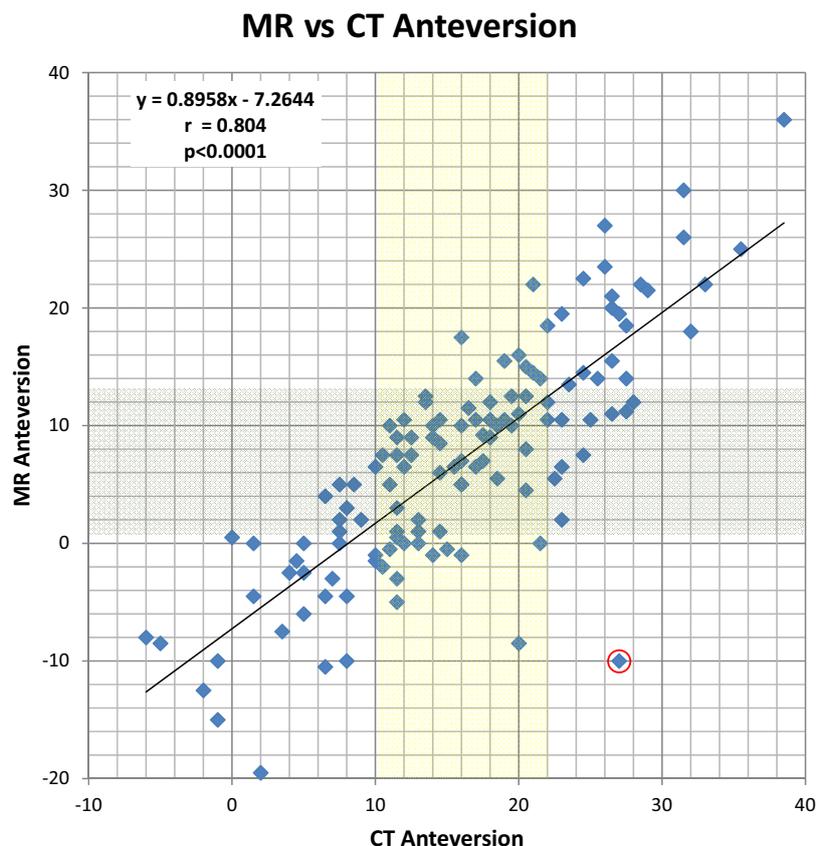


FIGURE 3. The relation between CT and MRI anteversion angles was found to be large ($r = 0.80$). The shaded areas represent the middle 2 quartiles of the anteversion measurement by CT (yellow) (group II) and by MRI (green). One patient (red circle) was measured to have high anteversion by CT and low anteversion by MRI.

75 female and 54 male patients. The mean height was 67 inches (range, 57 to 77 inches), the mean weight was 166 lb (range, 100 to 280 lb), and the mean body mass index was 25.3 (range, 17 to 43). The percentage of female patients was significantly different among the groups ($P = .002$), with 43.75% in group I, 52.3% in group II, and 84.4% in group III.

Anteversion Measurement

Large interobserver correlation was found between the 2 radiologists with regard to the anteversion measurement by CT and MRI ($r = 0.95$ and $r = 0.86$, respectively; $P < .0001$ for both). The mean anteversion value as measured by CT was 15.9° (range, -6° to 38.5°), whereas the mean MRI measurement was 7° (range, -19.5° to 36°). A statistically significant, large correlation was found between the 2 anteversion measurements ($r = 0.80$, $P < .0001$) (Fig 3). This linear correlation had a best-fit line with a slope of 0.89. However, in 96% of the cases, the MRI mea-

surement was smaller than the CT measurement, with a systematic bias of 8.9° difference (range, -37° to 1.5°); moreover, in 77% of the cases, the difference was larger than 5° . A Bland-Altman scatter plot (Fig 4) displays the differences between MRI and CT anteversion values plotted against the mean values of the 2 measurements.²⁵

Physical Examination Findings

The following mean measurements for ROM of the affected joint were found: abduction, 44° (range, 15° to 80°); flexion, 117° (range, 90° to 150°); internal rotation, 23° (range, 0° to 90°); and external rotation, 50° (range, 10° to 90°). A low but statistically significant correlation between the anteversion angle as measured by CT and internal rotation was found ($r = 0.36$, $P < .0001$). There was also a significant difference among the 3 groups in ROM for internal rotation (Fig 5). Internal rotation increased as the measured anteversion angle

Bland and Altman Plot for CT and MRI Anteverision

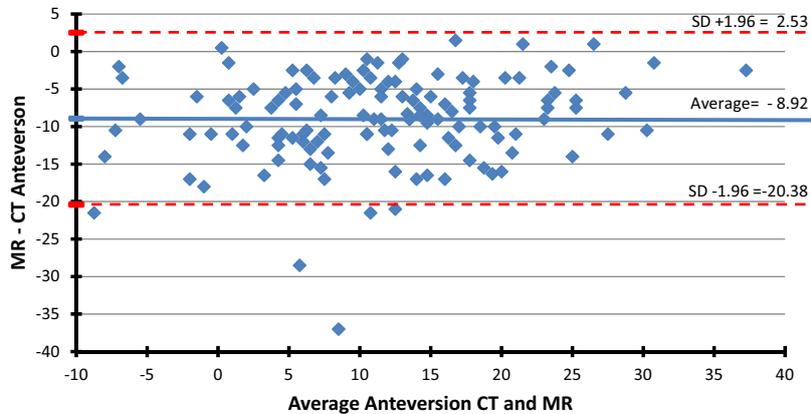


FIGURE 4. Scatter diagram of differences between MRI and CT anteverision values plotted against mean values of the 2 measurements. A solid horizontal line indicates the mean difference, and dashed horizontal lines denote the limits of agreement, defined as the mean difference plus and minus 1.96 times the standard deviation of the differences. The mean difference was 8.9°.

increased. Patients in CT group I had mean internal rotation of 15.8°, whereas patients in CT groups II and III had mean values of 22.7° and 29.7°, respectively ($P = .002$). However, no correlation was found between anteverision and external rotation ($r = -0.07$, $P = .41$). There was no statistical difference for flexion, abduction, or external rotation measurements determined among patients in groups I, II, and III ($P > .50$). No difference among the groups was found for the other physical exam-

ination tests, including the internal hip click and 3 impingement tests ($P > .50$ for all).

Radiographic Parameters

After radiographic evaluation, 64.3% of the hips (83 of 129) were found to have bony deformities that correlated with femoral acetabular impingement according to the AP pelvis findings and the MRI alpha angle. Isolated cam impingement with an alpha angle of 55° or greater on MRI was present in 19.4% of the patients, isolated pincer impingement in 28.7%, and combined lesion in 16.3% (Fig 6). Most patients with a pincer lesion had a positive crossover sign, 4 patients had protrusio acetabuli, and none had profunda. There was a significant difference ($P = .01$) among the groups regarding the distribution of the impingement types, with isolated cam lesion being most prevalent in group I, which had low CT anteverision values, and isolated cam lesion being most prevalent in group III, which had large CT anteverision values (Fig 6). However, no difference was found with regard to the alpha angle as measured on the Dunn view or MRI and the crossover sign among the 3 anteverision groups. In addition, non-significant correlation was found between MRI alpha angle and anteverision ($r = 0.13$, $P = .14$), and no correlation was found with alpha angle measured on the Dunn view ($r = -0.02$, $P = .74$).

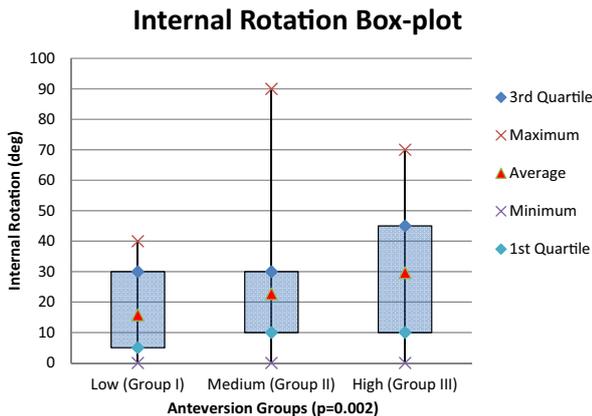


FIGURE 5. Internal rotation (in degrees) in the 3 anteverision groups, represented by a box-plot diagram, with the average range of internal rotation in the high anteverision group and lower in the low anteverision group. However, 3 patients with maximal internal rotation, of 90°, belonged to the medium anteverision group. A statistically significant difference was found among the groups ($P = .002$).

Overall, no correlation was found among all other radiographic findings and anteverision measurements. Moreover, there was no significant difference among

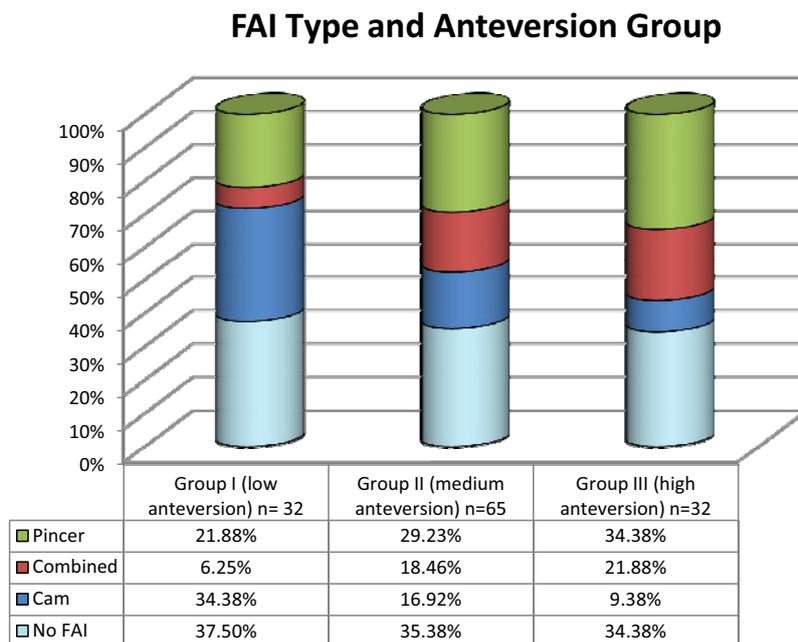


FIGURE 6. Femoral acetabular impingement types in correlation with anteversion groups. Cam impingement was defined when an alpha angle greater than 55° was found on MRI. Pincer impingement was defined as a positive crossover sign, coxa profunda, or protrusio acetabuli on the AP pelvis radiograph. The difference among the groups was found to be significant ($P = .01$).

groups I, II, and III with respect to their radiographic findings.

DISCUSSION

The 3 main findings of the study were (1) a large correlation between MRI and CT anteversion measurements but with a systematic bias toward larger values on CT (Figs 3 and 5); (2) significant correlation between these measurements and the range of internal rotation of the hip (Fig 5); and (3) significant relation between femoral acetabular impingement types and the 3 anteversion groups.

As shown in Fig 6, isolated cam-type impingement was correlated more with low anteversion whereas isolated pincer impingement was correlated with high femoral anteversion. However, no relation was found between the values of the alpha angle or crossover to the anteversion values. Hence, the relation represents the incidence of pincer, cam, and combined impingement in the groups. We are not aware of any other study that has shown a similar relation. It is difficult to explain these findings; both can be developmental problems. However, the cam lesion may affect the femoral neck axis at the time of anteversion measurement, and

the pincer lesion may be positional due to a pelvic tilt.

Our study has emphasized the correlation between internal rotation and the femoral anteversion angle (Fig 5). However, the ROM cannot point to the level of anteversion; as shown in Fig 5, the anteversion groups had overlapping ROMs. Furthermore, the 3 patients with the largest range of internal rotation (90°) had medium-range CT anteversion values (11.5°, 11.5°, and 21°). Many studies have evaluated physical examination techniques for their validity and reliability in measuring version.^{12,26-29} Of note, these studies used different and unproven modalities as their gold standard to compare against physical examination. Still, physical examination has been shown to be an inaccurate method for determining femoral version. The examination technique described by Souza and Powers²⁷ was found to have such a wide confidence interval that its clinical utility is called into question. In a study assessing several techniques, it was found that the currently available clinical methods do not accurately measure true torsion of the femur and tibia.²⁸

The comparison results between MRI and CT anteversion measurements (Figs 3 and 5) are comparable to those of a study by Tomczak et al.⁹ that was published in 1997. In that study a large correlation

coefficient of 0.77 was found, along with higher mean CT values for anteversion angles than those of MRI. CT imaging has been considered by many investigators to be the imaging modality of choice for the measurement of femoral version.^{9,19} In addition, MRI has also been promoted as an appropriate imaging modality for anteversion measurement.^{8,9} However, there have been no studies that prove the use of either CT or MRI as the gold standard. Our study shows a large correlation coefficient of 0.80 between CT and MRI for the measurement of femoral version (Fig 3). However, a systematic bias of 8.9° exists between MRI and CT anteversion measurement, with the CT results being higher in 96% of the cases (Fig 4).

One potential reason for the lower absolute values for anteversion on MRI is the longer time delay between imaging of the hip and imaging of the distal femur. During the intervening lag time, the patient may relax into greater external rotation of the hip, which would lead to systematic underestimation of anteversion. In contrast, CT has a very short time delay between imaging of the hip and imaging of the distal femur, which may avoid this pitfall. However, the MRI technicians did not note any pattern of change in position during the MRI examinations. Moreover, if there is motion, it should introduce certain randomness to the MRI measurement with respect to the CT measurement with higher and lower MRI measurements. What was observed, rather, was a systematic bias toward lower MRI anteversion values compared with the CT values. This speaks to a systematic problem rather than random, unpredictable patient motion-induced error. Many MRI and CT facilities do not control for rotation, so the findings of this study may be clinically relevant. Nonetheless, the lack of control of hip rotation during the examinations is a weakness of this study, and we recommend that the rotation of the hip be controlled throughout MRI or CT studies in the future.

Another potential source of bias may stem from a very slightly flexed hip position during the MRI examination. During the CT examination, the knees are kept extended as leg lengths are measured for possible discrepancies. This position is not difficult to achieve because the CT examination is very brief (a matter of seconds), and the hip should be in neutral flexion/extension with this type of positioning. However, for MRI, a pad is often placed beneath the knees for comfort. Patient comfort is essential because of the long length of the examination and the relative intolerance of MRI to motion artifacts. The knee flexion presumably results in some hip flexion. Hip flexion

was described previously as a source of bias toward lower angle measurements with hip flexion compared with neutral.³⁰ Although this would suggest that MRI should also be performed with the hip in full extension, patient comfort may prove a challenge.

A more complex reason for inconsistencies in anteversion measurement is the complex 3-dimensional morphology of the proximal femur. We believe that this complex anatomy does not lend 2-dimensional imaging modalities the ability to yield perfectly reproducible measurements. In fact, the level of complexity and variability of the 3-dimensional anatomy of the femur may call into question the possibility of measuring true femoral version with any technique at all.

The absolute difference that exists between the 2 modalities may be clinically important. The lower and higher quartiles in each modality have different borderlines. Whereas the lower anteversion quartile according to the CT measurement was below 10°, it was below 0° according to the MRI measurement (Fig 3). Similar reasoning applies to the high-anteversion quartile; the border was 22° according to CT but only 12.5° by MRI. Hence, diagnosis of excessive anteversion and the decision to perform femoral rotational osteotomy based on 1 study should have a different threshold than if based on the other study.

Both modalities showed large interobserver correlation; however, CT had a higher interobserver correlation of 95%, whereas the MRI correlation was 86%. Moreover, both modalities showed a correlation slope of almost 1 between the 2 observers, with the CT slope being higher (99.5% v 98.5%). This implies that CT has higher reproducibility and interchangeability for anteversion measurement than MRI. Nonetheless, the large interobserver correlation of both modalities raises the suspicion that the difference in the measurements stems from the examination itself.

The main limitation of the study is the fact that each of the studies was performed only once for each patient. A second set of MRI and CT examinations would help show the accuracy and reliability of the imaging methods beyond the accuracy of the measurement. Another limitation was the long time needed for MRI examination (approximately 45 minutes), during which there may be a potential error because of patient movement; although such movement was not detected, it is impossible to prove that it did not occur.

CONCLUSIONS

Although high correlation was found between anteversion angle measurements by CT and MRI, signif-

icant discrepancies in the absolute anteversion number between the 2 techniques suggest that they may not be interchangeable. Surgeons need to be aware that such differences could include or exclude patients depending on which study was performed and perhaps different thresholds should be used for each modality. Furthermore, CT was found to have higher interobserver reliability than MRI. Significant correlation with internal rotation of the hip was found as well. Clinically, the findings of the study show that the diagnosis of excessive femoral anteversion or retroversion should have different thresholds according to MRI and CT measurements; moreover, the diagnosis should not rely on hip joint ROM.

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