Spontaneous decrease in gastrocnemius spasticity after correction of knee flexion gait in children with cerebral palsy

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Abstract

**Purpose:** Synergistic neuro-excitability in the lower extremities may be related to gait disorders. This study aimed to report spontaneous changes after correcting knee flexion gait and discuss the underlying mechanisms. **Methods:** A prospective study of 23 children with cerebral palsy was conducted to assess postoperative changes in gross motor function, joint range of motion (ROM), and spasticity. Characteristics of children/limbs with spontaneous decrease in gastrocnemius spasticity were assessed. **Results:** In 10 patients (19 limbs) without gastrocnemius release, the Modified Ashworth scores in the gastrocnemius decreased in 6 limbs after 3 months and in 10 limbs after 6 months. Those limbs with spontaneous changes had worse preoperative knee flexion contracture than the limbs without spasticity changes (knee ROM limitation score 5.4 vs. 3.7, \( p = 0.026 \)). **Conclusions:** Patients with knee flexion contracture recruited greater plantar flexion–knee extension couple to balance knee flexion gait, and synergistic neuro-excitability of the gastrocnemius was enhanced. Our early results suggest preservation of the gastrocnemius in treating knee flexion gait, especially for patients with knee flexion contracture.

Keywords
cerebral palsy, gastrocnemius, hamstrings, spasticity

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Introduction

Cerebral palsy (CP) is a disease caused by nonprogressive injury to the immature brain. Spasticity, muscle contracture, and subsequent limited range of motion (ROM) are common disorders that cause dysfunctions in gait and posture.¹² A common pathologic gait pattern in children with CP is knee flexion gait, which is characterized by increased knee flexion throughout the stance phase of the gait cycle. Knee flexion gait incurs more energy for walking and can be classified as jump knee gait, apparent equinus gait, and crouch gait by different biomechanics in the ankle.³ Multi-level surgical correction is recommended for treating knee flexion gait to prevent decline in ambulatory ability.⁴

Synergistic movement is a common neuropathological sign in patients with stroke and encephalopathy.⁵ The primitive movement pattern interferes with coordinated voluntary movements. For example, patients with flexion synergy in the upper limbs show scapular retraction, shoulder adduction, elbow flexion, and wrist and finger...

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flexion at the same time. Patients lose independent control of selected muscle groups, resulting in coupled joint movements known as abnormal synergy that is often inappropriate for the desired task. Synergistic movement also occurs in the lower extremities as shown in hip flexion-adduction, knee flexion, and ankle plantar flexion. The hamstrings and the gastrocnemius are adjacent biarticular muscles akin to an extensor muscle during closed kinetic chain extension of the lower limb. The two biarticular muscles also allow a degree of flexibility in the motor control strategies for lower limb extension.

When the hamstrings and gastrocnemius are regarded as one synergistic muscle group in patients with CP, neuroexcitability of the two muscles may relate to each other. When one muscle is changed, the other muscles in one synergistic group may also be affected. Since surgical release is a strong perturbation for a muscle, we speculate that releasing the hamstrings may affect the gastrocnemius, and vice versa. In a clinical scenario where hamstrings alone are released for knee flexion gait, responses of the gastrocnemius offer a chance to investigate how a synergistic muscle group works. In this study, we aimed to show spontaneous changes in the length and spasticity of the gastrocnemius when surgery is performed in the hamstrings and to investigate the characteristics of the patients or the limbs with spontaneous change.

Materials and methods
Participants

After approval from the Institutional Review Board of Chang Gung Medical Foundation (103-3634C), a prospective study of surgical outcomes after myofascial release was conducted in children with CP between 2010 and 2013. Twenty-five children with spastic knee flexion gait participated in the study, with a mean age of 8.5 years (3.5–12.8). Knee flexion gait was defined by knee flexion angle greater than 30° throughout the entire stance phase by observational analysis. Signed consent forms were obtained from all the participants’ parents. There were 17 boys and 8 girls. Their gross motor function was level II in 9 patients, level III in 11 patients, and level IV in 5 patients by the Gross Motor Function Classification System (GMFCS).

Interventions

Single-event multilevel myofascial releases of both lower extremities were performed in all patients. The surgery involved the muscles at the knees, hips, and ankles based on clinical judgment by gait characteristics and physical examination. Surgical procedures performed around the hips were release of the adductor longus and gracilis for scissoring and/or the psoas for hip flexion contracture greater than 20° by the Thomas test. Surgical procedures around the knees were performed for the myofascial release of the semimembranosus and semitendinosus muscles for patients with knee flexion gait and the popliteal angle greater than 70°. Surgical procedures performed around the ankles included the release of the gastrocnemius for static equinus at knee extension and a positive Silfverskiold test. Patients who underwent osteotomies were not included in this study. After surgery, long-leg splints were applied for 2 weeks to facilitate training of standing with full extension of the knees. Non-articulated or ground reaction ankle–foot orthoses were applied for gait training. Postoperative physical therapy was conducted by two certified pediatric physical therapists.

Outcome measures

Muscle length was assessed by joint motion using a goniometer. A full range of joint motion suggested adequate length of the surrounding muscles. The degree of limitation in joint motion was correlated to the degree of shortening in muscle length. The Spinal Alignment and Range of Motion Measure was an ordinal score to measure limitations of ROM and was referred to the degree of muscle shortening. The hip was assessed according to six items including extension, flexion, abduction, adduction, external rotation, and internal rotation. ROM limitation of the knee was assessed by two items, namely, the knee extension and the hamstrings. Knee extension was assessed by the maximal angle of passive knee extension at hip extension and was classified as follows: 1, 0° or greater; 2, 0° to −10°; 3, −10° to −20°; and 4, more than −20°. The hamstrings were assessed by maximal angle of passive knee extension at hip flexion 90°. They were classified as follows: 1, less than 20°; 2, 20° to 45°; 3, 45° to 60°; and 4, more than 60°. ROM limitation of the ankle was assessed by two items, namely, dorsiflexion and plantarflexion, that were assessed at knee extension. ROM limitation of ankle dorsiflexion was a measure of gastrocnemius length and classified as follows: 1, more than 15°; 2, 15° to 15°; 3, −10° to 5°; and 4, more than −10°. The Spinal Alignment and Range of Motion Measure that was performed at 2-week interval had good test–retest reliability (intra-class correlation coefficients (ICC), 0.95–0.97) and good interrater reliability between the two physical therapists (ICC, 0.89).

Muscle spasticity was measured using the Modified Ashworth Scale (MAS). This five-point scale was scored as follows: 1, normal tone; 2, mild spasticity with catching in limb movement or minimal resistance throughout the remainder (<50%) of the ROM; 3, moderate spasticity with increased tone throughout most of the ROM; 4, severe spasticity with difficulty in passive motion; and 5, extreme spasticity with rigidity in flexion and extension. Spasticity was assessed at the hamstrings and gastrocnemius. The MAS scores were regarded as an ordinal variable. The MAS that was validated before the study showed good
test–retest reliability (ICC, 0.76–0.79) and interrater reliability (ICC, 0.86).

Gross motor function was evaluated using the Gross Motor Function Measure (GMFM), which is a standard measure to quantify gross motor ability in children with CP. In this study, the GMFM-66, which was a modified scale to improve the interpretability of changes following the interventions, was used. Higher scores indicated better gross motor function. The GMFM scores were regarded as continuous variables in this study. The test–retest reliability and interrater reliability were excellent (ICC, 0.997 and 0.998, respectively).

Each patient underwent assessments at the week prior to surgery and postoperative 3 months and 6 months. Outcome measures included the MAS, ROM, and GMFM. All these measures were performed by two pediatric physical therapists. The surgical effects for all three outcome measures were compared before and after the surgery using the Wilcoxon signed–rank test for the MAS and paired t-test for the ROM and GMFM. The characteristics of patients with spontaneous change at the gastrocnemius were compared with those of patients without change using t-tests for continuous variables (age, body mass index (BMI), ROM scores, GMFM-66 scores), Mann–Whitney test for ordinal variables (MAS scales), or χ² test for categorical variables (GMFCS, surgery). The possibility of a positive significant factor to be associated with spontaneous change was further analyzed using an odds ratio and 95% confidence interval. Correlations between the significant factor and other variables were assessed using Pearson correlation or Spearman correlation. A threshold for significance was set a priori at p < 0.05. All analyses were conducted using SPSS version 21.0.

Results
Twenty-five children with spastic diplegic or quadriplegic CP received bilateral multilevel myofascial release. Two of these children (two girls, one GMFCS level III and one level IV) did not complete the postoperative assessments, and the other 23 children with 46 limbs were the study participants. All the limbs had myofascial release in two or more muscle groups (Table 1).

General effects from surgery were increased GMFM scores, increased joint ROM, and decreased muscle spasticity. The GMFM scores improved from a mean of 55.9–57.5 (p = 0.005). The ROM limitation scores of the 43 operated hips improved from a mean of 9.8–8.5 (p < 0.001). The ROM limitation scores of the 46 operated knees improved from a mean of 5.1–3.7 (p < 0.001). The ROM limitation scores of the 27 operated ankles were not significantly change (from a mean of 3.6–3.7, p = 0.648), because only the gastrocnemius was released. The MAS of the hamstring in the 46 operated limbs decreased from a median of 3 to a median of 2 (p < 0.001). The MAS of the gastrocnemius in the 27 operated limbs decreased from a median of 4 to a median of 3 (p = 0.001).

The ROM scores were unchanged for the joints that did not undergo surgery. However, the MAS of the gastrocnemius decreased from a median of 4 (interquartile range 3–4) to a median of 3 (interquartile range 2–4) in the 19 limbs without gastrocnemius surgery (p = 0.006). The postoperative course was that 3 patients (6 limbs) had a spontaneous decrease in spasticity by one MAS scale in 3 months, and the phenomenon was noted in 5 patients (10 limbs) in 6 months. The other five patients (nine limbs) remained in the preoperative status. Between the two groups with different responses in terms of gastrocnemius spasticity to the surgeries, no significant differences were found in the patients’ age, BMI, GMFCS level, GMFM scores, surgical procedures, and limbs’ MAS scales. Only the preoperative ROM limitation of the knee was significantly different between the two groups of limbs with different responses (mean ROM limitation scores 5.4 in the limbs with change vs. 3.7 in the limbs without change, p = 0.026). The limbs with preoperative knee flexion contracture (knee extension score of 2 or more) were more likely to have spontaneous changes in spasticity (odds ratio = 8.00, 95% confidence interval 1.05–60.99) compared with the limbs with full passive knee extension (knee extension score of 1; Table 2). Correlation showed preoperative hip ROM scores and two subitems of knee ROM were significantly correlated to the preoperative knee flexion contracture. Age, BMI, GMFCS, GMFM, ankle ROM, and MAS score of the hamstrings and gastrocnemius were not correlated to knee flexion contracture.

Discussion
A unique phenomenon of spontaneous decrease in spasticity of the gastrocnemius was found in 50% of patients with CP who received hamstring release for knee flexion gait. The gastrocnemius muscle tone decreased by one MAS scale without surgical intervention. Myofascial release of the hamstrings and other muscles could change the underlying synergistic neuro-excitability in the lower extremities and result in decrease in spasticity of the gastrocnemius.

The only predictor for the phenomenon was preoperative knee flexion contracture. A possible biomechanical pathway is that patients with existing knee flexion contracture recruit more gastrocnemius-soleus muscle to produce plantar flexion–knee extension couple to balance knee flexion gait. More gastrocnemius-soleus muscle fibers are employed to control the advancement of the tibia over the foot as well as the orientation of the ground reaction vector with respect to the knee. Chronic and excessive recruitment of the gastrocnemius-soleus may lead to an increase in muscle tone. The coping response in the gastrocnemius muscle tone returns to its original level after surgical correction of knee flexion gait. This information raises concerns about the accuracy of the preoperative assessment of...
spasticity and electromyography. The neuro-excitability may be enhanced from original neural morbidity to a higher level by adding responses to musculoskeletal disorders.

No cast was applied to immobilize the ankle in the 19 patients who did not receive ankle surgery. Therefore, immobilization was not the cause of decreasing spasticity in the gastrocnemius. Improvement of dynamic ROM of the knee joint during standing and walking could affect afferent proprioceptive impulses from the lower extremities, as well as neural output in the spinal cord. The common pathological pathway in CP is central neurologic morbidity, which leads to peripheral musculoskeletal disorders. However, the study results suggested a reverse pathway from peripheral biomechanical disorders (correction

Table 1. Baseline data of the 23 study participants.

| No. | Age | Sex | BMI | CP  | GMFCS | GMFM | Side | ROM scores | Spasticity scales | Surgery |
|-----|-----|-----|-----|-----|-------|------|------|------------|------------------|---------|
| 1   | 3.5 | M   | 15.5| Qua | IV    | 21.78| R    | 9          | 4                | 2       | 4 PAH   |
| 2   | 4.6 | M   | 14.1| Qua | IV    | 46.47| R    | 10         | 5                | 1       | 2 3 PAH |
| 3   | 5.1 | M   | 13.6| Di  | III   | 50.64| R    | 10         | 4                | 3       | 2 1 PAH |
| 4   | 5.9 | M   | 18.3| Qua | III   | 67.28| R    | 10         | 5                | 2       | 3 2 PAH |
| 5   | 6.2 | M   | 14  | Qua | IV    | 44.93| R    | 9          | 4                | 4       | 3 4 PQHG|
| 6   | 6.2 | M   | 17.7| Qua | III   | 71.14| R    | 9          | 4                | 3       | 2 3 PQH |
| 7   | 6.9 | M   | 18.2| Di  | III   | 59.91| R    | 10         | 5                | 5       | 3 4 AHG |
| 8   | 7.4 | M   | 19.1| Qua | IV    | 40.69| R    | 14         | 8                | 5       | 4 3 PAH |
| 9   | 7.5 | M   | 19.5| Di  | II    | 95.03| R    | 9          | 2                | 2       | 3 4 PAHG|
| 10  | 8.1 | F   | 13.6| Tri | III   | 70.58| R    | 11         | 6                | 3       | 2 2 4 HG |
| 11  | 8.5 | M   | 13.9| Tri | III   | 64.81| R    | 11         | 7                | 4       | 3 2 4 PAHG|
| 12  | 8.9 | M   | 15.9| Tri | II    | 78.68| R    | 9          | 5                | 4       | 2 2 4 PAHG|
| 13  | 8.9 | M   | 16.2| Di  | II    | 93.27| R    | 8          | 4                | 3       | 2 1 4 AQHG|
| 14  | 9.2 | M   | 19.7| Di  | II    | 83.55| R    | 8          | 2                | 3       | 2 2 4 PQH |
| 15  | 9.3 | M   | 14.0| Di  | II    | 95.17| R    | 8          | 3                | 4       | 3 1 4 PAQHG|
| 16  | 9.7 | M   | 15.9| Di  | II    | 83.22| R    | 8          | 4                | 3       | 4 3 4 PAQHG|
| 17  | 10.3| M   | 19.8| Qua | III   | 64.82| R    | 11         | 7                | 3       | 4 2 4 PAHG |
| 18  | 10.55| F  | 15.4| Qua | III   | 41.04| R    | 11         | 8                | 5       | 4 4 3 AHG |
| 19  | 10.8| F   | 17.0| Di  | III   | 58.52| R    | 9          | 3                | 4       | 3 3 3 PAH  |
| 20  | 11.6| M   | 16.9| Di  | II    | 85.1 | R    | 7          | 5                | 2       | 3 1 4 PAQH |
| 21  | 11.8| M   | 14.9| Di  | II    | 94.57| R    | 10         | 7                | 2       | 4 3 4 AQH |
| 22  | 11.8| M   | 14.8| Di  | II    | 90.5 | R    | 12         | 5                | 4       | 1 1 3 AH  |
| 23  | 12.81| F  | 15.2| Di  | III   | 58.94| R    | 11         | 8                | 6       | 4 3 4 AHG |

BMI: body mass index; GMFCS: gross motor function classification system; GMFM: gross motor function measure; ROM: range of motion scores; Qua: quadriplegia; Tri: triplegia; Di: diplegia; P: psoas; A: adductor; Q: quadriceps; H: hamstrings; G: gastrocnemius; M: male; F: female.
of knee flexion gait) to spinal neural excitability (decrease of neural tone). It is a mutual interaction between central neural network and peripheral musculoskeletal disorders in patients with CP.

Spasticity is a major neuropathic sign of CP, but spasticity is not a good predictor for global motor function. Table 1 showed that the ROM scores and spasticity scale scores were not associated with the global GMFM scores or ambulatory function. We enrolled GMFCS level IV patients in this prospective study to evaluate whether global motor function (GMFM and GMFCS) affected the postoperative single muscle spasticity. The age range was also wide; consequently, the effect of age on the surgical outcomes is an important concern in clinical practice. The study results were contradictory to the hypothesis that global function and age are associated with the surgical effects on muscle spasticity.

This study has several limitations. First, the number of included patients was small and the follow-up period was short. The evidence is more convincing with more patients recruited. Second, this study did not include kinematic data or electromyographic data to record gait parameters and muscle neuro-excitability. Further study is required to analyze the relationship between kinematic correction and electromyographic change. Third, it was a clinical observational study to define gait pathology. No formal computerized gait analysis was obtained to differentiate apparent equinus gait and crouch gait that may be important in spontaneous decrease of spasticity in the gastrocnemius. Fourth, the MAS was ordinary variable to measure clinically apparent changes, but other measurements with continuous variables, such as Tardieu scale that records joint motion angle, are likely to offer more information. Fifth, static measurement of spasticity is different from dynamic measurement of spasticity on walking. The theory that patients with more knee flexion contracture may recruit more gastrocnemius to execute ankle plantar flexion–knee extension couple still needs further evidence. In the future, we aim to conduct a multi-center study including ambulation-independent and ambulation-dependent patients with CP. Dynamic electromyography with three-dimensional gait analysis is necessary to obtain more evidence on this spontaneous response.

**Conclusion**

This study reported a spontaneous decrease in spasticity of the nonoperated gastrocnemius after surgery for knee flexion gait. The association with knee flexion contracture suggests that neuropathy and musculoskeletal disorder affect each other mutually. Our early results suggest that cautious surgical decision-making by neuro-excitability, which is susceptible to other coexisting disorders, is required. The findings also support preservation of the gastrocnemius in treating knee flexion gait, especially for patients with knee flexion contracture.

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