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Effects of distal hamstring lengthening on sagittal motion in patients with diplegia Hamstring length and its clinical use☆

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A B S T R A C T

This study was undertaken to determine the effect of distal hamstring lengthening (DHL) on hip and knee sagittal kinematics, and to investigate the validity of modeled hamstring length for clinical use. Patient group consisted of 28 patients (56 limbs, mean age 7.4 years) with spastic diplegia who underwent bilateral DHL and tendo-Achilles lengthening with/without rectus femoris transfer (RFT) (DHL + RFT subgroup, 40 limbs; DHL subgroup, 16 limbs). Kinematic data was obtained by gait analysis, and hamstring lengths were obtained using a musculoskeletal modeling technique. Postoperatively, knee extension improved ($p < 0.001$) without aggravating anterior pelvic tilt ($p = 0.565$). However, DHL aggravated anterior pelvic tilt in the DHL subgroup (2.2°, $p = 0.011$). In terms of concurrent validity, hamstring length was found to be correlated with mean pelvic tilt ($r = 0.798$, $p < 0.001$) and popliteal angle ($r = -0.425$, $p = 0.001$), but the correlation between hamstring length and knee flexion at initial contact was minimal ($r = 0.068$, $p = 0.753$). In terms of construct validity, DHL did not lengthen mean hamstring length ($p = 0.918$). In conclusion, DHL appeared to significantly improve knee motion in patients with spastic diplegia. Furthermore, DHL did not increase pelvic tilt, when performed with RFT. Modeled hamstring length is believed to have limited validity in patients with cerebral palsy, because it does not reflect knee kinematics or postoperative change when DHL was combined with multilevel surgery.

1. Introduction

Distal hamstring lengthening (DHL) is one of the most common operations performed in patients with cerebral palsy. Previous reports have shown that DHL is effective at reducing knee flexion and improving knee motion [1–8]. However, there have been concerns that this procedure might aggravate anterior pelvic tilt, lumbar hyperlordosis, knee hyperextension, and eventually induce crouch gait [2,9,10]. In addition, the need for DHL has been challenged because hamstring length was not found to be shorter in patients with a crouch gait [11–13], and because the procedure can increase the lengths of already long muscles.

However, the majority of studies that have investigated the effect of DHL [1–8,10] have included various potentially confounding surgeries, because DHL is usually performed in the context of single event multilevel surgery, which is a standard treatment for patients with cerebral palsy. However, although this integration makes it difficult to evaluate the effect of DHL in isolation, we believed that we could investigate the effect of the procedure more precisely by controlling for confounding surgeries. In this study, we hypothesized that rectus femoris transfer (RFT) importantly confounds the effects of DHL, because the rectus femoris probably counteracts the hamstring muscle on sagittal kinematics.

Moreover, as far as we are aware, few investigations have been conducted on changes in hamstring length after DHL [14]. The validity of 'hamstring length', as defined by 3D graphic models [15], has been proposed to assist in decision-making regarding DHL, but this has not been clarified. Furthermore, previous studies also included a large number of confounding surgical procedures.

Therefore, the primary aim of this study was to determine the effect of DHL on hip and knee kinematics in a relatively homogeneous group of patients with cerebral palsy after controlling for confounding surgeries. The second aim was to clarify the validity of modeled 'hamstring length' for clinical usage. In validity

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test, the concurrent validity was examined by comparing hamstring length with hip and knee kinematics and popliteal angle, and the construct validity was determined by analyzing postoperative hamstring length changes.

2. Materials and methods

2.1. Inclusion/exclusion criteria and operative procedures

This retrospective study was approved by the institutional review board at our institute (a tertiary referral center for cerebral palsy), which waived the need for informed consent. The inclusion criteria used were as follows; ambulatory patients with spastic diplegia (GMFCS level I–III), a history of single event multilevel surgery between January 1998 and April 2006 with a follow-up period of over a year, and the availability of preoperative and postoperative 1-year gait analysis results. 288 patients fulfilled the inclusion criteria. The exclusion criteria applied were; a history of gait correcting surgery or selective dorsal rhizotomy, or a concurrent neuromuscular disease other than cerebral palsy. To ensure homogeneity, patients with asymmetric gait patterns who had undergone asymmetric procedures or procedures other than tendo-Achilles lengthening or DHL with/without RFT were also excluded. 28 patients (56 limbs) were allocated to patient group and were divided into two subgroups. Patients who had undergone bilateral DHL and tendo-Achilles lengthening were allocated to DHL subgroup, and the other patients who had undergone bilateral DHL, RFT, and tendo-Achilles lengthening were allocated to DHL + RFT subgroup. In addition, 12 healthy children (24 limbs) and 34 healthy adult volunteers (68 limbs) were recruited as child and adult control groups, respectively.

All surgical procedures were performed by a single surgeon as single event multilevel surgeries. Preoperative gait analysis revealed that all patients had a jump gait pattern, as described by Rodda et al. [16]. All patients underwent bilateral tendo-Achilles lengthening and DHL, the latter of which was composed of gracilis aponeurotic lengthening, semitendinosus tendon transfer to the adductor magnus, and aponeurotic lengthening of the semimembranosus. Accordingly, DHL was performed only on the medial side. For patients with stiff-knee gait patterns by preoperative gait analysis, RFT to the gracilis was also performed [17]. Following surgery, all patients underwent 3 weeks of immobilization with a short leg cast. Standing and weight bearing were resumed with leaf-spring type ankle foot orthoses, which were worn for the next 3 months. Subsequently, patients were referred back to a local rehabilitation center to continue muscle-strengthening exercises and gait training. During this period, ankle foot orthoses were recommended at night only to prevent the recurrence of Achilles tightness.

2.2. Acquisition of kinematic data

Gait analysis was performed a few days before surgery using a Vicon 370 (Oxford Metrix, Oxford, UK) equipped with seven cameras and two force plates, and was repeated after more than 1-year postoperatively. Kinematic data were archived as patients walked barefoot on a 9-m walkway. Three trials were averaged to determine the values of index variables. Preoperative kinematic variables were compared between adult control group and child control group and then between child control group and the patient group. Pre- and postoperative kinematic variables were compared to determine the effect of DHL on hip and knee kinematics in the patient group. Thereafter, subgroup analysis was done on each patient subgroup.

2.3. Validity of hamstring length

'Hamstring lengths' were determined using interactive musculoskeletal modeling software (SIMM, Motion Analysis Corporation, Santa Rosa, CA) [18] (Fig. 1A and B). Hamstring length was defined as the distance between its muscular origin and insertion. To standardize muscle lengths, hamstring lengths were divided by muscle lengths when the knee and hip were in the anatomic position [13]. The length of the semimembranosus was used as a representative hamstring length and charts were prepared of standardized hamstring lengths during the gait cycle.

Concurrent validity of modeled hamstring length was achieved by correlating hamstring lengths with reference variables, namely, mean pelvic tilt, knee flexion at initial stance, maximum hip flexion, and popliteal angle. To determine construct validity preoperative and postoperative hamstring lengths were compared.

2.4. Statistical analysis

Data were analyzed using SPSS Ver. 15.0 (SPSS, Chicago, IL). The normalities of distributions were tested for each variable using the Kolmogorov–Smirnov test.

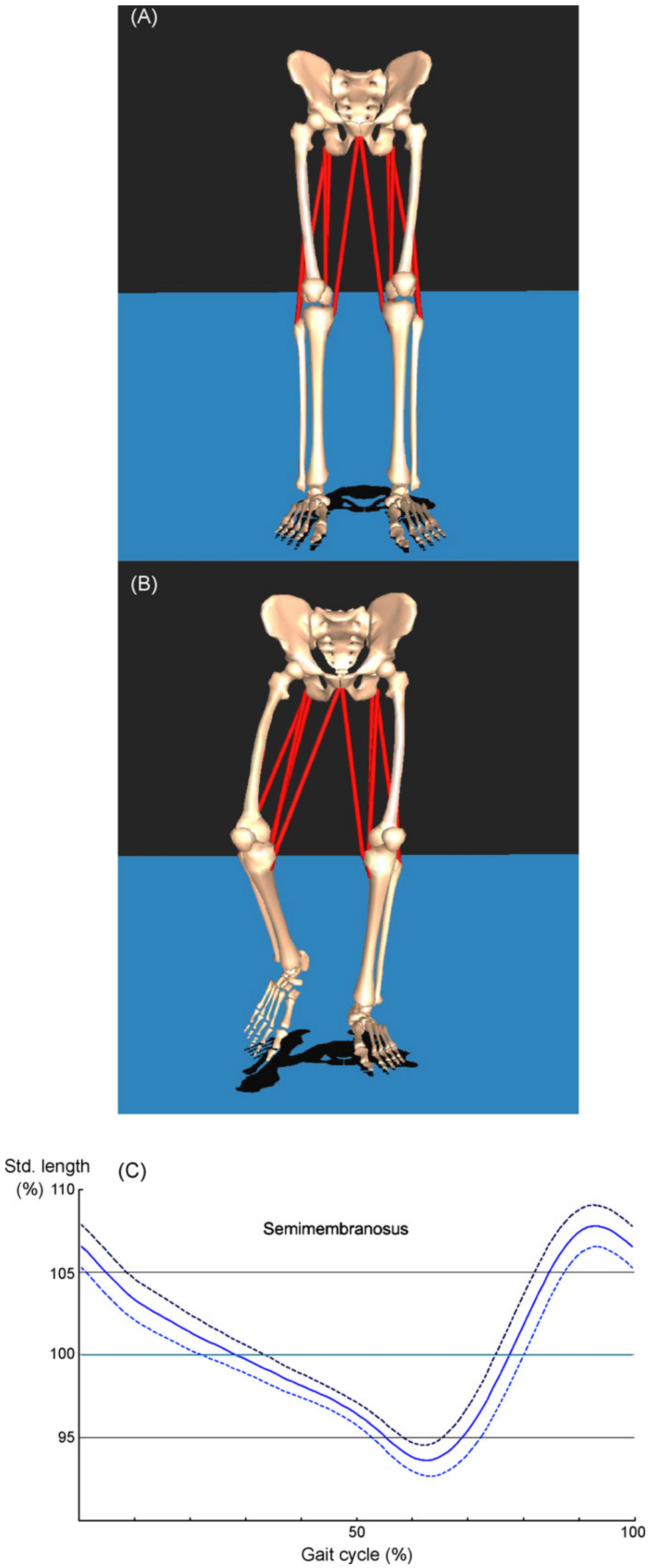

Fig. 1. Three dimensional musculoskeletal modeling images depicting hamstring muscles between their bony origins and insertions (A and B) and a graph of standardized semimembranosus length which was used as a modeled hamstring length (C). The three muscles are the gracilis, semimembranosus, and the long head of the biceps femoris. (A) Computer model in the anatomic position with the knee and hip joint in 0° of extension. Static hamstring lengths were measured in this position. (B) Hamstring length (distance between its bony origin and insertion) changed throughout the gait cycle. Standardized hamstring length was calculated by dividing changing hamstring lengths during gait by static hamstring length in the anatomic position. (C) This graph represents continuous changes in average standardized semimembranosus length (solid line) and standard deviations (dotted lines) during the gait cycle in the 'normal' control group. The minimum hamstring length occurred at maximum knee flexion, and maximum length during the late swing phase.

Table 1
Demographics and preoperative physical examinations of the study group.

	DHL subgroup	DHL + RFT subgroup	*p*-value	Total
N (limb)	8 (16)	20 (40)		28 (56)
M:F	7:1	15:5	0.640*	22:6
GMFCS (I/II)	5/3	15/5	0.651*	20/8
Mean age (SD) at preoperative gait analysis	7.3 (2.8)	7.4 (2.4)	0.888	7.4 (2.4)
Mean time interval (SD) from surgery to postoperative gait analysis	1.4 (0.8)	1.1 (0.3)	0.270	1.2 (0.5)
Preoperative physical examination				
Hip flexion (°)	138.8 (3.4)	138.9 (6.5)	0.909	138.9 (5.7)
Hip extension (°)	0.9 (2.0)	1.9 (3.6)	0.226	1.6 (3.2)
Knee flexion (°)	145.6 (5.4)	145 (5.7)	0.714	145.2 (5.6)
Knee extension (°)	0.9 (2.7)	0.5 (4.2)	0.718	0.7 (3.8)
Popliteal angle (°)	47.2 (20.3)	50.4 (13.7)	0.569	49.4 (15.8)
Ankle dorsiflexion (knee extension) (°)	1.0 (19.1)	−3.9 (11.5)	0.365	−2.5 (14.0)
Ankle dorsiflexion (knee flexion) (°)	10.3 (17.1)	5.8 (11.8)	0.347	7.2 (13.6)
Ely test	11 Limbs	38 Limbs	0.016**	49 Limbs

* Fisher's exact test.
** $p < 0.05$ by Fisher's exact test.

Standardized hamstring lengths, knee flexions, hip flexions, and pelvic tilts were compared using the *t*-test. Patients were compared with respect to pre- and postoperative kinematic variables and hamstring lengths using the paired *t*-test. Correlations between hamstring length, popliteal angle, and kinematic variables were tested using Pearson's correlation test. *p* values of <0.05 were considered significant.

3. Results

Of the 28 patients (56 limbs) included in this study, eight (16 limbs) were allocated to the DHL subgroup and 20 (40 limbs) to the DHL + RFT subgroup (Table 1). Preoperative physical examinations, functional levels, mean ages, and gender ratios were not significantly different between these two subgroups, except for Ely test findings, which is one of the reasons for performing RFT in the DHL + RFT subgroup (Table 1). Mean age of child control group was 8.7 years (SD 4.6 years) and that of adult control group was 26.8 years (SD 5.3 years). There was no significant difference in age ($p = 0.379$) and gender ratio ($p = 0.426$) between patient group and child control group.

3.1. Kinematic gait data including pelvic tilts and knee flexions

Knee flexion at initial contact and maximum hip flexion in terminal swing were significantly larger in the child control group than in the adult control group ($p < 0.001$, $p < 0.001$). Preoperative mean anterior pelvic tilts, maximum hip flexions in terminal swing and knee flexions at initial contact in the patient group were significantly larger than in the child control group ($p < 0.001$, $p < 0.001$ and $p < 0.001$, respectively). No significant differences were found preoperatively between the two patient subgroups in terms of anterior pelvic tilt, maximum hip flexion in terminal swing, or knee flexion at initial contact ($p = 0.829$, $p = 0.094$, and $p = 0.492$, respectively). However, maximum knee flexion in swing was significantly smaller in the DHL + RFT subgroup ($p = 0.013$).

Knee flexion at initial contact and maximum knee flexion in swing significantly improved following surgery in patient group ($p < 0.001$, $p = 0.031$) while the anterior pelvic tilt was unchanged ($p = 0.565$). Anterior pelvic tilt increased significantly postoperatively in the DHL subgroup ($p = 0.011$) but not in the DHL + RFT subgroup ($p = 0.247$). (Table 2).

3.2. Hamstring length and validity for clinical use

Standardized hamstring lengths were charted through gait cycles. Maximum length occurred during the terminal swing phase and minimum length at maximal knee flexion (Fig. 1C). Length patterns of hamstring muscles concurred with those found in similar studies [11,15].

Maximum hamstring length was significantly longer in child control group than in adult control group ($p = 0.003$), while there was no significant difference in mean hamstring length between the two control groups ($p = 0.433$). Preoperatively, the mean hamstring lengths of patients were longer than those of child control group ($p < 0.001$). However, preoperative hamstring lengths were not significantly different in the two patient subgroups ($p = 0.752$).

In terms of concurrent validity, hamstring length was found to be correlated with pelvic tilt ($r = 0.798$, $p < 0.001$) and popliteal angle ($r = -0.425$, $p = 0.001$). Furthermore, postoperative changes in hamstring length were found to be correlated with changes in mean pelvic tilt ($r = 0.634$, $p < 0.001$) and maximum hip flexion ($r = 0.611$, $p < 0.001$). However, maximum hamstring length was not found to be correlated with knee flexion at initial contact (Table 3).

In terms of construct validity, DHL did not increase mean hamstring length ($p = 0.918$) while maximum hamstring length increased postoperatively in the whole patient group ($p = 0.023$). Mean hamstring length increased significantly in the DHL subgroup postoperatively ($p = 0.036$), while it did not increase in the DHL + RFT subgroup ($p = 0.314$) (Table 2).

4. Discussion

DHL significantly improved knee kinematics in patients with spastic diplegic cerebral palsy and a jump gait pattern. Anterior

Table 2
Changes in the key variables after single event multilevel surgery.

	Control (adult)	Control (child)	Whole patient group ($N = 28$, 56 limbs)			DHL subgroup ($N = 8$, 16 limbs)			DHL + RFT subgroup ($N = 20$, 40 limbs)		
			Preop.	Postop.	*p*	Preop.	Postop.	*p*	Preop.	Postop.	*p*
Pelvic tilt (°)	9.4 ± 4.1	10.1 ± 3.9	16.2 ± 5.4	16.5 ± 5.4	0.565	16.0 ± 5.5	18.2 ± 5.9	0.011*	16.3 ± 5.4	15.8 ± 5.1	0.247
Knee flexion at IC (°)	7.0 ± 3.6	13.4 ± 6.1	31.1 ± 11.6	24.1 ± 9.4	<0.001*	32.9 ± 11.8	22.3 ± 8.7	0.001*	30.5 ± 11.7	24.9 ± 9.7	0.002*
Max knee flexion in swing (°)	63.7 ± 4.1	61.4 ± 6.8	56.9 ± 9.7	59.5 ± 6.0	0.031*	62.2 ± 9.6	59.8 ± 6.2	0.350	54.8 ± 9.0	59.4 ± 6.1	<0.001*
Max hip flexion in terminal swing (°)	33.7 ± 4.6	38.1 ± 6.1	45.3 ± 8.6	44.1 ± 6.4	0.179	48.2 ± 8.9	46.2 ± 7.6	0.135	44.1 ± 8.3	43.3 ± 5.7	0.461
Mean hip adduction (°)	1.3 ± 2.9	1.7 ± 2.2	0.2 ± 4.6	0.1 ± 3.8	0.903	−0.4 ± 4.4	0.4 ± 4.2	0.374	0.4 ± 4.8	0.0 ± 3.7	0.441
Mean HL(%)	100.5 ± 0.9	100.6 ± 1.1	101.8 ± 1.6	101.8 ± 1.7	0.918	101.7 ± 1.3	102.4 ± 1.5	0.036*	101.9 ± 1.8	101.6 ± 1.8	0.314
Max HL(%)	107.8 ± 1.3	109.3 ± 2.2	108.8 ± 2.4	109.4 ± 2.5	0.023*	109.8 ± 2.6	110.6 ± 2.4	0.099	108.4 ± 2.2	108.9 ± 2.3	0.101

Max, maximum; Preop., preoperative; Postop., postoperative; IC, initial heel contact; HL, hamstring length.
* $p < 0.05$.

Table 3
Concurrent validity of modeled hamstring length.

Correlation			Patients		Control (child)		Control (adult)	
			r	*p*	*r*	*p*	*r*	*p*
Mean HL	vs.	Mean pelvic tilt	0.824	<0.001	0.798	<0.001	0.894	<0.001
ΔMean HL	vs.	ΔMean pelvic tilt	0.634	<0.001	–	–	–	–
Max HL	vs.	Knee flexion at IC	0.106	0.435	0.068	0.753	−0.066	0.595
		Max. Hip flexion in TS	0.626	<0.001	0.229	0.281	0.689	<0.001
		Popliteal angle	−0.425	0.001	–	–	–	–
ΔMax HL	vs.	ΔKnee flexion at IC	0.059	0.667	–	–	–	–
		ΔMax. hip flexion in TS	0.611	<0.001	–	–	–	–

HL, modeled hamstring length; IC, initial contact; TS, terminal swing; Δ, postoperative change; max, maximum.

pelvic tilt increased significantly only in the DHL subgroup ($p = 0.011$), but this increase may not have been clinically important (2.2°). Preoperative hamstring lengths in patients with spastic diplegia were longer than in the child control group, and were found to be significantly correlated with pelvic tilt and popliteal angle, but not with knee kinematics. DHL did not appear to cause elongation of hamstring length necessarily when performed with RFT.

Before addressing the clinical implications of this study, the limitations of this study warrant consideration. First, muscle length, measured from bony origin to insertion by musculoskeletal modeling, might not have been as accurate in children with cerebral palsy, because the model was originally developed for normal adults [11,18]. Second, the reliability and validity of measurement should be considered. The small changes in kinematic variables observed in the present study were statistically significant, but may have been due to marker placement variabilities, despite this being performed by a single experienced operator. Furthermore, unlike gait analysis, preoperative physical examinations were performed by several orthopaedic surgeons with various levels of experience. Third, although we tried to exclude all confounding procedures, it was not possible to exclude all, because the majority of patients who required DHL or RFT also needed tendo-Achilles lengthening. Accordingly, confounding procedures were controlled by uniformly including only tendo-Achilles lengthening. However, tendo-Achilles lengthening could confound knee and hip kinematics [19]. Fourth, the number of cases in DHL subgroup was relatively small for comparison, and power might not be sufficient to detect the changes. We performed the post-hoc power analysis and calculated the Cohen's *d* and the effect-size correlation *r* [20]. If we assume that the 1% change of hamstring length is clinically relevant, power of detecting the change of maximum hamstring length was calculated to be 0.97 in whole patient group, 0.90 in DHL + RFT subgroup, and 0.50 in DHL subgroup. The change of mean hamstring length was calculated to be 0.99 in whole patient group, 0.99 in DHL + RFT subgroup, and 0.76 in DHL subgroup. The Cohen's *d* (effect-size *r*) of pelvic tilt, mean hamstring length, and maximum hamstring length in the

Table 4
Effects of distal hamstring lengthening on pelvic tilt and knee flexion.

Study	Subgroups	No. of Patients (limbs)	Confounding surgeries	Pelvic tilt			Knee flexion at initial contact		
				Preoperative mean (SD)	Postoperative mean (SD)	*p*	Preoperative mean (SD)	Postoperative mean (SD)	*p*
Current study	DHL + TAL	8 (16)	Controlled	16 (5)	18 (6)	0.011	33 (12)	22 (9)	0.001
	DHL + RFT + TAL	20 (40)		16 (5)	16 (5)	0.247	31 (12)	25 (10)	0.002
Gordon et al. [24]	DHL(ST)	29 (47)	Not controlled	20 (7)	22 (5)	0.027	26 (14)	19 (9)	<0.001
	DHL (LT)	19 (29)		18 (6)	18 (6)	0.558	27 (10)	20 (12)	0.001
Adolfsen et al. [6]	RFT, DHL, TAL	31 (39)	Not controlled	19 (6)	21 (6)	0.052	31 (8)	21 (10)	<0.001
Gough et al. [23]	SEMS	12 (24)	Not controlled	*	*	0.090	*§	*§	*
Chang et al. [5]	DHL	49 (83)	Not controlled	21 (6)	23 (7)	0.040	39 (11)		<0.001
	Revision DHL	12 (22)		20 (9)	26 (8)	0.006	35 (12)		0.001
Zwick et al. [10]	DHL + RFT	9 (18)	Controlled	19 (5)	20 (5)	0.080	30 (8)		0.068
	DHL + RFT + PL	8 (16)		18 (7)	30 (7)	0.023	32 (4)		0.045
Saraph et al. [4]	SEMS	25 (50)	Not controlled	18 (6)	21 (6)	0.016	30 (12)		<0.001
Deluca et al. [3]	MHL	73 (146)	Not controlled	19 (8)	18 (7)	0.578	30 (11)		<0.001
	MLHL			11 (9)	16 (7)	0.067	37 (11)		<0.001
	MHL + PL			26 (4)	24 (6)	0.378	33 (9)		0.001
	MLHL + PL			16 (5)	20 (6)	0.093	32 (10)		<0.001
Thompson et al. [25]	BTX(AHL)	7 (14)	No surgery	24	25	n.s.	$26^{\S}$	$13^{\S}$	0.018
	BTX(SHL)	3 (4)		24	20	n.s.	$26^{\S}$	$10^{\S}$	0.001
Thometz et al. [2]	DHL	31	Not controlled	15	20	n.s.	49		*

DHL, distal hamstring lengthening; RFT, rectus femoris transfer; PL, psoas lengthening; TAL, tendo-Achilles lengthening; ST, short term follow-up group; LT, long term follow-up group; MHL, medial hamstring lengthening; MLHL, medial and lateral hamstring lengthening; AHL, average hamstring length group; SHL, short hamstring length group; BTX, botox; SEMS, single event multilevel surgery not otherwise specified.
* Detailed data were not provided in the original paper.
§ Maximum knee extension.

DHL subgroup were 0.39 (0.19), 0.50 (0.24), and 0.32 (0.16), respectively.

The necessity of lengthening hamstring muscle has been questioned because this procedure has been reported to increase anterior pelvic tilt and has been suggested to worsen crouch gait eventually [9]. Furthermore, several studies have reported that hamstring length is not shorter in patients with cerebral palsy [11–13]. In addition, alternative procedures, such as, distal femoral extension osteotomy, patellar tendon advancement, and hemi-epiphysiodesis have been extensively proposed [21,22]. Previous studies about hamstring lengthening and pelvic tilt included various conditions such as extensive hamstring lengthening (including the biceps femoris) [3,5,6], revision surgery [5], hamstring lengthening in patients with hip flexion contracture [10], and concomitant confounding surgeries [2–6,23,24] (Table 4). In the present study, all confounding surgical procedures were relatively well controlled for and identical techniques were performed bilaterally. Our study shows the beneficial effect of DHL on knee kinematics without aggravation of anterior pelvic tilt even though preoperative hamstring lengths were longer than those of the control group. Furthermore, comparisons of the two patient subgroups, suggested that RFT might possibly counteract the effect of DHL on pelvic tilt and hamstring length. Therefore, the authors believe that DHL could be performed without aggravating anterior pelvic tilt by including RFT (when indicated).

Test validity usually refers to the content, construct, and concurrent validity of a test. Content validity refers to the extent to which a measure represents all logical facets of the phenomenon being measured. We presume that the content validity of modeled hamstring length has been established, in view of the number of studies that have attempted to measure hamstring length [13,14,25,26]. Concurrent validity concerns the correlation with other well-defined methods that have been previously validated. One of the weaknesses of modeled hamstring length is that there is no standard test, because actual measurements of dynamic hamstring length are as yet not possible. Instead, we use clinically well-established kinematic variables and physical examinations as points of reference. Finally, construct validity refers to the extent and sensitivity to which a measure reflects underlying construct of a particular focus, that is, in the context of this study, changes of hamstring length after DHL.

5. Conclusion

DHL was found to improve knee kinematics in patients with spastic diplegia, and not to aggravate anterior pelvic tilt when performed with RFT. In addition, hamstring length was found to be correlated with pelvic tilt and popliteal angle, but not with knee motion, and failed to detect postoperative changes according to the combined procedures. Care should be taken when using modeled hamstring length for clinical use because it appeared to have limited validity in some situations.

Conflict of interest statement

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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