A commentary by Carlos A. Guanche, MD, is linked to the online version of this article at jbjs.org.

Passive Hip Range of Motion Predicts Femoral Torsion and Acetabular Version

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Background: Orientation abnormalities of the acetabulum and femur have been implicated in early-onset coxarthrosis. The purpose of this study was to identify clinical examination findings predictive of such hip morphologies.

Methods: A consecutive cohort of 221 patients (442 hips) undergoing hip arthroscopy was included. Demographic characteristics including age, diagnosis, sex, height, weight, body mass index (BMI), and physical activity level were recorded. Passive range of motion was measured for all hips. Preoperative computed tomography scans were utilized to measure femoral torsion and central acetabular version, and a combined femoral torsion-acetabular version (COTAV) index was defined as their sum.

Results: The study cohort comprised 221 patients (sixty-four males, 157 females) with a mean age of 32.5 years and mean BMI of 24.2 kg/m^2. Overall, hips with femoral antetorsion and acetabular anteversion exhibited the greatest internal rotation range of motion at a neutral hip position (mean, 44.2°), whereas hips with femoral retrotorsion and acetabular retroversion demonstrated the lowest corresponding value (20.1°; $p < 0.001$). Femoral torsion was significantly associated with female sex ($p < 0.001$), BMI ($p < 0.001$), and presence of pathology corresponding to cam-type femoroacetabular impingement (FAI) ($p = 0.044$). Central acetabular version was significantly associated with age ($p = 0.021$), female sex ($p < 0.001$), and absence of mixed-type FAI pathology ($p = 0.025$). Increasing age and internal rotation range of motion at a neutral hip position were the most significant predictors of an increased COTAV index.

Conclusions: This study confirmed that passive hip range of motion significantly predicts combined femoral torsion and central acetabular version. Accurate clinical assessment of the COTAV index may inform surgical decision-making in hip preservation surgery.

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Abnormalities in femoral torsion and acetabular version have been found to be associated with prearthritic hip pain and may contribute to the development of early-onset coxarthrosis[1-3]. Classically, femoral torsion is defined as the angle between the femoral neck and the transcondylar axis in the axial plane, while central acetabular version is defined as the angle between the sagittal plane and the oblique line connecting the anterior and posterior margins of the acetabular rim[4]. In previous studies, femoral antetorsion has been associated with developmental hip dysplasia, pincer-type femoroacetabular impingement (FAI), and cerebral palsy[5-9]; femoral retrotorsion, in cam-type FAI and slipped capital femoral epiphysis (SCFE)[10,11]; acetabular anteversion, in developmental dysplasia of the hip[12,13]; and acetabular retroversion,

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TABLE I Patient Demographics and Baseline Characteristics (N = 221)

Patient Variable	Value
No. of patients (no. of hips)	221 (442)
Age* *(yr)*	32.5 ± 11.0
Male sex *(no. [%])*	64 (29.0)
Height* *(cm)*	169.8 ± 9.9
Weight* *(kg)*	70.1 ± 16.2
BMI*† *(kg/m²)*	24.2 ± 4.6
Level of physical activity‡ *(no. [%])*	
None	10 (4.5)
Active	83 (37.6)
Very active	119 (53.8)
Elite athlete	9 (4.1)
Clinical diagnosis of hips *(no. [%])*	
FAI	246 (55.7)
Cam	63 (14.3)
Pincer	52 (11.8)
Mixed	131 (29.6)
Hip dysplasia	29 (6.6)
FAI and hip dysplasia	12 (2.7)
No pathology	123 (27.8)
Other	32 (7.2)

*Values are given as the mean and the standard deviation. †For this study, BMI (in kg/m^2) was defined as follows: normal weight, 18.00 to 24.99; overweight, 25.00 to 29.99; and obese, ≥30.00. ‡Self-reported levels of weekly physical activity were evaluated on the following scale: 0, non-routine physical activity; 1, moderate physical activity or recreational sports involvement (two to three sessions per week); 2, vigorous physical activity or competitive sports involvement (four to five sessions per week); and 3, involvement in collegiate or semi-professional level of sport (at least four times per week).

in osteonecrosis of the femoral head and Legg-Calvé-Perthes disease[11,14].

Despite the importance of screening and evaluating for femoral torsion and acetabular version abnormalities, the high cost and radiation exposure associated with advanced three-dimensional imaging studies are widely considered problematic[15]. In this regard, physical examination of the hip may serve as a promising diagnostic tool. Emerging evidence has implicated increased hip internal rotation range of motion (ROM) and concurrently decreased external rotation ROM in association with femoral antetorsion or acetabular anteversion[16]. Other studies, however, have reported only nonsignificant effects of orientation abnormalities of the femur and acetabulum on hip ROM[16-18], and very few studies overall have examined the combined effect of femoral torsion and acetabular version on ROM.

The purpose of the present study was to evaluate whether hip ROM was associated with femoral torsion and acetabular version. We hypothesized that ROM would be independently predictive of both femoral torsion and acetabular version.

Materials and Methods

After institutional review board approval was obtained, we performed a single-center prospective study on both hips in a consecutive cohort of 221 patients undergoing hip arthroscopy. Inclusion criteria for patients selected for this study were (1) persistent hip pain and mechanical symptoms refractory to nonoperative management, (2) reproducible clinical examination findings suggestive of impingement and/or instability, and (3) a joint-space width of >3 mm on all radiographic and three-dimensional computed tomography (CT) views[19]. Common indications for hip arthroscopy were symptomatic FAI, hip instability due to dysplasia (prior to periacetabular osteotomy), and/or excessive femoral torsion (prior to femoral derotational osteotomy). Patients undergoing surgical treatment for diagnoses of SCFE, Legg-Calvé-Perthes disease, osteochondromatosis, or post-dislocation syndrome were excluded. Demographic characteristics including diagnosis, sex, height, weight, body mass index (BMI), and self-reported levels of weekly physical activity were recorded for all patients.

Clinical Examination

As part of a comprehensive clinical examination of the spine, hip, and pelvis[20], passive hip ROM was evaluated bilaterally with the patient placed in supine, prone, and lateral positions. Measurements of passive flexion and rotational ROM (internal and external rotation) at 90° of flexion were conducted following stabilization of the pelvis in the supine position. The abduction ROM was measured at a neutral hip position (0° of flexion/extension) with the patient in the supine position. Measurements of internal and external rotation ROM at a neutral hip position were performed with the patient lying prone, several weeks prior to the imaging.

Imaging Technique

A standardized series of preoperative anteroposterior pelvic radiographs and CT scans were made. The anteroposterior pelvic radiograph was obtained with the patient positioned supine with the lower extremities internally rotated 15° to maximize femoral neck length. A radiograph was considered adequate if the obturator foramina were symmetric and the distance between the coccyx and pubic symphysis was 1.0 to 3.0 cm[21-23].

CT scans were acquired in 1-mm-thick slices, with a 750-mm field of view from the iliac crests to the lesser trochanters and through the knee joints. Images were reconstructed in the axial, sagittal, coronal orthogonal, and oblique axial (oriented parallel to the long axis of the femoral neck) planes with a 2-mm slice thickness[4]. For all imaging modalities, the femoral head center was approximated using Mose templates[24].

Imaging Measurements

Central (equatorial) acetabular version was defined at the maximum diameter of the femoral head as the angle between the line connecting the anterior and posterior margins of the acetabulum and the line paralleling the sagittal plane[4]. For the measurement of femoral torsion, axial CT images of the central femoral head, lesser trochanter of the femur, and distal femoral condyles were first fused. Femoral torsion was then determined as the angle between the femoral neck axis and the transcondylar axis. Joint-space width was defined as the narrowest distance between the osseous contour of the acetabular rim and the femoral head. The lateral center-edge angle (LCEA) was defined, according to the modification of Ogata et al.[25], as the angle between (1) a vertical line drawn through the center of the femoral head and orthogonal to the transverse line passing through the teardrops of both hips, and (2) an oblique line drawn from the center of the femoral head to the lateral weight-bearing sclerotic zone (sourcil) of the acetabular rim. All angular measurements were made using the digital caliper on the OfficePACS (Picture Archiving and Communication System; Stryker) by an examiner blinded to the clinical ROM measurements and patient sex.

Femoral torsion was considered excessive (antetorsion) if >20°, normal if 10° to 20°, or reduced (retrotorsion) if <10°. Central acetabular version was considered excessive (anteversion) if >20°, normal if 15° to 20°, or reduced (retroversion) if <15°[4]. A combined femoral torsion-acetabular version (COTAV) index was calculated as the sum of femoral torsion and acetabular version components. The COTAV was considered excessive if >45°, normal if 20° to 45°, or reduced if <20° (Figs. 1 and 2).

TABLE II Effect of Femoral Torsion and Acetabular Version on Hip ROM*

Dependent Variable	Femoral Torsion†				Central Acetabular Version†			
	<10° (N = 170)	10°-20° (N = 120)	>20° (N = 152)	P Value	<15° (N = 89)	15°-20° (N = 120)	>20° (N = 233)	P Value
IR at 90° hip flexion *(deg)*	9.4 ± 8.8	15.7 ± 10.8	22.4 ± 12.9	<0.001‡	10.1 ± 9.0	13.5 ± 10.9	18.8 ± 12.9	<0.001‡
IR at neutral hip position *(deg)*	24.8 ± 12.5	30.9 ± 11.8	40.7 ± 14.8	<0.001‡	26.3 ± 12.0	29.7 ± 13.6	35.5 ± 15.3	<0.001‡
ER at 90° hip flexion *(deg)*	48.1 ± 9.1	47.8 ± 8.9	45.5 ± 8.2	0.022‡	47.4 ± 9.9	47.3 ± 8.2	46.9 ± 8.6	0.878
ER at neutral hip position *(deg)*	28.6 ± 11.7	26.4 ± 10.4	22.7 ± 11.8	<0.001‡	28.5 ± 12.1	25.0 ± 11.3	25.4 ± 11.5	0.080
Abduction *(deg)*	42.8 ± 7.3	43.3 ± 7.4	43.8 ± 6.6	0.485	43.3 ± 4.7	43.3 ± 7.5	43.3 ± 7.6	0.998
Flexion *(deg)*	108.8 ± 11.5	110.3 ± 14.3	111.4 ± 15.5	0.240	104.6 ± 17.6	110.6 ± 12.3	112.1 ± 12.3	<0.001‡

*IR = internal rotation, and ER = external rotation. P values were calculated by ANOVA. †Values are given as the mean and the standard deviation. ‡Significant ($p \leq 0.05$).

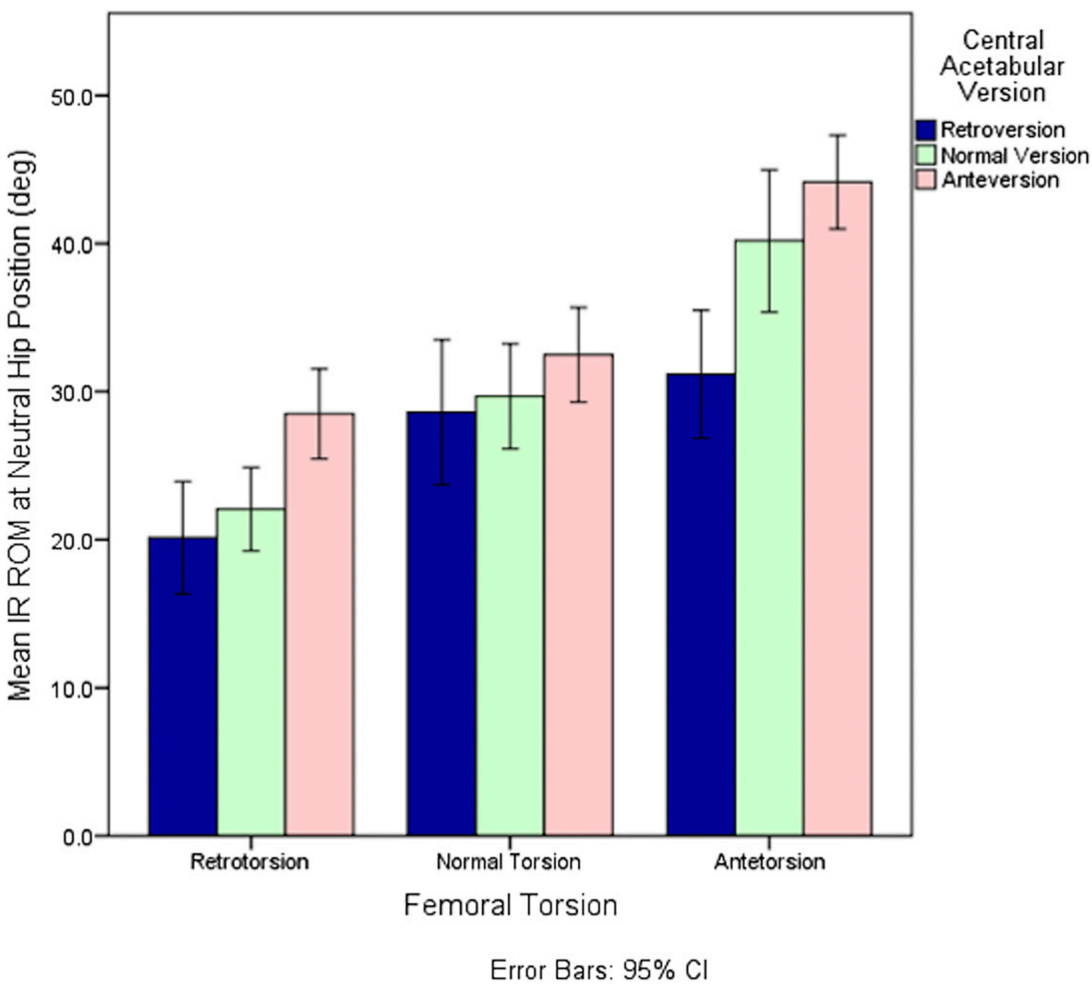

Fig. 1

Internal rotation (IR) ROM at a neutral hip position according to a combination of femoral torsion and acetabular version. CI = confidence interval.

TABLE III Measurements of ROM According to Combined Femoral Torsion-Acetabular Version (COTAV) Index*

	Group†			
	RT, RV (N = 33)	RT, NV (N = 52)	RT, AV (N = 85)	NT, RV (N = 26)
IR at 90° hip flexion† *(deg)*	5.7 ± 8.4	7.7 ± 7.3	11.8 ± 9.1	11.2 ± 7.8
IR at neutral hip position† *(deg)*	20.1 ± 10.5	22.1 ± 9.8	28.5 ± 13.6	28.6 ± 11.9
ER at 90° hip flexion† *(deg)*	48.6 ± 10.8	47.8 ± 7.2	48.0 ± 9.4	48.7 ± 10.3
ER at neutral hip position† *(deg)*	31.7 ± 14.7	27.5 ± 11.4	28.2 ± 10.6	27.5 ± 10.5
Abduction† *(deg)*	42.6 ± 3.6	43.8 ± 6.9	42.4 ± 8.5	43.8 ± 6.5
Flexion† *(deg)*	105.8 ± 11.0	108.5 ± 11.5	110.2 ± 11.6	104.2 ± 18.3

*RT = femoral retrotorsion, RV = acetabular retroversion, NV = normal acetabular version, AV = acetabular anteversion, NT = normal femoral torsion, AT = femoral antetorsion, IR = internal rotation, and ER = external rotation. P values were calculated with the Kruskal-Wallis test. †Values are given as the mean and the standard deviation. ‡Significant (p ≤ 0.05).

Clinical diagnoses of osseous impingement and/or acetabular dysplasia were determined according to accepted pathomorphologic signs and measurements[4,11]. Suggestive physical examination findings included reduced hip flexion ROM, reduced hip internal rotation ROM, and/or positive provocative tests[26]. The diagnosis was confirmed by imaging findings of focal acetabular overcoverage as indicated by an LCEA of >40° and/or a Tönnis angle of <0° for pincer-type FAI, the presence of an anterior or lateral cam lesion for cam-type FAI, and an LCEA of <20° and/or a Tönnis angle of >10° for lateral acetabular dysplasia.

Examiners

The degree of agreement between visual estimation and goniometric methods of measurement was previously evaluated in a pilot study of 100 consecutive hips using a two-way mixed, absolute-agreement single-measures intraclass correlation coefficient (ICC). The ICC value was 0.976 (95% confidence interval, 0.727 to 0.992), indicating excellent reliability[27]. Therefore, all measurements of passive ROM in the present study were performed using visual estimation by a single experienced hip preservation surgeon. CT measurements were evaluated by a dedicated musculoskeletal radiology team composed of four fellowship-trained musculoskeletal radiologists. Assessors were blinded to each other's measurements to reduce the risk of measurement bias.

Statistical Analysis

The distributions of all variables were evaluated for normality using a combination of histograms, quantile-quantile (Q-Q) plots, and Shapiro-Wilk tests. Descriptive statistics were summarized as means and standard deviations for quantitative variables and as counts and frequencies for categorical variables. The significance of mean differences between independent groups was evaluated using the independent-samples t test, analysis of variance (ANOVA) with a post-hoc Tukey HSD (honest significant difference) test or Games-Howell test, or the Kruskal-Wallis H test with a Dunn multiple-comparison post-hoc test. Correlations between continuous variables were analyzed using the Pearson correlation coefficient. A stepwise multiple linear regression procedure was performed to evaluate whether any significant ($p < 0.05$) or near-significant ($p < 0.10$) factors from the univariate analyses served as independent predictors of the COTAV index. Significance for all comparisons was set at $p < 0.05$ (two-tailed). All analyses were conducted using SPSS (version 22.0; IBM).

Source of Funding

No external funding was used for this study.

Results

Participants and Descriptive Data (Table I)

The study cohort comprised 221 patients (sixty-four males, 157 females) with a mean age of 32.5 ± 11.0 years and a mean BMI of 24.2 ± 4.6 kg/m^2. The clinical diagnoses included FAI without acetabular dysplasia in 246 hips (55.7% of the overall cohort), acetabular dysplasia without FAI in twenty-nine (6.6%),

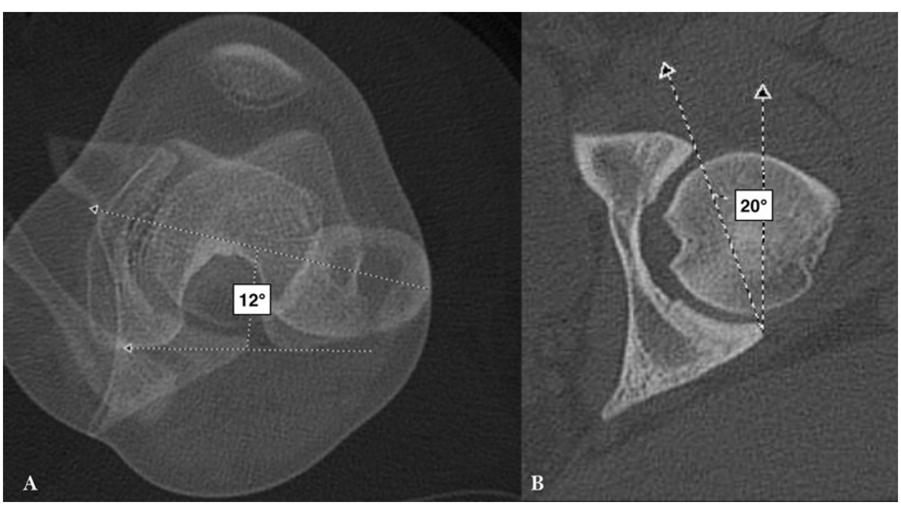

Fig. 2

Representative images of normal femoral torsion of 12° (**Fig. 2-A**) and normal central acetabular version of 20° (**Fig. 2-B**) on two-dimensional axial CT. In this patient, a COTAV index of 32° corresponded to internal rotation and external rotation ROM of 30° and 35°, respectively, at a neutral hip position.

TABLE III (*continued*)

Group†					
NT, NV (N = 32)	NT, AV (N = 62)	AT, RV (N = 30)	AT, NV (N = 36)	AT, AV (N = 86)	P Value
14.5 ± 10.0	18.2 ± 11.6	14.0 ± 8.8	20.6 ± 11.6	26.1 ± 13.2	<0.001‡
29.7 ± 9.8	32.5 ± 12.6	31.2 ± 11.3	40.2 ± 14.2	44.2 ± 14.8	<0.001‡
46.4 ± 8.3	48.1 ± 8.7	45.0 ± 8.3	47.2 ± 9.8	45.0 ± 7.5	0.102
24.1 ± 12.1	27.2 ± 9.4	25.9 ± 10.0	22.5 ± 10.2	21.8 ± 12.8	<0.001‡
41.7 ± 8.4	43.8 ± 7.2	43.5 ± 3.8	44.0 ± 7.5	43.8 ± 7.1	0.773
110.7 ± 12.1	112.7 ± 12.8	103.8 ± 22.7	112.9 ± 13.1	113.5 ± 12.4	0.011‡

FAI with concomitant acetabular dysplasia in twelve (2.7%), and normal findings in 123 (27.8%).

Passive ROM According to the Degree of Femoral Torsion or Acetabular Version (Table II)

Patients with femoral antetorsion had significantly greater internal rotation ROM at a neutral hip position (mean, 40.7°) compared with those with normal femoral torsion (30.9°) or femoral retrotorsion (24.8°) ($p < 0.001$). Similarly, in the acetabular anteversion group, internal rotation ROM at a neutral hip position was significantly greater (mean, 35.5°) compared with the normal version (29.7°) or acetabular retroversion (26.3°) groups ($p < 0.001$), with the latter two groups being statistically equivalent ($p = 0.216$). External rotation ROM at a neutral hip position was least for patients with femoral antetorsion (mean, 22.7°; $p < 0.001$) and did not differ significantly according to the degree of

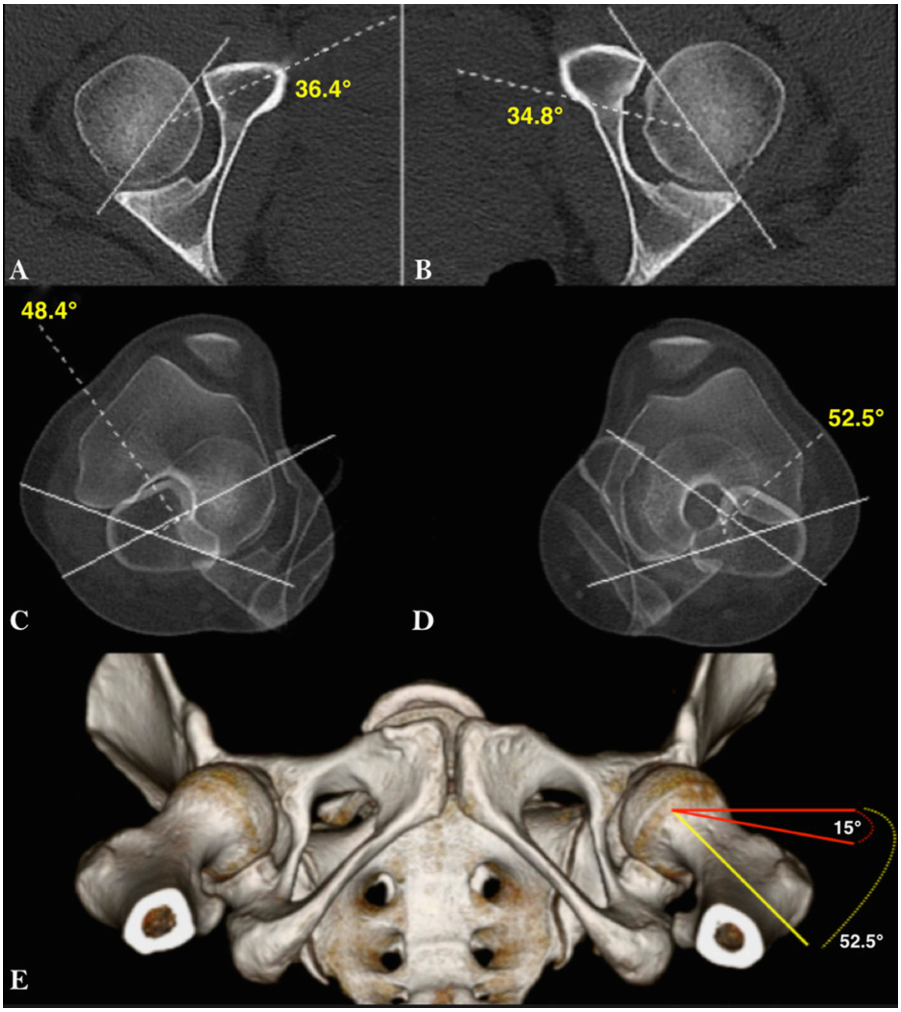

Fig. 3

Representative images of excessive acetabular anteversion (**Figs. 3-A and 3-B**) and femoral antetorsion (**Figs. 3-C and 3-D**) on two-dimensional axial CT, and excessive femoral torsion (yellow) relative to normal femoral torsion (red) on three-dimensional CT of the whole pelvis (**Fig. 3-E**). In this patient, excessive COTAV indices (right, 84.8°; left, 87.3°) resulted in substantial anterior instability, necessitating treatment with derotational femoral osteotomy and periacetabular osteotomy. Of note, internal rotation ROM at a neutral hip position was abnormally increased (right, 75°; left, 80°), while external rotation ROM at a neutral hip position was reduced (right, 15°; left, 25°).

TABLE IV Independent Predictors of Combined Femoral Torsion-Acetabular Version (COTAV) Index*

	Unstandardized Beta Coefficient	95% CI	P Value
Intercept	7.72	3.49-11.98	<0.001
IR ROM at neutral hip position	0.59	0.52-0.66	<0.001
Age	0.26	0.16-0.35	<0.001

*Significant predictors ($p \leq 0.05$) identified by multiple linear regression analysis. CI = confidence interval, and IR = internal rotation. The adjusted r^2 of the model was 0.384. The overall multiple linear regression model was approximately COTAV = 8.0 + (hip IR ROM at neutral hip position × 0.6) + (age × 0.3).

acetabular version. Similar trends were observed for hip rotation ROM evaluated at 90° of hip flexion. Hip flexion ROM did not differ according to femoral torsion, but it was significantly less (mean, 104.6°) in hips with acetabular retroversion compared with hips with normal or excessive acetabular version (110.6° and 112.1°, respectively) ($p < 0.001$).

Passive ROM According to the COTAV Index (Table III)

Overall, internal rotation ROM at a neutral hip position was greatest (mean, 44.2°) in hips with femoral antetorsion and concomitant acetabular anteversion (Fig. 3); conversely, it was least (20.1°; $p < 0.001$) in hips with femoral retrotorsion and concomitant acetabular retroversion. Trends observed for external rotation ROM were consistently the opposite of those described for internal rotation ROM.

Hip flexion ROM was greatest (mean, 113.5°) in hips with femoral antetorsion and acetabular anteversion and least (103.8°; $p = 0.011$) in hips with femoral antetorsion and acetabular retroversion.

Hip abduction ROM was statistically equivalent among all categories of combined femoral torsion and acetabular version ($p = 0.773$).

Demographic Factors Associated with Femoral Torsion or Central Acetabular Version

The degree of femoral torsion was significantly greater in females (mean, 17.1°) compared with males (9.4°; $p < 0.001$) and in hips with cam-type FAI pathology (15.3°) compared with those without (12.0°; $p = 0.044$). Additionally, the degree of femoral torsion was inversely proportional to BMI ($r = -0.171$, $p < 0.001$).

Similarly, the degree of central acetabular version was significantly greater in females (mean, 21.1°) compared with males (17.4°; $p < 0.001$). A directly proportional increase in the degree of central acetabular version was observed with increasing age ($r = 0.110$, $p = 0.021$). In contrast, the degree of central acetabular version was significantly less in hips with mixed-type FAI pathology (mean, 19.0°) compared with those without (20.5°; $p = 0.025$).

COTAV Index Predicted by Clinical Examination (Table IV)

Stepwise multiple linear regression analysis indicated that the COTAV index increased significantly with increasing internal rotation ROM at a neutral hip position (0.59° per degree increase in internal rotation ROM) and increasing age (0.26° per one-year increase in age). The adjusted r^2 value was 0.384, and the standard error of the estimate was 10.99. The regression model was significant ($F[2, 427] = 134.55$; $p < 0.001$).

Discussion

The results of this prospective study demonstrate that hip ROM significantly predicts femoral torsion and central acetabular version. Specifically, internal rotation ROM (both at a neutral hip position and at 90° of hip flexion) was greatest in hips with combined femoral antetorsion and acetabular anteversion, whereas external rotation ROM was correspondingly least in such hips. Conversely, internal rotation ROM was least in hips with femoral retrotorsion and acetabular retroversion, with the opposite trends observed for external rotation ROM. Multivariate analysis indicated that internal rotation ROM at a neutral hip position and patient age were independent predictors of the COTAV index, exhibiting the following relationship: COTAV = 8.0 + (0.3 × age) + (0.6 × internal rotation ROM at a neutral hip position).

Several previous papers have indicated a significant association between internal rotation ROM and femoral torsion or acetabular version. Consistent with our findings, Audenaert et al. demonstrated that 75% of the observed variance among measurements of internal rotation ROM at 90° of hip flexion could be attributed to femoral head asphericity, acetabular coverage, and femoral torsion in a cohort of thirty patients with no pathology, asymptomatic FAI, or symptomatic FAI[28]. Moreover, Kelly et al. reported mean values of internal rotation ROM at 90° of hip flexion that increased incrementally by at least 5° between patients with femoral retrotorsion (<5°), normal femoral torsion (5° to 20°), and femoral antetorsion (>20°)[29].

Mechanistically, hip internal rotation is thought to introduce a mechanical conflict between the anterolateral femoral head-neck junction and the acetabulum, whereas external rotation results in posterior impingement that occurs extra-articularly between the greater trochanter and the ischium[30] and intra-articularly between the femoral head-neck junction and the posteroinferior aspect of the acetabulum[31]. In support of this view, Ross et al. demonstrated that a 10° increase in anterior pelvic tilt (acetabular retroversion) caused mechanical conflict between the femur and acetabulum, reducing internal rotation ROM[32]. Moreover, Ejnisman et al. observed that hips with excessive femoral antetorsion had twofold greater odds of a labral tear extending beyond the three o'clock position[8]. Another important finding of our study was that abduction ROM was not associated with the degree of femoral torsion or acetabular version. This is consistent with findings by Bedi et al. demonstrating that restrictions in abduction ROM predominantly occur due to mechanical conflict between the superior femoral head-neck junction and the twelve o'clock position of the acetabulum, neither of which is significantly affected by femoral or central acetabular version abnormalities[30]. Finally, our study revealed that external rotation ROM at a neutral hip position is most strongly dependent on the degree of femoral torsion, not on the degree of central acetabular version. Indeed, this confirms previous reports suggesting that limitations in external rotation ROM at a neutral hip position occur primarily as a result of posterior impingement between the greater trochanter and the ischium, with little contribution from the acetabular rim[30]. Collectively, our findings suggest that limitations in passive ROM are largely determined by osseous alignment, and not by pain or apprehension arising from intra-articular and extra-articular pathology as previously suggested[15,33,34].

In our study, various demographic characteristics were significantly associated with femoral torsion and central acetabular version. Female patients exhibited greater femoral torsion and acetabular version, consistent with previous reports[9,35-37]. Additionally, a diagnosis of cam-type FAI was associated with decreased femoral torsion, and mixed-type FAI was associated with decreased acetabular version. Similarly, Sutter et al. determined that patients with cam-type FAI demonstrated approximately 9° less mean femoral torsion compared with patients with pincer-type FAI[9]. Likewise, acetabular retroversion has been previously implicated in pincer-type and mixed-type FAI[3,38-40]. Finally, we observed a significant correlation between age and the COTAV index, which outweighed the effects of all other demographic variables in our multivariate model. This may be explained by recognizing that a lower COTAV index may result in symptomatic pathology earlier in life because of a greater restriction in ROM.

Taken together, our results validate clinical examination of the hip as a reliable preliminary screening tool for femoral torsion or acetabular version abnormalities. Addressing such pathomorphologies with hip arthroscopy alone may fail to provide symptomatic relief and/or a delay in the progression of early-onset coxarthrosis[41-43]. The clinical examination of the hip is universally performed during the diagnostic evaluation of patients with symptomatic hip pathologies and therefore represents an economical, readily accessible, and radiation-free option for detecting hip orientation abnormalities. Another important implication is that our linear regression model enables an estimation of the expected COTAV index given a patient's age and internal rotation ROM; this may help to prevent overcorrection during periacetabular osteotomy—a well-known iatrogenic cause of pincer-type FAI[44]. Lastly, for patients who do undergo CT evaluation, a large discrepancy between the measured and the calculated COTAV index may indicate substantial capsular laxity or, alternatively, may help to quantify the extent of prior surgical correction in revision cases.

Indices involving measurements of both femoral torsion and acetabular version have been previously reported in pediatric patients with developmental hip dysplasia (the McKibbin Index)[45] and in patients with noncemented total hip arthroplasty implants[46,47]. Our study further validates the relevance of this combined index in a more general population by including both symptomatic and asymptomatic hips in patients of various ages. Lastly, we provide cutoff values for the COTAV index that, when used with our equation, may potentially reduce the number of unnecessary preoperative CT scans.

Our study has the following limitations. First, the applicability of our findings may be limited to normal hips and hips of patients undergoing treatment for relatively mild anatomic deformity of the proximal aspect of the femur and/or acetabulum. Patients with more substantial pathologies and deformities such as SCFE and Legg-Calvé-Perthes disease, who were excluded from this study, may demonstrate trends different from those reported herein[48]. Second, it is possible that the effects of femoral torsion and acetabular version on passive ROM are partially offset by anatomic factors of the hip joint that were not incorporated in our data analysis, such as hip capsular laxity and soft-tissue stiffness. Nonetheless, we believe that our results are clinically meaningful and valid given the relatively large sample size and the comprehensive evaluation of ROM.

In conclusion, our results demonstrate that passive ROM strongly predicts femoral torsion and central acetabular version. This understanding may enhance the role of clinical examination in the early detection of hip orientation abnormalities, thereby reducing the need for advanced imaging studies and informing surgical decision-making. ■

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