Does Proximal Rectus Femoris Release Influence Kinematics In Patients With Cerebral Palsy and Stiff Knee Gait?

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Abstract

Background Stiff gait resulting from rectus femoris dysfunction in cerebral palsy commonly is treated by distal rectus femoris transfer (DRFT), but varying outcomes have been reported. Proximal rectus femoris release was found to be less effective compared with DRFT. No study to our knowledge has investigated the effects of the combination of both procedures on gait.

Questions/purposes We sought to determine whether an additional proximal rectus release affects knee and pelvic kinematics when done in combination with DRFT;

specifically, we sought to compare outcomes using the (1) range of knee flexion in swing phase, (2) knee flexion velocity and (3) peak knee flexion in swing phase, and (4) spatiotemporal parameters between patients treated with DRFT, with or without proximal rectus release. Furthermore the effects on (5) anterior pelvic tilt in both groups were compared.

Methods Twenty patients with spastic bilateral cerebral palsy treated with DRFT and proximal rectus femoris release were matched with 20 patients in whom only DRFT was performed. Standardized three-dimensional gait analysis was done before surgery, at 1 year after surgery, and at a mean of 9 years after surgery. Basic statistics were done to compare the outcome of both groups.

Results The peak knee flexion in swing was slightly increased in both groups 1 year after surgery, but was not different between groups. Although there was a slight but not significant decrease found the group with DRFT only, there was no significant difference at long-term followup between the groups. Timing of peak knee flexion, range of knee flexion, and knee flexion velocity improved significantly in both groups, and in both groups a slight deterioration was seen with time; there were no differences in these parameters between the groups at any point, however. There were no group differences in spatiotemporal parameters at any time. There were no significant differences in the long-term development of anterior pelvic tilt between the groups.

Conclusions The results of our study indicate that the short- and long-term influences of adding proximal rectus femoris release on the kinematic effects of DRFT and on pelvic tilt in children with cerebral palsy are negligible.

Level of Evidence Level III, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

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Introduction

Biarticular muscle movement reduces energy consumption during walking because energy is transferred from one joint to the other [25, 37]. For this, a high level of motor control is needed to modulate muscle contraction (eccentric, concentric, or isometric) [14, 15]. Owing to this demand for a high level of motor control, biarticular muscle function is commonly disturbed and contractures may develop in children with cerebral palsy [17]. However, knowledge is limited regarding the synergism and connection between the proximal and distal parts of muscles in children with cerebral palsy, especially for the rectus femoris muscle.

In some children with cerebral palsy, activity is prolonged or continuous in the distal part of the rectus femoris muscle during the swing phase; this counteracts the knee flexion that is essential for an undisturbed clearance [1, 3, 8, 23, 30, 33]. This gait abnormality, known as stiff knee gait, causes increased energy expenditure and is accompanied by reduced gait velocity and step length and thus tripping and falling. Furthermore, electromyographic (EMG) activity is often abnormal in the rectus femoris muscle in the swing phase, while the vasti show a normal pattern [23, 33, 37]. A couple studies have shown that EMG activity of the rectus femoris in swing occurs too late for the muscle to decelerate the flexing knee given the delays between neural excitation and the development of muscle force [9, 10]. To improve knee flexion and swing phase clearance, standard surgical treatment involves distal femoris tendon transfer, which is commonly performed as part of single-event multilevel surgery. The beneficial effects after distal rectus femoris transfer (DRFT) for knee kinematics are well documented; however, inconsistent results have been reported [8, 11, 18, 20, 21, 27, 30, 33], and in some patients no effect was observed after DRFT [6]. Some authors suggested that even after transfer, a knee extensor moment remains in the rectus femoris [2, 3, 28].

The proximal part of the rectus femoris is believed to play an important role in pelvic tilt and hip flexion [16, 33]. To treat hip flexor contracture and increased anterior pelvic tilt, proximal rectus femoris release can be considered [16] and still is performed sometimes, although few studies have investigated its effects [16, 33]. However, McMulkin et al. [16] found no relevant influence of proximal rectus release on the knee in patients in whom DRFT was not performed [16]. Sutherland et al. [33] compared DRFT and proximal rectus release concerning the effect on knee kinematics and found significantly less effect for the group in which a proximal rectus release was performed.

The main effects of DRFT on stiff knee gait are seen mainly as consequences of its distal release and not as an augmentation of the knee flexor muscles [7]. Some authors

reported recurrence of stiff knee gait in a relevant number of patients [6] and scarring at the transfer site is believed to be one possible reason for recurrence [7]. Fox et al. [7] reported a potential indirect effect of the hip flexion on the knee induced by the rectus femoris. In the literature, there are no reports on the outcome if both ends of the rectus femoris are surgically treated simultaneously.

The question therefore arises regarding whether an additional proximal rectus release affects knee function when done simultaneously with DRFT. The purpose of our study was to investigate the effects of an additional proximal rectus release on the knee kinematics when done in combination with DRFT. We sought to determine whether an additional proximal rectus release affects knee and pelvic kinematics when done in combination with DRFT; specifically, we sought to compare outcomes using the (1) range of knee flexion in swing phase (2) knee flexion velocity and (3) peak knee flexion in swing, and (4) spatiotemporal parameters between patients treated with DRFT, with or without proximal rectus release. The effects on (5) anterior pelvic tilt in both groups were compared.

Patients and Methods

For this retrospective study, all ambulatory (Gross Motor Functional Classification System Levels I to III [22]) patients with spastic bilateral cerebral palsy who were treated with DRFT in combination with proximal rectus femoris release as a part of multilevel surgery were selected from our gait laboratory database. Twenty patients were included (nine males and 11 females) with a mean age of 11 years at surgery. These patients had to have had a standardized preoperative examination and one short-term (1-year) and one long-term examination at least 5 years after surgery. In this study, the results of these patients were compared with those from patients who received only DRFT and not an additional proximal rectus femoris release, who also were selected from the database in a matched-pair analysis. The matching criteria included: maximum knee flexion in swing and knee flexion range in swing and age at surgery, BMI, and the Gillette Gait Index [31]. Anterior pelvic tilt at baseline was significantly higher in the group which received DRFT and rectus femoris release, indicating that increased anterior pelvic tilt was one criterion to perform proximal rectus release in this group. Furthermore a hip flexion contracture greater than 10° measured with the Thomas test [13] was a criterion for proximal rectus femoris release. The study was approved by the local ethics committee.

In the DRFT group (13 males and seven females), the mean age of patients at surgery was 9.9 years. Fifteen patients were independent walkers and five from each group needed walking devices (Table 1). All patients from

Table 1. Demographics, global walking ability, and surgical procedures

Variable	DRFT			DRFT and release		
	Preoperative	1 year postoperative	9 years postoperative	Preoperative	1 year postoperative	9 years postoperative
Followup (years)	–	0.91 ($\pm$ 0.2)	8.47 ($\pm$ 2.1)	–	1.00 ($\pm$ 0.1)	9.17 ($\pm$ 2.2)
Patient age (years)	9.94 ($\pm$ 2.9)	11.05 ($\pm$ 3.0)	18.31 ($\pm$ 3.7)	11.00 ($\pm$ 3.4)	12.29 ($\pm$ 3.6)	20.58 ($\pm$ 4.7)
BMI (kg/m ²)	16.83 ($\pm$ 3.9)	17.77 ($\pm$ 3.8)	20.66 ($\pm$ 4.7)	18.11 ($\pm$ 3.2)	19.29 ($\pm$ 3.8)	21.77 ($\pm$ 5.1)
Sex	7 F, 13 M			11 F, 9 M		
GMFCS Level I	2	3	5	1	3	4
GMFCS Level II	13	10	11	14	9	12
GMFCS Level III	5	7	4	5	8	4
Surgical procedures						
DRFT	40			40		
Proximal rectus femoris release	0			40		
Psoas over the brim	2			2		
Hamstring lengthening	32			28		
Calf muscle lengthening	32			38		
Femoral derotation osteotomy distal	14			8		
Femoral derotation osteotomy proximal	9			18		
Tibial derotation osteotomy	3			2		
Bony foot stabilization	15			12		
Soft tissue foot	12			6		
Total number of procedures	159			190		
Average number per patient	7.95			9.5		

DRFT = distal rectus femoris transfer; F = female; M = male; GMFCS = Gross Motor Function Classification Scale.

both groups had undergone preoperative, 1-year postoperative, and 9-year postoperative (8.5 years in the DRFT only group; 9.2 years in the DRFT and proximal rectus release group) computerized three-dimensional (3-D) gait analysis to determine the spatiotemporal parameters and kinematics. A conventional, marker-based Vicon[®] 3-D-motion capture system (Oxford Metrics, Oxford, UK) was used to track the 3-D positions of 25 reflective markers during walking according to the Plug-in Gait marker set (Oxford Metrics) [12]. The kinetic and kinematic data were collected simultaneously during level walking over a 7-m walkway. For the kinetic analyses, two floor-mounted force plates were used (Kistler[®], Winterthur, Switzerland). All the data were integrated into a custom-made database. For each patient, 10 to 15 trials were recorded and the data of at least five representative strides of different trials were averaged. All examinations were performed by a specially trained physiotherapist (PA) and a study nurse (WS) with special education in neurodevelopmental disorders and long-term experience in working with children with cerebral palsy.

All surgical procedures were performed according to specific criteria based on clinical examination and gait analysis. All the patients had received single-event

multilevel surgery, including soft tissue and bony operations (Table 1). The patients in the DRFT group received DRFT only, whereas the other patient group received DRFT and a proximal rectus femoris release. Standard surgical techniques were used for both procedures [6, 16, 38].

For data analysis, the preoperative, 1-year, and 9-year postoperative data of kinematic measurements, spatiotemporal parameters, Gillette Gait Index, and clinical examinations in both groups were compared using one-way repeated measures ANOVA (factor time) with Tukey's post hoc test (Prism 5; GraphPad Software, La Jolla, CA, USA) and t-test for group analyses. The level of significance was set at p less than 0.05.

Results

Knee ROM in swing significantly ($p < 0.05$) increased in both groups after surgery with no significant group differences ($p = 0.80$) (Table 2). Between the 1-year and the long-term examination, range of knee flexion in swing had deteriorated in both groups without any group differences ($p = 0.68$) (Fig. 1). However, this deterioration was only significant for

Table 2. Gait analysis outcome parameters

Parameters	Normal reference	DRFT	DRFT and release			Group difference		
		Preoperative	1 year postoperative	9 years postoperative	Preoperative		1 year postoperative	9 years postoperative
Kinematics								
Maximum pelvic tilt (°)	13 (5)	21 (7)	22 (7)	21 (9)	24 (8)	25 (7)	24 (6)	Preoperative (0.036) Preoperative (0.028); 1 year postoperative (0.049)
Mean pelvic tilt (°)	12 (5)	16 (7)	19 (7)*	17 (9)	20 (7)	22 (7)	20 (7)	
Maximum hip flexion in stance (°)	34 (6)	40 (11)	39 (8)	39 (9)	43 (9)	42 (10)	43 (10)	Preoperative (0.035)
Mean hip flexion in stance (°)	9 (6)	16 (10)	16 (10)	17 (8)	21 (9)	19 (9)	20 (9)	
Peak knee flexion in swing (°)	56 (6)	52 (12)	55 (8)	53 (10)	51 (10)	54 (9)	55 (8)	
Timing of peak knee flexion (% GC)	72 (1)	81 (4)	79 (5)*	78 (3)*	80 (5)	78 (5)*	78 (5)*	
Knee flexion velocity (°/% GC)	1.6 (0.2)	0.8 (0.4)	1.2 (0.4)*	1.0 (0.5)*#	0.8 (0.3)	1.2 (0.4)*	1.1 (0.4)*	
Knee ROM (°)	53 (5)	40 (15)	54 (13)*	45 (14)*#	38 (13)	52 (13)*	47 (13)*#	
Knee ROM in swing (°)	50 (5)	22 (8)	37 (10)*	34 (11)*	22 (8)	37 (10)*	33 (10)*#	
Minimum knee flexion in stance (°)	4 (4)	13 (19)	2 (13)*	8 (13)	13 (14)	1 (13)*	8 (11)*	
Spatiotemporal								
Timing of toe-off (% GC)	60 (1)	66 (5)	68 (6)	64 (4)*#	64 (5)	67 (6)*	64 (6)*	
Normalized cadence† (steps/minute)	–	43.4 (7.5)	40.0 (9.1)	44.4 (6.6)	44.7 (11.1)	40.7 (11.3)	47.7 (10.3)	
Normalized speed† (m/second)	–	0.3 (0.1)	0.3 (0.1)	0.4 (0.1)*	0.3 (0.1)	0.3 (0.1)	0.4 (0.1)	
Normalized stride length† (m)	–	0.3 (0.1)	0.3 (0.1)	0.4 (0.1)*#	0.3 (0.1)	0.3 (0.1)	0.4 (0.1)	
Global gait								
Gillette Gait Index	–	426 (541)	212 (194)*	193 (116)*	350 (240)	187 (160)*	199 (198)*	

DRFT = distal rectus femoris transfer; GC = gait cycle; * significant difference from preoperative; # significant difference from 1 year postoperative; † this parameter is normalized to body height.

the group in which DRFT and proximal release was done. Knee flexion velocity improved significantly between baseline and 1 year postoperative in both groups (no group difference, $p = 0.55$) (Fig. 2). Between the 1- and the 9-year followups, a decrease in knee flexion velocity was found in both groups, but without any group differences ($p = 0.40$). Peak knee flexion in swing increased by approximately 3° in both groups (no group difference, $p = 0.98$) between the baseline and 1-year postsurgical examination. Although a slight decrease was found in the DRFT group, there was a slight increase in the group in which DRFT was done with additional proximal release between the 1-year and the long-term examinations. However, these changes were not statistically significant nor was there a significant group difference ($p = 0.30$). The timing of peak knee flexion decreased significantly after surgery in both groups (no group difference, $p = 0.43$) and remained without any group difference ($p = 0.98$) up to the long-term followup (Fig. 1). The minimum knee flexion (peak knee extension) in stance improved significantly in both groups after surgery (no group difference, $p = 0.75$). A significant recurrence in knee flexion in stance was found at the long-term examination for both groups without any group differences ($p = 0.91$) (Fig. 2).

The decrease in normalized cadence was not significant in both groups 1 year after surgery without any group differences ($p = 0.40$). At long-term followup the group with DRFT and release tended to show a higher normalized cadence ($p = 0.06$). The normalized speed in both groups initially decreased slightly 1 year after surgery without any difference between the two groups ($p = 0.37$). At long-term followup, normalized speed was found to be increased compared with 1 year postoperative in both groups (Table 2), however this increase was significant only for the DRFT only group ($p = 0.07$). The normalized stride length in the group with DRFT only was significantly ($p = 0.03$) improved at long-term followup, whereas the increase in the group with DRFT and release was not significant ($p = 0.13$). However, there was no significant difference in normalized stride length between the two groups at long-term followup ($p = 0.15$).

The Gillette Gait Index improved significantly in both groups ($p < 0.001$) in both groups. No significant differences were observed after surgery between the two groups at any examination (Table 2).

There was an increase of the pelvic anterior tilt between baseline and the 1-year postsurgical examination in both groups; this increase was significant in the DRFT only group and this group difference was significant ($p = 0.04$). In both groups between the 1- and the 9-year followups anterior pelvic tilt changed, and at long-term followup nearly baseline status was reached (Fig. 1). There was no significant group difference found at long-term followup ($p = 0.10$), indicating that function was comparable in both groups.

Discussion

An injury of the high-level motor control in patients with cerebral palsy affects the mechanisms of biarticular muscles considerably [24–26, 36]. The rectus femoris muscle, which was found to act independently of the vasti [19], is one of the biarticular muscles that is commonly involved in patients with cerebral palsy and causes stiff knee gait by reducing knee flexion during the swing phase of gait. It is believed to cause or aggravate increased anterior pelvic tilt. DRFT is commonly performed to correct stiff knee gait, however variable outcomes have been reported [5, 18, 20, 30]. A proximal rectus femoris release was done to eliminate rectus function at the pelvic level and to influence knee motion but was found to be less effective than DRFT. However, to our knowledge, the outcome after a combination of both procedures has not been reported. In our long-term study we could not find any beneficial effect of a proximal rectus femoris release on knee and pelvic kinematics and the indication for this procedure in addition to DRFT should be questioned.

Our study had numerous limitations. First, this was a retrospective study, which may influence the comparability of the two groups chosen, especially concerning the pre-operative indication for selected surgical procedures. Furthermore, the patients in our two study groups had several additional procedures (eight procedures per subject on average; Table 1) as part of single-event multilevel surgery. Some concomitant procedures affect knee kinematics, such as hamstring lengthening, which improves knee motion in the long term [1, 5]. Hamstring lengthening may increase anterior pelvic tilt [5], since the hamstrings stabilize the pelvis and lengthening may lead to insufficiency. However, hamstring lengthening was done in a nearly equal number of patients in both groups. There were more patients who received a proximal femoral osteotomy in the group with additional rectus release compared with the group with DRFT only. This may have influenced the results. Because proximal rectus femoris release also was done to reduce increased anterior pelvic tilt, the group with additional rectus femoris release had a significantly higher ($p = 0.03$) mean pelvic tilt at baseline compared with the DRFT only group. This may bias a comparison of pelvic tilt development between the groups. In this study only sagittal plane kinematics were evaluated. Potential changes in frontal and transversal plane kinematics are not reported. Finally, gait analysis systems are subject to measurement errors owing to inherent system characteristics and marker placement variability.

Ounpuu et al. [20] and Sutherland et al. [32] reported that proximal rectus femoris release reduces hip flexion contracture and lumbar lordosis but also improves knee flexion in swing. Since it was shown that DRFT leads to a

Fig. 1A–D Average sagittal plane kinematic mass graphs are shown for (A) pelvic tilt, (B) hip flexion, (C) knee flexion, and (D) ankle dorsiflexion and plantar flexion for all patients in the DRFT only group (red line), the DRFT and release group (blue line), and for an age-matched group of 48 subjects (gray area) (including 1 SD).

The dotted red and blue lines correspond to ± 1 SD. Graphs are presented for all preoperative, 1-year postoperative, and 9-year postoperative examinations. Positive values indicate anterior pelvic tilt, hip flexion, knee flexion, and ankle dorsiflexion.

Fig. 2A–B The graphs show the mean and SD for (A) maximum pelvic tilt before surgery, 1 year after surgery, and 9 years after surgery, and (B) knee ROM in swing before surgery, 1 year after surgery, and 9 years after surgery. * Significant difference from preoperative; #significant difference from 1 year postoperative; †differences between DRFT group versus DRFT and release group.

superior outcome compared with proximal release, it has become the gold standard. There are numerous reports regarding the treatment of stiff knee gait using DRFT or proximal rectus femoris release [1, 4, 6, 8, 11, 18, 20, 21, 23, 27, 30, 32, 33, 35, 38]. Good initial results were reported [1, 4, 8, 11, 20, 21, 23, 27, 32, 33, 38]. However, some authors have reported discrepant outcomes after DRFT [6, 18, 30, 35], and a poor or no response rate of approximately 20% was found in a recent long-term investigation [6]. These inconsistent outcomes may be explained by a persistent extensor moment of the rectus femoris after transfer [2, 3, 28]. In such cases an additional proximal rectus femoris release may have an additional beneficial effect on knee motion.

According to our findings, the kinematic knee parameters (range of flexion in swing phase, peak knee flexion in swing, and knee flexion velocity) were significantly improved in both groups independent of whether rectus release was performed. The short-term improvements were comparable to those reported in the literature [18, 20, 21, 33, 35]. The effects in the DRFT only group of our study were sustained at the long-term followup, with the expectation of knee ROM in swing corroborating the findings of previous studies investigating long-term results after rectus femoris transfer [6, 18, 30, 35]. Knee ROM in swing decreased significantly in both groups but mainly as an indirect effect of recurrence in the stance phase knee flexion. When comparing the outcome of the DRFT only group with the group that received the additional proximal rectus femoris release, we could not find any group differences 9 years after surgery. Therefore, the results of our study indicate that the short- and long-term influences of proximal rectus femoris release on DRFT effects on the knee are negligible.

Two possible interpretations of our findings should be considered: (1) if DRFT effectively removes the knee-extending function of the rectus femoris, no surgery on the proximal part should directly influence knee kinematics. In this case our results would underline the effectiveness of DRFT in correcting stiff knee gait by eliminating the rectus femoris muscle [1, 6, 8, 11, 18, 20, 21, 23, 27, 30, 33, 35, 38]. However, since the rectus femoris may secondarily influence knee motion by generating an internal hip flexion moment and a secondary external knee flexion moment [7], the proximal rectus release is potentially able to influence the effects of DRFT on the knee. Our results that there were no differences between those patients who received additional proximal release and those who did not may indicate that the proximal rectus femoris release does not relevantly influence this mechanism. (2) In cases of a persistent internal knee extensor moment of the rectus femoris on the knee after DRFT [2, 3, 28], additional surgery in the proximal part does not affect knee function. Therefore, although clearly

combined in biomechanics, clinically hip flexion and knee extension appear to be independent functions of the rectus femoris.

Causes of increased pelvis tilt can be a shortened rectus femoris or iliopsoas or/and weak hip extensors and poor selective motor control of the gluteus muscles and high femoral anteversion. Proximal rectus femoris release is performed to improve hip extension and to reduce increased anterior pelvic tilt. There were significant group differences in the maximum and mean pelvic tilt before surgery, reflecting the indication for an additional proximal rectus release in this group. This group difference remained at the 1-year followup for mean pelvic tilt, but at long-term evaluation no significant difference between the two groups was found. The pelvic tilt increased slightly in both groups after surgery and this increase should be seen mainly as the result of concomitant hamstring lengthening in many patients in both groups [5]. Therefore, the proximal rectus release did not prevent anterior pelvic tilt from increasing, corroborating the findings of McMulkin et al. [16]. This is underlined by the hip kinematics with no significant changes in hip motion being observed in either group. This is in accordance with the findings of Sutherland et al. [33]. We believe that surgery on the proximal parts of the rectus femoris does not relevantly influence pelvic and hip kinematics. It is a relevant question why we performed only a few psoas lengthening procedures [34]. We attempted to avoid psoas lengthening so as not to cause propulsion problems. It was done only if we were unable to correct a hip flexion contracture intraoperatively during proximal rectus release. It seems that increased hip flexion resolves after the correction of distal problems and this is in accordance with the results of Rutz et al. [29]. However, this needs to be investigated further.

We evaluated the effects on the knee and pelvis when DRFT and proximal rectus femoris release are performed simultaneously. Our short- and long-term results suggest that a combination of the two procedures does not further improve the effects of DRFT on stiff knee gait. Furthermore, we found no superior outcome concerning anterior pelvic tilt. Any additional effects of a concomitant proximal rectus femoris release on the knee and pelvis therefore are negligible.

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