Gait & Posture 66 (2018) 32–37

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

The effect of the Majestro-Frost procedure on internal hip rotation during gait in patients with cerebral palsy☆

Mauro César de Morais Filho[a,*], Francesco Camara Blumetti[a], Cátia Miyuki Kawamura[b], Cássio Luís Ferreira Júnior[c], José Augusto Fernandes Lopes[d], Marcelo Hideki Fujino[a], Daniella Lins Neves[a]

[a] Pediatric Orthopedic Surgeon, Gait Laboratory and Cerebral Palsy Clinic, AACD, São Paulo, Brazil
[b] Senior Physical Therapist, Gait Laboratory, AACD, São Paulo, Brazil
[c] Pediatric Orthopedic Fellow, AACD, São Paulo, Brazil
[d] Engineer, Gait Laboratory, AACD, São Paulo, Brazil

ARTICLE INFO

Keywords:
Cerebral palsy
Internal hip rotation
Majestro-Frost procedure
Soft tissues procedures
Gait

ABSTRACT

Background: Muscle imbalance is related to persistent internal hip rotation (IHR) after femoral derotation osteotomy (FDO) in cerebral palsy (CP). The aim of this study was to evaluate the effect of the Majestro-Frost soft tissue procedure (MFP), which potentially addresses muscle imbalance, on IHR in CP patients during walking.
Methods: A retrospective study of an existing database (medical records and gait laboratory data) was conducted and a search was performed using the following inclusion criteria: (1) diagnosis of spastic CP, (2) GMFCS levels I-III; (3) mean IHR during stance phase higher than 11° at baseline; (4) individuals who received single event multilevel orthopedic surgery in the lower limbs and had three-dimensional gait analyses (3DGA) before and after the intervention. Patients who underwent a FDO were excluded. Eighty-three individuals were considered for the study and they were divided into two groups: No MFP (45 patients who did not receive a MFP) and MFP (36 patients who underwent a MFP). A full clinical examination and 3DGA, with kinematics calculated according to a standard software procedure (Plugin Gait), were performed before and after the intervention, and the results were compared.
Results: The studied groups matched regarding demographic data and GMFCS distribution. The mean follow-up time was more than 20 months on both groups. The increase of clinical external hip rotation (EHR) on physical examination was observed only in the MFP group (from 26.4° to 33°, $p = 0.002$). During gait analysis, IHR decreased from 21.2° to 4.5° in the MFP group ($p < 0.001$) and from 16.9° to 7.9° in the No MFP group ($p < 0.001$). The reduction of IHR during gait was more significant in the MFP group ($p = 0.001$).
Significance: In the present study, patients who underwent a MFP showed more reduction of IHR during gait than those which did not undergo a MFP.

1. Introduction

Intoeing is a frequent gait disturbance in patients with spastic cerebral palsy (CP) and internal hip rotation (IHR) is the major cause of this condition [1,2]. Factors leading to IHR in patients with CP may be dynamic or static. O'Sullivan et al. [2] considered the dynamic IHR in CP a multifactorial problem, with unpredictable results after soft-tissue procedures. In 2016, Jung et al. mentioned that IHR could be improved after soft-tissue procedures in independently community-ambulant patients with spastic diplegic CP [3].

On the other hand, static IHR in CP is largely attributable to excessive femoral anteversion, for which femoral derotation osteotomy (FDO) is the preferred method of treatment [4,5]. In 2002, Õunpuu et al. [6] analyzed 20 CP patients following FDO and IHR correction was sustained after 5 years of follow-up. In 2017, Õunpuu et al. [7] published a long-term follow-up after FDO and the results were maintained 11 years post-surgical intervention. However, 9% of the cases showed recurrence of IHR, and age at surgery was considered one of the possible causes. The influence of age at surgery on IHR recurrence in patients with CP was also observed by Kim et al. (2005), de Morais

☆ The study was conducted at AACD (Association for the Care of Disable Children), São Paulo, Brazil.

* Corresponding author at: Rua Estado de Israel, 577 ap 82, São Paulo, Brazil.
E-mail address: mfmorais@terra.com.br (M.C. de Morais Filho).

https://doi.org/10.1016/j.gaitpost.2018.08.014
Received 22 March 2018; Received in revised form 9 August 2018; Accepted 17 August 2018

Filho et al. (2012) and Niklasch et al. (2015) [1,8,9]. Dreher et al. (2012) described good overall correction of IHR in a long-term follow-up, however persistent dynamic factors were related to recurrence in some cases [10]. In addition to this, Church et al. (2017) mentioned recurrence of IHR can occur in CP and it may be related to spasticity [11].

In 1971, Majestro and Frost described the posterior transposition of the origins of the tensor fascia latae and gluteus minimus in order to eliminate the internal hip rotation action of these muscles [12]. Theoretically, the Majestro-Frost procedure (MFP) could address spasticity of the internal hip rotators, being a treatment option for dynamic IHR in CP. Moreover, MFP could also be effective in the management of IHR in young patients, in order to postpone FDO and avoid recurrence.

However, there is no objective evaluation, using 3-dimensional gait analysis (3DGA), of the effects of MFP on hip rotation in CP population in the literature so far. For this reason, the purpose of this study was to evaluate if MFP is effective for the reduction of IHR in CP.

2. Methods

A retrospective study of an existing data base (medical records and gait laboratory data) was conducted, after approval by the local ethics committee. We performed an electronic search using the following inclusion criteria: (1) diagnosis of spastic CP, (2) GMFCS levels I-III; (3) mean IHR during stance phase higher than 11° at baseline; (4) individuals who received single event multilevel orthopedic surgery in the lower limbs and had 3DGA before and after the intervention. Patients who underwent a FDO were excluded.

Eight hundred and fifty-eight patients met the inclusion criteria; however, 775 of them underwent a FDO and were thus excluded. From the remaining 83 individuals, 79 of them had spastic diplegic CP while 4 were spastic hemiplegic CP. Considering that spastic hemiplegic CP patients have coronal and transverse planes profiles different than spastic diplegic ones, we decided to exclude the 4 patients with hemiplegia from the study. In addition to this, we also excluded one patient who received a tibial derotation osteotomy because this procedure could impact on the IHR profile during gait.

Finally, 78 patients were considered for the study. To assure independent observations, only the limb with higher mean IHR in stance phase on pre-operative kinematics in each patient was included for the analysis. After the identification of the limb with higher mean pre-operative IHR in stance, the patients were divided into two groups according to the surgical procedures received: No MFP (45 patients who did not receive MFP) and MFP (33 patients undergone MFP).

2.1. Surgical technique

The standard of care for the correction of IHR in CP patients at our hospital is FDO. However, we considered MFP when at least one the following situations was present in individuals with increased IHR (> 11°) on kinematics: (1) patients younger than 10 years of age at surgery, (2) difference between maximum passive internal and external hip rotation less than 20° and (3) patients who refused FDO. In the present study, two patients had refused FDO because of their religious restrictions about possible blood transfusions. However, they were classified as hemiplegic CP and they were excluded according to the criterion mentioned previously.

All MFP in the present study were performed by two pediatric orthopedic surgeons, acting together in the same surgical team and using the same technique, from March 2004 to March 2015.

The MFP is performed with the patient in supine position on the operating table. A bikini-type incision is done just below the iliac crest, from its mid-point to its anterior portion. The fascia of the tensor fascia latae and gluteus minimus were released from the iliac crest and their origins were stripped down from lateral table of the ilium to the adipose tissue superior and anterior to the hip capsule. The anterior border of the tensor fascia latae was released and the anterior edge of external fascia of the tensor fascia latae was pulled down to the superior aspect of hip capsule. Three or four interrupted sutures were applied to anchor the anterior edge of the tensor fascia latae to superior aspect of hip capsule. Subcutaneous and skin closures were performed in a standard fashion.

Post-operative immobilization was not used after MFP and patients were allowed to sit with inclination of up to 45° during the first two weeks. Ninety degrees sitting was allowed after two weeks of surgery and patients were allowed to start walking three weeks after the procedure.

2.2. Clinical assessment and gait analysis

Clinical assessments included examination of the lower limbs passive joint range of motion using a goniometer. A senior physical therapist and a pediatric orthopedic surgeon, both with more than 10 years of experience in gait analysis and the management of neuromuscular conditions, evaluated all the patients. The assessment the of rotational profile and bone torsions on physical examination was done with the patient prone on the examining table. Clinical femur anteversion was obtained using the method described by Ruwe et al. [13].

Kinematic data had been collected previously by means of conventional clinical gait analysis. Subjects were equipped with skin mounted reflective markers, placed on specific anatomical landmarks, as described by Kabada et al. [14]. Marker trajectories were captured by an opto-electronic system consisting of eight infrared cameras (Qualisys OQUS300 system) operating at 500 Hz. Patients were instructed to walk barefooted in a self-selected speed along an eight-meter walkway (26 feet). A minimum of six gait cycles for both lower limbs were collected, and a mean of these trials was obtained for the analysis and for consistency evaluation.

Kinematics were calculated according to a standard software procedure (Plugin Gait; Oxford Metrics, Oxford, United Kingdom) based on Kadaba et al. and Davis [14,15]. In order to improve orientation of the thigh segment, the Knee Alignment Device (KAD) was used during data collection. The knee varus/valgus kinematics graph is also checked for an eventual cross-talk with the knee flexion/extension graph, which could be caused by an inadequately determined knee axis and could potentially impact on the kinematic measure of IHR.

2.3. Parameters analyzed and statistics

Demographic data (age at surgery, gender distribution, GMFCS levels, topographic classification, follow-up time and surgical procedures performed), clinical measures (internal hip rotation, external hip rotation, femur anteversion, hip flexion contracture and hip abduction), dynamic parameters [mean internal hip rotation in the stance phase, minimum hip flexion in the stance phase, pelvic asymmetry in the transverse plane (the difference of mean pelvic rotation in the stance phase between right and left sides), pelvic asymmetry in the coronal plane (the difference of mean pelvic obliquity in the stance phase between right and left sides) and Gait Deviation Index (GDI)] were analyzed and the results compared between groups A and B [16].

For comparison of age at surgery, follow-up time, clinical and kinematic data among groups A and B, the ANOVA test was applied. The two proportions equality test was used to compare the gender and GMFCS level distributions, and surgical procedures performed. For the quantitative analysis, the student *t*-test was used for preoperative and postoperative analysis. The level of significance was set a p-value < 0.05 for all statistical tests [17].

3. Results

The studied groups matched regarding demographic data and GMFCS distribution. The mean follow-up time was 34.7 months

Table 1
Comparison of demographic data in No MFP and MFP groups.

	No MFP Group	MFP Group	*p*
Patients / sides	45 patients	33 patients	
Mean age at surgery	9y + 8 m (range, 6y to 22y + 1 m)	9y + 7 m (range, 6y + 1 m to 18y + 6 m)	0.986
Mean follow-up time	34.7 m	21.6 m	< **0.001**
Gender Male	30 patients (66.7%)	19 patients (57.6%)	0.412
Female	15 patients (33.3%)	14 patients (42.4%)	
GMFCS I	6 patients (13.3%)	3 patients (9.1%)	0.562
II	22 patients (48.9%)	21 patients (63.6%)	0.196
III	17 patients (37.8%)	9 patients (27.3%)	0.331

Legend: MFP (Majestro-Frost Procedure), y (years), m (months), GMFCS (Gross Motor Function Classification System).

(9.6–81.7 months) in the No MFP group and 21.6 months (8.9–73.7 months) in the MFP group ($p < 0.001$) (Table 1).

The MFP was performed only in patients from the MFP group. Medial hamstrings surgical lengthening ($p = 0.047$), triceps surae surgical lengthening ($p = 0.022$) and rectus femoris distal transfer ($p = 0.048$) were more frequently performed in the No MFP group, whereas varus foot surgical correction was more prevalent in the MFP group ($p = 0.016$) (Table 2).

The decrease of internal hip rotation on physical examination was observed in both groups after treatment. In the No MFP group, the reduction ($p = 0.038$) was from 72.1° (SD 10.2°) to 69.3° (SD 11.8°), whereas internal hip rotation decreased on clinical examination ($p = 0.002$) from 78.3° (SD 9.2°) to 71.9° (SD 10.9°) in the MFP group. However, the increase of external hip rotation (p = 0.002) from 26.4° (SD 8.9°) to 33° (SD 9.9°) occurred only in the MFP group after intervention.

The hip abduction with the knees in flexion decreased in the No MFP group ($p = 0.004$) from 30.2° (SD 12.9°) to 24.2° (SD 9.6°) and in the MFP group ($p < 0.001$), from 33.7° (SD 15.3°) to 22.3° (SD 9.4°) after surgery.

On kinematics, mean IHR decreased from 16.9° (SD 5.7°) to 7.9° (SD 8.8°) in the No MFP group ($p < 0.001$) and from 21.2° (SD 7.0°) to 4.5° (SD 10.3°) in the MFP group ($p < 0.001$). The increase on minimum hip flexion in the stance phase ($p = 0.014$), from 11.7° (SD 8.7°) to 15.3° (SD 9.8°) and on pelvic asymmetry in the coronal plane ($p = 0.004$), from 5.0° (SD 4.8°) to 8.8° (SD 7.4°), were seen only in the MFP group after the intervention. Finally, GDI has improved in the No MFP group ($p < 0.001$) from 47.4 (SD 11.7) to 60.7 (SD 10.0) and in the MFP group ($p < 0.001$) from 46.3 (SD 11.8) to 60.9 (SD 13.2), after treatment (Fig. 1).

In the comparison between groups, we observed that the increase of external hip rotation ($p = 0.049$) and the reduction of hip abduction with the hips and knees flexed ($p = 0.049$) on physical examination were more significant in the MFP group, as well the reduction of mean IHR ($p = 0.001$) and the increase of pelvic asymmetry in coronal plane ($p = 0.001$) on kinematics (Tables 3 and 4).

Finally, the kinematic results of patients who underwent unilateral MFP were similar to those who received bilateral MFP. We only found a significant difference in the GDI, which improved 16.29 after unilateral MFP and 9.07 after bilateral MFP ($p = 0.032$) (Table 5).

Table 2
Comparison of surgical procedures performed in No MFP and MFP groups.

Procedures	No MFP		MFP		*p*
	N	%	N	%	
MFP	0	0.0%	33	100%	< **0.001**
MHSL	33	73.3%	17	51.5%	**0.047**
TSSL	32	71.1%	15	45.5%	**0.022**
LCL	11	24.4%	10	30.3%	0.564
SVF	5	11.1%	11	33.3%	**0.016**
HAL	12	26.7%	6	18.2%	0.380
POB	10	22.2%	2	6.1%	0.051
RFT	5	11.1%	0	0.0%	**0.048**

LEGEND: N (number of procedures), MFP (Majestro-Frost Procedure), MHSL (Medial Hamstrings Surgical Lengthening), TSSL (Triceps Surae Surgical Lengthening), LCL (Lateral Calcaneal Lengthening), SVF (Spastic Varus Foot), HAL (Hip Adductors Surgical Lengthening), POB (Psoas Lengthening Over the Pelvic Brim), RFT (Rectus Femoris Transfer).
Bold values signifies p < 0.005.

4. Discussion

The effects of soft-tissue procedures on IHR during gait in CP is still controversial. In 2006, O'Sullivan et al. [2] considered the dynamic IHR in CP a multifactorial problem, with unpredictable results after soft-tissue procedures. On the other hand, Jung et al. (2016) mentioned that IHR could be improved after soft-tissue procedures in independently community-ambulant patients with spastic diplegic CP [3].

In the present study, the groups analyzed had similar demographics and matched regarding age at surgery, GMFCS classification and gender distribution. The reduction of IHR on kinematics was observed in both groups after treatment, however it was higher when MFP was performed.

In the No MFP group, there was a higher prevalence of medial hamstrings lengthening, triceps surae lengthening and rectus femoris distal transfer. On the other hand, the correction of spastic varus foot was performed more frequently in the MFP group. In the last decades, many authors have described the effects of soft tissue procedures on IHR in CP [18–22]. On the other hand, Arnold et al. demonstrated with a biomechanical model that neither the hamstrings nor the adductors are important contributors to excessive IHR [23]. In addition to this, Õunpuu et al. (1993) mentioned that there was no consistent change in transverse plane motion of the hip or foot progression angles after rectus femoris transfer, suggesting that this procedure does not affect gait abnormalities observed in the transverse plane [24].

Despite the controversy in the literature, we found in the present study a mild reduction of IHR during gait in the No MFP group, and we believe that this outcome may be produced by other procedures performed in the lower limbs, including medial hamstrings lengthening. Moreover, the higher prevalence of spastic varus foot correction present in the MFP group (11.1% in No MFP and 33.3% in MFP) may have produced some effect in the reduction of IHR.

The results obtained in the present study suggest that the MFP is related to a reduction of IHR during gait. The decrease of IHR in kinematics was higher in the group of patients who underwent MFP. Furthermore, the reduction of IHR during gait we found in this study is comparable to outcomes after FDO reported in the literature.

Dreher et al. (2012) described a reduction of mean IHR during gait from 17.3° to 0.7° three years after FDO in a group of CP patients, and their results were sustained after a 9-year follow-up [10].

In 2013, we published the results of FDO in our hospital and the reduction of IHR in kinematics was 11.1° for femoral osteotomies performed below the lesser trochanter and 14.6° for those done above it, with a mean follow-up time higher than three years [25].

Moreover, Carty et al. published in 2014 a systematic review and meta-analysis about the effects of FDO. The authors reported a mean decrease of IHR during gait of 17.6° for unilateral involvement and of 14.3° for bilateral involvement [26]. The authors mentioned a mean follow-up time from 0.9 to 3.1 years in the articles included in the meta-analysis.

In the present study, the mean reduction of IHR in kinematics was 15.5°. However, the follow-up was shorter compared to studies published by de Morais Filho et al. [25] and Carty et al. [26]. We believe that despite the good outcomes obtained on IHR during gait, the results

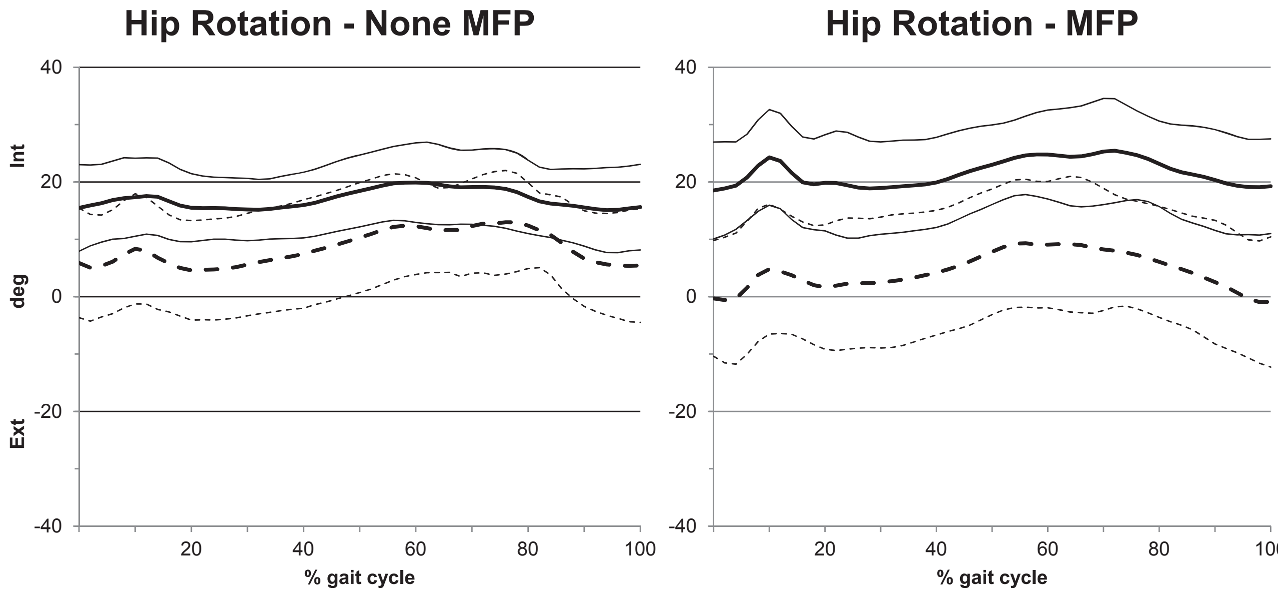

Fig. 1. Mean internal hip rotation (+/- one standard deviation). Solid lines: pre-treatment / dashed lines: post-treatment.

Table 3
Clinical parameters before and after intervention in No MFP and MFP groups. Comparison of pre and post-operative data intra groups and of outcomes inter groups.

Clinical Parameters			Mean	SD	Min	Max	N	*p*	*p* (No MFP X MFP)
Hip Internal Rotation	No MFP	Pre	72.1°	10.2°	55.0°	90.0°	45	**0.038**	0.098
		Post	69.3°	11.8°	40.0°	90.0°	45		
	MFP	Pre	78.3°	9.2°	60.0°	90.0°	33	**0.002**	
		Post	71.9°	10.9°	50.0°	90.0°	33		
Hip External Rotation	No MFP	Pre	28.1°	11.2°	5.0°	60.0°	45	0.447	**0.049**
		Post	29.4°	10.6°	10.0°	50.0°	45		
	MFP	Pre	26.4°	8.9°	5.0°	45.0°	33	**0.002**	
		Post	33.0°	9.9°	20.0°	70.0°	33		
Femur Anteversion	No MFP	Pre	30.1°	8.7°	10.0°	50.0°	45	0.094	0.792
		Post	27.7°	8.5°	10.0°	40.0°	45		
	MFP	Pre	30.3°	8.2°	15.0°	40.0°	33	0.084	
		Post	27.3°	5.9°	15.0°	40.0°	33		
Hip Abduction (hip and knee flexed)	No MFP	Pre	30.2°	12.9°	10.0°	60.0°	45	**0.004**	**0.049**
		Post	24.2°	9.6°	10.0°	60.0°	45		
	MFP	Pre	33.7°	15.3°	10.0°	75.0°	33	< **0.001**	
		Post	22.3°	9.4°	10.0°	60.0°	33		
Hip Abduction (hip and knee extended)	No MFP	Pre	17.2°	8.5°	0.0°	35.0°	45	0.050	0.511
		Post	19.9°	11.4°	5.0°	60.0°	45		
	MFP	Pre	21.2°	10.1°	5.0°	60.0°	33	0.513	
		Post	22.4°	11.4°	5.0°	60.0°	33		
Hip Flexion Contracture	No MFP	Pre	7.6°	6.8°	0.0°	25.0°	45	0.523	0.239
		Post	8.6°	8.0°	0.0°	30.0°	45		
	MFP	Pre	8.3°	7.4°	0.0°	20.0°	33	0.290	
		Post	6.7°	7.1°	0.0°	25.0°	33		

Legend: Pre (pre-operative), Post (post-operative), SD (standard deviation), Min (minimum), Max (maximum), N (number of lower limbs).
Bold values signifies $p < 0.005$.

of the present study should be analyzed taking in account the short-term follow-up.

Mild reduction of clinical IHR was observed on both groups, however, only patients who underwent the MFP exhibited an increase of external hip rotation after treatment on physical examination. We believe that the release of shortened anatomic internal hip rotators can be an explanation for the results obtained. However, these findings should be analyzed in the light of the potential source of errors and accuracy problems related to physical examination. Gajdosik and Bohannon reported that the measurement error during physical examination could be up to 10% [27].

Finally, patients who received MFP showed a slight increase of pelvic asymmetry in coronal plane (3.8°), whereas subjects from No MFP group did not. Eighteen patients from the MFP group (54.5%) had a change in the coronal plane pelvic asymmetry lower than 5° (lower than 2 SD of the normal mean of our gait laboratory database). However, 10 patients (30.3%) showed a change between 5 and 10°, while 5 subjects (15.2%) exhibited an increase on pelvic asymmetry in the coronal plane higher than 10° after treatment.

We believe that this result is important, and it should be considered during the decision-making process involving the indication for the MFP. During the MFP, the extension of the tensor fascia latae and gluteus minimus release from the iliac crest was not clearly defined in the original technique description. As a consequence, some variability during surgery may occur and some hip abductor weakness can be present after more extensive tensor fascia latae and gluteus releases, producing pelvic asymmetry in the coronal plane. However, we believe that further investigation is necessary in order to identify factors related to pelvic asymmetry in the coronal plane after the MFP.

It is important to state that the present study has limitations. First of

Table 4
Kinematics parameters before and after intervention in No MFP and MFP groups. Comparison of pre and post-operative data intra groups and of outcomes inter groups.

Kinematics Parameters			Mean	SD	Min	Max	N	*p*	*p* (No MFP X MFP)
Mean Internal Hip Rotation in Stance Phase	No MFP	Pre	16.9°	5.7°	11.2°	40.3°	45	< **0.001**	**0.001**
		Post	7.9°	8.8°	−7.7°	33.3°	45		
	MFP	Pre	21.2°	7.0°	14.1°	48.1°	33	< **0.001**	
		Post	4.5°	10.3°	−18.8°	32.1°	33		
Pelvic Asymmetry in Transverse Plane	No MFP	Pre	13.8°	10.3°	0.3°	33.7°	45	0.116	0.416
		Post	11.0°	10.9°	0.3°	46.2°	45		
	MFP	Pre	14.5°	11.9°	0.5°	51.5°	33	0.990	
		Post	14.6°	16.8°	0.2°	84.1°	33		
Minimum Hip Flexion in Stance Phase	No MFP	Pre	13.1°	11.2°	−7.0°	41.3°	45	0.913	0.093
		Post	13.2°	9.5°	−7.2°	35.0°	45		
	MFP	Pre	11.7°	8.7°	−17.6°	31.6°	33	**0.014**	
		Post	15.3°	9.8°	−6.5°	43.1°	33		
Pelvic Asymmetry in Coronal Plane	No MFP	Pre	6.7°	5.8°	0.2°	29.8°	45	0.128	**0.001**
		Post	5.3°	5.8°	0.1°	29.4°	45		
	MFP	Pre	5.0°	4.8°	0.0°	15.9°	33	**0.004**	
		Post	8.8°	7.4°	0.1°	31.5°	33		
GDI	No MFP	Pre	47.4	11.7	30.0	72.7	45	< **0.001**	0.952
		Post	60.7	10.0	30.3	80.5	45		
	MFP	Pre	46.3	11.8	26.2	72.3	33	< **0.001**	
		Post	60.9	13.2	28.6	92.5	33		

Legend: GDI (Gait Deviation Index), Pre (pre-operative), Post (post-operative), SD (standard deviation), Min (minimum), Max (maximum), N (number of lower limbs).
Bold values signifies p < 0.005.

Table 5
Comparison of the kinematics outcomes between patients undergone unilateral versus bilateral Majestro-Frost procedure.

Parameters		Mean	SD	Min	Max	N	*p*
Mean Internal Hip Rotation in Stance Phase	Bilateral	−13.4°	8.5°	−30.8°	1.5°	19	0.109
	Unilateral	−18.2°	12.6°	−39.9°	6.9°	14	
Pelvic Asymmetry in Transverse Plane	Bilateral	3.6°	11.3°	−6.3°	30.3°	19	0.160
	Unilateral	−3.2°	21.9°	−37.4°	58.4°	14	
Minimum Hip Flexion in Stance Phase	Bilateral	5.2°	9.0°	−7.4°	27.2°	19	0.381
	Unilateral	3.1°	7.1°	−10.4°	24.5	14	
Pelvic Asymmetry in Coronal Plane	Bilateral	2.9°	4.7°	−4.6°	8.1°	19	0.526
	Unilateral	4.0°	8.4°	−8.0°	20.9°	14	
GDI	Bilateral	9.0	10.7	−9.5	33.6	19	**0.032**
	Unilateral	16.3	12.5	−5.2	41.9	14	

Legend: GDI (Gait Deviation Index), Bilateral (bilateral Majestro-Frost procedure), Unilateral (unilateral Majestro-Frost procedure), SD (standard deviation), Min (minimum), Max (maximum), N (number of lower limbs).

all, the No MFP group had a longer follow-up time than the MFP group. The differences in follow-up times between the two groups may have an implication on IHR recurrence. Despite the absence of previous studies about the results of the Majestro-Frost procedure, it is expected that the rates of IHR recurrence may increase in a longer follow-up time. However, the lack of scientific evidence about the results of Majestro-Frost procedure so far, does not allow us to make conclusions about this topic at this point. In addition, the two groups did not match regarding surgical procedures received. The possible effects of the difference in procedures performed in the two groups were discussed previously in this section. Finally, while the control group (No MFP) provides an ability to understand the treatment outcome there is no natural history group in this study for comparison. However, Bell et al. (2002) in their study about the natural history of gait abnormalities in CP, observed that IHR did not exhibit significant change over the time in the included patients [28].

Nevertheless, to our knowledge the present study was the first to analyze the kinematic effects of the posterior transposition of the origins of the tensor fascia latae and gluteus minimus muscles (MFP). The reduction of IHR was more significant when MFP was performed. Our data leads us to consider that MFP can reduce IHR in CP and this procedure may be a treatment option for young patients and recurrent cases.

5. Conclusion

In the present study, patients who underwent the MFP had a higher reduction of IHR during gait than individuals from a control group in the short-term follow up.

Conflicts of interest

The authors declare that there is no conflict of interest and no financial support was received for this work

Funding

The authors did not receive any outside funding or grants in support of their research for or in preparation of this work.

References

[1] H. Kim, M. Aiona, M. Sussman, Recurrence after femoral derotational osteotomy in cerebral palsy, J. Pediatr. Orthop. 25 (6) (2005) 739–743.
[2] R. O´Sullivan, M. Walsh, P. Hewart, A. Jenkinson, L. Ross, T. O´Brien, Factors associated with internal hip rotation gait in patients with cerebral palsy, J. Pediatr. Orthop. 26 (4) (2006) 537–541.
[3] H.J. Jung, J.Y. Yoon, M.K. Oh, Y.C. Kim, J.H. Kim, T.W. Eom, K.B. Park, Effects of soft tissue surgery on pelvic and hip rotation in patients with spastic diplegia: a meta-analysis, Clin. Orthop. Surg. 8 (2) (2016) 187–193.
[4] E.E. Bleck, Mechanism and treatment of internal rotation of the hip deformity in cerebral palsy, Acta Orthop. Belg. 50 (3) (1984) 273–274.
[5] J.R. Gage, P.A. DeLuca, T.S. Renshaw, Gait analysis: principles and applications: emphasis on its use in cerebral palsy, J. Bone Joint Surg. Am. 77-A (1995) 1607–1623.
[6] S. Õunpuu, P. DeLuca, R. Davis, M. Romness, Long-term effects of femoral derotation osteotomies: an evaluation using three-dimensional gait analysis, J. Pediatr. Orthop. 22 (2) (2002) 139–145.
[7] S. Õunpuu, M. Solomito, K. Bell, K. Pierz, Long-term outcomes of external femoral derotation osteotomies in children with cerebral, Gait Posture 56 (2017) 82–88.
[8] M.C. de Morais Filho, C.M. Kawamura, C.A. dos Santos, R. Mattar Jr, Outcomes of correction of internal hip rotation in patients with spastic cerebral palsy using

proximal femoral osteotomy, Gait Posture 36 (2) (2012) 201–204.
[9] M. Niklasch, S.I. Wol, M.C. Klotz, A. Geisbüsch, R. Brunner, L. Döderlein, T. Dreher, Factors associated with recurrence after femoral derotation osteotomy in cerebral palsy, Gait Posture 42 (4) (2015) 460–465.
[10] T. Dreher, S.I. Wolf, D. Heitzmann, B. Swartman, W. Schuster, S. Gantz, S. Hagmann, L. Döderlein, F. Braatz, Long-term outcome of femoral derotation osteotomy in children with spastic diplegia, Gait Posture 36 (3) (2012) 467–470.
[11] C. Church, N. Lennon, K. Pineault, O. Abousamra, T. Niiler, J. Henley, K. Dabney, F. Miller, persistence and recurrence following femoral derotational osteotomy in ambulatory children with cerebral palsy, J. Pediatr. Orthop. 37 (7) (2017) 447–453.
[12] T.C. Majestro, H.M. Frost, Spastic internal femoral torsion, Clin. Orthop. 79 (1971) 44–56.
[13] P.A. Ruwe, J.R. Gage, M.B. Ozonoff, P.A. DeLuca, Clinical determination of femoral anteversion. A comparison with established techniques, J. Bone Joint Surg. Am. 74 (6) (1992) 820–830.
[14] M.P. Kabada, H.K. Ramakrishan, M.E. Wootten, Measurement of lower extremity kinematics during level walking, J. Orthop. Res. 08 (1990) 383–392.
[15] R.B. Davis, S. Ounpuu, D.J. Tyburski, A gait analysis data collection and reduction technique, Hum. Mov. Sci. 10 (1991) 575–587.
[16] M.H. Schwartz, A. Rozumalski, The gait deviation index: a new comprehensive index of gait pathology, Gait Posture 28 (3) (2008) 351–357.
[17] W.U. Conover, Pratical Nonparametric Statistics, John Willy & Sons, New York, 1971.
[18] H.H. Banks, W.T. Green, Adductor myotomy and obturador neurectomy for the correction of adduction contracture of the hip in cerebral palsy, J. Bone Joint Surg. Am. 42 (1960) 111–126.
[19] D.H. Sutherland, E.R. Schottstaedt, L.J. Larsen, R.K. Ashley, J.N. Callander, P.M. James, Clinical and electromyographic study of seven spastic children with internal rotation gait, J. Bone Joint Surg. Am. 51-A (1969) 1070–1082.
[20] K.C. Chong, C.D. Vojnic, A.O. Qu Anbury, R.M. Letts, The assessment of the internal rotation gait in cerebral palsy, Clin. Orthop. 132 (1978) 145–150.
[21] G. Steinwender, V. Saraph, E.B. Zwick, C. Uitz, W. Linhart, Assessment of hip rotation after gait improvement surgery in cerebral palsy, Acta Orthop. Belg. 66-63 (2000) 259–264.
[22] R.C. Sullivan, J.A. Krzyzanowski, G.F. Harris, Rotational changes in the lower limb following distal medial hamstrings surgery in cerebral palsied children, Orthop. Trans. 10 (1986) 153.
[23] A.S. Arnold, D.J. Asakawa, S.L. Delp, Do the hamstrings and adductors contribute to excessive internal rotation of the hip in persons with cerebral palsy? Gait Posture 11 (2000) 181–190.
[24] S. Õunpuu, E. Muik, R.B. Davis 3rd, J.R. Gage, P.A. DeLuca, Rectus femoris surgery in children with cerebral palsy. Part I: the effect of rectus femoris transfer location on knee motion, J. Pediatr. Orthop. 13 (1993) 325–330.
[25] De Morais Filho, D.L. Neves, F.P. Abreu, C.M. Kawamura, C.A. dos Santos, Does the level of proximal femur rotation osteotomy influence the correction results in patients with cerebral palsy? J. Pediatr. Orthop. B 22 (2013) 8–13.
[26] C.P. Carty, H.P. Walsh, J.G. Gillett, T. Phillips, J.M. Edwards, M. deLacy, R.N. Boyd, The effect of femoral derotation osteotomy on transverse plane hip and pelvic kinematics in children with cerebral palsy: A systematic review and meta-analysis, Gait Posture 40 (2014) 333–400.
[27] R.L. Gajdosik, R.W. Bohannon, Clinical measurement of range of motion: review of goniometry emphasizing reliability and validity, Phys. Ther. 12 (1987) 1867–1872.
[28] K.J. Bell, S. Õunpuu, P.A. DeLuca, M.J. Romness, Natural progression of gait in children with cerebral palsy, J. Pediatr. Orthop. 22 (2002) 677–682.