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ORIGINAL PAPER

Do changes in torsional magnetic resonance imaging reflect improvement in gait after femoral derotation osteotomy in patients with cerebral palsy?

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Abstract
Purpose Femoral derotation osteotomy (FDO) is commonly used to correct internal rotation gait (IRG) in spastic diplegia. The purpose of this study was to investigate whether the extent of intraoperative derotation is reflected in changes in static (clinical ROM and anteversion angle measured on torsional MRI) and dynamic parameters (transverse plane kinematics in three-dimensional gait analysis) after FDO in children with spastic diplegia.
Methods In a prospective study, 30 children with spastic diplegia and IRG were treated with FDO as part of a multilevel surgery and were examined pre- and postoperatively clinically, by three-dimensional gait analysis and by torsional MRI according to a standardised protocol.
Results A correlation (r=0.317, p=0.015) between the extent of intraoperative derotation and mean hip rotation in stance as well as the anteversion angle measured on torsional MRI (r=0.454, p<0.001) was found. However, no significant correlation was observed between anteversion angle (tMRI) and mean hip rotation in stance, either before or after FDO.
Conclusions Significant improvements were found in IRG after FDO, confirming the results of previous studies. There was no correlation between the anteversion measured on MRI and the mean hip rotation in stance in 3D gait analysis before or after FDO. Thus, the data suggest that if the intraoperative extent of derotation is determined only by the anteversion angle, the result will not be better after FDO. It might only help to avoid retroversion and indicate the maximum amount of femoral derotation. In this study the extent of the intraoperative derotation was orientated at the preoperative midpoint of rotation. Based on the small, but significant correlation between the clinical midpoint and the mean hip rotation in stance in the gait analysis, determination of the intraoperative extent of derotation according to the mean hip rotation in stance seems to give the best results.

Keywords Cerebral palsy · Gait analysis · Femoral derotation · Torsional MRI · Internal rotation gait

Introduction

Internal rotation gait (IRG) is a common gait abnormality in children with spastic bilateral cerebral palsy (CP) [1]. The pathogenesis of IRG is complex and not fully understood [2, 3]. Patients with this condition often subsequently develop functional and cosmetic gait disturbances [4] which are frequently accompanied by an increase in the internal foot progression angle. Understanding transverse plane gait deviations is difficult as they are typically also associated with frontal and sagittal plane deviations [1, 5]. Pelvic retraction is seen as one compensatory mechanism to correct an internal foot progression angle [6].

Two major factors should be taken into consideration: static and dynamic components. Children with spastic bilateral CP often present with increased femoral anteversion (static component) that leads to IRG [7]. In contrast to the physiological development in healthy children, in whom femoral anteversion decreases over time, it often does not decrease in patients with CP [3, 8–11]. However, not all ambulatory children with CP and IRG present with an increase in femoral anteversion and it

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is therefore obvious that dynamic factors need to be considered [2, 8, 12, 13]. Muscular imbalance, crouch gait, and spasticity of the hip internal rotators may also contribute to IRG [14]. Furthermore, IRG might represent a compensatory mechanism since increased femoral anteversion shortens the lever arm for the hip abductors [15].

In the treatment of IRG, the static factor (increased femoral anteversion) is mainly managed by performing femoral derotation osteotomy (FDO), which is commonly applied to correct IRG [2, 4]. It can be carried out at the inter-trochanteric level (proximal FDO) or at the supracondylar level (distal FDO) [16, 17]. There is agreement that both methods provide comparable static and functional results but that distal osteotomy is less complicated [4, 16, 18]. However, recent studies have shown a high rate of over- and undercorrection [2] and recurrence [19–21] of IRG following FDO in contrast to previous studies [4].

Since FDO only addresses the static factor and inconsistent outcome is reported after FDO, the relationship between femoral anteversion and functional outcome in the gait analysis (mean hip rotation in stance) represents a major issue. A weak correlation between femoral anteversion and dynamic hip rotation was found by Radler et al. [22] in patients without neurological disorder, while Kerr et al. [23] described the same finding for patients with CP. Indeed, the selection of the intraoperative extent of femoral derotation may represent one possible factor contributing to this inconsistent outcome.

The purpose of this study was, therefore, to compare the extent of intraoperative derotation with the changes in femoral anteversion (static) as measured by torsional MRI (tMRI) and mean hip rotation in stance during gait (dynamic) as determined by 3D gait analysis. Is the functional outcome (gait analysis) after FDO fully reflected in the change in passive rotation at clinical examination? Is the extent of intraoperative derotation fully represented in the changes in the anteversion angle measured on MRI? Do the MRI findings correlate with the functional outcome?

Material and methods

For this prospective, monocentric study 30 ambulatory (GMFCS I-III) patients (12 female, 18 male, aged 11.6±2.9 years) with spastic bilateral cerebral palsy and IRG scheduled for single-event multilevel surgery (SEMLS) including FDO were recruited from the CP specialty clinics.

Exclusion criteria were nonambulatory patient, tetra- or hemiparesis, dyskinetic CP, and bony interventions no longer than one year prior to recruitment.

The study was approved by the local ethics committee and each participant provided informed written consent. The preoperative Gillette Gait Index (GGI) [24] was 540±820. Seven patients walked with assistance, four patients required a posterior walker, three patients used crutches, and 23 were able to walk without walking aids. The indication for FDO was gait disturbance with functionally and cosmetically compromising IRG and mean hip internal rotation in stance of more than one SD above the normal reference. The extent of derotation was determined by the midpoint of rotation on clinical examination [23]. The derotation angle was monitored intraoperatively by two K-wires inserted proximally and distally at the osteotomy site [2]. Directly before plate fixation, three conditions were checked: (a) clinical midpoint in neutral position, (b) at least 20° of passive internal rotation remaining, and (c) the legs assuming external rotation position spontaneously. If any of the aforementioned conditions was not met, the derotation angle was modified.

Internal fixation was performed by using angle stable locking plates or angle plates. The extent of the derotation was measured by a Moeltgen® goniometer and controlled after the plate was fixed. The intraoperative extent of derotation in all 30 patients (56 legs) averaged 23.0° (± 8.5°, range 10–40°).

According to a standardized protocol all patients were prospectively examined both before (E0) and after FDO (E1: 13± 2 months). The test procedure included a clinical examination (ROM, TPAT [trochanteric prominence angle test] [25]), conventional three-dimensional (3D) gait analysis, and tMRI of the lower extremities to determine femoral anteversion.

Two physiotherapists trained in paediatric neurodevelopmental therapy and who had extensive experience treating children with CP carried out all examinations. Standardised 3D gait analysis was performed according to Davis et al. [26].

A 120-Hz nine-camera system (Vicon®, Oxford Metrics, UK) and two piezoelectric force plates (Kistler®, Winterthur, Switzerland) were used to obtain 3D gait data. Reflective markers were positioned at bony landmarks as described by Kadaba et al. [27]. Two static trials were performed using a knee alignment device (KAD) before motion capturing. In case of a discrepancy of more than 5°, a third trial was carried out. At both pre- and postoperative analysis, patients were asked to walk barefoot along a seven metre walkway at a self-selected walking speed. Joint kinematics and kinetics were calculated using Vicon Plug-in-Gait® 4.6 and averaging at least five valid strides.

Torsional MRI was carried out with a 1.0 Tesla system using a T1-weighted gradient echo sequence (TR 400 ms, TE 10 ms). Femoral anteversion was determined using the method described by Schneider et al. and Guenther et al. [24, 28, 29]. A block of 20 slices (thickness of four millimetres) was positioned in the area of the femoral head, knee joint, and ankle joint. For each block, the measurement time was 1:30 minutes. Sections best displaying the regions required for measurement of femoral head, neck, and the condyles were chosen and a proximal line was drawn through the centre of the femoral head and the centre of the femoral neck. A second line was drawn as a distal reference point at the dorsal borders of the femoral condyles. Two experienced examiners performed the examination.

The preferred surgical technique was distal FDO and was carried out in 41 legs. Proximal FDO was carried out in 15 legs, where additional pelvic osteotomies were required or patients were aged 14 years or older. Four patients only required FDO on one side. All procedures carried out during SEMLS are presented in Table 1.

Standard approaches were used for both techniques [16, 30], with a lateral approach to the distal femur at the supracondylar level for distal FDO. Postoperative management consisted of early mobilisation in a wheel-chair and weight-bearing with ankle casts from the fourth or fifth postoperative week onwards, depending on the concomitant procedures.

SPSS Inc PASW Statistics 18 was used to evaluate the data. The parameters from MRI, 3D gait analysis, and clinical examination were compared by using Spearman-Rho correlations. Additionally the Wilcoxon-Test was applied for pre-post comparison. P-values below 0.05 were regarded as significant.

Results

Clinical examination

Passive internal rotation decreased significantly by 15.9°, from 69.9 to 54.0° (comp. Table 2), whereas external rotation increased by 14.3°. Hence, the midpoint of passive rotation also changed significantly from a mean of 24.4° (internal) to 9.5° (internal) after FDO. In addition, the anteversion angle (TPAT) decreased from 31.2° to 22.9°. No significant changes were found in average tibial torsion as measured at the clinical examination.

Table 1 Surgical procedures

Level	Procedure	*n*
Pelvis	Dega procedure	3
Hip	Intramuscular psoas recession	8
	Intramuscular adductus longus lengthening	3
	Proximal recession of rectus femoris	12
Femur	Proximal femoral derotation osteotomy	15
	Distal femoral derotation osteotomy	41
Knee	Distal rectus-femoris-transfer	31
	Medial hamstring-lengthening	28
Tibia	Tibial derotation osteotomy	4
Ankle and foot	Baumann procedure	30
	Strayer procedure	2
	Tendo Achilles lengthening	3
	Split posterior tibial tendon transfer	9
	Split anterior tibial tendon transfer	3

Table 2 Parameters pre (E0) and post-op (E1)

Parameters	E0 (pre)	E1 (1 year post)	*p*-value
Three-dimensional gait analysis			
Mean hip rotation in stance	13.8°±14.8	0.4°±10.2	< 0.001
Mean foot progression angle in stance	11.1°±16.0	−1.3°±8.4	< 0.001
Gilette gait index	540.2±819.7	249.8±243.6	< 0.001
Clinical examination			
Femoral anteversion angle / TPAT	31.2°±6.8	22.9°±7.9	< 0.001
Torsional MRI			
Femoral anteversion angle	33.1°±11.8	17.0°±15.1	< 0.001
Tibial torsion	22.67°±10.11	24.2°±8.23	0.053

Gait analysis and MRI

Between pre- and postoperative examinations, mean hip internal rotation in stance decreased significantly by 13.4°, the foot progression angle almost normalised, and the average GGI was reduced from 540 to 250 (comp. Table 2). Correspondingly, the anteversion angle on tMRI showed a decrease of 16.1°. No significant change in tibial torsion was observed (p=0.053).

Correlations

A significant correlation (r=0.611) was found between the intraoperative extent of derotation and the preoperative midpoint of passive rotation.

Only a weak (r=0.317, p=0.015) correlation was found between the extent of intraoperative derotation and the changes in mean hip rotation in stance (Fig. 1).

The changes in the femoral anteversion angle as measured by tMRI correlated moderately (r=0.454, p<0.001) with the extent of intraoperative derotation.

There was no significant correlation between anteversion measured by tMRI and mean hip rotation in stance in the 3D gait analysis preoperatively (Fig. 2). Neither before nor after the FDO did the MRI findings and the mean hip rotation in stance show a correlation. In contrast, the intraoperative extent of derotation correlated weakly with the midpoint of preoperative hip rotation.

Discussion

Significant improvements in IRG after FDO were found in our investigation, corroborating the findings of previous studies. However, a discrepancy was found between the intraoperative extent of derotation and the decrease in anteversion as

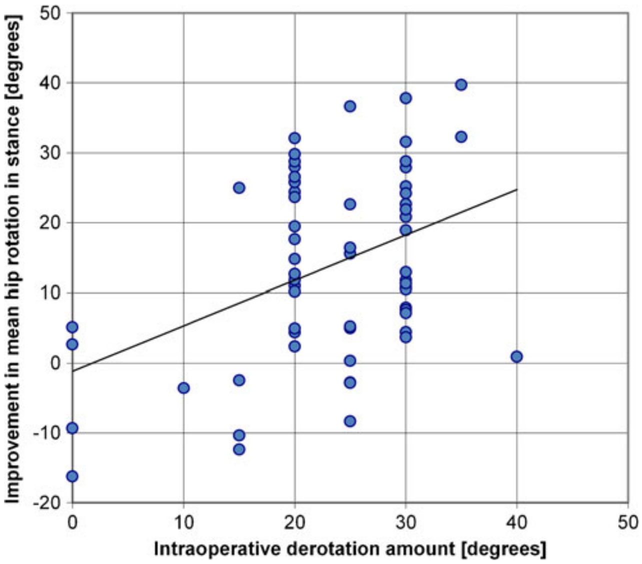

Fig. 1 Comparison of intra-operative derotation with changes of mean hip rotation (preoperative to postoperative) in stance with 3D gait analysis

measured by tMRI and clinical examination (TPAT test). Furthermore, functional outcome as measured by 3D gait analysis did not reflect the total intraoperative extent of derotation, only 60 %, which supports the findings of Kay and Dreher [18, 20]. IRG is a multi-factorial problem, there are static (torsion of femur and tibia) and dynamic (spasticity of the glutei and equinus foot) components. However, femoral derotation osteotomy only influences one of these components. This might be a reason why only 60 % of the intraoperative extent of derotation is reflected in the findings

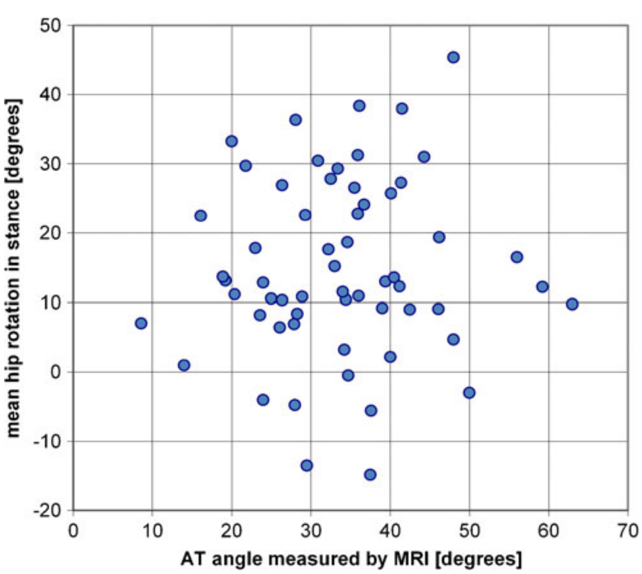

Fig. 2 Comparison of mean hip rotation in stance with 3D gait analysis and AT angle measured by preoperative MRI

of three-dimensional gait analysis. However, FDO still represents the golden standard for the treatment of internal rotation irrespective of the underlying causes.

Improvements in anteversion have been described in several other reports [6, 16–18]. In previous studies, a high rate of over- and under-correction and a high variance of the results of mean hip rotation in stance in the 3D gait analysis after FDO have been shown [2]. However, the range of the functional results is too high. Improvements in transverse plane kinematics, midpoint of passive rotation, anteversion, and global parameters such as GGI were found in our study, indicating that FDO as a part of SEMLS provides a satisfactory overall correction of IRG in the mean. However, the variability of functional outcome reflected in a high over- and under-correction rate is not satisfying. One reason for unpredicted outcomes could be the soft tissue procedures during SEMLS, some of which have an influence on IRG. Gaston et al. found a relationship between equinus foot and the transverse plane kinematic of the hip during gait [31]. Allison et al. found that neither the medial hamstrings nor the adductor brevis, adductor longus, or gracilis are likely to be important contributors to excessive internal rotation of the hip. They concluded that these muscles should not be lengthened to treat excessive internal rotation of the hip and that other factors are more likely to cause internally-rotated gait in these patients [32].

The question, then, is whether the tMRI results are better and show less variation in the functional results. Kerr et al. found a correlation between hip rotation in gait and femoral anteversion (r=0.43–0.47) [23]. However, in our study there was no correlation between anteversion measured with tMRI and mean hip rotation in stance measured in 3D gait analysis. The error of measurement in the tMRI does not explain this as no significant change in the tibial torsion was observed on MRI (p=0.053). Furthermore, the anteversion measured on MRI and the mean hip rotation in stance in 3D gait analysis before and after FDO did not correlate either. Thus, the data suggest that if the intraoperative extent of derotation is determined only according to the anteversion angle, this will not lead to a better result after FDO. It might only be helpful in avoiding a retroversion and indicates the maximum extent of femoral derotation.

The extent of derotation in this study was determined at the clinical examination using the midpoint of rotation [23]. These data show a significant correlation between the intraoperative extent of derotation and the preoperative midpoint of passive rotation (r=0.611).

The weak correlation (r=0.317) of changes in mean hip rotation in stance and the intraoperative derotation extent indicates that correcting anteversion, which is a static parameter, does not necessarily result in the same correction in functional parameters. Only 60 % of the intraoperative extent of derotation is shown in the functional result (mean hip rotation in stance), which is a similar result as described by Kay and Dreher [18, 20].

The conventional method of estimating the intraoperative extent of derotation—(a) clinical midpoint in neutral position, (b) at least 20° of passive internal rotation remaining, and (c) the legs assuming external rotation position spontaneously—gives a large variance in mean hip rotation in stance in the 3D gait analysis after FDO. In this study the extent of the intraoperative derotation was orientated at the preoperative midpoint of rotation. Intraoperatively, it was measured with a Moeltgen® goniometer. By using this method, we estimate the error in evaluating the extent of derotation to be about 10°. However, among the available methods the technique based on guide-pins yields more accurate results than other techniques [33].

The aim of the FDO performed during SEMLS is to improve function and the ultimate goal is to achieve neutral rotation during walking. Dreher et al. [2] described a small but significant correlation between the clinical midpoint and the mean hip rotation in stance in the gait analysis. Therefore, determining the intraoperative amount of derotation according to the mean hip rotation in stance in 3D gait analysis seems to give the best results. However, retroversion must be avoided because diminished femoral antetorsion is a cause of pain and osteoarthritis [34]. To avoid retroversion, tMRI might be helpful. Whether that provides better results and less variance in the functional results after FDO needs to be demonstrated in further studies.

Conflict of interest None.

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