HHS Public Access
Author manuscript
J Pediatr Orthop. Author manuscript; available in PMC 2018 December 01.

Published in final edited form as:
J Pediatr Orthop. 2017 December ; 37(8): 557–562. doi:10.1097/BPO.0000000000000712.

Measurement of Femoral Version by MRI is as Reliable and Reproducible as CT in Children and Adolescents with Hip Disorders

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Abstract

Background—Femoral version measurement techniques based on MRI studies have been developed as an alternative to the high levels of ionizing radiation associated with CT based methods. Previous studies have not evaluated the reliability, repeatability, and accuracy of MRI based femoral version measurements in an adolescent population.

Methods—Subjects that underwent MRI and CT studies for clinical suspicion of hip pain secondary to hip dysplasia or femoroacetabular impingement between 2011 and 2013 were identified. Rapid sequence femoral version images were obtained from MRI Hip dGEMRIC and/or post arthrogram studies. Femoral version images were also obtained from bilateral CT lower extremity, without contrast, studies. Measurements were made by one fellowship trained, pediatric hip preservation attending surgeon, two pediatric orthopaedic surgical fellows and one fellowship trained musculoskeletal radiologist on two separate occasions. Linear mixed models were used to estimate the reliability and repeatability associated with CT and MRI based measurements (Intraclass correlation coefficients, ICC) and to estimate the agreement (CT – MRI) between the two techniques.

Results—The mean age of 36 subjects was 15.4 yrs (±4.1 yrs). Inter-rater reliability was 0.91 [95% CI: 0.86–0.95] for the CT technique compared to 0.90 [95% CI: 0.86–0.94] for the rapid sequence MRI technique. Intra-rater reliability for the CT technique was 0.96 [95% CI: 0.91–0.98] compared to 0.95 [95% CI: 0.90 to 0.97] for the MRI technique. The agreement between the MRI and CT based techniques (Bias: 1.9°, Limits of Agreement: −11.3–14.9°) was similar to the agreement between consecutive MRI measurements (Bias: 0.4°, Limits of Agreement: −7.8–8.6°) as well as consecutive CT measurements (Bias: 0.5°, Limits of Agreement: −8.8–9.9°).

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Conflict of Interest
The authors have no relevant financial conflicts of interest to disclose.

Conclusions—The inter- and intra-rater reliability and repeatability estimates (ICC values) associated with both techniques was excellent (>0.90). Acquirement of axial images at the pelvis and knee during MRI for investigation of adolescents with hip pain allows for reliable measurement of femoral version.

Level of Evidence—II – Diagnostic Study

Introduction

Femoral version is defined as the rotation of the femoral neck axis around the femoral shaft in the transverse plane. Abnormality of femoral version is associated with various hip disorders including but not limited to developmental dysplasia of the hip (DDH),[1] Legg–Calvé–Perthes disease, [2] femoroacetabular impingement (FAI),[3, 4] and slipped capital femoral epiphysis (SCFE).[5] Abnormal femoral version has also been reported to play a role in the etiology of hip osteoarthritis.[6, 7] When treating children and adolescents with hip disorders, especially when surgical intervention is anticipated, an accurate assessment of femoral version is paramount. Although physical examination may allow for estimation of femoral version,[8] a poor correlation between physical examination and imaging has been reported.[9]

Computed Tomography (CT) has traditionally been the most widely used imaging method to measure femoral version.[10–16] Recently, because of the growing awareness of the risks of ionizing radiation, there has been an interest in the application of magnetic resonance imaging (MRI).[10, 17–20] However, there is limited data on the reliability and reproducibility of MRI based measurements of femoral version. Similarly, the interchangeability of MR and CT methods for measuring femoral version is controversial.[10]

MRI of the hip is routinely used for investigation of intra-articular pathology in adolescents with hip pain associated with deformities secondary to FAI, DDH, SCFE and Legg–Calvé–Perthes disease. In these conditions, assessment of femoral version is important for treatment planning. We recently added a rapid MRI sequence to obtain axial images in the proximal and distal femur to our routine hip MRI protocol. We questioned whether the axial MRI images would allow for reliable measurement of femoral version. Therefore, the purpose of this study was to compare the measurement of femoral version in a series of adolescents presenting with hip pain who were assessed by both MRI and CT studies.

Methods

Patients

After Institutional Board Review approval, patients who underwent hip preservation surgery for the treatment of either hip dysplasia or FAI between October 2011 and May 2013 were identified. Inclusion criteria consisted of patients who had both preoperative CT and MRI scans performed at our institution with appropriate axial views of the hip and knees. Historically, CT of the lower extremity has been the study of choice for determination of femoral version at our institution. MRI has been used to investigate intra-articular hip pathology. Between 2011 and 2013, we established a modification of the MRI protocol to include axial, T2-weighted sequences along the proximal and distal femur to allow for femoral version measurements. During the study period, 61 patients who underwent hip preservation were identified. Patients were excluded due to the following: absence of a preoperative CT scan (N=21), or inadequate imaging quality (N=4).

Imaging protocol

For CT imaging acquisition, patients were positioned supine on the scanner with their feet taped together to allow for the patella to face anteriorly. CT scan was performed on a Siemens Sensation Somatom 40-CT system (Siemens Healthcare, Erlangen Germany) with a helical acquisition. To determine the effective radiation dose, the International Commission on Radiological Protection recommendation for organ weighting factors were utilized.[21] Effective doses were calculated and reported using the Enterprise Dose Management Software (Radimetrics TM Bayer Health Care). The radiation exposure associated with a typical CT scan was estimated around 4.5 mSv. This value represents 11 to 12 months of background radiation in our geographic area (5 to 6 mSv per year). For MR imaging acquisition, patients were positioned identical to CT examination supine on the scanner. MR images were obtained using a 1.5-T unit (Siemens, Erlangen, Germany) using 2 body matrix coils, one at the pelvis and one at the knees. In addition to the standard sequences used for the hip MRI protocol, limited field-of-view T2 fast spin echo (FSE) sequences through bilateral hips and knees were added to measure femoral version. Acquisition at each level takes less than one minute, for a total of less than two minutes of additional scanning time.

Measuring Protocol

A single investigator de-identified and randomized all CT and MRI studies in separate folders for the purpose of ensuring the observers were blinded. All measurements were performed using Picture Archiving Communications Systems (Fujifilm Medical Systems, Stamford CT) measurement tools. Measurement of femoral version using CT scan was performed using the method described by Weiner et al[16] (Figure 1). Briefly the femoral neck axis was identified on an axial slice in which the anterior and posterior cortices were parallel to each other. The femoral neck axis was defined as the midline between the anterior and posterior cortices. The femoral neck angle was measured as the angle formed by the femoral neck axis and a horizontal line. There was no pre-determined axial image to be measured. At the level of the distal femur, the axis of the femoral condyles was defined as the posterior tangent line to the femoral condyles. The distal femur angle was measured as the angle formed by the posterior condylar line and a horizontal line. Measurements of femoral version on MRI were performed using an equivalent method used for CT, following the technique described by Koenig et al[18] (Figure 2). The definition of the femoral neck axis was similar to the CT method, using the midline of the femoral neck parallel to the anterior and posterior cortices pointing towards the center of the femoral head. At the level of the knee the posterior condylar axis was defined at the subchondral bone plate. For both CT and MRI technique the femoral version angle was determined based on the femoral neck angle and on the distal femoral angle. As described by Koenig et al,[18] if the distal femur was rotated outward relative to the femoral neck, the distal femoral condyle angle was subtracted from the femoral neck angle. If the distal femur was rotated inward relative to the femoral neck, the angle measured at the femoral condyle was added to the femoral neck angle.

Four independent observers (1 hip preservation attending surgeon, 2 pediatric orthopaedic fellows, and 1 fellowship trained musculoskeletal radiologist) measured the images. Each observer completed a second session of measurements a minimum of two weeks after the first measurement session.

Statistical Method

Linear mixed-effects models were used to estimate the reliability and repeatability associated with the MRI and CT-based version measurements. Potential correlation due to the inclusion of multiple hips from the same subject was considered. Due to model convergence issues, one hip from each subject was randomly selected for inclusion in the analysis. Variance components specified in the linear mixed model (subject error, σ_S^2, observer error, σ_O^2, subject*observer random error, $\sigma_{S(O)}^2$, and residual or within subject error, σ_ε^2) were used to calculate the intra-class correlation coefficient (ICC) values representing inter-rater ($\sigma_S^2/\sigma_S^2+\sigma_O^2+\sigma_{S(O)}^2+\sigma_\varepsilon^2$) and intra-rater ($\sigma_S^2+\sigma_O^2+\sigma_{S(O)}^2/\sigma_S^2+\sigma_O^2+\sigma_{S(O)}^2+\sigma_\varepsilon^2$) reliability. The 95% confidence intervals associated with these estimates were calculated based on previously described methods.[22–24] Bland-Altman plots of agreement between the MRI and CT-based version measures were generated. The Bland Altman limits of agreement for the overall plot were calculated as $1.96 * \sqrt{\sigma_S^2+\sigma_O^2+\sigma_{S(O)}^2+\sigma_\varepsilon^2}$. Bland-Altman plots representing the agreement between the first and second MRI and CT measurements were also generated.

Results

The mean age and BMI of the 36 subjects was 15.4 years (±4.1 years) and 22.7 kg/m^2 (±6.2 kg/m^2), respectively. The population consisted of 14 male and 22 female subjects. The distribution of right and left hips in the population was 31% and 69%, respectively. Developmental dysplasia of the hip (DDH) and Legg-Calvé-Perthes disease were the most prevalent diagnoses in the study cohort (Table 1). Based on the linear mixed models, the average version measurement was 22.3 [95% CI: 14.8 to 29.7] for the CT based technique and 20.4 [95% CI: 12.8 to 28.0] for the MRI based technique.

Inter-rater reliability was 0.91 [95% CI: 0.86 to 0.95] for the CT technique compared to 0.90 [95% CI: 0.86 to 0.94] for the rapid sequence MRI technique. Intra-rater reliability for the CT technique was 0.96 [95% CI: 0.91 to 0.98] compared to 0.95 [95% CI: 0.90 to 0.97] for the MRI technique. Bland-Altman plots representing the overall agreement as well as Bland-Altman plots representing the agreement between the first and second MRI and CT measures are described in figures 3–5.

Discussion

Abnormalities of femoral version are associated with various hip disorders.[1–5, 7] When managing adolescents with hip pain, accurate assessment of femoral version is an important part of the diagnosis and planning for surgical treatment. Despite the risk of radiation exposure, measurement of femoral version is typically performed using CT imaging. In this study, we investigated the reliability and reproducibility of an MRI based method for assessing femoral version.

We observed similar intra- and inter-rater reliability of femoral version measurement using MRI as compared to CT studies. Although CT has been reported as a very accurate method for measuring femoral version,[10–16] limited data is available on the reliability and reproducibility of MRI.[10, 17, 19, 20] Guenther et al[17] was the first investigator to use MRI to measure femoral version in 19 children before correctional osteotomy. A high (r=0.77) correlation between MRI results and CT scan as well as excellent inter-rater as well as intra-rater reliability for MRI (r = 0.97 for both) and CT (r=0.99 and r=0.96) was reported. Botser et al[10] compared CT and MRI assessment of femoral version in adult hips before arthroscopic surgery. They reported high inter-observer correlation for measurement by CT and MRI (r=0.95 and r=0.86, respectively) with a high correlation with each other (r = 0.80). Muhamad et al[19] assessed lower extremity torsional profile on 34 patients with CT and 28 patients with MRI. Both technique were associated with excellent reliability.

The Bland-Altman limits of agreement approach was also used to assess agreement between the CT and MRI measurements. This analysis is distinct from measures of reliability or reproducibility in that agreement is focused on the degree of similarity between two measurement techniques rather than the degree of precision associated with each of the respective techniques.[25, 26] The estimate of bias, or mean difference between measurements, indicated the CT based measurements were an average of 2° higher than the MRI based measurements. The limits of agreement ranged from −11 to 15°. The limits of agreement are typically interpreted as the range within 95% of the differences between measurements is expected to fall. If measurements within the limits of agreement are not considered clinically important, the two measurement systems can be considered to be interchangeable.[26] To our knowledge, clinically relevant thresholds for versions measurements have not yet been established. Therefore, we also estimated agreement between consecutive MRI and CT measurements to determine whether limits of agreement between consecutive measurements were similar to limits of agreement representing differences between the techniques. The limits of agreement between CT and MRI based measurements were similar to consecutive CT measurements (−8 to 9°) as well consecutive MRI measurements (−9 to 10°). These findings suggest that both MRI and CT scan can be used interchangeably for the assessment of femoral version in adolescents presenting with hip disorders.

The limits of agreement between the MRI and CT based version measurement in the current study were consistent with related studies. Botser et al [10] compared CT and MRI assessment of femoral anteversion in 129 hips before arthroscopic surgery. The limits of agreement was reported to be between 2.53 and −20.38°. The bias or mean difference between techniques observed in current study was also consistent with previous studies.[10, 17, 20] Guenther et al[17] reported that mean version angles obtained by CT (34.0°, range 5–82°) were larger than the MRI values (23.2°, 0–65°) because of different measurement techniques. [17] Boster et al[10] also reported higher version measurements based on CT imaging compared MRI based version measurements (mean difference: 8.9°). Compared to related studies, we reported the smallest difference between MRI and CT scans. The small estimate of bias in our study is likely due to the utilization of the same principles to define the femoral neck axis during the MRI and CT measurements.

CT has been widely used for measurement of femoral version despite the associated risk of ionizing radiation exposure. In this study, the radiation exposure of CT was estimated around 4.5 mSv, which represents 11 to 12 months of background radiation in our geographic area. The clinical relevance of this exposure is not well defined, yet increased radiation from CT scans may have serious additive consequences in the pediatric population.[27–29] Increased scrutiny on the exposure of pediatric patients to radiation as well as increased availability of MRI with rapid sequencing technique has increased the demand for MRI over CT scan in the clinical setting.[30] The T2-FSE non-fat-saturated MR sequences used in our study allowed for good quality bone images and reproducible assessment of femoral version. The majority of adolescents who present with hip pain secondary to hip disorders may be candidates for a hip MRI to evaluate for intra-articular pathology. In this setting, we believe that the protocol described here should be added to the standard hip MRI protocol to allow for additional information regarding measurement of femoral version as it adds minimum time, allows for equivalent measurement of femoral version when compared to CT scan, and avoids risk of ionizing radiation.

We acknowledge several limitations. First, we included patients with different proximal femoral morphological abnormalities. The inclusion of a heterogeneous group of hip abnormities may have increased the variability in the difference or agreement between the two measurement techniques. However, by including a study cohort that is representative of the population of patients the pediatric hip surgeon typically encounters in clinical practice, we believe that this strategy improved the generalizability of the study results. Second, we did not control for patient movement between acquisition of proximal and distal femoral images. It is possible that movement could occur despite the fast acquisition time. Finally, we measured femoral version using multiple axial slices to determine the femoral neck axis. This technique has been criticized because it does not take into consideration the proximal femoral anatomy and does not allow for identification of the center of rotation.[11, 13, 15, 31] Kim et al[13] advocated adding an intertrochanteric axis to the evaluation of femoral rotation to allow for identification of the level of rotational deformity. Although Murphy et al[15] reported underestimation of version using single femoral neck axis cuts, Georgiadis et al[11] found equivalent accuracy for version measurement using single axis technique, adding a intertrochanteric axis, and using a volumetric 3-dimensional reconstruction. It is unclear whether the measurement error attributed to the single axis technique is clinically significant. Future research should focus on the feasibility of adding the intertrochanteric axis using MRI or using oblique axial slices parallel to the axis of the femoral neck.[32] Despite these limitations, we believe our study has important strengths. We included patients who underwent both CT and MRI scans, allowing for direct comparison of the two modalities.

Conclusion

The results of the current study indicate that MRI is a safe and effective technique for measuring femoral version in adolescents with hip pathology. The pediatric orthopaedic surgeon should consider MRI as an alternative to CT for assessment of femoral version in patients who are already undergoing a hip MRI for investigation of intra-articular pathology. Our findings suggest that acquirement of axial images at the pelvis and knee during MRI for investigation of adolescents with hip pain allows for reliable measurement of femoral version. However, we caution that version measurements based on CT scans tend to be slightly higher than measurements based on MRI.

Acknowledgments

Source of Funding: The work was supported in part by NIH/NCRR Colorado CTSI Grant Number UL1 RR025780. Contents are the authors' sole responsibility and do not represent official NIH views.

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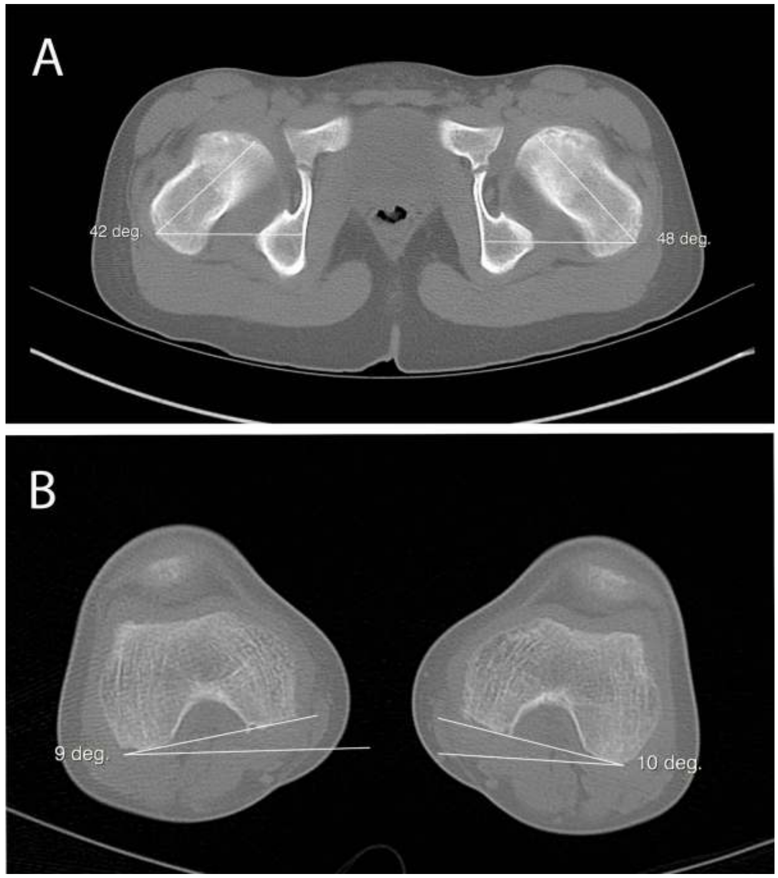

Figure 1.

Femoral version assessed on CT. The distal femur was rotated outward in the right and left lower extremities; therefore the distal femoral condyle angle was subtracted from the femoral neck angle. Femoral version measured 33° on the right and 38° on the left

A. At the level of the hip the femoral neck axis was defined as the midline between the anterior and posterior cortices. The femoral neck angle was measured as the angle formed by the femoral neck axis and a horizontal line.

B. At the level of the distal femur, the axis of the femoral condyles was defined as the posterior tangent line to the femoral condyles. The distal femur angle was measured as the angle formed by the posterior condylar line and a horizontal line.

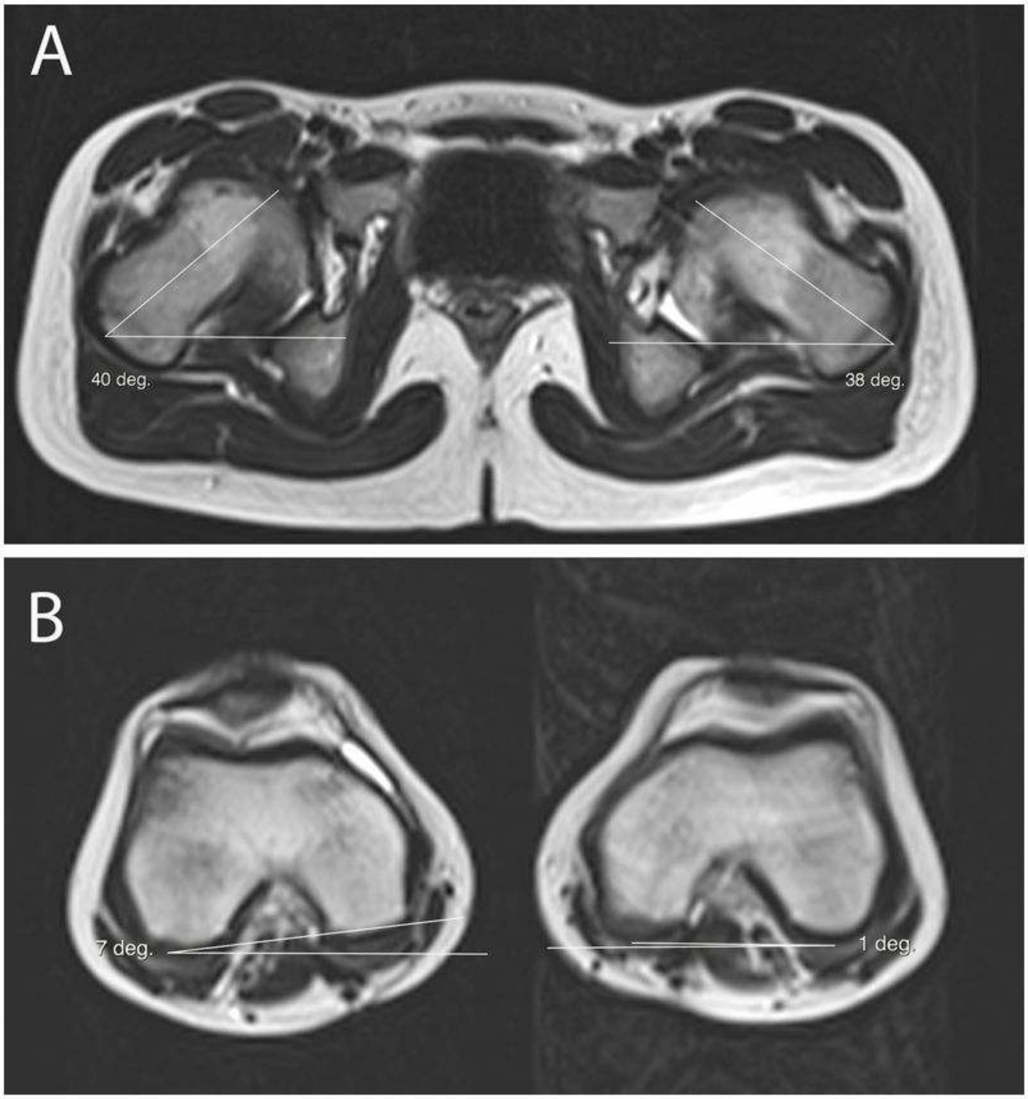

Figure 2.
MRI images for femoral version assessment for the patient described in figure 1[18]. The distal femur was rotated outward in the right and left lower extremities; therefore the distal femoral condyle angle was subtracted from the femoral neck angle. Femoral version measured 33° on the right and 37° on the lef.

A. Axial T2 image at the level of the hip shows how the femoral neck angle is obtained.

B. Axial T2 image at the level of the posterior femoral condyles.

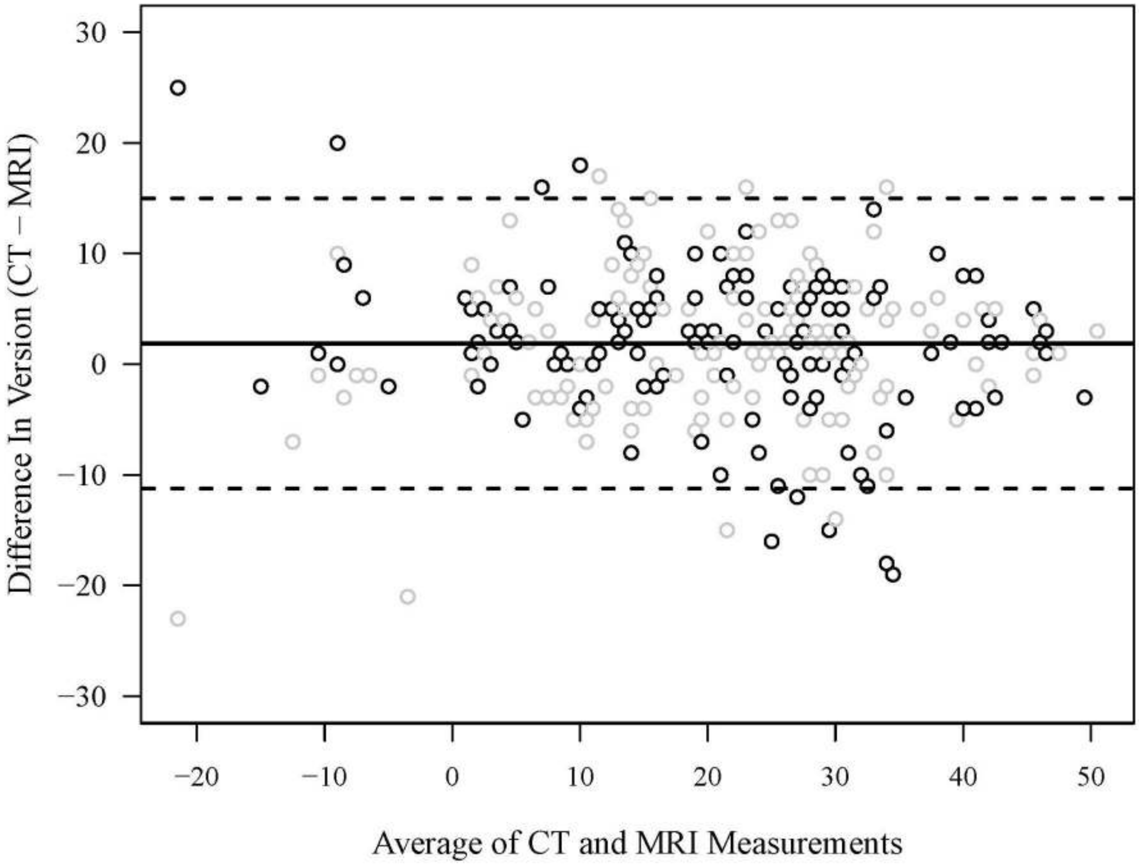

Figure 3.

Bland-Altman plot representing agreement based on all measurements. The black dots represent the initial measurements; the gray dots represent the follow-up measurements. The solid line represents the bias or the mean difference (1.87°); the dashed lines represent the limits of agreement (mean difference ± 1.96 times the standard deviation = −11.25 to 14.99°).

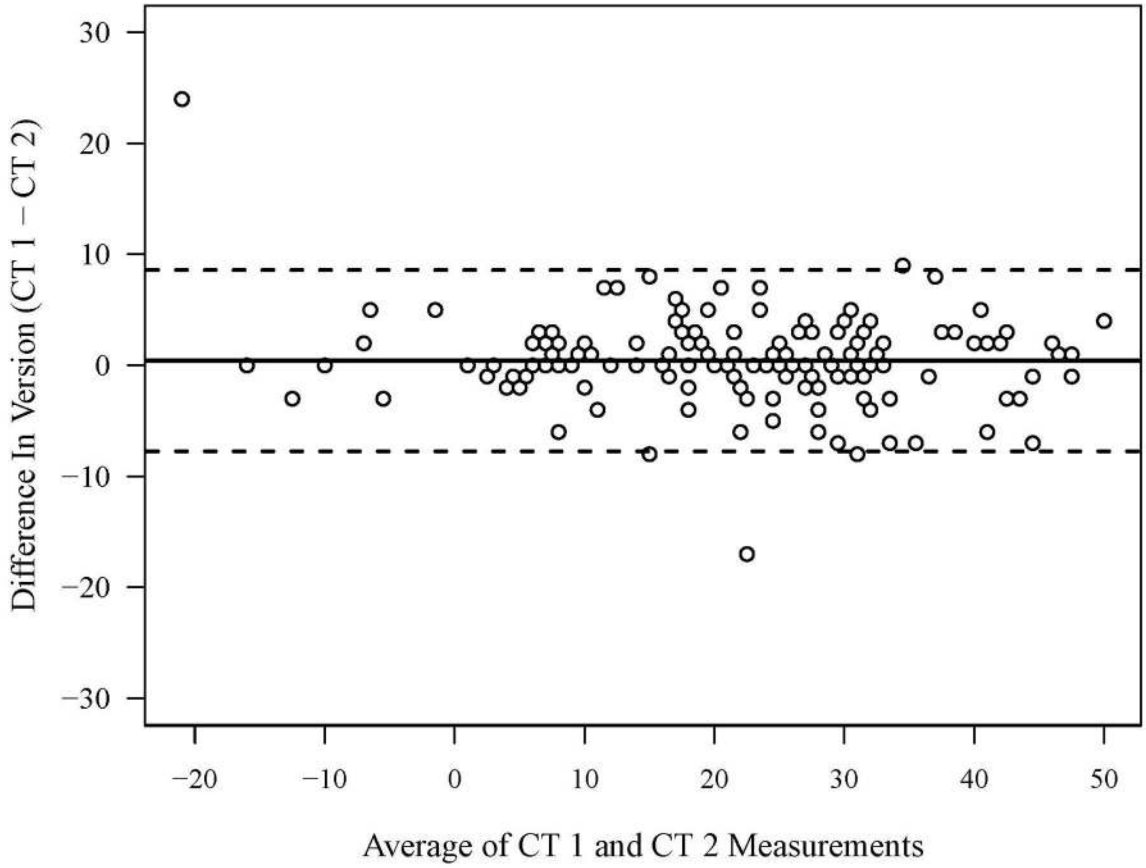

Figure 4.

Bland-Altman plot representing variability between consecutive CT Scan measurements. The solid line represents the bias or the mean difference (0.41°); the dashed lines represent the limits of agreement (−7.76 to 8.58°).

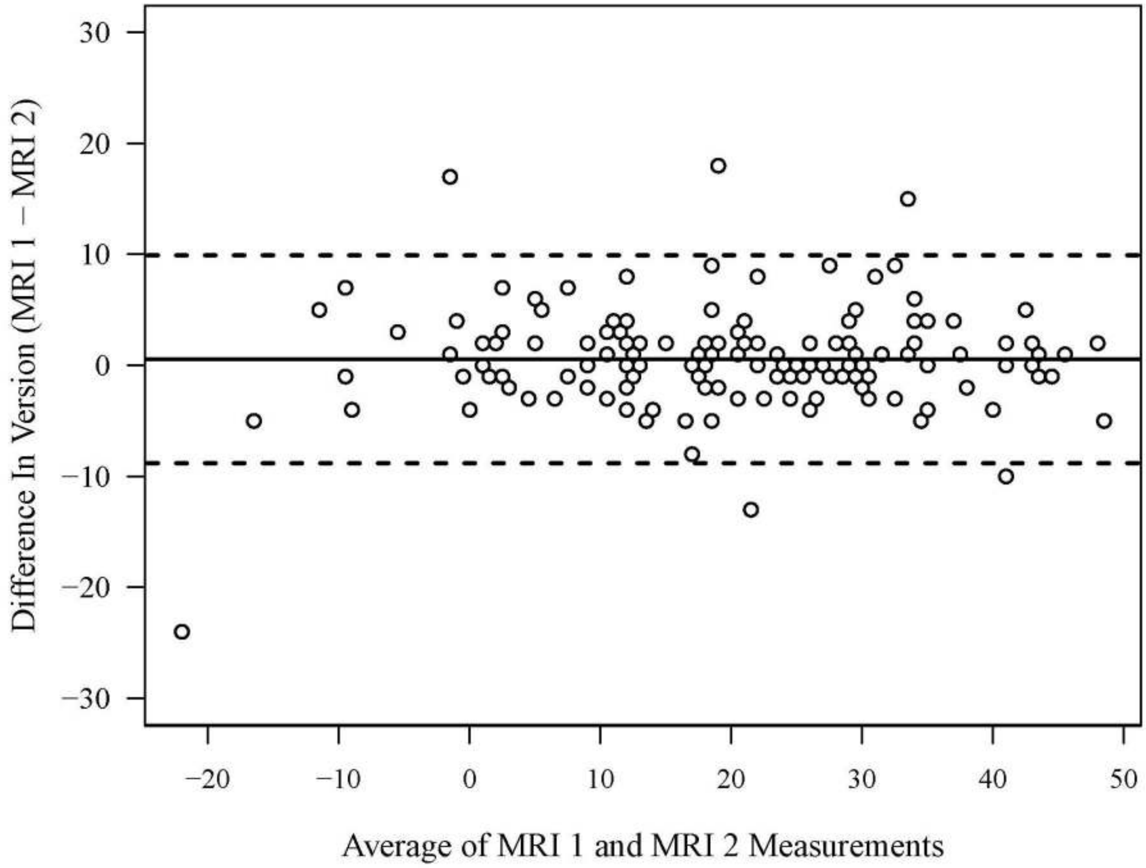

Figure 5.
Bland-Altman plot representing variability between consecutive MRI measurements. The solid line represents the bias or the mean difference (0.54°); the dashed lines represent the limits of agreement (−8.83 to 9.91°).

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Table 1

Primary Diagnosis

	N	%
Femoroacetabular Impingement	10	27.8%
Developmental Dysplasia of the Hip	11	30.6%
Legg-Calvè-Perthes	11	30.6%
Slipped Capital Femoral Epiphysis	2	5.6%
Excessive Anteversion	1	2.8%
Traumatic Posterior Hip Dislocation	1	2.8%