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SYMPOSIUM: CURRENT APPROACHES IN CEREBRAL PALSY, A FOCUS ON GAIT PROBLEMS

Rectus Femoris Transfer Improves Stiff Knee Gait in Children With Spastic Cerebral Palsy

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Abstract
Background Stiff knee gait is common among children with ambulatory cerebral palsy (CP). When surgery is indicated, rectus femoris transfer as a primary treatment enhances knee range of motion, reduces time to peak knee flexion, increases peak knee flexion, and reduces toe drag.
Questions/purposes We determined whether (1) distal rectus femoris transfer improved knee range of motion, time to peak knee flexion, peak knee flexion, and toe drag in children with CP diagnosed with stiff knee gait; and (2) patients in some subgroups (eg, those with relatively high knee range of motion compared with those with low knee range of motion before rectus femoris transfer) had greater improvement in these parameters.
Methods We retrospectively reviewed gait data from 56 patients (99 limbs) preoperatively, short-term, and long-term. Subgroup analyses were performed to determine whether patients with high knee range of motion relative to those with low or moderate knee range of motion improved differentially after rectus femoris transfer. The minimum followup was 7 years (mean ± SD, 10 ± 2 years; range, 7–13 years).
Results The mean peak knee flexion increased from baseline to short-term and to long-term followup. Patients with low peak knee flexion had the greatest improvement of peak knee flexion after rectus femoris transfer relative to the moderate and high peak knee flexion subgroups. Similarly, the greatest improvement after rectus femoris transfer for knee range of motion occurred in the low knee range of motion subgroup relative to moderate and high subgroups. Rectus femoris transfer improved mean time to peak knee flexion at short-term and long-term followup compared with baseline. Likewise, there was a decrease in toe drag at short- and long-term after rectus femoris transfer.
Conclusion Distal rectus femoris transfer selectively improved peak knee flexion, toe drag, and reduced time to peak knee flexion in ambulatory children with CP with stiff knee gait.
Level of Evidence Level IV, therapeutic study. See guidelines for authors for a complete description of levels of evidence.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

Stiff knee gait (stiff knee gait) is relatively common in ambulatory children with cerebral palsy (CP) [16]. This most frequently results from increased activity of the rectus femoris muscle in the swing phase and is associated with reduced peak knee flexion (PKF) and total knee ROM as well as delayed time to the PKF [6]. Stiff knee gait also occurs as a result of poor ankle power in late stance. Indeed, timing and magnitude of swing phase knee flexion are dependent on walking velocity, which accounts for the implication of poor ankle power in stiff knee gait [12]. Surgery remains an effective approach to improving motion and kinematics in spastic stiff knee gait [4, 6].

Rectus femoris transfer in children with CP with stiff knee gait is intended to increase knee flexion during the swing phase and improve foot clearance thereby reducing toe drag. Increased knee flexion at the swing phase is achieved by increasing knee ROM, decreasing time to PKF, and increasing PKF in the swing phase, whereas foot clearance is enhanced by decreased toe drag. Rectus femoris transfer removes the action of this biarticular muscle from knee extension [1] and preserves its function as a hip flexor [6]. Usually the contraction pattern is appropriate for hip flexion, and for it to have an effect on the knee, it should work as a knee flexor. This procedure provides a certain degree of knee flexion improvement in the early swing phase that is adequate for ground clearance [6, 14]. Neither proximal [6, 15] nor distal rectus release [3, 10] has demonstrated similar improvements in PKF, time to PKF, knee ROM, and toe drag seen with distal rectus femoris transfer. The rectus femoris is removed from its insertion on the patella and transferred to some other muscle with sartorius and gracilis being the most common sites [6]. The specific site of transfer does not appear to affect outcome [9].

Rectus femoris transfer is performed more frequently in children [16] in whom, with ensuing growth and maturation, the progressive impairment in stiff knee gait may influence the long-term improvement in PKF, time to PKF, knee ROM, and toe drag [4, 13]. Furthermore, functional improvement after surgery may take more than 1 year to develop [8] and Saraph et al. [13] advocate 3 years of postoperative followup to determine its advantage in enhancing kinematics. In two previously published series [7, 14], the maximum time to endpoint was 4.5 years; the end points were not predictable.

Given the kinematic and clinical benefits of rectus femoris transfer may be short-term and vary by preoperative kinematics, patients with high knee ROM for instance who had rectus femoris transfer might not have needed one in the first place. In this circumstance, the rectus femoris transfer may not show prolonged increase in knee ROM, indicative of very little or relatively no long-term improvement in knee ROM in patients who might have had a relatively high preoperative knee ROM.

We therefore asked whether (1) rectus femoris transfer improves PKF, time to PKF, knee ROM, and toe drag; (2) a subgroup of patients with low PKF (< 50°) and those with low knee ROM (< 36°) benefit most from rectus femoris transfer; and (3) a combination of preoperative indicators of stiff knee gait improvement (knee ROM, time to PKF, PKF, and toe drag) defines the subgroup of patients to whom rectus femoris transfer may improve stiff knee gait the most.

Patients and Methods

From 1992 to 1999, 175 ambulatory children with spastic CP underwent distal rectus femoris transfer for stiff knee gait in our institution. Stiff knee gait was defined by delayed and/or decreased PKF in the swing phase and reduced dynamic knee ROM during the gait cycle. The inclusion criteria for rectus femoris transfer were (1) a history or observation of toe drag; (2) PKF < 60°; (3) low total knee ROM < 50°; and (4) late PKF in swing. Although exclusion criteria were difficult to define, if the purpose of rectus femoris transfer was primarily to improve toe drag, then absence of toe drag served as an exclusion. Similarly, if the primary purpose of surgery was to improve PKF or increase the knee ROM, then PKF > 60° and knee ROM > 50° were considered exclusions. However, because patients who presented with either of these inclusion criteria were eligible for this study, inclusion criteria were relaxed to apply to any of four inclusion criteria. In addition, we excluded (1) patients with previous surgery to the rectus femoris muscle and those who underwent surgery in other institutions; (2) patients who underwent gait analysis in other gait laboratories; and (3) patients with missing data points. With these exclusions we were left with 56 patients (32%) with 99 operated limbs. There were 33 males and 23 females. All patients were functional ambulators and among them, 50 had diplegia, five hemiplegia, and one quadriplegia. The mean age of participants at baseline was 8 ± 2 years (range, 7–13 years). Patients who met the criteria for preoperative and short-term postoperative followup were called to return for the long-term minimum of 8 years after surgery. We cannot make any comment about the patients who did not return for long-term followup because only those who returned had data. This retrospective cohort study (case-only) received Institutional Review Board approval.

We performed post hoc power analysis to determine whether we had enough power to assess the differences between the preoperative and the followup PKF. In determining this, we used $\alpha = 0.05$, an effect size of 9°, which is the difference between the mean preoperative and followup PKF (SD = 14.03, sample size n = 99), and repeated-measures analysis of variance (ANOVA). With these parameters, we estimated the power to be 95.8%, which is sufficient power. We applied the same procedure to knee ROM and used $\alpha = 0.05$ (mean difference, 9°; SD, 16.15; n = 99) and computed a power of 89.3%. For time to PKF, using similar parameters with a mean difference of 5% change in time to PKF and SD = 7, we estimated the power to be 98%. We also estimated the post hoc statistical power for the subgroup (low, moderate, and high knee ROM, PKF, time to PKF) analysis using repeated-measure ANOVA and obtained sufficient power for PKF, knee

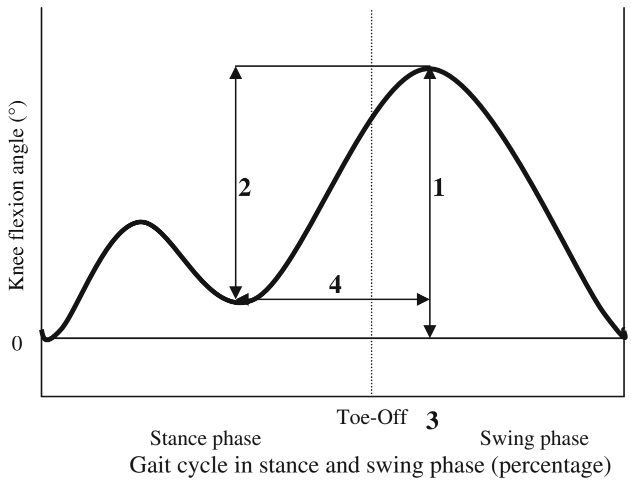

Fig. 1 The four kinematic parameters selected to measure the outcome of stiff knee gait during a gait cycle: (1) peak knee flexion (PKF) in the swing phase; (2) knee ROM between maximum extension at stance and PKF at swing (knee ROM); (3) timing of PKF (TiPKF); and (4) velocity of knee flexion (VKF).

ROM, and time to PKF (> 80%). The parameters used for these estimations were $\alpha = 0.05$, effect size, and sample size as demonstrated in the preoperative or baseline measures.

Miller et al. [6] described the mean age at surgery for the performance of rectus femoris transfer. The distal part of the rectus femoris was transferred to either sartorius or gracilis muscle at a mean age of 7.5 years (± 2.3). Other procedures were often performed concurrently and are described elsewhere [5, 6].

Patients had three full gait analyses: preoperatively at an average of 6 months before surgery (mean, 6 ± 5 months), postoperatively less than 3 years after surgery (mean, 2 ± 1 years) (short-term), and at final followup 10 years after surgery (mean, 10 ± 2 years) (long-term). A motion analysis system (Motion Analysis Corp, Santa Rosa, CA, USA) with Orthotrac software was used to measure and calculate the kinematics of gait. The Cleveland Clinic marker set was used to measure upper extremity, trunk, and

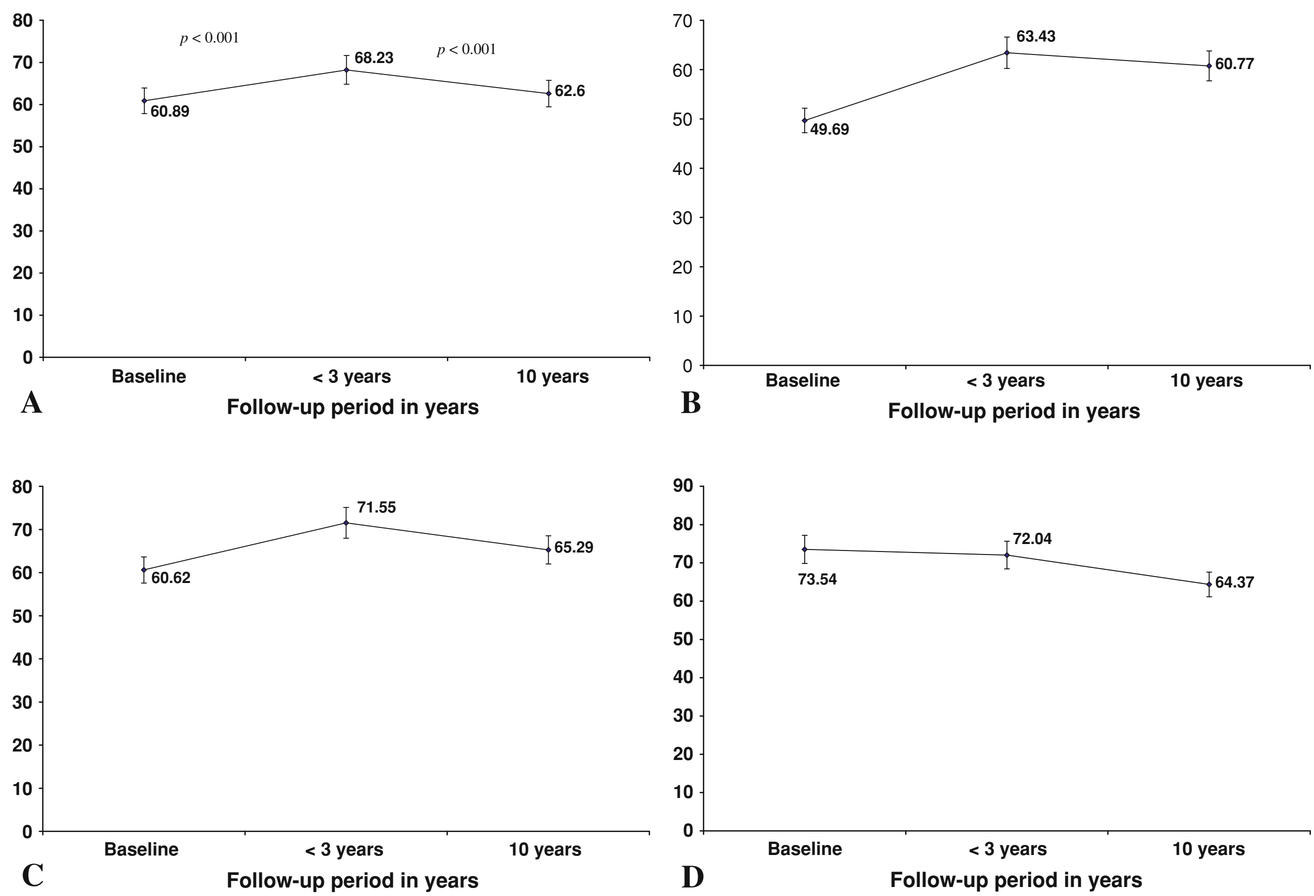

Fig. 2A–D (**A**) Changes in PKF after surgery in the overall study population of children with CP with SKG. (**B**) Changes in PKF after surgery in the low PKF subgroup of children with CP with SKG. (**C**) Changes in PKF after surgery in the moderate PKF subgroup of children with CP children with SKG. (**D**) Changes in PKF after surgery in the high PKF subgroup of children with CP with SKG. SKG = stiff knee gait.

lower extremity motion. Ten to 20 gait cycles were recorded for each patient at a self-selected pace. The following kinematic outcome variables were selected: PKF in the swing phase, knee ROM measured between the maximum knee extension in the stance phase and PKF, and time to PKF in regard to the gait cycle (%) (Fig. 1). We also measured the presence or absence of toe drag from videotapes of the subject's gait. Toe drag was measured on a binary scale as either a "yes" or "no" and was scored as 0 (absent) or 1 (present). After initial analysis, three other possible predictors were discarded as a result of their skewed distribution (Ely test, electromyography, and rectus tone).

To examine which patients benefited most from surgery, we created three subgroups (low, moderate, and high baseline or preoperative kinematics) to examine the effect of rectus femoris transfer on these subgroups. In effect, to achieve these subgroups, we used the mean baseline values of these parameters as well as their 95% CI, minimum, and maximum values. Specifically, to obtain the low, moderate, and high knee ROM, time to PKF, PKF, and toe drag, we obtained the summary statistic for the total sample. For knee ROM, time to PKF, and PKF, we examined these data for normality and used the mean, SD, and 95% CI to determine low, moderate, and high knee ROM, time to PKF, and PKF subgroups. The low knee ROM for example represented the values below the lower 95% CI limit of mean, the moderate > 95% lower CI boundary to the mean, and high > mean to the upper 95% CI boundary. With these subgroups generated, we obtained the summary statistics (mean, SD) and tested these subgroups for normality assumption before the hypothesis-driven analysis. A similar approach was applied to toe drag using median ranking and interquartile range to categorize the sample into low, moderate, and high subgroups (Fig. 2).

We first examined the shape and distribution of the data using normality test for skewness as well as for outliers. To assess the relationship between rectus femoris transfer end point variables (PKF, knee ROM, time to PKF, velocity of knee flexion, toe drag) and the independent or predictor variables (age, gross motor function measure, gait velocity,

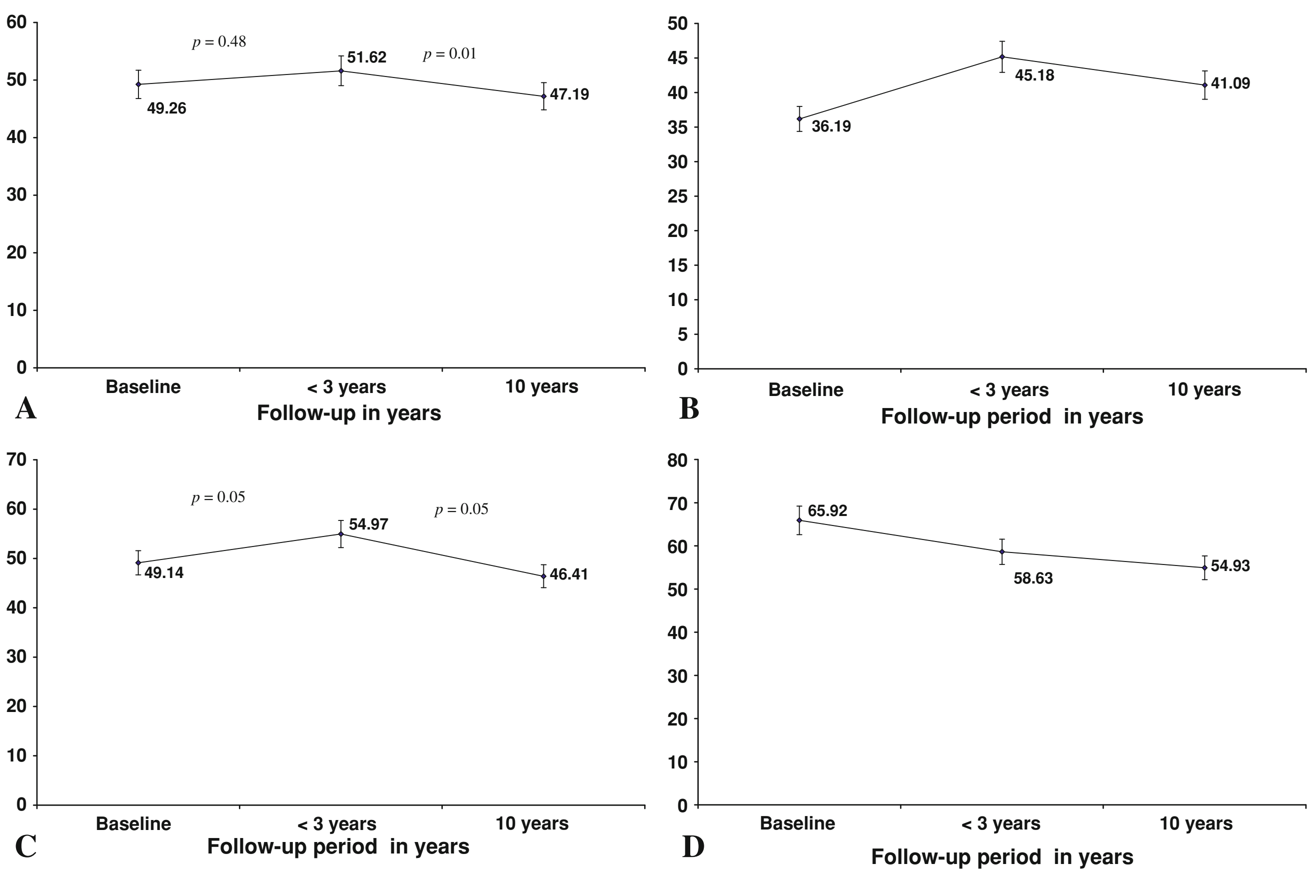

Fig. 3A–D (**A**) Changes in knee ROM after surgery in overall sample of children with CP with SKG. (**B**) Changes in knee ROM after surgery in the low knee ROM subgroup of children with CP with SKG. (**C**) Changes in knee ROM after surgery in the moderate knee ROM subgroup of children with CP with SKG. (**D**) Changes in knee ROM after surgery in the high knee ROM subgroup of children with CP with SKG. SKG = stiff knee gait.

popliteal angle), we used robust simple linear regression, which is not sensitive to normality assumption violation of this model. To test for the primary composite hypothesis of the study, rectus femoris transfer increases (1) PKF; (2) knee ROM; and (3) rectus femoris transfer decreases time to PKF; we used a repeated-measure ANOVA. The subgroup hypothesis complex that (1) rectus femoris transfer increases PKF more in the subgroup with PKF < 50° relative to those with PKF > 50° over time; (2) rectus femoris transfer increases knee ROM in the subgroup with knee ROM < 36° compared with those with knee ROM > 36°; and (3) rectus femoris transfer decreases time to PKF in those with high time to PKF relative to those with low time to PKF was tested using repeated-measure ANOVA. This test statistic is adequate given a single sample (children with CP with stiff knee gait who underwent rectus femoris transfer) with more than one repeated measure of the response variable. In this analysis, a subject becomes its own control, which eliminates the between-subject variability, making this a very effective design in measuring long-term impact of surgery or treatment. Because repeated-measure ANOVA generates an overall model F statistic and p value, which is significant whenever there is a significant mean difference between any of the measures with the preoperative or baseline measure, a pairwise comparison using the Bonferroni method was performed. This method allows one to examine the significant difference for example in knee ROM, comparing preoperative knee ROM with short-term knee ROM and preoperative knee ROM with long-term knee ROM. The Friedman test, which is a nonparametric alternative to repeated-measure ANOVA, was also used when data did not follow normal distribution. For example, to test the hypothesis of a decrease in the proportion of toe drag over time comparing preoperative and postoperative toe drag (short-term and long-term), the Friedman test and chi square with Fisher's exact were used. Furthermore, to determine the combination of preoperative outcome factors, mainly knee ROM, time to PKF, PKF, and toe drag, that may improve stiff knee gait in patients to whom rectus femoris transfer is indicated, we used the multiple linear regression model. Finally, to determine which combinations of kinematics will be most adequate in assessing the rectus femoris transfer effect in improving stiff knee gait, we performed a correlation coefficient analysis among the PKF, knee ROM, and time to PKF adjusting for multiple comparisons with the Bonferroni method with $p < 0.01$ resulting from the inclusion of three variables in the correlation matrix. The repeated-measure ANOVA was performed using SPSS software (Version 17.0; SPSS Inc, Chicago, IL, USA), whereas the summary statistic and linear regression model were done using STATA, Version 10.0 (Statacorp, College Station, TX, USA) (Fig. 3).

Results

This study was conducted to assess whether or not (1) rectus femoris transfer improves PKF, time to PKF, knee ROM, and toe drag; (2) a subgroup of patients with low PKF (< 50°) and those with low knee ROM (< 36°) benefit most from rectus femoris transfer; and (3) a combination of preoperative indicators of stiff knee gait improvement (knee ROM, time to PKF, PKF, and toe drag) defines the subgroup of patients to whom rectus femoris transfer may improve stiff knee gait the most (Table 1).

Compared with the baseline mean PKF (61 ± 14), there was an increase ($p < 0.001$) at short-term (68 ± 10) as well as long-term followup PKF (63 ± 11; $F = 17$; Table 2). We observed an increase in knee ROM, comparing the baseline knee ROM (49° ± 16°) with knee ROM after the short-term postoperative period (52° ± 15°) but a decrease at the last followup (47° ± 14°; $F = 4$, $p = 0.02$) (Table 2). Likewise, compared with the baseline

Table 1. The relationship between the outcome/dependent variables and potential predictors (simple linear regression analysis model) at baseline (preoperative period)

Variable	β	t-value	95% CI	p value
Peak knee flexion				
Age	−0.28	−0.45	−1.53–0.96	0.65
GMFM	0.03	0.56	−0.09–0.15	0.58
GV	0.04	0.99	−0.04–0.13	0.32
PA	−0.01	−0.09	−0.18–0.16	0.93
Knee ROM				
Age	−0.26	−0.37	−1.70–1.17	0.71
GMFM	−0.03	−0.41	−0.17–0.11	0.68
GV	0.01	0.28	−0.08–0.11	0.78
PA	0.02	0.17	−0.18–0.21	0.86
Timing of peak knee flexion				
Age	−0.003	−1.01	−0.009–0.003	0.31
GMFM	< 0.0001	0	−0.0006–0.0006	0.99
GV	0.0001	0.49	−0.0003–0.0005	0.63
PA	0.0002	0.55	−0.0006–0.001	0.58
Velocity of knee flexion				
Age	−0.15	−0.03	−9.91–9.62	0.98
GMFM	0.81	0.79	−1.24–2.88	0.43
GV	0.59	1.68	−0.11–1.30	0.09
PA	0.44	0.65	−0.90–1.77	0.52
Toe drag				
Age	−1.8	−2.21	−3.42 to −0.18	0.03
GMFM	6.21	0.72	−10.81–23.23	0.47
GV	0.001	1.27	−0.0006–0.003	0.21
PA	0.004	8.7	0.57–0.91	0.007

GMFM = gross motor function measure; GV = gait velocity; PA = popliteal angle.

time to PKF, there was a decrease at the short-term as well as long-term postoperative period (F = 4, p = 0.01). The baseline velocity of knee flexion (210 ± 108) increased ($p < 0.001$) at the short-term (287 ± 136) as well as long-term followup (239 ± 115; F = 20). We also assessed whether toe drag decreased after rectus femoris transfer in children with stiff knee gait and found a decrease ($p < 0.001$) in toe drag. The preoperative toe drag was 92% versus 8% (nontoe drag), whereas the proportion of toe drag during the followup period < 3 years was 29% versus 71% (nontoe drag), indicative of postoperative decrease in toe drag, and this difference was significant (chi square [df, 1] = 83, $p < 0.001$). Similarly, compared with the 10-year followup period, the toe drag significantly decreased to 33% from 92% preoperative toe drag, and this difference was significant as well (chi square [df, 1] = 74.2, $p < 0.001$). Overall, we observed a mean increase in knee ROM, PKF, and time to PKF over time as well as a decrease in the proportion of toe drag over time (Table 3).

The low PKF group had the most increase ($p < 0.001$) in PKF after rectus femoris transfer at both short-term and long-term followup (Table 4). The low knee ROM group had a greater increase ($p < 0.001$) in PKF compared with the knee ROM between the baseline and short-term postoperative followup with no decrease in knee ROM at long-term followup. In the low time to PKF group, defined by the least percentage of time to PKF (n = 38, mean = 74 ± 5), there was an increase (p = 0.003) in the time to PKF at short-term and long-term followup (Fig. 4).

We also attempted to address the question as to whether or not a single or combined measure of rectus femoris transfer effectiveness was most appropriate or adequate to determine the indication for surgery. To answer this question, we performed a correlation coefficient analysis among the PKF, knee ROM, and time to PKF adjusting for multiple comparison with the Bonferroni method but found no correlation ($p > 0.05$). Because the time to PKF correlated with toe drag in our model (Table 1), we performed a multivariable linear regression analysis on the groups in which rectus femoris transfer showed the most improvement in increasing knee ROM and PKF and decreasing time to PKF as well as reducing the proportion of toe drag, which were the subgroups with low PKF, low knee ROM, high time to PKF and a higher proportion of toe drag. We found a negative linear relationship between time to PKF and knee ROM (p = 0.001) but not with PKF (p = 0.98).

Discussion

Children with CP often present with stiff knee gait; however, it is not fully understood if rectus femoris transfer improves kinematics and toe drag equally among

Table 2. Outcomes after rectus femoris transfer in children with stiff knee gait

Kinematics	Preoperative baseline		Postoperative short-term		Postoperative long-term		F	df	p value
	Mean	SD	Mean	SD	Mean	SD			
PKF	60.89	14.03	68.23	10.08	62.6	10.78	16.78	1	< 0.001
KROM	49.26	16.15	51.62	14.95	47.19	14.01	3.95	1	0.02
TiPKF	81	7	80	5	79	6	4.43	1	0.01
VKF	210.19	108.16	286.74	135.54	238.74	115.34	20.45	1	< 0.001

PKF = peak knee flexion in degrees; KROM = knee ROM in degrees; TiPKF = time to peak knee flexion in percent of the gait cycle; VKF = knee flexion velocity in degrees/second; F is the ratio of the variances for the analysis of variance model, whereas df is the degree of freedom.

Table 3. Multiple comparisons between the intervention cycles with relation to the outcomes after rectus femoris transfer surgery in children with stiff knee gait

Variables	Intervention cycle: pre- and postoperative measures								
	Preoperative versus short-term			Preoperative versus long-term			Short-term versus long-term		
	Mean	SE	p value	Mean	SE	p value	Mean	SE	p value
PKF	7.33	1.37	< 0.001	1.71	1.43	0.7	−5.62	1.16	< 0.001
KROM	2.36	1.67	0.483	−2.08	1.58	0.57	−4.43	1.48	0.01
TiPKF	−1	0.006	0.19	−2	0.007	0.04	−1	0.005	0.53
VKF	76.55	13.6	< 0.001	28.55	11.78	0.05	−48	10.73	< 0.001

PKF = peak knee flexion in degrees; KROM = knee ROM in degrees; TiPKF = time to peak knee flexion in percent of the gait cycle; VKF = knee flexion velocity in degrees/second; the significance level is 0.01.

Table 4. Outcomes of rectus femoris transfer in patients with cerebral palsy with stiff knee gait comparing low, moderate, and high peak knee flexion (PKF), knee ROM (KROM), and time to peak knee flexion (TiPKF)

Evaluation cycle	PKF (mean, SD)			KROM (mean, SD)			Ti PKF (mean, SD)		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Baseline	49.69 ± 7.36	60.62 ± 1.46	73.54 ± 6.12	36.19 ± 6.95	49.14 ± 1.99	65.92 ± 9.35	74.19 ± 5.27	81.56 ± 0.90	86.87 ± 3.42
< 3 years	63.43 ± 10.01	71.55 ± 10.98	72.04 ± 7.74	45.18 ± 15.50	54.97 ± 10.26	58.63 ± 11.90	77.22 ± 4.65	80.60 ± 4.58	82.59 ± 4.45
> 7 years	60.77 ± 7.53	65.29 ± 7.32	64.37 ± 12.75	41.09 ± 12.04	46.41 ± 7.38	54.93 ± 14.10	77.27 ± 5.64	77.64 ± 4.79	81.98 ± 4.88

Low PKF group: $F_{(2)} = 44.49$, $p < 0.001$, moderate PKF group: $F_{(2)} = 7.69$, $p = 0.002$, high PKF group: $F_{(1.71)} = 15.21$, $p < 0.001$; low KROM group: $F_{(2)} = 7.5$, $p < 0.001$, moderate KROM group: $F_{(2)} = 3.64$, $p = 0.05$, high KROM group: $F_{(1.87)} = 14.81$, $p < 0.001$; low TiPKF group: $F_{(2)} = 6.15$, $p = 0.003$, moderate Ti PKF group: $F_{(2)} = 3.43$, $p = 0.05$, high Ti PKF group: $F_{(2)} = 36.06$, $p < 0.001$; the F is the test statistic for the repeated measure analysis of variance model, whereas the value within the parenthesis is the degree of freedom.

these patients. This study was therefore designed to answer the following questions: (1) Does rectus femoris transfer increase PKF and knee ROM and does it decrease time to PKF as well as toe drag among children with CP diagnosed with stiff knee gait? (2) Does a subgroup of patients with low PKF (< 50°) and those with low knee ROM (< 36°) benefit most from rectus femoris transfer? (3) Does a combination of preoperative indicators of stiff knee gait improvement (knee ROM, time to PKF, PKF, and toe drag) define the subgroup of patients to whom rectus femoris transfer may improve stiff knee gait the most?

First, the rectus femoris transfer data obtained in this study indicate that rectus femoris transfer increases mean knee ROM and PKF while decreasing mean time to PKF and toe drag proportion. In fact, although the long-term mean PKF and knee ROM were slightly lower than the short-term means, both short-term and long-term means were higher than the preoperative means. The previous reports have found improvements in PKF 1 to 3 years after the procedure varying from 3° to 17° [3, 7, 9, 14, 15]. This improvement with a range of variations was very similar to our current study with the short-term followup improvement of 7° in PKF. Also, there are two longer-term studies, one reporting no change at 4.6 years [14] and the other reporting 5° of loss of PKF [13], which is comparable to our 10-year followup that found a mean 6° loss of PKF from the short followup time. The kinematic variables knee ROM and the time to PKF showed similar changes. There have been no previous attempts to correlate toe drag with kinematic improvements. Our findings suggest that time to PKF is most sensitive to improvement in toe drag as assessed by videotape analysis.

Second, do children with relatively high knee ROM, high PKF, low time to PKF, and less severe toe drag experience the least improvement for stiff knee gait after rectus femoris transfer? We demonstrated that children with CP with stiff knee gait who had high PKF, or high knee ROM, and or low time to PKF were less likely to improve in stiff knee gait after rectus femoris transfer. Most of these were children with severe crouch whose surgical indication was related primarily to improving knee extension but the goal of the rectus transfer was to preserve knee flexion in swing, not to improve knee flexion in swing. In fact, the high PKF group had a decrease of PKF after the short-term followup and a further decrease 10 years thereafter. This is likely the result of the fact that high PKF was already in the normal or even above normal range. Whereas high knee ROM and low time to PKF groups showed no benefit of surgery, they also did not show deterioration between short-term and long-term followup. We also observed that patients with the least time to PKF values may not benefit from

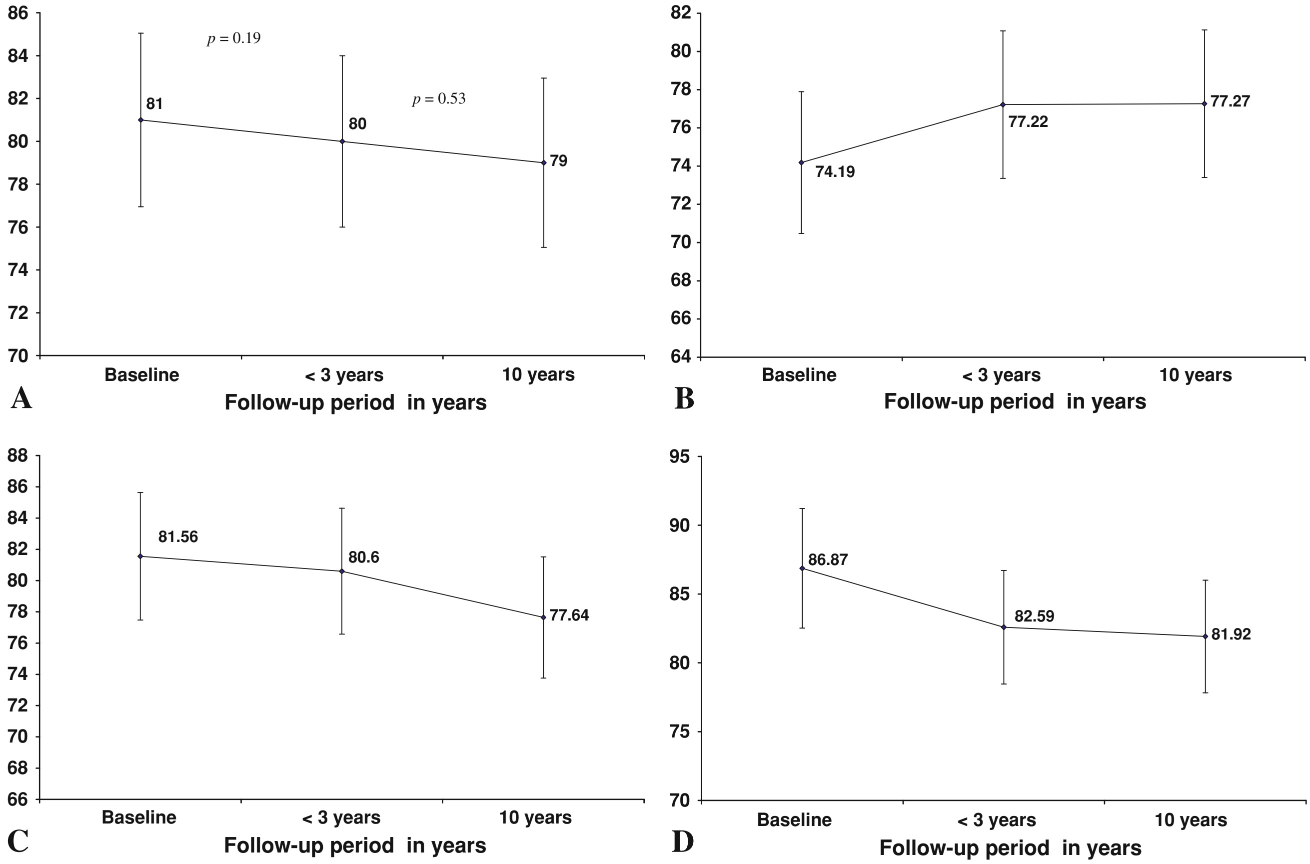

Fig. 4A–D (**A**) Changes in time to PKF after surgery in the overall sample of children with CP with SKG. (**B**) Changes in time to PKF after surgery in the low time to PKF of children with CP with SKG. (**C**) Changes in time to PKF after surgery in the moderate time to PKF subgroup of children with CP with SKG. (**D**) Changes in time to PKF after surgery in the high time to PKF subgroup of children with CP with SKG. SKG = stiff knee gait.

rectus femoris transfer in improving toe drag, which directly correlates with time to PKF. In our sample, rectus femoris transfer contrary to our expectations and the natural history [2, 11, 14] resulted in a decreased time to PKF at less than 3 years followup with similar decrease at 10 years followup compared with baseline. Therefore, the indication for rectus femoris transfer should consider time to PKF because it is the kinematic variable that best correlates with toe drag.

Third, which combination of preoperative indicators of stiff knee gait defines the subgroup of patients to whom rectus femoris transfer may improve stiff knee gait the most? Our data suggest that the patient who will benefit most from both short- and longer-term improvement in toe drag, knee ROM, and PKF will be the child with late time to PKF, a low magnitude of PKF, and low total knee ROM. Therefore, the patients who will benefit the most from surgery are those with moderate to highest time to PKF (> or equal to 80%), and those with low PKF (30° to less than 59) or with moderate PKF (60° to less than 64°) as characterized by our study. Consequently, patients with the highest PKF (64° to less than 86°) are less likely to benefit from rectus femoris transfer and therefore require assessment of other factors such as time to PKF and knee ROM before surgical decision-making. Using our grouping, among those with whom surgery is indicated, low PKF, low knee ROM, and high time to PKF, the most reliable kinematics for the indication of rectus femoris transfer remain knee ROM and time to PKF where there are inconsistent data on PKF.

In summary, despite the limitations of this study mainly a retrospective design, distal rectus femoris transfer provides long-term improvement in stiff knee gait with better improvement observed if time to PKF is late and preoperative PKF and knee ROM are low.

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