Comparison of hamstring lengthening with hamstring lengthening plus transfer for the treatment of flexed knee gait in ambulatory patients with cerebral palsy

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Abstract

Purpose Children with spastic diplegic and hemiplegic cerebral palsy frequently ambulate with flexed knee gait. There has been concern that hamstring lengthening used to treat this problem may weaken hip extension. This study evaluates the primary outcome of hamstring transfer plus lengthening in comparison with traditional hamstring lengthening in treating flexed knee gait in ambulatory patients with cerebral palsy.

Methods A total of 47 children (67 lower limbs) ranging in age from 5 to 17 years old were included in this study. All subjects underwent a variety of additional surgeries at the time of the hamstring surgery as part of a multilevel treatment plan. All patients who met the inclusion criteria were divided into two groups, the hamstring lengthening alone group (HSL) and the hamstring transfer plus lengthening group (HST). Full gait analysis studies were done for all subjects pre-operatively and 1 year post-operatively.

Results There were 25 patients (35 limbs) in the HSL group and 22 patients (32 limbs) in the HST group. There was no significant difference in age, gender, or the time from surgery to post-operative gait analysis between groups. On physical examination, both HSL and HST groups showed improvement in passive knee extension,

popliteal angle, and straight leg raise. Maximum knee extension in stance phase was improved in both groups. The maximum hip extension in late stance phase was significantly improved only in the HST group. The peak hip extension power in stance phase showed significant improvement only in the HST group and a significant decrease for the HSL group.

Conclusions The findings of this study demonstrated that both the HSL and HST procedures resulted in similar amounts of improvement in passive range of motion of the knee, as well in knee extension in stance during gait at 1 year post-operatively. However, with the HST procedure, there was better preservation of hip extension power and improved hip extension in stance. The HST procedure should be considered when hamstring surgery is performed.

Keywords Cerebral palsy · Pediatrics · Hamstring lengthening · Hamstring transfer · Outcome

Introduction

Ambulatory children with spastic cerebral palsy frequently develop excessive knee flexion during the stance phase of gait [1]. In spastic diplegia, this can manifest as crouch gait, jump gait, or a mixed pattern [2]. In hemiplegia, this can present as knee flexion with apparent or true equinus [3]. The knee flexion is due to a variety of factors. The primary factor is dysphasic and excessive activity of the hamstrings, which tends to get progressively worse with time and is detrimental to the patient, as it requires increased work by the quadriceps to prevent the knee from collapsing.

If the hamstrings are functionally tight or shortened, then surgical lengthening is indicated [4–6]. However, the hamstrings also contribute to hip extension power, which is

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the critical element of gait that moves the center of mass forward. Hamstring lengthening could weaken hip extension power, with resultant deterioration of posture and gait.

In theory, transferring the semitendinosus to an attachment site above the knee, rather than lengthening alone, may maintain its activity as a hip extensor. Furthermore, this transfer of the semitendinosus along with gracilis may lessen the opportunity of the tendons to reconstitute, thereby, reducing the risk of recurrence.

The purpose of this study is to: (1) observe the results of transfer of the semitendinosus and gracilis to a site proximal to the knee joint, along with fractional lengthening of the semimembranosus $\pm$ biceps femoris (HST), to treat flexed knee gait and (2) compare the differences between this procedure and hamstring lengthening (HSL) alone.

Methods

Subjects

A retrospective review was conducted of all data collected in the Gait Analysis Laboratory on patients between 2000 and 2010, who had undergone either hamstring lengthening surgery or hamstring lengthening surgery in combination with transfer of the distal hamstring tendons. In general, HSL was performed prior to 2004, while HST was introduced after this time and became the standard procedure of both surgeons based on the perceived theoretical benefits of this modification. Both surgeons were quite experienced and had been performing hamstring lengthening procedures for 10–20 years before this review began. The general protocol for post-operative care remained the same between 2000 and 2010. Institutional review board approval of this retrospective study was obtained.

A total of 38 children ranging in age from 5 to 17 years old were included in this study. There were 26 males and 12 females in the group, and their ages at the time of surgery averaged 11.2 ± 3.4 years. Many subjects underwent a variety of additional surgeries at the time of the hamstring surgery (Table 1). The Gross Motor Function Classification System (GMFCS) level was distributed in the population as follows: there were 17 patients at GMFCS level I, 8 patients at level II, and 13 at level III. Patients were excluded from this study if they had undergone concomitant femoral bony surgery, iliopsoas lengthening, or adductor lengthening. In addition, patients who had a prior history of selective dorsal rhizotomy or significant extrapyramidal involvement were excluded.

A detailed description of the patients is shown in Table 1. All patients who met the inclusion criteria were divided into two groups, HSL group (20 patients) or HST group (18 patients; Table 1).

Surgical technique

All patients underwent an aponeurotic lengthening of the semimembranosus. In the group with lengthening alone, the semitendinosus was tenotomized or lengthened by an intramuscular tendon release. The gracilis had an intramuscular lengthening. In those patients undergoing transfer, the semitendinosus and the gracilis were isolated, and tenotomy was done as far distal as possible, which was usually just proximal to their insertion into the pes anserinus. A baseball-type suture was inserted in the proximal detached tendons. The adductor magnus insertion site was identified and the semitendinosus along with the gracilis were passed through a slit in the adductor magnus tendon and sewn back onto themselves. An alternative approach used by one of the surgeons was to anchor the semitendinosus and gracilis to the posterior aspect of the femoral metaphysis with a suture anchor. The biceps femoris was lengthened by an intramuscular lengthening that was done with one or two cuts in the aponeurosis similar to the semimembranosus, depending on its tightness.

Complications

There were no nerve palsies or major post-operative infections requiring operative intervention, other than a few minor superficial skin dehiscences or superficial stitch infections, which were treated as outpatients, not requiring surgery. Both surgeons, as well as hospital staff providing post-operative care, were very sensitive to the problem of nerve stretch and were careful to avoid aggressive acute extension in the early post-operative period, which accounted for the absence of this complication.

Post-operative care

Patients were placed in a knee immobilizer post-operatively for comfort, but forced extension was avoided in order to prevent nerve stretch. They were instructed to avoid passive hip flexion (of greater than 30°), as long as the knees were in the immobilizers to reduce the risk of stretching the sciatic nerve. Patients were kept on bed rest for 36 h, with physical therapy usually starting with standing and then progressing to walking within 2–3 days following surgery. As soon as the patients were strong and comfortable enough to stand unassisted, the knee immobilizers were no longer used during the day time. However, the knee immobilizers were still used at night time for a minimum of 6 weeks (in some cases, longer if there was fixed knee flexion contracture pre-operatively). No patients were placed in long leg casts, although most patients were placed into ankle–foot orthoses (frequently of the ground

Table 1 Subject characteristics

Characteristic	HSL (<i>n</i> = 20 patients)	HST (<i>n</i> = 18 patients)
Diagnosis		
Monoplegia	2	1
Spastic diplegia	15	14
Spastic triplegia	0	2
Spastic quadriplegia	0	1
Hemiplegia	3	0
Age at surgery (years)	11.9 ± 3.0 (5.6–17.1)	10.1 ± 3.4 (5.0–15.6)
Gait study follow up time (months)	13.1 ± 2.9 (9.1–18.6)	12.8 ± 3.8 (4.5–17.5)
GMFCS level		
I	10	7
II	3	5
III	7	6
Subjects that had surgery for the first time (%)	25	22
Previous surgeries		
Hamstring lengthening	3	5
Hamstring transfer	1	0
Rectus femoris transfer	1	0
Adductors release	5	6
Gastrocnemius lengthening	3	4
Posterior tibial tendon lengthening	3	2
Tendon Achilles lengthening	4	4
Anterior tibial tendon transfer	1	0
Iliopsoas lengthening	4	5
Femoral osteotomy	5	5
Tibial osteotomy	0	3
Foot surgery	2	2
Subjects with concomitant surgeries (%)	80	83
Concomitant surgeries		
Rectus femoris transfer	6	11
Gastrocnemius lengthening	3	3
Tendon Achilles lengthening	2	2
Tibial osteotomy	1	0
Foot surgery	1	2
Number of subjects with biceps femoris lengthening	17	18

reaction type). Some patients were temporarily placed in short leg casts in order to provide a strong ground reaction force to assist with knee extension while walking.

Gait study

Motion Lab evaluation included a comprehensive history and physical examination, complete kinematics, video recording of the gait, and kinetic analysis if possible (no assistive device). The motion analysis was performed with an eight infrared camera Vicon Motion System (Oxford, UK), with two AMTI Force Plates and Vicon Software. Full gait analysis studies are routinely completed in our laboratory on all ambulatory patients prior to undergoing

surgery for the treatment of cerebral palsy gait problems, as well as at 1 year post-operatively.

Statistical analysis

All data were analyzed with paired *t*-tests to determine changes following surgery and with unpaired *t*-tests to detect differences between the two groups. The Chi-square test for independence was also used to determine if there is a relationship between the type of surgery and change in hip extension and hip power. The significance level was set at 0.05. All statistical analyses of the data was done only for the right legs so as to meet the statistical requirement for independence.

Results

There was no significant difference in age at the time of surgery between the two groups. The average age for the HSL group was 11.9 ± 3.0 years (range, 5.6–17.1 years) and the average age for the HST group was 10.1 ± 3.4 years (range, 5.0–15.6 years). There was also no difference between the amount of time between surgeries and follow up gait study, with the HSL group being 13.1 ± 2.9 months (range, 9.1–18.6 months) and the HST group being 12.8 ± 3.8 months (range, 4.5–17.5 months).

The unpaired *t*-test showed no difference between the groups both pre-operatively and post-operatively in static range of motion measures, which included straight leg raise, static knee extension range with the hip extended, and popliteal angle. There were significant improvements in all of these measures post-operatively in both groups (Table 2).

The two groups had no significant differences in terms of kinematics pre-operatively, including: minimum dynamic knee flexion in stance, average pelvic tilt in stance, and minimum hip flexion in stance (Table 2). Similar improvements were made after surgery for minimum dynamic knee flexion during stance in both groups; the HSL group improved $8.5^\circ \pm 10.5^\circ$ (range, 30.8° to -10.8°) and the HST group improved $13.7^\circ \pm 10.7^\circ$ (range, 35.6° to -11.0°). The average dynamic pelvic tilt was more anterior after surgery for both groups; the HSL group increased $2.5^\circ \pm 7.5^\circ$ (range, 16.4° to -14.8°) and the HST group increased $6.5^\circ \pm 7.8^\circ$ (range, 22.1° to -4.5°), with no statistical differences between the two groups before or after surgery. Post-operatively, dynamic hip extension at the end of stance increased more for the

HST group, $3.6^\circ \pm 8.4^\circ$ (range, 29.2° to -6.2°), than the HSL group, $1.3^\circ \pm 8.8^\circ$ (range, 15.9° to -16.1° ; Table 2). The HST group showed a statistically significant change after surgery in hip extension and the HSL group showed no change (Table 2). The Chi-square test for independence did not show a statistically significant relationship, although it was approaching the significance level [χ^2 (1, $n = 38$) = 3.709, $p = 0.054$; Table 3].

Pre-operatively, the HST group and the HSL group showed no difference in hip power in stance ($p = 0.7$). However, post-operatively, there were statistical differences between the two groups for peak hip power in stance, with the HSL group losing power after surgery, -0.3 ± 0.4 (range, 0.1 to -1.5 , $p < 0.05$) W/kg and the HST group increasing power after surgery, 0.4 ± 0.4 (range, 1.0 to -0.4 , $p < 0.05$) W/kg (Table 2). The Chi-square test for independence showed a statistically significant relationship [χ^2 (1, $n = 27$) = 16.436, $p < 0.001$; Table 4]. Not all patients had kinetic data, since the collection of this parameter requires the patient to walk without an assistive device. Fourteen HSL patients and thirteen HST patients had kinetic data.

Three subjects in the HSL group had only medial hamstrings lengthenings. However, the results were similar even after these subjects were removed from the statistical analysis (Table 5).

Discussion

In spastic cerebral palsy, the hamstrings may be dysphasic and overactive during the stance phase of gait, limiting normal knee extension. Without intervention, this deformity

Table 2 Pre-operative and post-operative measurements for the hamstring lengthening alone (HSL) and the hamstring transfer plus lengthening (HST) groups

	HSL				HST			
	Pre-operative	Post-operative	Change	<i>p</i> -value	Pre-operative	Post-operative	Change	<i>p</i> -value
Physical examination	<i>n</i> = 20				<i>n</i> = 18			
Straight leg raise (°)	57.5 ± 8.7	63.8 ± 10.0	6.3 ± 12.8	<0.05	56.4 ± 9.2	66.3 ± 14.2	9.1 ± 11.2	<0.05
Knee extension (°)	-6.5 ± 8.9	-1.4 ± 4.9	5.1 ± 7.3	<0.05	-8.1 ± 6.2	-1.7 ± 5.4	6.4 ± 7.3	<0.05
Popliteal angle (°)	61.4 ± 13.5	46.2 ± 9.9	-15.2 ± 14.0	<0.05	57.8 ± 11.7	45.3 ± 14.7	-12.5 ± 16.9	<0.05
Kinematics	<i>n</i> = 20				<i>n</i> = 18			
Average pelvic tilt (°)	19.1 ± 8.4	21.6 ± 5.6	2.5 ± 7.5	0.15	15.7 ± 6.1	22.2 ± 6.9	6.5 ± 7.8	<0.05
Minimum knee flexion in stance (°)	31.7 ± 11.5	23.2 ± 11.6	-8.5 ± 10.5	<0.05	32.6 ± 11.0	18.9 ± 9.8	-13.7 ± 10.7	<0.05
Minimum hip flexion in stance (°)	8.4 ± 11.8	7.1 ± 9.1	-1.3 ± 8.8	0.55	8.9 ± 9.4	5.3 ± 10.7	-3.6 ± 8.4	<0.05
Kinetics	<i>n</i> = 14				<i>n</i> = 13			
Peak hip power in stance (W/kg)	1.1 ± 0.5	0.8 ± 0.3	-0.3 ± 0.4	<0.05	1.0 ± 0.5	1.4 ± 0.8	0.4 ± 0.4	<0.05

Table 3 Number of patients split into two categories according to the change in hip extension

	Group A: HSL	Group B: HST
Number of patients with preserved or improved dynamic hip extension	6	11
Number of patients with decreased dynamic hip extension	14	7

Table 4 Number of patients split into two categories according to the change in hip power

	Group A: HSL	Group B: HST
Number of patients with preserved or improved hip power	2	12
Number of patients with decreased dynamic hip power	12	1

Table 5 Pre-operative and post-operative measurements for the HSL and the HST groups after the three subjects with only medial hamstrings lengthenings were removed

	HSL				HST			
	Pre-operative	Post-operative	Change	p-value	Pre-operative	Post-operative	Change	p-value
Physical examination	<i>n</i> = 17				<i>n</i> = 18			
Straight leg raise (°)	56.5 ± 8.6	63.5 ± 10.0	8 ± 12.0	<0.05	56.4 ± 9.2	66.3 ± 14.2	9.1 ± 11.2	<0.05
Knee extension (°)	−6.4 ± 9.3	−1.2 ± 4.9	5.8 ± 7.9	<0.05	−8.1 ± 6.2	−1.7 ± 5.4	6.4 ± 7.3	<0.05
Popliteal angle (°)	62.3 ± 14.3	46.9 ± 10.0	−13.5 ± 15.3	<0.05	57.8 ± 11.7	45.3 ± 14.7	−12.5 ± 16.9	<0.05
Kinematics	<i>n</i> = 17				<i>n</i> = 18			
Average pelvic tilt (°)	19.0 ± 8.8	22.0 ± 6.4	2.7 ± 7.8	0.16	15.7 ± 6.1	22.2 ± 6.9	6.5 ± 7.8	<0.05
Minimum knee flexion in stance (°)	31.6 ± 11.4	21.4 ± 10.5	−10.2 ± 10.6	<0.05	32.6 ± 11.0	18.9 ± 9.8	−13.7 ± 10.7	<0.05
Minimum hip flexion in stance (°)	7.2 ± 11.2	6.7 ± 9.5	−0.5 ± 8.8	0.84	8.9 ± 9.4	5.3 ± 10.7	−3.6 ± 8.4	<0.05
Kinetics	<i>n</i> = 13				<i>n</i> = 13			
Peak hip power in stance (W/kg)	1.1 ± 0.5	0.8 ± 0.3	−0.3 ± 0.4	<0.05	1.0 ± 0.5	1.4 ± 0.8	0.4 ± 0.4	<0.05

worsens with skeletal growth, resulting in eventual shortening of the musculotendinous unit, which will further exacerbate the increased stance knee flexion.

A standard surgical procedure for shortened hamstrings has been tenotomy or Z lengthening of the semitendinosus and gracilis, along with an intramuscular lengthening of the aponeurosis of the semimembranosus with or without lengthening of the biceps femoris. Hamstring lengthening procedures were designed to improve stance phase knee flexion in gait. Many studies have shown improvement in the popliteal angle [7], which is a measure of hamstring shortening, along with improvement of dynamic knee extension during the stance phase of gait, which is a measure of dynamic function [4–6] following hamstring surgeries.

However, there is a concern that hamstring lengthening may have deleterious side effects, primarily, loss of hip extension power and range, along with increased anterior pelvic tilt [8, 9]. It has been shown that the hamstrings not only function as knee flexors, but they also contribute 25 % of the overall hip extension power, with the gluteus maximus providing the rest [10]. Another possible undesirable

side effect of hamstring surgery may include the development of knee hyperextension or recurvatum [8]. We found no patients in this series with development of knee recurvatum. This can usually be avoided by making sure that there is no plantar flexion–knee extension couple following the hamstring surgery, and lengthening the Achilles tendon or releasing the gastrocnemius at the time of hamstring surgery. An additional concern is the development of increased anterior pelvic tilt, with associated increased lumbar lordosis following hamstring surgery. However, we believe that an increase in anterior pelvic tilt is inevitable when flexed knee gait is corrected, since the oblique femur during stance becomes more vertical, thereby, rotating the pelvis into more of an anterior tilt, unless the hip extension is reciprocally increased. It has been shown that the anterior pelvic tilt may decrease in the long term following an increase after hamstring surgery [11]. One theoretical approach to maintain hamstring function at the hip is to maintain integrity of the biceps femoris function by surgically addressing only the medial hamstrings. However, this has the drawback of leaving behind a continued counterproductive knee flexion force, which will limit the

correction of pathologic knee flexion. The second approach is to transfer the semitendinosus to the femur, which should reduce its contribution to stance phase knee flexion, while potentially maintaining its activity as a hip extensor.

Gordon et al. [11] observed an increase of anterior pelvic tilt after percutaneous hamstring lengthening for ambulatory children with cerebral palsy, but only in a short-term follow up group (less than 18 months after the surgery). However, the anterior pelvic tilt decreased in the long term, suggesting that this effect may only occur in the short term.

In this study, both the HSL group and the HST group showed a clinically, as well as statistically, significant decrease in the static measures of straight leg raise, passive knee extension with hip extension, as well as popliteal angle at 1 year post-operatively. Both groups also showed improvement of the kinematic parameter of knee flexion in stance phase after surgery (Table 2). The hip extension power during stance decreased slightly following HSL, while it improved slightly in the HST group (Tables 2 and 4). In addition, the maximum hip extension in stance phase was also improved in the HST patients, while in the HSL group, this parameter did not change significantly (Tables 2 and 3). This seems to indicate that the transfer was effective in not only maintaining hip extension power, but also in improving hip extension range. Finally, the pelvic tilt increased 2.5° in the HSL group and 6.5° in the HST group, which, although statistically significant, may not be clinically significant.

Ma et al. [12] found similar improvements in popliteal angle, static knee extension, and dynamic knee function parameters in their study of the lengthening and transfer of hamstring for flexion deformity of the knee in children with bilateral GMFCS levels III and IV cerebral palsy. In their study, they only transferred the semitendinosus and lengthened the gracilis and semimembranosus.

One limitation of our study was that there were no radiodense markers placed into the tendons at the transfer site; therefore, it is unknown if the transfer placement was maintained at follow up. Another limitation was that, within the hamstring lengthening group, there were three subjects that had only medial hamstring lengthening based on intra-operative assessment. The number of subjects with only medial hamstring lengthenings (three in the HSL group) was too small to carry out a subgroup analysis, but this difference could influence the comparison between the two groups. However, eliminating the three subjects with only medial hamstring lengthening did not change the results (compare the significant differences between Tables 2 and 5). Kay et al. [13] showed that, although it was not statistically significant, there was a suggestion that combined medial/lateral hamstring lengthening may provide greater improvement in popliteal angle and maximum knee extension in stance. The majority of our subjects in

both groups had combined medial/lateral hamstring lengthening, which may explain the greater improvement in popliteal angle and maximum knee extension in stance for both groups. Kay et al. [13] also noted that there appeared to be a greater risk of knee hyperextension during gait after combined medial and lateral hamstring lengthening than after medial hamstring lengthening alone; however, none of our subjects presented with knee hyperextension during gait.

In addition, the number of patients is relatively small, and there is variation in the types of associated surgical procedures, which is common in most retrospective studies of subjects with cerebral palsy. Although the changes in stance knee extension were robust, the magnitude of the improvement in hip extension range and power were of questionable clinical significance, despite reaching statistical significance. Another limitation was that gait deviations on the opposite side may have impacted gait kinematics on the side analyzed. Concurrent functional outcome measures may have been useful to judge the clinical importance of these findings; however, they were not available, since this was a retrospective study. This study provides sufficient evidence of the benefits of hamstring transfer to justify larger prospective comparative studies to verify these findings. A study is currently being conducted to observe if the rate of recurrence is different between these two groups.

Although the transfer may add 10–15 min to the surgical time for each limb, it does seem to provide improved hip extension power and range, and may reduce the incidence of recurrence, and, therefore, may be a useful modification of the traditional hamstring lengthening surgery.

Conflict of interest None.

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