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ORIGINAL CLINICAL ARTICLE

Treatment of fixed knee flexion deformity and crouch gait using distal femur extension osteotomy in cerebral palsy

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Abstract
Purpose The purpose of this study was to evaluate the results of distal femur extension osteotomy and medial hamstring lengthening in the treatment of fixed knee flexion deformity in patients with spastic diparetic cerebral palsy.
Methods A retrospective study was done in a group of 12 diparetic cerebral palsy patients. A distal femur extension osteotomy was performed as part of multilevel surgery on lower limbs. The fixed knee flexion deformity was measured during physical examination, whereas hip and knee flexion in the stance phase and anterior pelvic tilt were both analyzed at kinematics. The pre- and post-surgery results were compared and analyzed statistically. A medical record review was done in order to identify the complications. The mean follow-up was 28 months.
Results A significant reduction of fixed knee flexion deformity at physical examination and knee flexion in the stance phase at kinematics was observed, but with no decrease in hip flexion. As a non-desired effect, there was an increase in anterior pelvic tilt after surgical procedures. With regard to complications, a single patient had skin breakdown at a calcaneous area on one side and the recurrence of deformity was seen in 27% of cases.
Conclusions In this study, in which fixed knee flexion deformity did not exceed 40° before surgery, the distal femur extension osteotomy was effective in increasing knee extension in the stance phase. However, an increase in anterior pelvic tilt, deformity recurrence and necessity for walking aids are possible complications of this procedure.

Keywords Distal femur extension osteotomy · Knee flexion deformity · Cerebral Palsy

Introduction

Spastic cerebral palsy (CP) is generally associated with musculoskeletal deformities that occur during body growth [1]. The knee flexion deformity is common in those with CP and is usually determined by progressive contracture of spastic hamstrings combined with a quadriceps weakness.

The fixed knee flexion compromises the passive mechanisms of joint stabilization at mid and terminal stance in children with CP [2]. The results are development of crouch gait, increase of energetic expenditure and anterior knee pain [3–5].

Several methods have been described in the literature for treatment of fixed knee flexion deformity (FKFD) in patients with CP, such as hamstring lengthening, posterior knee capsulotomy and serial casting [6, 7]. Complications such as neurovascular injuries, femoral fractures, skin breakdown, recurrence and hyperextension are more likely

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to occur with severe deformities [8]. The distal femur extension osteotomy (DFEO) has been considered as an alternative to posterior knee capsulotomy for cases in which total extension was not achieved after the soft tissue release [9]. However, there are few studies in the literature regarding use of this approach in CP patients (Fig. 1).

At our institution, FKFD in those with CP has been primarily treated using soft tissue procedures in the medial hamstrings. Femoral biceps muscle lengthening is generally not performed, in order to avoid knee hyperextension and an increase of anterior pelvic tilt after surgery [10, 11]. If residual knee flexion deformity persists after the procedures at soft tissues, the DFEO is performed using a modified Iacovone technique [12].

Therefore, the purpose of this study was to evaluate the effectiveness of DFEO for treatment of FKFD and crouch gait in a group of patients with spastic diparetic CP. Potential complications such as sciatic nerve injury, skin breakdown at hind foot, infection and recurrence of the deformity were also investigated.

Materials and methods

All patients with spastic diparetic CP who had undergone DFEO were identified in the gait laboratory database of our institution. Only the cases submitted to gait analysis before the surgical treatment and that returned for postoperative control after rehabilitation were considered. A total of 12 patients (22 sides) matched the inclusion criteria and formed the sample of this retrospective study; the GMFCS levels were II (3 subjects), III (8 subjects) and IV (1 subject). Previous surgeries had been performed in 7 patients, and the Aquiles tendon lengthening had been done in five (41.6%) before the development of crouch gait. The DFEO was performed by our orthopedic surgeons' staff, from 1997 to 2003. The same surgical technique was applied and the DFEO was indicated when semi-membranosus and gracilis muscle lengthening along with the transfer of the semi-tendinosus to adductor tubercle were not effective enough for the total knee extension. The femoral bicep lengthening was not performed in any patients of this study, because this procedure has only been recommended for severe deformities, usually those greater than 50° (Tables 1, 2).

If the FKFD was less than 30°, the surgical technique consisted of multiple perforations in the supracondilar area of the femur wedge-like anterior base with posterior cortical integrity maintenance in order to obtain stability. Under fluoroscopy, the osteotomy was performed with the use of a chisel, and the knees were gently manipulated until the total extension was reached. There was no use of any method of internal fixation and a long leg plaster was applied until consolidation. After plaster removal, the use of knee immobilizers was prescribed for 1 year at night. Only one patient (two sides) presented with a FKFD greater than 30°, and trapezoidal wedge resection was required to avoid neurovascular injury. In this case, the internal fixation with crossed Kirschner wires was used. The physical therapy was standardized and started after plaster removal in the out-patient clinic, with a duration of 1 year or until recovery of preoperative functional status.

The average age at the time of the surgery was 13.11 years (9.11–19.9 years). Of the patients, 5 were male and 7 were female. The use of walking aids was not required for 5 of them, whereas 2 used a walker, 4 used

Fig. 1 Lateral radiograph of maximum knee extension of patient 9. **a** Before surgery with fixed knee flexion deformity. **b** After distal femur extension osteotomy, with long leg plaster, in the operating room. **c** 8 weeks after surgical procedures. Knee with full extension and distal femur osteotomy healed

Table 1 Patient information summary, including gender, ages at the time of surgery and procedures combined with fixed knee flexion deformity correction. *R* right side, *L* left side, *RF* rectus femoris transfer, *PSOAS* psoas lengthening over the pelvic brim), *GS* gastrocnemius lengthening, *PTS* patellar tendon shortening, *TA* triple arthrodesis of foot, *TO* tibia derotational osteotomy, *LCL* lateral collum lengthening, *AS* subtalar arthrodesis, *AD* hip adductors release, *TXTA* anterior tibialis split

	Patients	Gender	Age	Procedures
1	V.T.T.	Male	9 years + 3 months	RF R/L, PSOAS R/L
2	M.T.	Female	10 years + 3 months	RF R/L, GS R
3	K.F.P.	Female	16 years + 5 months	PTS R/L, TA R, TO L
4	F.D.C.C.	Female	16 years + 3 months	PSOAS R/L, TA R/L
5	L.S.	Female	11 years + 8 months	PSOAS R/L, LCL + AS R/L
6	A.D.S.T.	Male	15 years + 8 months	PSOAS R/L, LCL + AS R/L, TO R/L
7	V.S.	Female	17 years	PTS R/L, AD D
8	O.D.R.	Male	19 years + 9 months	TO R/L, GS R/L, TXTA R/L, PTS R/L, PSOAS R/L
9	J.L.B.O.	Male	10 years + 5 months	PSOAS R/L
10	R.O.	Female	13 years + 11 months	GS R/L, TO R/L, LCL+ AS R/L, PSOAS R/L
11	C.A.A.S.	Male	16 years + 7 months	LCL+AS R/L, PSOAS R/L, TO D,
12	C.D.	Female	10 years + 2 months	PSOAS R/L, AD R/L, TXTA R/L

Table 2 Previous surgeries and complaint of pain before and after crouch gait treatment. *R* right side, *L* left side, *pre-op* before crouch gait treatment, *post-op* after crouch gait treatment, *AD* hip adductors release, *ATL* aquiles tendon lengthening, *HAM* hamstring lengthening, *PSOAS* psoas lengthening, *RF* rectus femoris transfer, *FDO* femoral derotational osteotomy

Patients	Previous surgeries	Pain (pre-op)	Pain (post-op)
1	No	No	No
2	AD, ATL, HAM R/L	Yes (knee)	No
3	AD, PSOAS, RF, FDO R/L	No	No
4	HAM, ATL R/L	Yes (foot)	No
5	AD, ATL, HAM R/L	No	No
6	AD, ATL, HAM R/L	Yes (foot)	No
7	No	No	Yes (lumbar)
8	No	No	No
9	No	No	No
10	AD, HAM, RF R/L	No	No
11	ATL R/L	Yes (knee)	No
12	No	No	No

Canadian crutches and 1 held on to another person for support. During preoperative evaluation, 4 individuals complained of pain either in the knees (2 cases) or the feet (2 cases).

The use of ground reaction ankle foot orthosis (GRAFO) is part of the treatment for crouch gait at our institution when ankle dorsiflexion is increased at stance phase. In this study, 8 patients had an indication of GRAFO at preoperative gait analysis, but only 5 were able to use the orthosis during data collection. Even with GRAFO, the FKFD kept these patients in crouch gait before surgery. Patients 4–6 had significant planus valgus deformities on their feet making it impossible for adequate GRAFO use; thus data were collected without orthosis. The DFEO was always performed along with other surgical procedures (an average of 5.2 procedures per patient) and the postoperative gait analysis was carried out for 28 months on average after the surgery.

The three-dimensional gait analysis was done in the movement laboratory of our hospital. The patients were required to walk along an 8-m-long walkway at their own pace after photo-reflective marker placement [13]. From each patient, 10 gait cycles were collected and the most representative was chosen for analysis after the data processing according to reduction of technique [14].

The FKFD was evaluated during physical examination of the patient in supine position, with hips extended, through the maximum passive extension and measured using a goniometer. Minimum hip and knee flexion, and mean anterior pelvic tilt in the stance phase were analyzed at kinematics pre- and post-surgery. It was considered as a complete recurrence of deformity when the FKFD in the postoperative analysis was equal to or greater than the analysis pre-surgery.

The Wilcoxon test [15] was used for statistical analysis, and the rejection level of null hypothesis was set at 0.05 or 5%.

Results

Of the 12 patients evaluated, 7 required walking aids (4 used Canadian crutches; 2 used anterior walkers; and 1 used hand support) before the surgical intervention. After surgery, of the 5 patients that did not need any walking aids before the surgical intervention, 2 started to demand it (1 started to use Canadian crutches and 1 started to use an anterior walker). The patient who had previously required the use of hand support started to use Canadian crutches, but there was no change with the others.

The 4 patients who had pain at preoperative evaluation showed regression of symptoms, but one individual developed lumbar discomfort after treatment.

All patients (eight individuals) who, after surgical procedures, had increased ankle dorsiflexion during stance phase were able to use GRAFO during follow-up gait analysis. The correction of feet deformities allowed patients 4–6 wear the orthosis.

The average immobilization period when using long leg plaster was 6 weeks (with a minimum of 3 and a maximum of 8 weeks). For one of the patients, a skin breakdown at the left calcaneous area was observed, which was treated with local bandage and care. During the postoperative period, alterations such as sensibility reduction and distal paralysis, pain and hyperesthesia of the feet—which would indicate a sciatic nerve injury—were not observed. Recurrence of the knee flexion deformity, however, occurred in six lower limbs (27.27%).

No statistical differences in the evaluated parameters between the left and right sides were observed, with the exception of the mean anterior pelvic tilt, for which increased values were demonstrated on the left side ($P = 0.05$) during the postoperative period. Thus, the FKFD and the hip and knee flexion in the stance phase, in the kinematics, behave in a similar way for the left and right sides, both during pre- and postoperative periods (Tables 3, 4).

The FKFD was significantly reduced after treatment. There was a reduction in the mean value from 15.91° to 5.68° ($P = 0.05$). At kinematics, the minimum knee flexion in the stance phase had its mean value reduced from 43.56° to 22.29° ($P = 0.001$), while the minimum hip flexion was not altered in a significant way. The mean hip flexion in the stance phase during the preoperative period was 15.56° and became 15.46° after the surgical procedures ($P > 0.45$).

Mean anterior pelvic tilt increased significantly from 12.04° to 21.91 ($P = 0.00$) after the correction of the FKFD. The results of surgical procedures at knee extension in the kinematics were similar between patients of different ages in this study. However, all patients older than 13 years (7 individuals) showed an increase of anterior pelvic tilt at follow-up whereas 40% of patients younger than 13 years (5 individuals) exhibited reduction of anterior inclination of the pelvis after treatment of crouch gait.

Discussion

The knee flexion deformity is associated with crouch gait in patients with CP and it causes impairment in the maintenance of the erect position, along with the possibility of generating pain due to the pressure between femur and patella [2]. The increase of energetic expenditure for walking has also been described in the literature as one of the adverse effects of knee flexion deformity [5].

In 2002, Kay et al. [10] observed that the medial hamstring lengthening reduced the mean knee flexion deformity from 3° to 1°. In more severe cases, in which the mean flexion deformity was of 5°, the femoral biceps muscle lengthening was combined with the medial hamstring lengthening, and there was a postoperative reduction

Table 3 Knee flexion deformity at clinical examination and hip flexion, knee flexion and anterior pelvic tilt in the kinematics. Values are expressed in degrees. *FKFD* fixed knee flexion deformity at clinical examination, *KFK* knee flexion at kinematics, *APT* anterior pelvic tilt at kinematics, *HFK* hip flexion at kinematics, *Pre* before surgery, *Post* after surgery, *R* right side, *L* left side

Patients	FKFD				KFK				APT				HFK			
	Pre		Post		Pre		Post		Pre		Post		Pre		Post	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	5	10	5	5	23.3	28	11.9	20.5	12.5	11.9	13.9	13.8	0.6	−2.3	−3	0.8
2	15	0	15	30	54.3	31	61.6	42.5	10.8	10.4	13	12.6	17.5	5.8	21.2	5.3
3	15	20	0	0	45.3	57.1	15.5	13.5	11.8	11.7	31.1	30.7	14.2	22.1	31.8	35.2
4	25	20	5	10	59.6	54.5	47.5	30.7	17.2	16.9	26.8	28.5	29	34.3	23.7	37.2
5	10	5	10	0	17.6	0.6	7.6	11.5	18.5	15.2	13.8	13.6	15.5	16.4	6	6.5
6	20	20	15	20	33.2	30.8	31.9	33.2	8.5	8.4	20.3	19.1	9	7.1	13	30.3
7	15	20	0	0	48	51.4	0.7	20.4	10.6	10.1	25.2	24.3	13.3	24.7	12	19.2
8	40	40	0	0	83.8	76.8	19.6	24	−2.5	−2.8	20.5	21.6	15	24.4	5	12.7
9	20	30	0	0	38.1	44.5	3.,6	14	17.3	15.9	28.1	28.9	15.8	13	9.4	15.8
10	5	10	0	0	61.5	60.1	9	14.5	8.3	8.1	24.2	23.7	21.3	21.3	15	17.3
11		0		0		16.5		14.5		25.6		29.3		12.6		12.3
12		5		10		42.5		41.5		20.5		19.1		11.8		13.5

Table 4 Comparison between pre- and post-surgery values using Wilcoxon test. Mean and median values are expressed in degrees. *FKFD* fixed knee flexion deformity at clinical examination, *KFK* knee flexion at kinematics, *APT* anterior pelvic tilt at kinematics, *HFK* hip flexion at kinematics, *PRE* before surgery, *POST* after surgery, *s* significant, *ns* non-significant, *z calc.* Wilcoxon test

	FKFD		KFK		APT		HFK	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Mean	15.91	5.6818	43.56	2.25	12.04	21.91	15.56	15.46
Median	15	0	44.90	7.55	11.75	22.65	15.25	13.25
z calc.	−2.86		−3.230		−3.702		−714	
p	0.05		0.001		0.0		0.45	
	s		s		s		ns	

for mean values of 2°. We agree with Kay that when the FKFD is mild and generally below 5°, the medial hamstring lengthening is enough to achieve extension.

The correction of FKFD through knee flexor lengthening and serial casting has been described in the literature for patients with CP [7, 16], but the complications are not infrequent. The use of DFEO makes possible the correction of knee flexion at the end of the surgical procedure and a long leg plaster is used to keep total extension up to the complete consolidation. The average period of immobilization in this study was 6 weeks, and there was no need for serial casting to obtain extra correction.

In the studied group, the mean FKFD value collected during the preoperative gait analysis was 15.91°. Two members of the group (patients 2 and 11) had no FKFD during the period of kinetics and kinematics data collection, but these patients were submitted to DFEO. This happened as a consequence of the evolution of deformity during the period between three-dimensional gait analysis and surgical intervention (11 months for patient 2 and 8 months for patient 11), which made the approach to medial hamstrings not sufficient to achieve total knee extension. As observed by Moen et al. [5] in patients with spina bifida, the knee flexion deformity at kinematics had been superior to the mean FKFD values at physical examination, a fact that reinforces the use of gait analysis during the decision-making process.

Zimmermann et al. [8] mentioned a reduction of FKFD from 41° to 13° with the use of shortening supracondilar femur osteotomy in 20 patients with a different diagnosis (non-spastic group), with an average follow-up of 4 years and 6 months. In the sample analyzed, the percentage of correction for the FKFD was similar, but the mean preoperative value was inferior (15.91°) as well as the residual deformity (5.68). With utilization of serial casting after medial hamstring lengthening, Westberry et al. [7] observed a reduction of knee flexion deformity at physical examination from 16.7° to 5.6° in CP patients and an average age of 12.7 years. After a 1-year of follow-up, a loss in the obtained correction was verified, and the mean contracture was 10.1°.

Reduction of knee flexion in the stance phase for the patients studied after DFEO was observed. The residual knee flexion at kinematics was higher than that observed at physical examination, and dynamic factors, such as weakness of soleus and hip extensors muscles, can be considered as a cause for this difference. After hamstring lengthening, the literature also mentions an increase of knee extension in the stance phase [10, 11], but the magnitude of the preoperative flexion noted in these studies is inferior when compared with our sample, and the mean values do not exceed 30° at the kinematics.

Gage [2] described that the increase in knee extension in the stance is obtained via a combination between femur extension osteotomy and shortening of the patellar tendon. In our study, a significant reduction of crouch gait pattern was observed after correction of FKFD and orthotic management, when indicated. The shortening of patellar tendon was performed only in three patients, and we consider this procedure a good option for recurrent cases. We do not use patellar tendon shortening combined with FEO for non-recurrence, thus avoiding complications such as anterior pain, hyperextension at stance phase and stiffness of knee after surgery.

Even without femoral bicep lengthening and with the transfer of the semi-tendinosus to adductor tubercle, a major increase in anterior pelvic tilt was observed in the studied group. The mean anterior pelvic tilt changed from 12.04° to 21.91° and is superior to the values described by DeLuca et al. [11] in a study in which medial hamstring lengthening was combined with the lengthening of the femoral biceps (increase from 11° to 16°). Gage [2] also mentioned an increased anterior pelvic tilt and consequently an increased lumbar lordosis in a group submitted to femur extension osteotomy combined with a shortening of the patellar tendon. The increase in the number of patients needed to make use of walking aids in the post-surgery study is probably related to elevation of center of mass after correction of knee flexion and it can lead to anterior pelvic tilt increase. Another possible etiology is the deficiency of hamstrings generated by the shortening of lever arm occasioned by the DFEO.

All patients older than 13 years showed an increase of anterior pelvic tilt at follow-up study; 71.5% of them (5 individuals) had even undergone an intrapelvic psoas tenotomy as a part of surgical treatment. However, patients younger than 13 years (5 individuals) exhibited reduction of anterior pelvic tilt in 40% of cases. The intrapelvic psoas tenotomy was performed in 80% of patients younger than 13 years, and all individuals whose pelvic position improved at second gait study received this procedure as a part of treatment. The data suggest that patients older than 13 years are more likely to show an increase of anterior pelvic tilt after treatment of crouch gait, and psoas lengthening seems to be more effective at a younger age to maintain or improve pelvic position at the sagittal plane.

The increase of anterior pelvic tilt was a non-desired effect of FKFD correction by medial hamstring lengthening and DFEO. The possible causes are weakness of hip extensors and the raise of anterior trunk inclination after surgical procedures. The weakness of hip extensors can be generated by medial hamstring lengthening combined with the shortening of femur lever arm after extension osteotomy. Despite the fact of the literature does not mention increase of anterior pelvic tilt after medial hamstring lengthening, we do believe that it can occur when DFEO is associated with soft tissue procedures. The increase in the number of patients who use crutches or walkers after treatment is related to increase of mean anterior pelvic tilt as well. The trunk is more inclined forward when patients walk with crutches or anterior walkers and, consequently, the anterior pelvic tilt is increased. Psoas lengthening was not effective in avoiding this increase, especially in those requiring walking aids [16].

In the sample analyzed, the significant increase of knee extension in the stance phase did not generate an increase in hip extension. Of the 12 patients, 9 (75%) were submitted to an intrapelvic psoas tenotomy in the same surgical session for the knee flexion deformity correction and, even after this procedure, the increased hip flexion in the stance phase was not reduced. We agree with Davids et al. [17], who observed that, in the great majority of cases, an increase in hip flexion during the gait is a tertiary alteration and a recovery is expected after appropriate treatment of the knee flexion. We believe that the maintenance of hip flexion in the stance phase observed in this study, even with a suggestive increase in the knee extension, is directly related to the increase in anterior pelvic tilt that happened post-surgical intervention.

With regard to complications, the most frequent was the deformity recurrence (27.27%). Zimmermann et al. [8] described a recurrence of 20% for patients who had undergone DFEO after a follow-up period of 4 years, but diagnosis in the studied group was very heterogeneous. We believe that the recurrence was higher in our sample because all the patients were diagnosed with spastic CP in association with a growing skeleton, and these factors were related to the deformity recurrence [1]. No signs of neurological injury or surgical infection were observed, and one patient had skin breakdown at a calcaneous area as a consequence of plaster immobilization. Westberry et al. [7], in a recent study, referred 17.3% of soft tissue compromise, 12% of transitory neuropraxia and 1.3% of posterior tibial subluxation to be complications when the knee flexion deformity in CP was treated with serial casting and hamstring lengthening.

Another important aspect to consider is the use of walking aids after surgery. Although 5 patients were able to walk without support before surgery, 2 of them (40%) lost this ability after surgical procedures. The necessity of crutches or walkers following DFEO is a possible undesirable effect accompanying the treatment of crouch gait in CP patients.

In general, the complications were infrequent in our study when compared with those described in the literature [8], and we impute the results to the fact that the values of FKFD were not severe in our sample. Only one patient presented with a knee flexion deformity greater than 30° before the surgical intervention, and the average value of the group was 15.91%, far inferior to the group studied by Zimmermann et al. [8].

In conclusion, the DFEO along medial hamstring management was an effective procedure for reduction knee flexion deformity in the population studied, but deformity recurrence, increase at anterior pelvic tilt and the need for walking aids after surgery are possible complications.

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