Title	Changes in Sagittal Plane Kinematics and Kinetics after Distal Release of Medial Hamstrings in Cerebral Palsy
Author(s)	Eid, MKT; To, MKT; Chow, W
Citation	Journal of Functional Morphology and Kinesiology, 2015, v. 1, p. 6-15
Issued Date	2015
URL	http://hdl.handle.net/10722/220181
Rights	Creative Commons: Attribution 3.0 Hong Kong License

J. Funct. Morphol. Kinesiol. **2016**, *1*, 6-15; doi:10.3390/jfmk1010006

OPEN ACCESS

Journal of

Functional Morphology and Kinesiology

ISSN 2411-5142

www.mdpi.com/journal/jfmk

Article

Changes in Sagittal Plane Kinematics and Kinetics after Distal Release of Medial Hamstrings in Cerebral Palsy

Mohamed Abdel-Moneim Eid [1,*], Michael Kai-Tsun To [2] and Wang Chow [2]

[1] Department of Orthopaedic Surgery, Ain Shams University, 11591 Cairo, Egypt

[2] Division of Pediatric Orthopaedics, The Duchess of Kent Children's Hospital, Hong Kong University, Hong Kong, China; E-Mails: michaelktto@gmail.com (M.K.-T.T.); wchowa@hku.hk (W.C.)

* Author to whom correspondence should be addressed; E-Mail: moham_eid@yahoo.com; Tel.: +20-100-616-3919.

Academic Editor: Giuseppe Musumeci

Received: 5 August 2015 / Accepted: 19 August 2015 / Published: 24 August 2015

Abstract: The purpose of this study is to analyze the effect of distal release of the medial hamstrings on the gait of patients who had spastic cerebral palsy. Twenty-two patients had preoperative and postoperative gait analysis. Standard parameters, such as cadence, velocity, and stride length, were evaluated, as were sagittal plane motion graphs of the pelvis, hip, knee, and ankle, in addition to sagittal plane kinetic analysis. Extension of the knee in stance phase significantly improved postoperatively ($p < 0.002$), and the improvement was accompanied by a proportional decrease in knee flexion during swing with minimal net gain in the arc of knee motion. Knee range of motion could be improved more by concomitant rectus transfer in selected patients. The statistically significant increase in anterior pelvic tilt ($p < 0.002$) has been a main concern. There was no significant change in the hip extensor moments or power generation during stance. Increased knee extension during stance after distal release of medial hamstrings is the kinematic gain that improved the gait pattern in cerebral palsy patients. The authors recommend a concomitant rectus transfer to help improve the knee range of motion in patients with rectus over-firing during swing, hence avoiding a stiff knee gait.

Keywords: cerebral palsy; hamstrings release; flexion contracture; gait analysis; sagittal kinematics; sagittal kinetics

1. Introduction

Spasticity of the hamstrings is a common problem in the management of patients who have cerebral palsy. It may not only lead to flexion deformity of the knee but it also shortens stride length, produces a crouched gait pattern, and interferes with sitting balance. A flexed knee needs greater muscular power to prevent the patient from collapsing, and this flexion may lead to compensatory flexion of the hip and equinus of the ankle when the tight gastrocnemius muscle is spastic. These factors lead to a gait pattern that is inefficient in terms of consumption of energy. The treatment has traditionally consisted of proximal or distal lengthening of the hamstrings, distal transfer of the hamstrings, and distal tenotomy of the hamstrings [1].

Questions have been raised about the need for hamstring lengthening due to the possibility that it could aggravate crouch gait by increasing anterior pelvic tilt and weakening hip joint extension. It was found that the hamstring lengths during stance phase in most of patients with crouch gait were longer than the resting length and that hamstrings functioned as hip extensors during a significant portion of stance phase. Therefore, surgeons should be careful to avoid hamstring over-lengthening to prevent an increased anterior pelvic tilt and consider lengthening the iliopsoas. On the other hand, surgeons can encounter patients with crouch gait and hamstring contracture, and some orthopedic surgeons still believe that hamstring lengthening is an effective treatment in these patients. In addition, many authors have reported that hamstring lengthening is effective for treating knee flexion contracture and improving joint movement [2].

Identification of gait patterns in cerebral palsy offers a common language for clinicians and contributes to management algorithms [3]. The importance of gait analysis in the evaluation of the results of many types of surgical intervention in children who have cerebral palsy has become clear in recent years. Apart from reporting the results of hamstring release in terms of decreased crouch or improved straight leg raising and ambulatory status, gait analysis provides a more objective assessment tool to study changes in motion and overall gait performance quantitatively [4].

This article describes the outcome of distal release of the medial hamstrings in patients with cerebral palsy. Changes in gait function have been evaluated using relevant kinematic and kinetic parameters before and after surgery. It is hypothesized that the surgical procedure would increase the knee extension during stance, thus improving the gait pattern and, at the same time, would have an impact on hip extension power and pelvis tilt.

2. Experimental Section

Our study included 22 patients who had cerebral palsy and were managed with distal release of the medial hamstrings that had been performed in a consistent manner between March 2012 and August 2014 at The Duchess of Kent Children’s Hospital, Hong Kong University. Informed consent was taken for all patients. Gait laboratory studies were performed for all patients preoperatively and at one year after surgery. We paid particular attention to sagittal plane analysis of kinematics and kinetics on preoperative and postoperative gait laboratory graphs.

There were 13 male and nine female patients. At the time of the operation, the youngest patient was eight years old and the oldest was 19 years old, with a mean age of 12 years. Spasticity was the predominant neurological disturbance in all patients in this series. Fifteen patients were diplegic; three patients were quadriplegic; two patients were triplegic; and two patients were hemiplegic as a result of cerebral palsy. Thirteen of our patients were community walkers; nine were exercise walkers.

Only the medial hamstrings, semi-tendinosis and semi-membranosis, were distally released in all patients. Twenty patients had bilateral medial hamstring release and two patients had unilateral hamstring release.

The indications for the procedure were tightness of the hamstrings or a knee-flexion deformity severe enough to impair the patient's ability to walk or their sitting balance, or a crouched-gait pattern. The distal release of the hamstrings was often done in combination with operations on the hip, ankle, and foot to improve the overall alignment of the limb. The most common concomitant surgical procedures were gastrocnemius recession (ten patients) and rectus transfer (nine patients). Other procedures included adductor tenotomy (seven patients), psoas release (five patients), varus derotation osteotomy of the femur (three patients), calcaneal lengthening osteotomy and medial placation (three patients), subtalar fusion (two patients), elongation of tendoachilis (one patient), and split tibialis anterior transfer (one patient).

In the management of patients with cerebral palsy, we believe that there is no consensus regarding "the best" method of treatment, but the surgical treatment should be tailored according to the particular requirements of each case. Therefore, it was difficult isolating a patient group with a single index procedure or multiple index procedures to perform such a study. Instead, after presenting the statistical outcome of the index procedure, we stratified the patients into four subgroups to study the influence of concomitant procedures on the motion graphs on a descriptive basis.

3. Results

Values of time/distance parameters and sagittal plane kinematics are shown in Table 1. Overall, velocity, stride length, and cadence did not show significant improvement. The cadence slightly decreased postoperatively, a change towards normal. However, motion analysis demonstrated marked improvement in extension of the knee during the stance phase of gait.

The improvement in the extension of the knee varied with the specific event in the gait cycle. The greatest improvement, which was 12.9 degrees (from a preoperative mean of 22.8 degrees to a postoperative mean of 9.9 degrees of flexion), occurred during ipsilateral heel-strike. Although there was improved extension at initial contact ($p < 0.001$) and during stance phase at the knee joint, there was little change in the total arc of motion of the knee, which was 36.3 degrees preoperatively and 42.2 degrees postoperatively. This mean increase of only 5.9 degrees indicated that the increase in extension of the knee during stance was accompanied by a proportional decrease in flexion of the knee during swing.

Table 1. Time-distance parameters and sagittal plane kinematics evaluated. Values in brackets represent SDs. Reference values represent data obtained on healthy children in the same laboratory. For the hip and ankle, negative values indicate extension and plantarflexion, respectively.

Time-Distance Parameters and Sagittal Plane Kinematics	Normal	Diplegic CP (*n* = 22)		*p* value (pre/post)
		Preoperative	Postoperative	
Time-distance parameters				
Cadence (steps/min)	111 (12.3)	122.0 (26.5)	116.3 (23.1)	0.092
Speed (m/s)	1.06 (0.155)	0.848 (0.25)	0.846 (0.33)	0.968
Stride length (m)	1.14 (0.112)	0.840 (0.20)	0.872 (0.31)	0.420
Pelvis (degrees)				
Mean anterior tilt	9 (7.0)	10.6 (11.4)	19.0(6.4)	<0.002
Pelvic range of motion	3 (1.2)	9.69 (3.1)	7.91 (3.58)	<0.016
Hip (degrees)				
Flexion at initial contact	35 (9.7)	39.6 (9.46)	44.4 (8.26)	<0.008
Min flexion in stance	−14 (8.3)	1.7 (11.05)	7.97 (13.19)	<0.012
Max flexion in swing	35 (9.9)	43.6 (10.6)	48.2 (7.82)	<0.025
Range of motion	50 (8.3)	41.9 (7.0)	40.2 (9.09)	0.375
Knee (degrees)				
Flexion at initial contact	9 (4.5)	37.7 (14.09)	24.2 (8.35)	<0.000
Min flexion in stance	6 (5.4)	22.8 (20.5)	9.9 (11.4)	<0.002
Max flexion in swing	53.7 (7.0)	59.2 (12.1)	52.2 (6.9)	<0.020
Range of motion	58 (3.8)	36.3 (14.8)	42.2 (12.4)	<0.040
Ankle (degrees)				
Angle at initial contact	5 (2.9)	0.82 (13.4)	−2.38 (7.74)	0.246
Angle at toe-off	−14 (4.4)	−12.4 (19.1)	−10.9 (10.0)	0.665
Max dorsi flexion in swing	12 (2.7)	14.0 (13.0)	11.9 (9.5)	0.318
Range of motion	26 (3.5)	26.5 (10.1)	22.8 (9.01)	0.137

There was a statistically significant increase in the mean anterior pelvic tilt ($p < 0.002$) and a decrease in the pelvis range of motion. The mean anterior pelvic tilt increased by 8.4 degrees from a preoperative mean value of 10.6 to 19 degrees postoperatively. The hip joint showed increased flexion at initial contact, mild loss of extension (minimum flexion) in stance, and a minimal increase in flexion in swing, with no overall significant increase in the dynamic range of motion.

The ankle joint showed loss of dorsal flexion (minimum plantar flexion) at initial contact and during maximal dorsi flexion in swing phase. Similarly, there was a slight decrease of plantar flexion angle at toe-off, with a resultant overall decrease in ankle range of motion. An example of kinematic analysis for sagittal plane motion graphs has been shown in Figure 1.

Kinetic parameters are illustrated in Table 2. The hip joint showed very minimal or no improvement of loading as demonstrated by the insignificant slight increase in the peak extensor movement in the first half of the stance, and nearly no change in the flexor movement in the second half of the stance. Peak power generation during the first half of the stance and during swing decreased slightly. Peak absorption in the second half of the stance remained nearly the same.

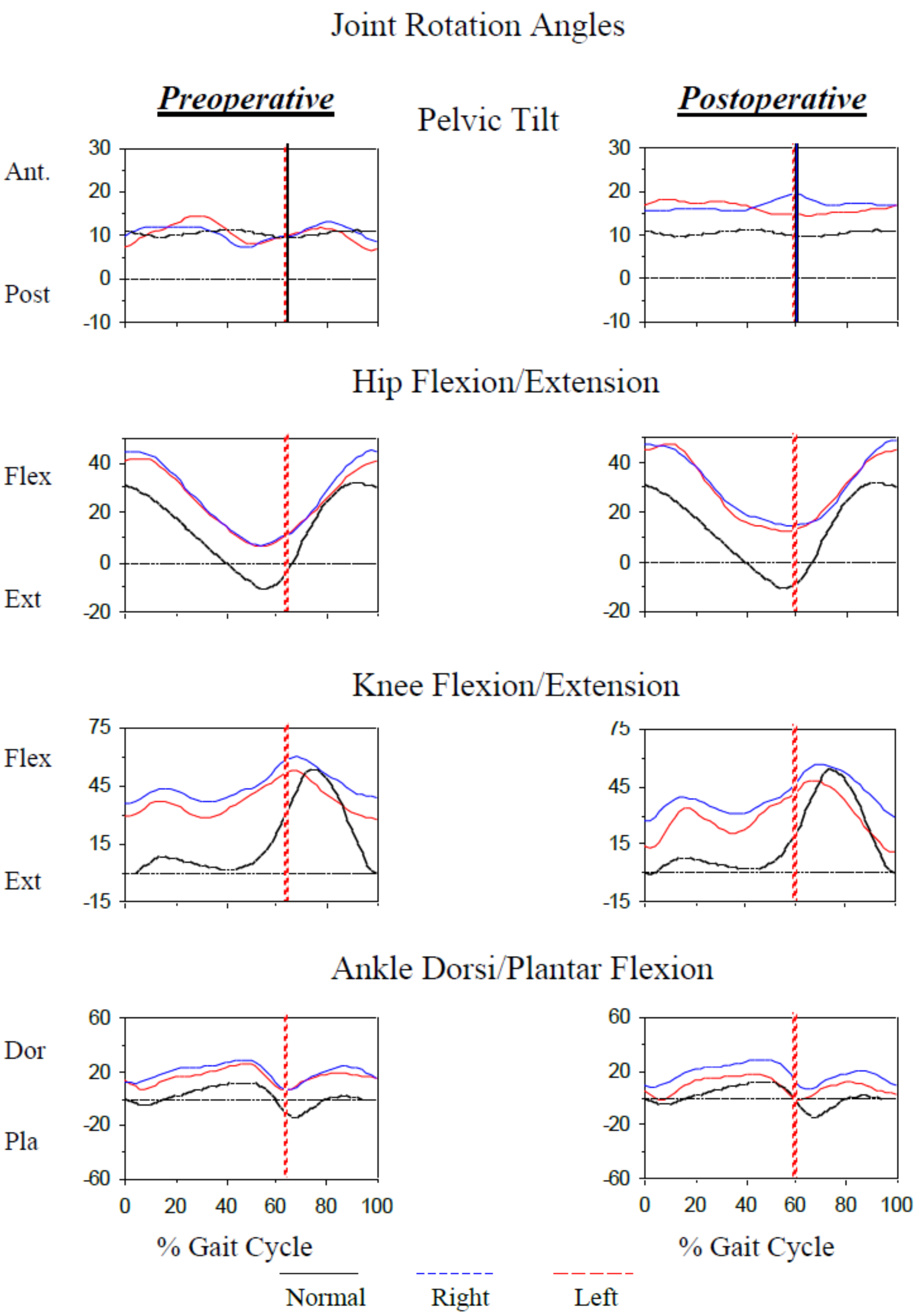

Figure 1. Sagittal plane kinematic analysis for patient (L.P.), preoperative and at one year after surgery. Notice the increased anterior pelvic tilt, initial hip flexion, and improved knee extension during stance.

At the ankle joint, there was a reduction of peak plantar flexor movements in the first half of the stance, with a slight increase in the peak movement in the second half of the stance. For the group of patients who had concomitant gastrocnemius recession in addition to hamstring release, such reduction was even more significant, from a mean preoperative value of 1.2 to 0.7 postoperatively. The minimum ankle power in a single leg support for the same group also significantly increased from −2.64 to −1.15 postoperatively.

Table 2. Relevant sagittal plane kinetics evaluated. Values in brackets represent SDs. Reference values represent data obtained on healthy children in the same laboratory. Negative values for hip movements denote flexor movements. Negative values for hip and ankle powers denote absorption.

Kinetic Parameters	**Normal**	**Diplegic CP (*n* = 22)**		***p* value (pre/post)**
		Preoperative	**Postoperative**	
Hip Movements (Nm/kg)				
Max in first half of stance	1 (0.4)	1.52 (0.63)	1.63 (0.81)	0.454
Min in second half of stance	−1 (0.3)	−1.07 (0.39)	−1.03 (0.50)	0.710
Hip Powers (W/kg)				
Max in first half of stance	1 (0.7)	2.68 (2.3)	2.45 (1.5)	0.639
Min in second half of stance	−1 (0.6)	−1.23 (0.66)	−1.13 (0.62)	0.604
Max in swing	1 (0.5)	0.911 (0.44)	0.828 (0.34)	0.573
Ankle Plantar Flexor Movements (Nm/kg)				
Peak in first half of stance	1 (0.2)	1.05 (0.46)	0.674 (0.39)	<0.004
Peak in second half of stance	1 (0.3)	0.877 (0.30)	0.907 (0.22)	0.705
Ankle Powers (W/kg)				
Min in single support	−1 (0.3)	−1.75 (1.31)	−0.96 (0.66)	<0.007
Max in preswing	2 (0.7)	0.98 (0.57)	0.844 (0.45)	0.313

4. Discussion

Several different operative procedures have been advocated for the treatment of tightness of the hamstrings. Silfverskiold, in 1924, recommended the transfer of the proximal origin of the hamstrings to the posterior region of the femur, which converts a two-joint muscle to a one-joint muscle and causes the hamstrings to function as knee flexors and not as hip extensors [5].

Green and McDermott, advised a sliding lengthening of the tendons at one or more levels [6]. Eggers, in 1952, described a transfer of all of the hamstrings from their insertion on the tibia to the back of the distal part of the femur, which eliminates their function as knee flexors [7]. Evans reviewed the results of the Eggers procedure and found a high prevalence of genu recurvatum and loss of flexion of the knee. Evans and Julian subsequently modified the Eggers procedure [8].

Seymour and Sharrard favored proximal release of the hamstrings, but Drummond *et al.* reported that after proximal release, genu recurvatum developed in 28% of their patients and 16% of their patients had increased lumbar lordosis and pelvic tilt [9,10]. Keats and Kambin advocated the advancement of the patellar tendon in association with procedures on the hamstrings, but this is not a widely accepted procedure [11].

Baumann *et al.*, as well as Grujic and Apanisi, reported favorable results with distal elongation of the hamstrings [1,12,13]. Reimers compared the results of the modified Eggers procedure to those of proximal release of the hamstrings and distal lengthening of the hamstrings. He concluded that the latter two procedures were simpler and offered several advantages compared with the modified Eggers procedure [14].

Damron *et al.* [15] combined a proximal release of the semimembranosus with a distal release of the semitendinosus and gracilis with good results. They did not approach the lateral hamstring. Sutherland *et al.* transferred the medial hamstrings laterally to decrease internal rotation of the lower limb [4]. Frost thought that the lengthening of the hamstrings was not necessary and that a crouched gait was acceptable [16].

Out of 94 patients with cerebral palsy, 56 underwent surgery (37 had muscle-tendon surgery; 11, osteotomy; and 8, selective dorsal rhizotomy) and 38 did not have surgery. Feger *et al.* concluded that patients who undergo selective dorsal rhizotomy and, to a lesser extent, muscle-tendon procedures, demonstrate greater improvements in kinematic gait variables compared with nonsurgical interventions in patients with spasticity resulting from cerebral palsy [17].

The main aim of this study was not to prove superiority of any surgical procedure over another, but to investigate the overall effect of a surgical procedure on the hamstrings, whether alone or combined with other procedures, and on the overall change of sagittal plane kinematics and kinetics of the lower limb. The resultant data could be useful for future decision-making, the prediction of outcomes, or further investigation of the surgical procedures at hand for treatment of such special group of patients.

In this study, there was no overall significant improvement of time-distance parameters. However, even without any marked increase in walking speed, the increased extension of the knee in stance was a notable gain for our patients, thus decreasing the abnormal work load on the quadriceps to support the body. Emphasis has been made on the tremendous increase in the energy that is needed for walking when the knee is flexed more than 20 degrees [1,18].

In the current series, as in others [1,12,19,20], there was little change between the preoperative and postoperative total arcs of motion of the knee joint. Postoperatively, increased extension in the stance phase was accompanied by a decrease in flexion in the swing phase; the gait pattern was thereby altered from a crouch towards a stiff-legged gait, with the potential for reduced clearance of the foot in swing. To prevent this, we believe in concomitant rectus transfer in selected patients whose electromyographic studies show increased firing of the rectus femoris during the swing phase of gait. Koca *et al.* demonstrated that static parameters, time-distance parameters, and knee and ankle kinematics were improved following combined hamstring release and rectus transfer in children with cerebral palsy without any cases of stiff knees [21].

Thometz *et al.* emphasized the value of examining the contour of the knee flexion curve during swing in addition to noting the quadriceps' activity before selecting patients for rectus transfer and believed that the reason behind decreased postoperative knee flexion in swing was that there is only momentum to counteract the activity of the quadriceps after lengthening or release of the distal hamstrings [22]. Gage *et al.* reported on the successful use of distal transfer of the rectus femoris to obtain greater flexion of the knee in swing in these patients [20].

The statistically significant increase in the mean anterior pelvic tilt after surgery raises concerns about increasing lumbar lordosis and the further weakening of the strength of hip extension. Future gait analysis comparative studies along with other surgical procedures aimed at lengthening, transfer, or reattachment of the medial hamstrings are necessary to investigate the superiority of one surgical procedure over another in terms of the effect on postoperative anterior pelvic tilt and hip extension power.

At the hip joint, power generation for the propulsive function during gait is, during the first half of stance, contributed by the hip extensor muscles (gluteal and hamstrings) and, in early swing, is made by active contraction of the hip flexors [18]. Waters *et al.* found that hamstrings accounted for approximately one-third of the total hip extensor power [23].

Our kinetic results revealed no significant change in the hip power generation in the first half of stance and in early swing. The patients showed maintenance of hip flexion during swing with an increased hip flexion angle at initial contact. There was no overall significant change in the dynamic motion of the joint. Thus, distal release of the hamstrings even with concomitant psoas release for hip fixed flexion contractures in well-selected cases did not weaken the power-generating capacity of the hip joint.

The effect of concomitant procedures on the final outcome has been studied from the motion graphs by stratifying the patients into four groups. The first group had only isolated medial hamstring release, the second group had concomitant rectus transfer, the third group had had concomitant gastrocnemius recession, and the fourth group had psoas release in addition to medial hamstring release.

Our kinematic results demonstrated that the greatest improvement of knee extension during stance and at initial contact was achieved in patients who had isolated hamstring release. However, these patients were also found to have more anterior pelvic tilt than the other groups. Patients who had rectus transfer achieved greater recovery of the knee range of motion than the first group, together with more reduction in the pelvic range of motion and increased hip flexion at initial contact. Jones *et al.* advocated the division of the proximal semimembranosus aponeurosis during fractional lengthening of the distal hamstring in patients with cerebral palsy that resulted in a significant reduction in the flexion deformity [24]. Rectus femoris transfer as part of a single-event multilevel surgery was effective in treating stiff knee gait. In serial postoperative gait analyses, patients with gross motor function at classification system level I or II showed a better prognosis than those at level III with regard to the timing of peak knee flexion in the swing phase [25].

The maximum reduction in ankle range of motion was found in the group who had gastrocnemius recession. This incidence, together with the results of ankle kinetic changes noted in the same group, might be related more to alterations in the muscle power of the plantar flexors of the ankle after gastrocnemius recession.

The maximum improvement of knee range of motion occurred in the group who had concomitant psoas release. In the latter group, there was no significant change in the anterior pelvic tilt and the knee angle at initial contact improved, but to a lesser extent than in the isolated hamstring release group. Finally, it was noted that the group of patients who had combined gastrocnemius recession and psoas release with the hamstring release showed slight improvements in cadence, velocity, and stride length.

5. Conclusions

In conclusion, a comprehensive evaluation of the distal release of medial hamstrings and the procedure’s effect on gait in cerebral palsy using kinematic and kinetic data is presented. Gait analysis documented that the main benefit was increased extension of the knee in the stance phase of gait. This increase was accompanied by a proportional loss of flexion of the knee in the swing phase of gait, with an overall minimal effect on the arc of knee motion. There was no significant improvement of velocity, stride length, and cadence postoperatively.

The postoperative mean anterior pelvic tilt increased significantly. Power generation at the hip joint has been maintained. Future comparative gait studies should focus on the outcome of different surgical procedures on the hamstrings, whether isolated or combined with psoas release, in terms of increased anterior pelvic tilt and effect on hip extension power. Increased knee extension during stance after the distal release of medial hamstrings is the kinematic gain that improved the gait pattern in cerebral palsy patients. The authors recommend a concomitant rectus transfer to help improve the knee range of motion in patients with rectus over-firing during swing, hence avoiding a stiff knee gait.

Acknowledgments

The authors acknowledge the efforts of the Gait Laboratory staff at the Duchess of Kent Children's Hospital.

Author Contributions

Conception and design: Wang Chow; Analysis and interpretation: Mohamed Abdel-Moneim Eid; Data collection: Mohamed Abdel-Moneim Eid; Writing the article: Mohamed Abdel-Moneim Eid; Critical revision of the article: Michael Kai-Tsun To; Statistical analysis: Mohamed Abdel-Moneim Eid.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Dhawlikar, S.H.; Root, L.; Mann, R.L. Distal lengthening of the hamstrings in patients who have cerebral palsy. Long-term retrospective analysis. *J. Bone Joint Surg. Am.* **1992**, *74*, 1385–1391.
2. Tae-Yon, R.; Ki Hyuk, S.; Moon, S.P.; Kyoung, M.L.; Chin, Y.C. Hamstring and psoas length of crouch gait in cerebral palsy: A comparison with induced crouch gait in age- and sex-matched controls. *J. Neuroeng. Rehabil.* **2013**, *10*, doi:10.1186/1743-0003-10-10.
3. Sangeux, M.; Rodda, J.; Graham, H.K. Sagittal gait patterns in cerebral palsy: The plantarflexor-knee extension couple index. *Gait Posture* **2015**, *41*, 586–591.
4. Sutherland, D.H.; Schottstaedt, E.R.; Larsen, L.J.; Ashley, R.K.; Callander, J.N.; James, P.M. Clinical and electromyographic study of seven spastic children with internal rotation gait. *J. Bone Joint Surg.* **1969**, *51*, 1070–1082.
5. Silfverskiold, N. Reduction of the uncrossed two-joints muscles of the leg to one-joint muscles in spastic conditions. *Acta Chir. Scand.* **1924**, *56*, 315–330.
6. Green, W.T.; McDermott, L.J. Operative treatment of cerebral palsy of spastic type. *J. Am. Med. Assoc.* **1942**, *118*, 434–440.
7. Eggers, G.W.N. Transplantation of hamstring tendons to femoral condyles in order to improve hip extension and to decrease knee flexion in cerebral spastic paralysis. *J. Bone Joint Surg.* **1952**, *34*, 827–830.
8. Evans, E.B.; Julian, J.I. Modifications of the hamstring transfer. *Dev. Med. Child Neurol.* **1966**, *8*, 539–551.
9. Drummond, D.S.; Rogala, E.; Templeton, J.; Cruess, R. Proximal hamstring release for knee flexion and crouched posture in cerebral palsy. *J. Bone Joint Surg.* **1974**, *56*, 1598–1602.
10. Seymour, N.; Sharrard, W.J.W. Bilateral proximal release of the hamstrings in cerebral palsy. *J. Bone Joint Surg.* **1968**, *50*, 274–277.

11. Keats, S.; Kambin, P. An evaluation of surgery for the correction of knee-flexion contracture in children with cerebral spastic paralysis. *J. Bone Joint Surg.* **1962**, *44*, 1146–1154.
12. Baumann, J.U.; Ruetsch, H.; Schurmann, K. Distal hamstring lengthening in cerebral palsy. An evaluation by gait analysis. *Int. Orthop.* **1980**, *3*, 305–309.
13. Grujic, H.; Aparisi, T. Distal hamstring tendon release in knee flexion deformity. *Int. Orthop. (SICOT)* **1982**, *6*, 103–106.
14. Reimers, J. Contracture of the hamstrings in spastic cerebral palsy. A study of three methods of operative correction. *J. Bone Joint Surg.* **1974**, *56*, 102–109.
15. Damron, T.; Breed, A.L.; Roecker, E. Hamstring tenotomies in cerebral palsy: Long-term retrospective analysis. *J. Prosthet. Orthot.* **1991**, *3*, 514–519.
16. Frost, H.M. Cerebral palsy. The spastic crouch. *Clin. Orthop.* **1971**, *80*, 2–8.
17. Feger, M.A.; Lunsford, C.D.; Sauer, L.D.; Novicoff, W.; Abel, M.F. Comparative effects of multilevel muscle tendon surgery, osteotomies, and dorsal rhizotomy on functional and gait outcome measures for children with cerebral palsy. *PM&R* **2015**, *7*, 485–493.
18. Steinwender, G.; Saraph, V.; Zwick, E.-B.; Christiane, U.; Linhart, W. Assessment of gait improvement surgery in diplegic children using computerised gait Analysis. *Acta Chir. Austriaca* **2000**, *32*, 237–242.
19. Gage, J.; Fabian, D.; Hicks, R.; Tashman, S. Pre- and postoperative gait analysis in patients with spastic diplegia. A preliminary report. *J. Pediatr. Orthop.* **1984**, *4*, 715–725.
20. Gage, J.; Perry, J.; Hicks, R.; Koop, S.; Werntz, J. Rectus femoris transfer to improve knee function of children with cerebral palsy. *Dev. Med. Child Neurol.* **1987**, *29*, 159–166.
21. Koca, K.; Yildiz, C.; Yurttaş, Y.; Bïlgïç, S.; Ozkan, H.; Kürklü, M.; Balaban, B.; Haznecï, B.; Başbozkurt, M. Outcomes of combined hamstring release and rectus transfer in children with crouch gait. *Ortop. Traumatol. Rehabil.* **2009**, *11*, 333–338.
22. Thometz, J.; Simon, S.; Rosenthal, R. The effect on gait of lengthening of the medial hamstrings in cerebral palsy. *J. Bone Joint Surg. Am.* **1989**, *71*, 345–353.
23. Waters, R.L.; Perry, J.; McDaniels, J.M.; House, K. The relative strength of the hamstrings during hip extension. *J. Bone Joint Surg.* **1974**, *56*, 1592–1597.
24. Jones, S.; Al Hussainy, H.A.; Ali, F.; Garcia, J.; Fernandes, J.A.; Davies, A.G. Distal hamstring lengthening in cerebral palsy: The influence of the proximal aponeurotic band of the semimembranosus. *J. Pediatr. Orthop. B* **2006**, *15*, 104–108.
25. Lee, S.Y.; Kwon, S.S.; Chung, C.Y.; Lee, K.M.; Choi, Y.; Kim, T.G.; Shin, W.C.; Choi, I.H.; Cho, T.J.; Yoo, W.J.; *et al*. Rectus femoris transfer in cerebral palsy patients with stiff knee gait. *J. Gait Posture* **2014**, *40*, 76–81.