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Calf lengthening may improve knee recurvatum in specific children with spastic diplegic cerebral palsy

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Abstract

Purpose Knee hyperextension in stance is a difficult condition to treat in children with spastic diplegic cerebral palsy (CP). In children with passive knee hyperextension, the presence of contracture or spasticity of the calf leads to knee hyperextension in stance phase. We hypothesize surgical treatment of the contracture of the calf will lead to less knee hyperextension.

Methods We performed a retrospective review of children who were evaluated in our movement laboratory over 23 years with a diagnosis of CP Gross Motor Function Classification System I, II or III. We selected children who had passive knee hyperextension on exam and who underwent calf lengthening surgery. Children were divided into two groups: early recurvatum (ER) (n = 20) and late recurvatum (LR) (n = 14).

Results There was no difference in the preoperative passive knee extension among the groups or the surgeries performed. For children who had passive knee hyperextension, calf lengthening improved static dorsiflexion with knee flexion on clinical exam by 9.3° in the ER group, 9.6° in the LR group as well as dorsiflexion with knee extension on clinical exam by 9.5° in the ER group and 6.4° in the LR group. The kinematic data showed that the ER group improved their knee hyperextension by 11° ($p < 0.001$), whereas the LR group did not significantly change their stance phase knee position.

Conclusion Children with passive knee hyperextension who have a calf contracture and walk in knee hyperextension in the first half of stance phase may improve after calf lengthening.

Level of Evidence: III

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Introduction

Gait in children with cerebral palsy is well studied with typical gait patterns described. The main stance phase gait deviations at the knee are flexed or recurvatum regardless of the hip and ankle position. The most common pattern seen in children with spastic diplegic cerebral palsy (SPDI) is a flexed knee gait pattern;[1,2] therefore, there is more literature aimed at the diagnosis and treatment of this pattern.[3-7] However, there is a subset of children that walk with knee recurvatum[8,9] with less known about the natural history and treatment of this pattern. Bauer et al.[10] examined a cohort of children that had passive knee hyperextension on clinical exam and determined that the presence of contracture or spasticity of the gastroc-soleus complex and the consequent plantar-flexion knee extension couple led to knee hyperextension in stance phase. Bauer et al.[10] also found that children who had knee hyperextension in early stance were more likely to have a contracture of the gastroc-soleus than children who had hyperextension in late stance. Given the difficulty in treatment of the knee hyperextension, we aimed to examine the results of surgical intervention in a similar group of patients who have dynamic knee recurvatum and who underwent calf lengthening surgery. Specifically, our hypotheses were: 1) surgical treatment of the contracture of the gastroc-soleus would lead to less knee hyperextension in stance phase by reducing the plantar flexion-knee extension couple; 2) the timing of the knee hyperextension, early or late, would influence the surgical outcome.

Materials and methods

We performed a retrospective review of all children who were evaluated in our movement analysis laboratory between 1 January 1994 and 31 December 2018 with a diagnosis of SPDI cerebral palsy Gross Motor Function Classification System I, II or III. We selected all children who had passive knee hyperextension on clinical exam of >0° and who also underwent calf lengthening surgeries. We excluded all children who had concomitant surgery on the hamstrings or rectus tendon at the same time period or any prior history of hamstring surgery (lengthening,

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release or transfers) as either of these surgeries may affect the minimum knee extension in stance.[3,7,11] Any child with an athetoid or ataxic form of cerebral palsy or any child that had botulinum toxin A administration within a year of the surgery was excluded from the study. Of the initially identified 929 children with SPDI, 60 children had passive knee hyperextension of >0° on clinical exam and no history of hamstring surgery. In all, 34 of those 60 children underwent calf lengthening surgery and showed knee hyperextension on their preoperative movement analysis graphs.

The 34 children were divided into two groups: early recurvatum (ER) (n = 20) and late recurvatum (LR) (n = 14). Early recurvatum of the knee was defined as dynamic knee hyperextension started in the first 50% of the stance phase, and late recurvatum was defined as dynamic knee hyperextension started in the second 50% of stance phase.[12] We then evaluated the clinical and kinematic outcomes.

Gait study

Movement analysis evaluation included a comprehensive history and physical examination, complete kinematics and kinetic analysis along with video recording of the gait. The movement analysis was performed with a 10 infrared camera VICON Motion Analysis System (Vicon Motion Systems Ltd, Oxford, UK) with five AMTI Force Plates (AMTI Inc., Watertown, Massachusetts). Full gait analysis studies are routinely completed in our laboratory on all ambulatory children undergoing surgery for treatment and are also performed at one-year postoperatively. Preoperative studies are completed in order to assist in surgical decision-making as well as to provide a baseline to assess outcome for each individual patient. Reflective markers were placed on the child at several anatomical landmarks: the base of the sacrum midway between the posterior superior iliac spines, both anterior superior iliac spines, the lateral epicondylar ridge of the distal end of the femur along the flexion-extension axis of the knee, the lateral aspect of the thigh along the axis of the knee (on a 10-cm long aluminum wand fastened here), the most prominent point of the lateral malleolus in line with the transmalleolar axis (on an aluminum wand) and the midfoot between and slightly proximal to the second and third metatarsal heads. The children walked at their self-selected speed, and only the barefoot condition was evaluated. Each session consisted of three barefoot walking trials, and the average of the three trials of each subject was used in the statistical analysis.

Statistical analysis

A chi-squared test of independence was run to detect significant association between the timing of knee recurvatum (early *versus* late) and the type of surgery (Achilles lengthening *versus* gastrocnemius surgery). Unpaired *t*-test was ran to detect differences between the two groups (early *versus* late) and paired *t*-test was run to determine changes following surgery. In addition, a two-way analysis of variance (ANOVA) was conducted to examine the effect of the timing of knee recurvatum and the type of surgery on the change in knee extension. All statistical analysis of the data was done only for the right legs unless only the left leg met the inclusion criteria to meet the statistical requirement for independence.[13]

Results

There was no statistical significant difference in age at the time of surgery between the groups (p = 0.27). The mean age for the ER group was 13.2 years (SD 4.4) and the LR group was 10.9 years (SD 3.8) (Table 1). The types of calf lengthening surgery performed for the subjects are presented in Table 1. A chi-squared test of independence showed that there was no significant association between type of surgery and timing of knee recurvatum (early *versus* late) chi-squared (1, N = 34) = 1.40; p = 0.24.

Table 1 Subject characteristics, type of calf surgeries and concomitant surgeries

	Early (n = 20)	Late (n = 14)
Mean age at surgery, yrs (SD)	13.2 (4.4)	10.9 (3.8)
Mean gait study follow-up time, yrs (SD)	1.4 (0.6)	1.3 (0.4)
Patients		
Male	8	9
Female	12	5
Gross Motor Function Class System level		
I	9	6
II	7	0
III	4	1
Unknown	0	7
Type of calf surgery		
Tendon Achilles lengthening	6	7
Gastrocmnemius surgery	14	7
Concomitant surgeries		
Femur osteotomy	2	4
Posterior tibialis lengthening	1	1
Psoas lengthening	0	1
Adductor lengthening	0	1

Table 2 Preoperative static and dynamic measurements for the early and late groups. Negative signs indicate plantarflexion or knee/hip extension

	Early (n = 20)	Late (n = 14)	p-value*
Physical exam, ° (SD)			
Knee extension	5.7 (4.6)	4.1 (4.1)	0.29
Straight leg raise	61.0 (7.5)	66.8 (6.7)	0.03
Popliteal angle	46.5 (12.4)	37.5 (14.4)	0.06
Knee flexion (prone)	138.0 (10.3)	145.7 (3.9)	0.24
Hip flexion	110.0 (9.0)	119.6 (7.2)	0.012
Dorsiflexion with knee flexed	-3.3 (13.2)	3.6 (8.6)	0.10
Dorsiflexion with knee extended	-7.8 (13.7)	-5.0 (6.5)	0.49
Kinematics, ° (SD)			
Minimum knee flexion in stance	-10.1 (5.6)	-3.6 (3.8)	< 0.001
Maximum dorsiflexion in stance	-6.3 (16.3)	-2.2 (11.8)	0.43
Average pelvic tilt in stance	20.5 (6.2)	23.4 (6.5)	0.21
Minimum hip flexion	-0.7 (10.9)	0.04 (6.9)	0.82

* p-value of paired t-test (two-tailed) is reported.

Preoperatively, there was no difference in the clinical exam measurements of knee hyperextension between the two groups (ER 5.7° (SD 4.6°); LR 4.1° (SD 4.1°); p = 0.29) (Table 2). There was no difference between the static dorsiflexion with both the knee flexed (ER -3.3° (SD 13.2°); LR 3.6° (SD 8.6°) (p = 0.10) or extended (ER -7.8° (SD 13.7°); LR -5.0° (SD 6.5°) (p = 0.49) (Table 2). There was a difference in dynamic minimum knee flexion in stance between the two groups (ER -10.1° (SD 5.6°; -23.43° to -1.1°); LR -3.6° (SD 3.8°; -14.30° to -0.17°) (p < 0.001). This is consistent with previous findings in the literature.[10]

Postoperatively, the static range of movement of dorsiflexion improved after calf lengthening surgery in both conditions (with the knee flexed or extended) in both groups (Tables 3 and 4). The static dorsiflexion with knee flexion on clinical exam increased by 9.3° (SD 15.4°) in the ER group (p = 0.015) (Table 3) and 9.6° (SD 8.0°) in the LR group (p < 0.001) (Table 4). The dorsiflexion with knee extension on clinical exam increased by 9.5°(SD 13.5°) in the ER group (p = 0.005) (Table 3) and 6.4° (SD 11.0°) in the LR group (p = 0.048) (Table 4). There was an increase in stance phase dorsiflexion for both groups after surgery (ER preoperative -6.3°(SD 16.3°), ER postoperative 9.5° (SD 5.5°); p = 0.001) (Table 3); (LR preoperative -2.1° (SD 11.8°), LR postoperative 6.5°(SD 9.9°); p = 0.009) (Table 4).

Most interestingly, a review of the kinematic data showed that the children with early recurvatum improved their minimal knee flexion in stance from a preoperative value of -10.1° (SD 5.6°) to a postoperative value of 0.9° (SD 7.6°) (p < 0.001) after calf lengthening (Table 3). In contrast, children in the late recurvatum group did not show significant change in minimum knee flexion in stance after surgery (Table 4).

A two-way ANOVA that examines the effect of the timing of knee recurvatum and the type of surgery on the change in knee extension showed the main effect of timing of knee recurvatum was significant, F(1, 34) = 8.79, p = 0.006. The early group showed significantly more improvement in knee extension than the late group (Early 11.0°± 8.9°, Late 1.6°± 8.9°). The main effect of type of surgery was not significant: F(1, 34) = 0.90; p =0.35. There was not a significant interaction between the timing of knee recurvatum and the type of surgery: F(1, 34) = 0.42; p = 0.52.

Table 3 **Preoperative to postoperative changes in static and dynamic measurements for the early group (n = 20). Negative signs indicate plantarflexion or knee/hip extension**

	Preoperative	Postoperative	Change	p-value*
Physical exam, ° (SD)				
Knee extension	5.7 (4.6)	4.3 (4.4)	-1.6 (5.1)	0.22
Straight leg raise	61.0 (7.5)	59.5 (7.1)	-1.5 (5.9)	0.27
Popliteal angle	46.5 (12.4)	47.3 (10.9)	0.8 (7.7)	0.67
Knee flexion (prone)	138.0 (10.3)	138.0 (11.6)	0 (7.3)	NS
Hip flexion	110.0 (9.0)	107.5 (8.5)	-2.5 (6.6)	0.11
Dorsiflexion with knee flexed	-3.3 (13.2)	6.0 (10.5)	9.3 (15.4)	0.015
Dorsiflexion with knee extended	-7.8 (13.7)	1.8 (8.2)	9.5 (13.5)	0.005
Kinematics, ° (SD)				
Minimum knee flexion in stance	- 10.1 (5.6)	0.9 (7.6)	11.0 (8.9)	< 0.001
Maximum dorsiflexion in stance	-6.3 (16.3)	9.5 (5.5)	15.8 (18.3)	0.001
Average pelvic tilt in stance	20.5 (6.2)	20.7 (5.1)	-0.2 (8.5)	0.93
Minimum hip flexion	-0.7 (10.9)	0.9 (9.1)	1.7 (11.0)	0.51

NS, not significant
* p-value of paired t-test (two-tailed) is reported.

Table 4 **Preoperative to postoperative changes in static and dynamic measurements for the late group (n = 14). Negative signs indicate plantarflexion or knee/hip extension**

	Preoperative	Postoperative	Change	p-value*
Physical exam, ° (SD)				
Knee extension	4.1 (4.1)	2.4 (5.5)	-1.7 (0.3)	0.21
Straight leg raise	66.8 (6.7)	67.1 (11.4)	0.4 (12.0)	0.91
Popliteal angle	37.5 (14.4)	36.4 (26.8)	-1.1 (28.6)	0.89
Knee flexion (prone)	145.7 (3.9)	142.1 (9.3)	-3.6 (10.1)	0.21
Hip flexion	119.6 (7.2)	117.5 (5.8)	-2.1 (5.8)	0.19
Dorsiflexion with knee flexed	3.6 (8.6)	13.2 (10.7)	9.6 (8.0)	< 0.001
Dorsiflexion with knee extended	-5.0 (6.5)	1.4 (11.2)	6.4 (11.0)	0.048
Kinematics, ° (SD)				
Minimum knee flexion in stance	-3.6 (3.8)	-2.0 (9.7)	1.6 (8.9)	0.52
Maximum dorsiflexion in stance	-2.1 (11.8)	6.5 (9.9)	8.7 (10.7)	0.009
Average pelvic tilt in stance	23.4 (6.5)	20.3 (5.0)	-3.1 (7.5)	0.15
Minimum hip flexion	0.04 (6.9)	-0.9 (7.3)	-1.0 (6.5)	0.58

* p-value of paired t-test (two-tailed) is reported.

Discussion

Knee hyperextension in the stance phase has many clinical implications including decreasing propulsion at late stance[8] as well as concern for joint damage.[14] Our study set out to find whether treatment of the equinus by calf lengthening surgery would reduce the hyperextension at the knee. The results showed that knee hyperextension was reduced in the early recurvatum group but not in the late recurvatum group after calf lengthening, which indicates early knee recurvatum is associated with calf contractures and late knee recurvatum is not associated with calf contractures and is possibly more associated with a late spastic response. Bauer et al.[10] previously found that children who had knee hyperextension in early stance were more likely to have a contracture of the gastroc-soleus compared with children who had hyperextension in late stance. Therefore the majority of children with late knee recurvatum did not have calf contractures. Nevertheless, the few subjects that had late knee recurvatum and calf surgery showed no significant change in knee extension following calf lengthening procedures. This gives more credence to the theory that late knee recurvatum is not caused by calf contractures.

Prior studies have looked at how knee kinematics are affected by gastroc-soleus lengthening in children with cerebral palsy. Baddar et al.[15] examined 34 children with diplegic cerebral palsy and primarily flexed knee gait patterns and found that lengthening led to improved knee extension at foot contact, but excessive midstance knee flexion persisted. They also found that 'the correlation between knee and ankle kinematic data during single-limb stance was lost after surgery'. Klotz et al.[16] also studied 19 children with SPDI and that had knee hyperextension in stance, and underwent either gastroc-soleus lengthening or Achilles lengthening as part of a multilevel surgery. They found an improvement in 77% of the limbs. Their study was limited by the concomitant surgeries performed, the analysis of each limb (rather than one limb per patient) and the heterogeneity of the patient population. Klotz et al.[16] further delineated the timing of the recurvatum with their outcomes. Another study[17] similarly found more correction of the knee extension in stance towards normal in the early recurvatum group. A different study by Klotz et al.[18] also found that treatment of the spasticity by botulinum toxin A injection did not improve the knee hyperextension. Other causes of knee hyperextension, such as over lengthening of the hamstrings,[19] have been proposed. Hence, we excluded any child who had prior hamstring release, lengthening or transfer. In order to ensure calf lengthening surgery was the direct cause of the change in knee kinematics, we only chose children who had calf lengthening surgery without concomitant hamstring or rectus surgery, thus eliminating other potential influencing factors.

Gait analysis has been recognized as a useful clinical tool that assists in treatment planning.[20] The findings from this study have implications for management. The results demonstrated that children with early knee recurvatum showed significant decrease in knee recurvatum following calf lengthening procedures. In contrast, children with late knee recurvatum did not show significant improvement in knee recurvatum following calf lengthening surgery. The findings from this study support the importance influence of the timing of the recurvatum (early *versus* late) on outcome. This may be difficult to determine without 3D kinematic gait analysis data.

While this study was retrospective in nature and subject to the inherit limitations of a retrospective study design, all the data were collected using a standardized clinical gait analysis evaluation protocol for all subjects in this study. While patient data was obtained concurrently, we cannot determine the exact indications the treating surgeon had when deciding whether to perform a surgery at the level of the achilles or more proximal. The children in this study were selected based on the measurement of passive knee extension in a clinical exam, which is subject to measurement error. However, we have a standardized exam that was performed by two experienced clinicians. This is also not a longitudinal study, rather a snapshot of the child's gait. Additionally, the limits of gait reproducibility and marker placement are limitations of any study of movement analysis. Opportunities for future studies include evaluating the role of an ankle foot orthosis to modulate the knee hyperextension in stance phase.

In conclusion, calf lengthening may reduce knee recurvatum in children with diplegic cerebral palsy who have a calf contracture, passive knee hyperextension and dynamic knee hyperextension in the first half of the stance phase.

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ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: A waiver of informed consent has been granted from the institutional review board as this is a retrospective study.

ICMJE CONFLICT OF INTEREST STATEMENT

JB reports personal fees from Orthopediatrics, outside the submitted work.

The other authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

JB: Study idea, Study design, Data Analysis, Manuscript preparation and review, Final approval of manuscript.

KPD: Study idea, Study design, Data collection, Data analysis, Manuscript review, Final approval of manuscript.

JF: Data analysis, Manuscript review, Final approval of manuscript.

MA: Study design, Data analysis, Manuscript review, Final approval of manuscript.

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