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Research Article

Hip Rotation Arc

Sepand Heidari[1], Mohammad Hossein Nabian[2], Mohammad Mahdi Ebrahim Nasab[3,*]

[1] Resident, Department of Orthopedic Surgery, Joint Reconstruction Research Center, Tehran University of Medical Sciences, Tehran, Iran
[2] Assistant Professor, Center of Orthopedic Trans-Disciplinary Applied Research (COTAR), Tehran University of Medical Sciences, Tehran, Iran
[3] Assistant Professor, Department of Orthopedic Surgery, Joint Reconstruction Research Center, Tehran University of Medical Sciences, Tehran, Iran

[*]Corresponding author: Mohammad Mahdi Ebrahim Nasab; Department of Orthopedic Surgery, Joint Reconstruction Research Center, Tehran University of Medical Sciences, Tehran, Iran. Tel: +98-21-61192767; Email: dr.mohammadebrahiminasab0303@gmail.com

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Abstract

Background: Rotational deformities of the lower extremity, such as altered femoral neck anteversion (FNA) and tibial torsion (TT), are common pediatric orthopedic conditions associated with intoeing gait. Accurate diagnosis is essential for effective treatment, yet the correlation between clinical examination and three-dimensional (3D) computed tomography (CT) measurements remains unclear. This study evaluates the agreement between clinical assessments and 3D CT in children with rotational deformities.

Methods: In a cross-sectional study at Imam Khomeini Hospital, Tehran City, Iran, 21 children (42 limbs) aged ≥10 years (girls) or ≥11 years (boys) with intoeing gait were assessed. Clinical measurements included hip internal rotation (HIR), hip external rotation (HER), and thigh-foot angle (TFA). Low-dose 3D CT (0.8-1.3 mSv) measured FNA and TT. Pearson correlation coefficients evaluated relationships between clinical and CT findings, with sliding threshold analysis to assess the impact of total hip rotation arc (HIR + HER) on correlations.

Results: Mean clinical measurements were: HIR = 63.54° ± 9.30°, HER = 42.11° ± 6.80°, and TFA = 9.60° ± 8.50°. CT measurements showed FNA 27.71° ± 6.60° and TT 16.11° ± 9.90°. Correlations were moderate (HIR vs. FNA: r = 0.41; HER vs. FNA: r = 0.57; TFA vs. TT: r = 0.483). At a total arc threshold of 98.5°, HIR-FNA correlation increased to r = 0.74 for arcs > 98.5°.

Conclusion: Clinical and 3D CT measurements show moderate correlation, suggesting complementary roles. Greater hip rotation arc enhances clinical reliability, supporting refined examination protocols to reduce imaging reliance in pediatric rotational deformity assessment.

Keywords: Tibial Torsion; Three-Dimensional Image; Computed Tomography; Bone Anteversion

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Background

Rotational deformities of the lower extremity, particularly alterations in femoral neck anteversion (FNA), represent common orthopedic challenges that can lead to a broad spectrum of musculoskeletal disorders, including developmental dysplasia of the hip, rotational malalignment of the lower limbs, and osteoarthritis. Accurate diagnosis of these deformities, especially in pediatric patients, is crucial for appropriate treatment planning, including corrective surgery, physical therapy, and orthotic interventions (1, 2).

In healthy children, FNA typically decreases from approximately 30 degrees in infancy to around 10 degrees by adolescence, reflecting age-related changes. This angle significantly increases during the fetal period and gradually declines until skeletal maturity. Evidence suggests further reduction of femoral anteversion in adulthood and old age; however, the underlying mechanisms are not understood (3, 4). Mechanical forces from daily activities likely influence FNA changes. Notably, altered FNA is observed in populations with neuromuscular disorders or conditions such as breech birth and cerebral palsy (CP) (5, 6).

Various methods exist for measuring FNA, with discrepancies up to 15 degrees reported within the same limb due to measurement tools or examiner variability (7, 8). Tibial torsion (TT), another key component of lower limb rotation, typically ranges from 15° to 25° of external rotation (ER) in adults, but measurement methods (e.g., goniometers, torsion meters) yield varying results. In this study, the transmalleolar axis (TMA) was used to minimize confounding factors such as heel varus/valgus or foot adduction/abduction (6, 9).

Computed tomography (CT) and magnetic resonance imaging (MRI) are standard clinical tools for measuring bone rotation. However, their application in longitudinal and population studies, especially in children, is limited by cost, scan duration, and ionizing radiation exposure. More practical methods like ultrasound and functional tests suffer from limited evidence of accuracy, highlighting the need for a reliable and valid method to assess FNA. Nevertheless, CT use in pediatric populations raises ethical concerns due to radiation exposure (10, 11).

In the present study, CT imaging was performed with an effective radiation dose between 0.8 and 1.3 mSv to minimize exposure while ensuring image quality, appropriate for the pediatric cohort (12, 13).

Both two-dimensional (2D) and three-dimensional (3D) CTs are commonly used to assess lower limb rotation. 3D CT offers detailed bone structure visualization and multiplanar reconstructions, providing comprehensive anatomical and spatial information, allowing precise localization of rotational deformities. However, comparative accuracy of these imaging modalities against clinical examination has not been fully established (14-16).

The primary objective of this study is to evaluate the correlation between clinical measurements of lower extremity rotation and values derived from 3D CT scans. Conducted at Imam Khomeini Hospital, Tehran City, Iran, this research aims to provide clinically applicable data to

improve diagnosis and management of lower limb rotational deformities, aiding in protocol development, imaging method selection, and surgical planning (8, 17).

Methods

Study Design: This cross-sectional study was conducted at Imam Khomeini Hospital, with approval from the Ethics Committee of Imam Khomeini Hospital, affiliated with Tehran University of Medical Sciences (IR.TUMS.IKHC.REC.1403.335) and was in accordance with the principles outlined in the Declaration of Helsinki.

Study Setting and Participants: Participants were recruited from the pediatric orthopedic outpatient clinic at Imam Khomeini Hospital. Inclusion criteria were: 1. age ≥ 10 years for girls and ≥11 years for boys, 2. clinical evidence of rotational deformity exceeding 5° beyond normal reference values for femoral or tibial rotation, and 3. deformity associated with either cosmetic concern or functional impairment.

Exclusion criteria included: 1. the presence of orthopedic or developmental disorders affecting gait (e.g., CP, neuromuscular disease), 2. age < 10 years in girls or < 11 years in boys, 3. a history of lower limb surgery, and 4. generalized ligamentous laxity with a Beighton score≥4.

Clinical Assessment: All patients underwent standardized clinical evaluation by two fellowship-trained orthopedic surgeons. Assessment included observation of gait pattern, measurement of hip internal rotation (HIR) and hip ER (HER), bilateral thigh-foot angle (TFA), screening for metatarsus adductus using the heel bisector method, and joint laxity assessment using validated criteria.

Hip rotation was evaluated in the prone position, with the hips extended and knees flexed to 90°. Maximal internal and ER angles were defined by the tibial axis relative to the body midline. Movements were passive and gravity-assisted, and stabilization of the pelvis and knees was ensured to minimize compensatory motion. For ER, the contralateral limb was abducted to prevent mechanical interference, and the endpoint was defined by a firm end-feel without pelvic tilt (Figures 1 and 2).

Figure 1. Method of measuring maximum bilateral hip internal rotation (HIR) with the patient in the prone position and the knees flexed to 90 degrees

TFA was measured with the patient in the prone position with knees at 90° and ankles in neutral alignment.

Figure 2. Method of measuring maximum bilateral hip external rotation (HER) with the patient in the prone position and the knees flexed to 90 degrees

The angle was defined by the intersection of the thigh axis and the bisector of the calcaneus, using a handheld goniometer. Positive values indicated internal TT; negative values represented external torsion (Figure 3).

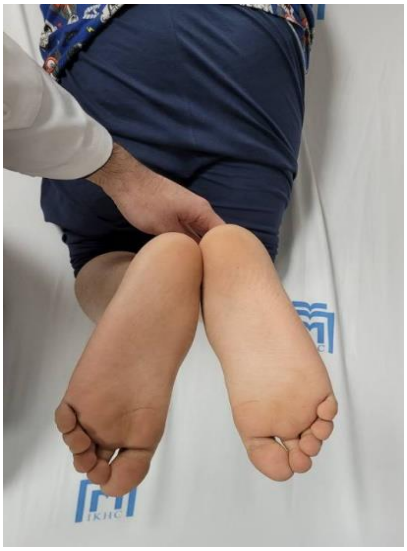

Figure 3. Positioning of both lower limbs for measurement of the thigh-foot angle (TFA) prior to goniometer placement

Foot progression angle (FPA) was not measured, as it reflects a composite of femoral, tibial, and forefoot rotations and may obscure individual contributors to intoeing. Instead, direct comparisons were made between clinical findings and CT-derived anatomical measurements.

CT Imaging Protocol: All CT scans were performed using a 64-slice Brilliance CT scanner (Philips Medical Systems, The Netherlands at a tertiary referral center in Tehran, Iran), utilizing low-dose protocols (0.8-1.3 mSv) to minimize radiation exposure. Images were reconstructed with optimized algorithms for pediatric low-dose imaging. Patients were positioned supine with lower

limbs fully extended and stabilized using restraining straps to prevent motion during acquisition. Bilateral scans were obtained in a single session.

Scan parameters included:

- Table feed: 44.4 mm/rotation
- Gantry rotation time: 1 second
- Slice thickness: optimized for low-dose reconstruction.

It is acknowledged that 3D CT scanning involves radiation exposure, which poses potential long-term risks, especially in pediatric and sensitive populations. To mitigate these risks, the ALARA principle (As Low As Reasonably Achievable) was strictly observed, and up-to-date low-dose imaging protocols were utilized. These advanced techniques ensure precise measurement of limb rotation while minimizing radiation dose.

3D CT Measurements

- *Femoral Anteversion (3D):* Reconstructed using volume rendering in Extended Brilliance Workspace (v2.0), following the method described by Byun et al. (18). The femoral neck axis was defined by a line connecting the centers of the femoral head and neck in the craniocaudal direction. The condylar axis (distal reference) was drawn through the most posterior points of the medial and lateral condyles in a caudocranial view. The anteversion angle was calculated using the following rule:
- If the neck and condylar axes were oriented in the same direction relative to the horizontal axis, the anteversion angle equaled the difference between the two angles.
- If oriented in opposite directions, the two angles were summed.

This method is recognized for its high accuracy and reliability in femoral anteversion assessment (Figure 4).

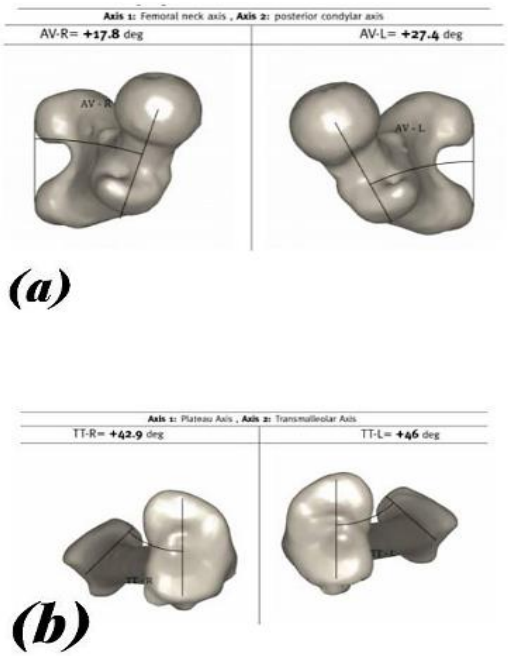

Figure 4. a) Method of measuring femoral anteversion using three-dimensional (3D) computed tomography (CT); b) Method of measuring tibial torsion (TT) using 3D CT

TT (3D): Measured based on the technique described by Edmonds et al. (17). Volume-rendered axial images were used to identify the posterior edges of the proximal tibial condyles and the anterior/posterior borders of the medial malleolus. The mechanical axis of the tibia was aligned within the software, and the following lines were drawn on a transverse plane perpendicular to that axis:

- A line through the posterior tibial condyles
- A line through the midpoints of the medial and lateral malleoli.

The angle between these two lines defined the TT.

Data Analysis: To assess interobserver reliability of clinical measurements, two orthopedic surgeons independently performed all physical examinations. The average of their measurements was used for final analysis and comparison with 3D CT values.

For the 3D CT reconstructions, angular measurements were performed independently by two trained operators, each conducting two sets of measurements one week apart. This allowed evaluation of both intraobserver and interobserver reliability. The final value used for analysis was the average of the four measurements (two by each operator).

Pearson correlation coefficients were used to evaluate the relationships between: 1. FNA measured by 3D CT and clinical HIR and HER, 2. TT measured by 3D CT and TFA on physical examination.

Additionally, a sliding correlation analysis was performed to investigate the influence of total hip rotation range (HIR + HER) on the strength of correlation between clinical HIR and CT-derived FNA. In this method, various threshold values for total hip rotation were tested, and the Pearson correlation was recalculated separately in subgroups with lower and higher ROM than each threshold.

A P-value < 0.05 was considered statistically significant. All analyses were performed using SPSS software (version 26.0, IBM Corporation, Armonk, NY, USA).

Results

The analysis included 42 lower limbs (left and right) from 21 children presenting with intoeing gait. The mean clinical measurements were as follows: HIR = 63.54° ± 9.30°, HER = 42.11° ± 6.80°, and TFA = 9.60° ± 8.50°. Corresponding mean values obtained from 3D CT scans were: FNA = 27.71° ± 6.60°, TT = 16.11° ± 9.90°, and total arc = 103.15° ± 9.40° (Table 1).

Table 1. Descriptive statistics for clinical and computed tomography (CT) measurements (n = 42)

Parameter	Minimum	Maximum	Mean ± SD
HIR	43°	80°	63.54° ± 9.30°
HER	30°	60°	42.11° ± 6.80°
TFA	-10°	20°	9.60° ± 8.50°
FNA	16°	39°	27.71° ± 6.60°
TT	-5°	30°	16.11° ± 9.80°
Total arc angle	91°	125°	103.15° ± 9.40°

HIR: Hip internal rotation; HER: Hip external rotation; TFA: Thigh-foot angle; FNA: Femoral neck anteversion; TT: Tibial torsion; SD: Standard deviation

Interobserver reliability for the clinical examination measurements demonstrated excellent agreement. The intraclass correlation coefficients (ICCs) were 0.979 for HIR, 0.902 for HER, and 0.938 for TFA, all indicating statistically significant and clinically acceptable interobserver reliability (Table 2).

Interobserver and intraobserver reliability for FNA and TT measurements using 3D CT imaging were excellent, with ICC values ranging from 0.963 to 0.980 for FNA and 0.967 to 0.987 for TT. These findings confirm the high precision and reproducibility of rotational assessments performed with this imaging modality (Table 3).

Table 3. Interobserver and intraobserver reliability for femoral neck anteversion (FNA) and tibial torsion (TT) measured by three-dimensional (3D) computed tomography (CT) imaging

Parameter	Reliability type	ICC range	Interpretation
FNA	Interobserver	0.963-0.980	Excellent reliability
FNA	Intraobserver	0.963-0.980	Excellent reliability
TT	Interobserver	0.967-0.987	Excellent reliability
TT	Intraobserver	0.967-0.987	Excellent reliability

FNA: Femoral neck anteversion; TT: Tibial torsion; ICC: Intraclass correlation coefficient

Correlation analysis between physical examination findings and 3D CT measurements was performed by comparing HIR and HER with FNA angle on 3D CT, as well as TFA with TT angle on 3D CT. The correlation coefficients were 0.41, 0.57, and 0.483, respectively. These results indicate a moderate correlation between clinical examination and 3D CT measurements, with some comparisons showing low correlation. For example, in certain children with approximately 70 degrees of HIR, FNA angles ranged widely from 16.5° to 52.6°, reflecting high variability in individual measurements (Table 4) (Figure 5).

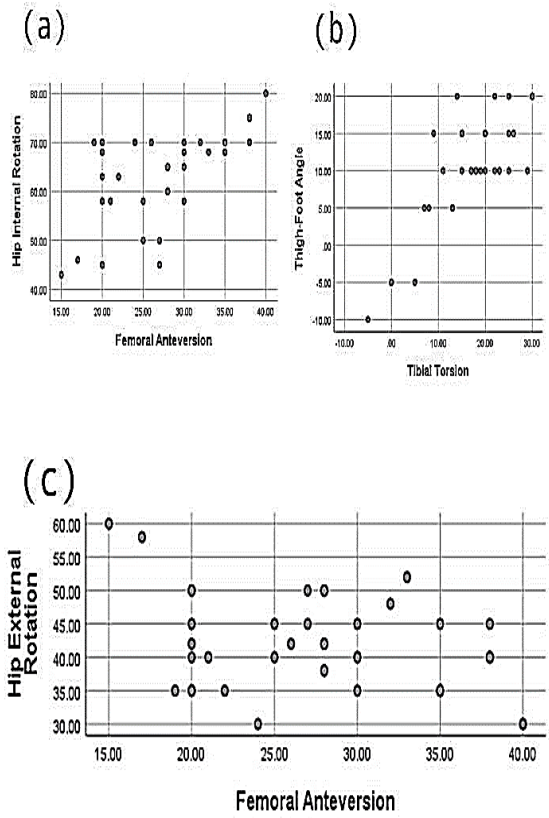

Figure 5. Scatter plot showing the relationship between physical examination findings and three-dimensional (3D) computed tomography (CT) scan measurements

a: HIR vs CT FA; b: TFA vs CT TT; c: HER vs CT FA

To explore whether the relationship between clinical HIR and CT-based FNA depends on the total arc of hip rotation, a threshold-based subgroup correlation analysis was conducted.

Table 4. Correlation between physical examination and three-dimensional (3D) computed tomography (CT) measurements

Clinical parameter	CT measurement parameter	Pearson correlation (r)	Strength of correlation
HIR	FNA	0.410	Low positive
HER	FNA	0.570	Moderate
TFA	TT	0.483	Low positive

HIR: Hip internal rotation; HER: Hip external rotation; TFA: Thigh-foot angle; FNA: Femoral neck anteversion; TT: Tibial torsion; CT: Computed tomography

For each subject, the total arc of hip rotation was calculated by summing the average passive internal rotation (IR) and ER angles measured in the prone position. The anteversion angle of the femur was obtained from axial CT images using standard measurement protocols.

A sliding threshold approach was applied by incrementally testing possible cut-off values for the total arc. At each threshold, the sample was divided into two groups: one with total arc ≤threshold and one with total arc > threshold. For each group, the Pearson correlation coefficient between IR and CT-measured FNA was computed.

The analysis revealed a distinct shift in correlation strength at a total arc threshold of 98.5 degrees. In patients with total arc ≤ 98.5°, the correlation between IR and anteversion was r = 0.41, while in those with a total arc > 98.5°, the correlation markedly increased to r = 0.74.

These findings suggest that IR measurements are more reflective of underlying FNA when total hip rotational mobility is relatively preserved (Table 5).

Table 5. Correlation between clinical hip internal rotation (HIR) and computed tomography (CT)-based femoral neck anteversion (FNA) across total arc threshold

Total arc group	Number (limbs)	Pearson correlation (r)	Interpretation
≤98.5°	18	0.41	Moderate correlation
>98.5°	24	0.74	Strong correlation

Discussion

This study aimed to investigate the correlation between clinical examination findings and measurements obtained from 3D CT scans in children presenting with intoeing gait.

Using 3D CT imaging, TT and FNA angles were assessed. Clinical examinations included measurements of the TFA as well as HIR and HER, which correspond to TT and FNA, respectively.

Multiple studies, including cadaveric investigations, have validated the accuracy of CT measurements for TT and FNA. In the present study, correlations between these variables were analyzed to identify differences or similarities between clinical and imaging methods (19).

Our results demonstrated a moderate correlation between TT and TFA, as well as between FNA and maximum hip rotation during clinical examination. These findings suggest that CT-based measurements and clinical examinations may reflect different aspects of lower limb rotational status. In other words, these two methods are complementary and cannot be considered interchangeable. The differences in correlation may be attributed to variations in the anatomical structures assessed, the precision and reproducibility of the measurements, and the influence of functional and muscular factors during clinical examination.

The moderate correlation observed between TT and TFA can be explained by the differing reference points used in these measurements. In CT-based TT assessment, the distal tibia at its lowest portion serves as the reference, whereas TFA uses the plantar surface of the foot as the standard reference line. Consequently, TFA reflects not only the tibial bone but also the overall foot position (20).

Therefore, when evaluating rotational deformities of the lower limb particularly in children with foot deviations or deformities, high-level measurements, such as the transmalleolar angle, may provide more focused information than assessments based solely on the tibia (21).

The FNA angle measured by 3D CT represents the torsional relationship between the femoral head/neck and the distal femoral condyles. In contrast, clinical assessment of HIR and HER reflects not only this torsional alignment but also the positional orientation of the femoral head within the acetabulum. As such, hip rotation measurements can be influenced by factors beyond true bony torsion and may vary independently from the actual FNA angle.

In CT-based measurement of FNA, the angle is calculated between two anatomical axes: a proximal axis connecting the center of the femoral head and neck, and a distal axis defined by the line connecting the posterior aspects of the femoral condyles. This method evaluates only the osseous structure of the femur, without accounting for the spatial relationship between the femoral head and the pelvis (2).

This fundamental difference in measurement principles helps explain the modest correlation observed between clinical hip rotation and CT-based FNA. In some cases, HIR or HER may fall outside the expected clinical range despite a normal FNA angle, due to variations in femoral head positioning within the acetabulum.

Based on these findings, it can be concluded that the diagnostic value of physical examination in accurately identifying the etiology of intoeing gait is limited compared to 3D CT-based measurements. In particular, the low correlation between clinical hip rotation and CT-derived FNA highlights the limited validity of physical examination as a standalone tool for localizing the source of rotational deformity.

3D CT provides a direct and precise evaluation of osseous torsional parameters and may be especially valuable in complex cases or when significant rotational deformity is suspected, aiding in more informed treatment decisions. Nevertheless, physical examination remains an essential, accessible, and radiation-free modality for initial screening and longitudinal follow-up, particularly due to its low cost and ease of use (22).

All participants in this study were between 10 and 19 years of age, and none demonstrated metatarsus adductus. Analysis of 3D CT measurements of FNA and internal TT revealed that a clear age-based distinction between these two etiologies was not always achievable. In many cases, both deformities were present concurrently in abnormal ranges (8).

Age-related distribution patterns also revealed that in children aged 10 and 11, internal TT accounted for 50% of the cases of intoeing, while increased FNA was noted in only 20% and 30% of cases, respectively. Conversely, in children aged 13 and 14, increased FNA was identified as the primary cause of intoeing in 50% and 100% of cases, respectively, with no cases of internal TT detected in these age groups.

Overall, internal TT was more frequently observed in children under the age of 14, whereas increased FNA became more prevalent beginning around age 10 and was increasingly dominant in older age groups.

Although this study demonstrated a weak linear correlation between clinical measurements of HIR and HER with FNA as measured on the 3D CT, these findings do not negate the potential relationship between the two assessment modalities. Rather, they highlight that the accuracy and reliability of physical examination may be improved through optimization of examination techniques, careful evaluation of compensatory movements, and the use of auxiliary measurement tools (20).

Building on this observation, the finding that higher total hip rotation improves the correlation between clinical IR and CT-measured FNA has practical implications for clinical assessment. Specifically, it suggests that evaluating the total arc of hip rotation may serve as a useful indicator of the reliability of physical examination findings. In patients with greater hip mobility, clinicians may achieve a more accurate and dependable estimation of FNA without the immediate need for advanced imaging.

In this study, we compared our clinical and 3D-CT assessment results of femoral anteversion and lower extremity rotational deformities with the reliability data reported by Byun et al. (18). Byun et al.'s study demonstrated excellent intra- and inter-rater reliability of 3D-CT measurements of FNA, with ICC values exceeding 0.89, establishing 3D-CT as a highly reproducible imaging modality (18). Our findings align with this by confirming that 3D-CT provides precise quantitative data, reinforcing its value in the diagnosis and management of pediatric rotational deformities.

However, unlike Byun et al.'s focus on measurement reliability, our study evaluated the correlation between clinical examination parameters such as HIR, HER, and TFA and 3D-CT measurements. We found only moderate correlations overall, though the association improved significantly in children with a larger hip rotation arc. This suggests that while clinical assessment alone may not be sufficient to fully characterize rotational deformities, it plays a complementary role to 3D imaging. The comparison of these two studies underscores the importance of integrating reliable imaging techniques with thorough clinical evaluation to optimize diagnosis while minimizing radiation exposure (18).

This could be particularly valuable in pediatric populations, where minimizing radiation exposure is a priority. By identifying thresholds of hip motion that predict more trustworthy clinical measurements, this approach could reduce the need for further imaging studies in selected cases. Moreover, it opens avenues for future research focused on refining physical examination protocols and establishing standardized rotational thresholds to optimize decision-making. Ultimately, such strategies may help streamline clinical workflows, limit unnecessary investigations, and promote safer, more cost-effective care in children with suspected rotational deformities (19).

If such refinements are implemented, physical examination may serve as a more dependable screening method, potentially reducing the need for advanced imaging in less complex cases and limiting unnecessary exposure to radiation and healthcare costs. This underscores the continued clinical value of physical examination in the initial evaluation and management of rotational deformities.

Conclusion

The findings of this study demonstrated a generally low correlation between classical physical examination and 3D CT measurements in assessing rotational deformities of the lower limb in children with intoeing gait. This discrepancy likely reflects the multifactorial and complex nature of rotational deformities. Therefore, it is recommended that clinical examination and 3D CT imaging be considered complementary tools rather than alternatives for accurate evaluation.

Importantly, our analysis also revealed that the correlation between clinical hip rotation - particularly IR -

and CT-measured FNA increased significantly when the total arc of hip rotation exceeded a specific threshold. This suggests that in patients with a larger range of hip motion, physical examination findings may more reliably approximate actual FNA.

These insights emphasize the need for future research to develop more reliable clinical tests that could potentially replace advanced imaging in certain cases. Further studies with larger pediatric cohorts are also recommended to better delineate age-related patterns of rotational deformity and improve diagnostic precision.

Conflict of Interest

The authors declare no conflict of interest in this study.

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Written informed consent for the use of clinical images (including photographs and radiographs) was obtained from the patient's parents.

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