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The increase of anterior pelvic tilt after crouch gait treatment in patients with cerebral palsy☆

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ABSTRACT

Background: The increase of anterior pelvic tilt (APT) has been described after the treatment of crouch gait in cerebral palsy (CP). The ideal treatment option for flexed knee gait in CP should provide knee extension improvement in the stance phase without generating the increase of APT.
Research question: The purpose of this study was to compare three different approaches used for the treatment of crouch gait in CP [distal femur extension osteotomy (DFEO), patellar tendon shortening (PTS) and the combination of DFEO +PTS] regarding the increase of APT after the interventions.
Methods: The inclusion criteria were: (1) diagnosis of spastic diplegic CP, (2) GMFCS levels I–III, (3) patients who underwent DFEO and/or PTS and (4) with complete documentation in the gait laboratory before and after the intervention. The included patients were divided into 3 groups, according to the procedures performed for crouch gait treatment: PTS (19 patients), DFEO (54 patients) and PTS + DFEO (22 patients).
Results: During stance phase, knee flexion decreased from 41.6^0 to 13.6^0 in the PTS group ($p < 0.001$), from 46.0^0 to 30.7^0 in the DFEO group ($p < 0.001$) and from 52.3^0 to 29.5^0 in the PTS + DFEO group ($p < 0.001$). APT increased 14^0 ($p < 0.001$) in the PTS group, 7.1° ($p < 0.001$) in the DFEO group and 6.6^0 ($p < 0.001$) in the PTS + DFEO group after surgical intervention. The PTS group presented a more significant deterioration of pelvic tilt than the DFEO ($p = 0.002$) and PTS + DFEO ($p = 0.001$) groups. The increase of APT was higher when HSL was also performed in the PTS + DFEO group ($p = 0.016$).
Significance: The increase of APT was observed in all studied groups, but it was more significant for those who underwent a PTS. The inclusion of HSL in the surgical plan was related a higher increase of APT in the PTS + DFEO group.

1. Introduction

Knee flexion deformity (KFD) is frequently seen in patients with cerebral palsy (CP) and it can impact standing, gait and activities of daily life [1]. Spasticity and progressive contracture of the hamstrings are one of the causes of KFD and crouch knee gait in CP [2,3].

Hamstrings surgical lengthening (HSL) has been frequently used for correction of KFD in CP. However, Zwick et al. described in 2002 an increase of anterior pelvic tilt (APT) after this procedure, as a result of the loss of hip extensors strength [4]. Moreover, hamstrings weakness has been considered a potential cause of the increase in APT by many authors [5–9].

The increase of APT with a compensatory lumbar lordosis was also reported after the treatment of crouch gait using patellar tendon advancement or shortening [10,11]. Feng et al. mentioned that an increase of APT is inevitable when crouch gait is corrected, since the oblique femur becomes more vertical during stance, thereby rotating the pelvis into more of an anterior tilt [12].

However, the compensatory lumbar lordosis may later lead to back pain and reduction of mobility [13]. For that reason, the treatment goal for crouch gait in CP should be to improve knee extension in the stance phase without an increase in APT in the sagittal plane during gait.

☆ The study was conducted at AACD (Association for the Care of Disable Children), São Paulo, Brazil.
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Thus, the purpose of this study was to compare three different approaches used for the treatment of crouch gait in CP (distal femur extension osteotomy, patellar tendon shortening and the combination of the two procedures) regarding the increase of APT after the interventions.

2. Methods

2.1. Subjects

This was a retrospective cohort study approved by the local ethics committee. At our institution, the standard of care for ambulatory patients with CP includes three-dimensional gait analysis for treatment decision-making and post-operative evaluation. For the present study, we searched the gait laboratory database considering the inclusion criteria: (1) diagnosis of spastic diplegic CP, (2) GMFCS levels I–III, (3) patients who underwent distal femur extension osteotomy and/or patellar tendon shortening and (4) with complete documentation in the gait laboratory before and after the intervention.

One hundred and sixteen patients met the inclusion criteria, however 21 were excluded because they had been treated in another hospital, using different surgical techniques.

The remaining 95 patients were divided into 3 groups, according to the procedures performed for crouch gait treatment: patellar tendon shortening group [PTS (19 patients/34 lower limbs)], distal femur extension osteotomy group [DFEO (54 patients/88 lower limbs)] and patellar tendon shortening + distal femur extension osteotomy group [PTS + DFEO (22 patients/42 lower limbs)].

2.2. Clinical assessment and gait analysis

The clinical assessment included the examination of lower limb passive joint range of motion using a calibrated goniometer. Rectus femoris (RF) spasticity was graded using Ashworth Scale and triceps surae strength by manual scale [14]. All of the patients were evaluated by a senior physical therapist and a pediatric orthopedic surgeon, both with more than 10 years of experience in gait analysis and in the management of neuromuscular conditions.

Kinematic data had been previously collected using reflective markers that are strategically placed on specific anatomical landmarks on each participant, as described by Kadaba et al. [15]. The trajectory of the markers within the laboratory space was captured through an electronic optical system consisting of infrared cameras. An eight-camera Qualisys OQUS300 system (500 Hz) was used for movement capture. Patients were instructed to walk barefooted in a self-selected speed through an eight-meter walkway (26 feet). A minimum of six gait cycles for each assessed lower limb was collected; for consistency in evaluation, a representative trial was also selected for the analysis. Data were processed using the software Vicon Clinical Manager (VCM, Oxford Metrics, Oxford, UK), according to the technique described by Davis [16].

2.3. Surgical indications

The indication for DFEO was the presence of a fixed knee flexion deformity of 10^0 or more, and a minimum knee flexion in the stance phase more than 10^0 (more than two standard deviations of normal mean). If an extension lag more than 20^0 and a patella alta at lateral view knee radiographs were also observed, PTS was included in the treatment plan. However, PTS was indicated only for adolescents (girls older than 10.5 years and boys older than 12 years) in our hospital and isolated DFEO (without PTS) was applied for crouch gait management before this age. Finally, PTS was performed without DFEO at adolescents with increased knee flexion in the stance phase (more than 10^0), but with full knee extension at physical examination.

2.4. Parameters analyzed and statistics

Demographic data (age at surgery, gender distribution, GMFCS levels, follow-up time and concomitant surgical procedures), clinical data (mean KFD, hip flexion deformity, popliteal angle, passive ankle dorsiflexion with knees extended, RF spasticity and triceps surae strength, before and after treatment), dynamic parameters (mean anterior pelvic tilt, minimum hip and knee flexion in the stance phase, knee flexion at initial contact, peak knee flexion in swing phase, ankle dorsiflexion in stance phase, gait velocity, and Gait Deviation Index (GDI) and Gait Profile Score (GPS)/Movement Analysis Profile (MAP) before and after treatment) were analyzed and the results compared between groups [17,18]. A secondary comparison was done in each group considering the inclusion of HSL in the surgical plan.

The ANOVA test was used for comparisons among groups regarding age at surgery, follow-up time, clinical and kinematic data. Two proportions equality test was used to compare relative frequencies among groups. For the quantitative analysis, the comparison between preoperative and postoperative values was done using the paired t-Student test. The level of significance was set at 5% for all statistical tests.

3. Results

Demographic data is presented in Table 1. Gender distribution, follow-up time and GMFCS levels were comparable among groups.

The surgical procedures performed simultaneously to the PTS and DFEO are described in the Table 2. Medial hamstrings surgical lengthening was done more frequently in patients from the DFEO group than those from the PTS ($p = 0.026$) and PTS + DFEO groups ($p < 0.001$). Biceps femoris surgical lengthening was performed less frequently in the PTS + DFEO than in the DFEO group ($p = 0.044$).

Psoas lengthening over the pelvic brim was more prevalent in the DFEO than in the PTS ($p < 0.001$) and PTS + DFEO groups ($p = 0.006$), and in the PTS + DFEO than in the PTS group ($p = 0.004$).

In PTS group, 5 (26.3%) patients did not require walkers or crutches for walking before surgery and 2 (10.5%) maintained the same pattern after treatment ($p = 0.209$). Nine patients (47.4%) used crutches before and 12 (63.2%) after intervention ($p = 0.328$), while 5 (26.3%) required walkers pre-operatively and they did not change the pattern in post-operative analysis ($p = 1.000$).

The number of patients who did not require assistive devices

Table 1
Demographic data.

	PTS	DFEO	PTS + DFEO	*p*
Patients/Sides	19/34	54/88	22/42	
Age at surgery (years)	15.7	12.8	14.6	**0.003**
Follow-up (months)	28.9	34.3	33.2	0.763
Gender				
Male	57.9%	61.1%	81.8%	PTS/DFEO 0.805
Female	42.1%	38.9%	18.2%	PTS/PTS + DFEO 0.093
GMFCS				DFEO/PTS + DFEO 0.081
I	5.3%	1.9%	0%	PTS/DFEO 0.433 PTS/PTS + DFEO 0.276 DFEO/PTS + DFEO 0.521
II	5.3%	20.4%	18.2%	PTS/DFEO 0.126 PTS/PTS + DFEO 0.207 DFEO/PTS + DFEO 0.828
III	89.4%	77.7%	81.8%	PTS/DFEO 0.265 PTS/PTS + DFEO 0.489 DFEO/PTS + DFEO 0.695

Legend: PTS (PTS group), DFEO (DFEO group), PTS + DFEO (PTS + DFEO group)

Table 2
Surgeries performed in the same surgical event.

PROCEDURES	PTS		DFEO		PTS + DFEO		*p*	
	N	%	N	%	N	%		
AD	3	8.8%	12	13.6%	8	19%	PTS/DFEO	0.468
							PTS/PTS + DFEO	0.208
							DFEO/PTS + DFEO	0.424
MED HAMS	18	52.9%	65	73.9%	15	35.7%	**PTS/DFEO**	**0.026**
							PTS/PTS + DFEO	0.132
							DFEO/PTS + DFEO	**< 0.001**
ST TX	14	41.2%	26	29.5%	5	11.9%	PTS/DFEO	0.220
							PTS/PTS + DFEO	**0.003**
							DFEO/PTS + DFEO	**0.027**
BICEPS	2	5.9%	8	9.1%	0	0.0%	PTS/DFEO 0.562	
							PTS/PTS + DFEO	0.111
							DFEO/PTS + DFEO	**0.044**
FDO	5	14.7%	14	15.9%	7	16.7%	PTS/DFEO	0.869
							PTS/PTS + DFEO	0.816
							DFEO/PTS + DFEO	0.913
TDO	13	38.2%	23	26.1%	7	16.7%	PTS/DFEO	0.189
							PTS/PTS + DFEO	**0.034**
							DFEO/PTS + DFEO	0.231
PLANOVALGUS	18	52.9%	35	39.8%	13	31%	PTS/DFEO 0.188	
							PTS/PTS + DFEO	0.052
							DFEO/PTS + DFEO	0.330
VARUS FOOT	1	2.9%	13	14.8%	1	2.4%	PTS/DFEO 0.066	
							PTS/PTS + DFEO	0.879
							DFEO/PTS + DFEO	**0.033**
GS	2	5.9%	23	26.1%	0	0.0%	**PTS/DFEO**	**0.013**
							PTS/PTS + DFEO	0.111
							DFEO/PTS + DFEO	**< 0.001**
PSOAS	2	5.9%	52	59.1%	14	33.3%	**PTS/DFEO**	**< 0.001**
							PTS/PTS + DFEO	**0.004**
							DFEO/PTS + DFEO	**0.006**

Legend: AD (hip adductors tenotomy), MED HAMS (medial hamstrings surgical lengthening), ST TX (semitendinosus transfer to distal femur), BICEPS (biceps femoris surgical lengthening), FDO (femoral derotation osteotomy), TDO (tibial derotation osteotomy), PLANOVALGUS (bone procedures for the correction of planovalgus feet), VARUS FOOT (bone and soft tissue procedures for the correction of varus feet), GS (gastrocnemius surgical lenthening) and PSOAS (psoas lengthening over the pelvic brim).

reduced from 17 (31.5%) to 9 (16.7%) in DFEO group ($p = 0.072$), whereas the use of crutches increased from 15 (27.8%) to 24 (44.4%) after treatment ($p = 0.071$). In this group, 22 subjects (40.7%) used walkers before and 21 (38.9%) after intervention ($p = 0.844$).

In PTS + DFEO group, 4 patients (18.2%) did not require crutches or walkers before and after surgery ($p = 1.000$). Nine (40.9%) patients used crutches before and 12 (54.5%) after treatment ($p = 0.365$) whereas 9 (40.9%) had walkers in the first gait analysis and 6 (27.3%) in the post-operative evaluation ($p = 0.340$).

Regarding clinical assessment data, the mean knee flexion deformity was reduced from 5.6^0 to -0.3^0 in the PTS group ($p < 0.001$), from 15.5^0 to 7.0^0 in the DFEO group ($p < 0.001$) and from 15.1^0 to 6.4^0 in the PTS + DFEO group ($p = 0.002$).

Popliteal angle decreased in all groups and RF spasticity increased in the PTS (from 1.85 to 2.35, $p = 0.011$) and DFEO groups (from 1.82 to 2.31, $p < 0.001$) after surgery.

Passive ankle dorsiflexion with knees extended increased in DFEO group (from 7.52^0 to 11.19^0, $p = 0.011$) whereas a reduction was observed in PTS + DFEO group (from 15.71^0 to 12.90^0, $p = 0.039$). Triceps surae strength improved from 1.68 to 1.94 ($p = 0.028$) in DFEO group, while no significant change was detected in PTS and PTS + DFEO groups (Table 3).

The analysis of kinematics showed that the GDI improved in all groups after treatment. The improvement was from 48.3 to 55.7 in the PTS group ($p < 0.001$), from 43.6 to 50.3 ($p < 0.001$) in the DFEO group and from 43.7 to 51.0 ($p < 0.001$) in the PTS + DFEO group.

On the other hand, normalized gait velocity (gait velocity/lower limb length) decreased in all groups after intervention. The reduction of gait velocity was from 0.70 to 0.53 ($p = 0.001$) in the PTS group, from 0.72 to 0.59 ($p = 0.001$) in the DFEO group and from 0.57 to 0.45 ($p = 0.016$) in the PTS + DFEO group.

During stance phase, knee flexion decreased from 41.6^0 to 13.6^0 in the PTS group ($p < 0.001$), from 46.0^0 to 30.7^0 in the DFEO group ($p < 0.001$) and from 52.3^0 to 29.5^0 in the PTS + DFEO group ($p < 0.001$). Knee flexion at initial contact decreased and minimum hip flexion in stance did not change, in the three groups after the intervention.

The ankle dorsiflexion in stance phase was reduced in PTS (from 21.12^0 to 14.56^0, $p = 0.003$) and PTS + DFEO (from 27.52^0 to 16.95^0, $p < 0.001$) groups after intervention, whereas DFEO exhibited an increase (from 12.29^0 to 16.75^0, $p = 0.028$).

The peak knee flexion in swing phase was reduced in all groups after intervention. The reduction was from 62.26^0 to 50.61^0 ($p < 0.001$) in the PTS group, from 67.88^0 to 57.45^0 ($p < 0.001$) in DFEO group and from 70.47^0 to 54.33^0 in PTS + DFEO group ($p < 0.001$).

The pre-operative (initial) APT was 12.41^0 in the PTS group, 12.74^0 in the DFEO group and 12.45^0 in the PTS + DFEO group. There was not observed difference at severity of APT before intervention in comparison among the groups ($p = 0.976$).

The APT increased 14^0 (from 12.41^0 to 26.49^0, $p < 0.001$) in the PTS group, 7.1° (from 12.74^0 to 19.91^0, $p < 0.001$) in the DFEO group and 6.6^0 (from 12.45^0 to 19.12^0, $p < 0.001$) in the PTS + DFEO group after the surgical intervention. The increase of APT was similar between the DFEO and PTS + DFEO groups ($p = 0.956$). The PTS group presented with a more significant deterioration of pelvic tilt than the DFEO ($p = 0.002$) and PTS + DFEO ($p = 0.001$) groups.

The amount of increase of APT was classified according standard deviations (SD) of normal data base ($SD = 4.7^0$) in: mild ($< 4.7^0$), moderate (from 4.7^0 up to 9.4^0) and severe ($> 9.4^0$).

In PTS group, the increase of APT was mild in 8 (23.5%), moderate

Table 3
Clinical parameters, before and after the intervention, in the PTS, DFEO and PTS + DFEO groups.

		PTS	p	DFEO	p	PTS + DFEO	p
Hip flexion def	Pre-op	11.32	**0.001**	12.22	0.726	11.67	0.881
	Post-op	6.91		11.82		11.43	
Knee flexion def	Pre-op	5.59	< **0.001**	15.51	< **0.001**	15.12	**0.002**
	Post-op	−0.29		7.05		6.43	
Popliteal angle	Pre-op	48.53	< **0.001**	60.06	< **0.001**	57.50	< **0.001**
	Post-op	35.29		45.57		46.31	
Ankle dorsiflexion (knees in extension)	Pre-op	11.03	0.083	7.52	**0.011**	15.71	**0.039**
	Post-op	13.25		11.19		12.90	
Triceps surae strength	Pre-op	2.03	0.281	1.68	**0.028**	1.83	0.213
	Post-op	1.82		1.94		2.00	
Rectus femoris spt	Pre-op	1.85	**0.011**	1.82	< **0.001**	2.14	0.058
	Post-op	2.35		2.31		2.52	

Legend: Pre-op (pre-operative), Post-op (post-operative), def (deformity), spt (spasticity).

in 6 (17.7%) and severe in 20 (58.8%) of patients. In DFEO group 38 (43.2%) patients had a mild increase, 10 (21.6%) a moderate and 31 (35.2%) a severe. Finally, we observed a mild increase of APT at 19 patients (45.2%), a moderate at 6 (14.3%) and a severe at 17 (40.5%) of patients from PTS + DFEO group.

The prevalence of patients with severe increase of APT was higher than mild ($p = 0.003$) and moderate ($p < 0.001$) ones only in PTS group. In addition to this, mild increase was less frequently observed in PTS group than DFEO ($p = 0.045$) and PTS + DFEO ($p = 0.049$) groups.

According GMFCS distribution, APT increased 7.89^0 in level II and 14.90^0 in level III patients in PTS group ($p = 0.170$), 2.52^0 in level II and 8.20^0 in level III in DFEO group ($p = 0.016$) and 3.83^0 in level II and 7.33^0 in level III in PTS + DFEO group ($p = 0.415$) (Table 4).

The reduction of knee flexion in the stance phase (KFSt) and the increase of APT were compared among groups regarding the inclusion of HSL in the treatment. The reduction of KFSt was more significant in the DFEO ($p = 0.016$) and PTS + DFEO groups ($p = 0.004$) when HSL was performed in the same surgical session. The increase of APT exhibited a trend to be more relevant when HSL was performed, with significant results ($p = 0.016$) in the PTS + DFEO group (Table 5).

Finally, GPS decreased from 18.2 to 14.5 ($p < 0.001$) in PTS group, from 20.6 to 17 ($p < 0.001$) in DFEO group and from 20.7 to 17.3 ($p < 0.001$) in PTS + DFEO group. Although, there was an increase in MAP at pelvis (anterior/posterior) in PTS (from 9.6 to 15.8, $p < 0.001$), DFEO (from 8.3 to 11.3, $p < 0.001$) and PTS + DFEO groups (from 6.0 to 12.3, $p < 0.001$).

Table 5
− Comparison of the reduction of knee flexion in the stance phase and the increase of anterior pelvic tilt in the groups, with and without the inclusion of hamstrings surgical lengthening in the treatment plan.

		PTS	p	DFEO	p	PTS + DFEO	p
Reduction of **KFSt**	**HSL**	30.0	0.559	18.5	**0.016**	37.9	**0.004**
	NO-HSL	25.5		6.2		14.4	
Increase of APT	**HSL**	16.4	0.134	8.0	0.106	11.9	**0.016**
	NO-HSL	11.4		4.6		3.7	

Legend: KFSt (Knee Flexion in Stance Phase), APT (Anterior Pelvic Tilt), HSL (Hamstrings Surgical Lengthening), NO-HSL (Without Hamstrings Surgical Lengthening).

The reduction of GPS did not show difference in the comparison among groups ($p = 0.985$), however the increase of the MAP at pelvis in sagittal plane was higher in PTS and PTS + DFEO than DFEO groups ($p = 0.014$) (Table 6).

4. Discussion

In the present study, reduction of knee flexion during the stance phase was seen in all groups. Moreover, the increase of APT occurred regardless of the approach applied for correction of crouch gait. In the comparison among groups, the increase of APT was more significant in patients who underwent PTS alone. Moreover, the prevalence of patients with severe increase of APT was higher than mild and moderate

Table 4
Kinematic parameters, before and after the intervention, in the PTS, DFEO and PTS + DFEO groups.

		PTS	p	DFEO	p	PTS + DFEO	p
Mean APT	Pre-op	12.41	< **0.001**	12.74	< **0.001**	12.45	< **0.001**
	Post-op	26.49		19.91		19.12	
Min Hip Flex St	Pre-op	13.99	0.068	17.51	0.485	19.81	0.735
	Post-op	17.04		18.43		19.36	
Knee Flexion IC	Pre-op	46.0	< **0.001**	54.2	< **0.001**	58.2	< **0.001**
	Post-op	28.4		39.1		40.7	
Min Knee Flex St	Pre-op	41.60	< **0.001**	46.03	< **0.001**	52.34	< **0.001**
	Post-op	13.66		30.73		29.50	
Peak Knee Flex	Pre-op	62.26	< **0.001**	67.88	< **0.001**	70.47	< **0.001**
	Post-op	50.61		57.45		54.33	
Ankle Dors St	Pre-op	21.12	**0.003**	12.29	**0.028**	27.52	< **0.001**
	Post-op	14.56		16.75		16.95	
Norm Velocity (velocity/lower limb length)	Pre-op	0.70	**0.001**	0.72	**0.001**	0.57	**0.016**
	Post-op	0.53		0.59		0.45	
GDI	Pre-op	48.33	< **0.001**	43.61	< **0.001**	43.75	< **0.001**
	Post-op	55.72		50.31		51.05	

Legend: Pre-op (pre-operative), Post-op (post-operative), APT (anterior pelvic tilt), Min Hip Flex St (minimum hip flexion in stance phase), Knee Flexion IC (knee flexion at initial contact), Min Knee Flex St (minimum knee flexion in stance phase), Peak Knee Flex (peak knee flexion in swing phase), Ankle Dors St (ankle dorsiflexion in stance phase), Norm Velocity (normalized velocity), GDI (Gait Deviation Index).

Table 6
–Gait Profile Score and Movement Analysis Profile before and after intervention in groups PTS, DFEO and PTS + DFEO.

		PTS	*p*	DFEO	*p*	PTS + DFEO	*p*
GPS (Overall)	Pre-op	18.2	< **0.001**	20.6	< **0.001**	20.7	< **0.001**
	Post-op	14.5		17.0		17.3	
Pelvis anterior/posterior	Pre-op	9.6	< **0.001**	8.3	< **0.001**	6.0	< **0.001**
	Post-op	15.8		11.3		12.3	
Hip flexion/extension	Pre-op	19.0	0.549	19.8	0.515	21.4	0.198
	Post-op	19.7		20.3		19.9	
Knee flexion/extension	Pre-op	31.1	< **0.001**	36.1	< **0.001**	40.2	< **0.001**
	Post-op	20.6		25.9		26.8	
Ankle dorsiflexion/plantarflexion	Pre-op	13.3	**0.002**	17.9	< **0.001**	18.5	< **0.001**
	Post-op	10.0		12.2		13.7	
Pelvic Up/Down	Pre-op	5.0	0.242	5.0	0.277	4.6	**0.006**
	Post-op	4.7		5.3		6.3	
Hip Adduction/Abduction	Pre-op	7.2	0.095	7.5	0.230	7.4	0.178
	Post-op	6.2		7.0		6.8	
Pelvic Internal/External	Pre-op	9.0	0.187	9.5	0.123	11.4	0.286
	Post-op	9.8		10.5		10.5	
Hip Internal/External	Pre-op	15.4	**0.008**	16.5	0.075	13.3	0.700
	Post-op	11.2		14.5		13.7	
Foot Internal/External	Pre-op	17.7	**0.019**	20.3	**0.009**	14.6	0.292
	Post-op	12.3		16.4		16.5	

Legend: Pre-op (pre-operative), Post-op (post-operative), GPS (Gait Profile Score).

ones only in PTS group, and mild increase was less frequently observed in PTS group than DFEO and PTS + DFEO groups.

There was trend for higher increase in APT when HLS was performed in the same surgical session; however, significant results were only seen in the PTS + DFEO group.

The HSL has been considered by many authors as one of the factors related to the increase in APT after the correction of KFD in CP [4–9]. In the present study, the pelvis became more anterior in the sagittal plane after surgery in all three groups. The PTS group presented with a more significant deterioration of APT when compared to the other groups, even though medial HSL was more prevalent in the DFEO group. On the other hand, concomitant HSL was related to a higher increase in APT after treatment only in the PTS + DFEO group. Our results might suggest that the weakening of hip extensors after HSL is related to the increase in APT after crouch gait treatment, however other factors must be considered as well.

In the present study, it was observed an increase of RF spasticity at clinical examination and a reduction of peak knee flexion in swing phase after crouch gait treatment, and we believe that PTS may be related to these outcomes. During PTS procedure, the knee extensors are pulling down which can make RF muscle relatively shortened and more spastic.

Another possible explanation for the increase of RF tone after intervention is the imbalance between knee flexors and extensors. RF spasticity became more relevant also in DFEO group and PTS was not performed in this group. On the other hand, the majority of patients from DFEO group (73.9%) received medial HSL.

In addition to this, it is important to state that none of the patients in the present study had received a RF transfer previously or concomitant to PTS, because in our hospital, the management of RF stiff knee gait is done after resolution of crouch gait.

As a consequence of it, the increased tone of RF may explain the changes at APT and knee flexion in swing phase after PTS in our study. In 2017, Böhm et al. [19] suggested that the main reasons for increased APT following the treatment of flexed knee gait were the tone of RF and shortness of psoas muscles. According the authors, the increase of the spasticity of RF after PTS may also explain the reduction of the knee flexion in swing phase. Moreover, Dreher et al. and Blumetti et al. also observed a decrease at knee range of motion in swing phase after PTS [20,21]. Klotz et al. reported that PTS may lead to stiff knee gait and higher increase of APT [22].

In addition to this, Wolf et al. advocated in 2014 that knee flexors and extensors strength imbalance is a major feature to determine why mean pelvic position is tilted anteriorly whereas maximum passive hip extension is of minor importance [5].

Stout at al. and Sossai et al. reported a higher APT after DFEO and patellar tendon shortening or distal advancement [11,12]. We understand that hamstrings could become relatively longer after DFEO because the standard procedure includes some degree of femoral shortening, in order to achieve knee flexion correction without a neurovascular injury. As a consequence, increase of APT has been mentioned after DFEO without concomitant patellar tendon procedures [23].

Nevertheless, we observed in our study that APT also increased after isolated PTS, which suggests that the anterior drop of the pelvis in the sagittal plane after crouch gait treatment may have a multifactorial cause, including postural issues.

Finally, Feng et al. mentioned that an increase of APT is inevitable when crouch gait is corrected, since the oblique femur becomes more vertical during stance, thereby rotating the pelvis into more of an anterior tilt [12].

Our results combined to the current literature lead us to consider that the increase of APT after crouch gait treatment seems to be a multifactorial problem, determined by postural changes and muscle imbalance. However, it is important to state that the present study has limitations. The retrospective design itself can be a source of bias. Despite that fact, the groups matched regarding gender, GMFCS distribution, and follow-up time; although patients in the DFEO group were younger at surgery. This finding reflects the approach for crouch gait treatment in our hospital, which considers the indication of patellar tendon procedures for patients after the growth spurt.

Another possible source of bias is the surgical procedures performed in the same session of knee flexion deformity correction. As mentioned previously, concomitant HSL was more prevalent in the DFEO group. Moreover, psoas lengthening over the pelvic brim (POB) was also done more frequently in the DFEO group (59% of the limbs, while only 5.9% of lower limbs from the PTS group underwent POB. Considering all of this information, we believe that the more significant increase of APT observed in the PTS group could be influenced by the lowest prevalence of concomitant POB in this group.

5. Conclusion

There was an increase of APT in all studied groups which was more significant for those who underwent a PTS. The inclusion of HSL in the surgical plan was related to higher increase in APT in the PTS + DFEO group.

Conflict of interest

The authors declare no conflicts of interest.

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References

[1] Y. Temelli, N.E. Akalan, Treatment approaches to flexion contractures of the knee, Acta Orthop. Traumatol. Turc. 43 (2) (2009) 113–120.
[2] T. Dreher, D. Vegvari, S.I. Wolf, A. Geisbüsh, S. Gantz, W. Wenz, F. Braatz, Development of knee function after hamstring lengthening as a part of multilevel surgeryin children with spastic diplegia − a long-term outcome study, J. Bone Jt. Surg. [Am.] 94 (2012) 121–130.
[3] J.R. Davids, A.M. Bagley, Identification of common gait disruptions patterns in children with cerebral palsy, J. Am. Acad. Orthop. Surg. 22 (2014) 782–790.
[4] E.B. Zwick, V. Saraph, G. Zwick, C. Steinwender, W.E. Linhart, G. Steinwender, Medial hamstrings lengthening in the presence of hip flexor tightness in spastic diplegia, Gait Posture 16 (3) (2002) 288–296.
[5] S.I. Wolf, R. Mikut, A. Kranzl, T. Dreher, Which functional impairments are the main contributors to pelvic anterior tilt during gait in individuals with cerebral palsy? Gait Posture 39 (1) (2014) 359–364.
[6] P.A. DeLuca, S. Ounpuu, R.B. Davis, J.H. Walsh, Effect of the hamstring and psoas lengthening on pelvic tilt in patients with spastic diplegic cerebral palsy, J. Pediatr. Orthop. 18 (6) (1998) 712–718.
[7] A.S. Arnold, M.Q. Liu, M.H. Schwartz, S. Ounpuu, S.L. Delp, The role of estimating muscle-tendon lengths and velocities of the hamstrings in the evaluation and treatment of crouch gait, Gait Posture 23 (3) (2006) 273–281.
[8] M.T. Healy, M.H. Schwartz, J.L. Stout, J.R. Gage, T.F. Novacheck, Is simultaneous hamstring lengthening necessary when performing distal femoral extension osteotomy and patellar tendon advancement? Gait Posture 33 (1) (2011) 1–5.
[9] T. Dreher, D. Vegvari, S.I. Wolf, A. Geisbusch, S. Gantz, W. Wenz, et al., Development of knee function after hamstring lengthening as a part of multilevel surgery in children with spastic diplegia: a long-term outcome study, J. Bone Jt. Surg. [Am.] 94 (2) (2012) 121–130.
[10] J.L. Stout, J.R. Gage, M.H. Schwartz, T.F. Novacheck, Distal femoral extension osteotomy and patellar tendon advancement to treat persistent crouch gait in cerebral palsy, J. Bone Jt. Surg. [Am.] 90 (11) (2008) 2470–2484.
[11] R. Sossai, P. Vavken, R. Brunner, C. Camathias, H.K. Graham, E. Rutz, Patellar tendon shortening for flexed knee gait in spastic diplegia, Gait Posture 41 (2) (2015) 658–665.
[12] L. Feng, K.P. Do, M. Aiona, J. Feng, R. Pierce, M. Sussman, Comparison of hamstring lengthening with hamstring lengthening plus transfer for the treatment of flexed knee gait in ambulatory patients with cerebral palsy, J. Child Orthop. 6 (2012) 229–235.
[13] T. Harada, S. Ebara, M.M. Anwar, I. Kajiura, S. Oshita, K. Hiroshima, K. Ono, The lumbar spine in spastic diplegia: a radiographic study, J. Bone Jt. Surg. [Br.] 75 (1993) 534–537.
[14] K.C. Lee, L. Carson, E. Kinnin, V. Patterson, The Ashworth Scale: a reliable and reproducible method of measuring spasticity, J. Neurorehabil. 03 (1989) 205–209.
[15] M.P. Kabada, H.K. Ramakrishan, M.E. Wootten, Measurement of lower extremity kinematics during level walking, J. Orthop. Res. 08 (1990) 383–392.
[16] R.B. Davis, S. Ounpuu, D.J. Tyburski, A gait analysis data collection and reduction technique, Hum. Mov. Sci. 10 (1991) 575–587.
[17] M.H. Schwartz, A. Rozumalski, The gait deviation index: a new comprehensive index of gait pathology, Gait Posture 3 (2008) 351–357.
[18] R. Baker, J.L. McGinley, M.H. Schwartz, S. Beynon, A. Rozumalski, H.K. Graham, O. Tirosh, The gait profile score and movement analysis profile, Gait Posture 30 (2009) 265–269.
[19] H. Böhm, M. Hösl, L. Döderlein, Predictors for anterior pelvic tilt following surgical correction of flexed knee gait including patellar tendon shortening in children with cerebral palsy, Gait Posture 54 (2017) 8–14.
[20] T. Dreher, B.K. Krautwurst, K. Hirsch, S.I. Wolf, M. Klotz, Patella tendon shortening for the correction of flexed knee gait in cerebral palsy –a randomized controlled trial, Gait Posture 49S (2016) 113.
[21] F. Blumetti, M. Morais Filho, C. Kawamura, J. Leite, M. Fujino, J. Lopes, Development of stiff knee after crouch gait treatment in cerebral palsy − the role of patellar tendon shortening, Gait Posture 49S (2016) 114.
[22] M.C. Klotz, B.K. Krautwurst, K. Hirsch, M. Nicklasch, M.W. Maier, S.I. Wolf, T. Dreher, Does additional patella tendon shortening influence the effects of multilevel surgery to correct flexed knee gait in cerebral palsy: a randomized controlled trial, Gait Posture 60 (2018) 217–224.
[23] M. Morais Filho, D.L. Neves, F.P. Abreu, Y. Juliano, L. Guimarães, Treatment of fixed knee flexion deformity and crouch gait using distal femur extension osteotomy in cerebral palsy, J. Child Orthop. 2 (2008) 37–43.