Rectus Femoris Distal Tendon Resection Improves Knee Motion in Patients With Spastic Diplegia

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Abstract

Background Children with spastic diplegia frequently show excessive knee extension (stiff-knee gait) throughout swing phase, which may interfere with foot clearance. Abnormal rectus femoris activity is commonly associated with a stiff-knee gait. Rectus femoris transfer has been recommended to enhance knee flexion during swing. However, recent studies suggest the transfer does not generate a knee flexor moment but diminishes knee extension moment in swing and MRI studies show the transferred tendons can be constrained by scarring to underlying muscles. Thus, it is possible knee flexion would be improved by distal rectus release rather than transfer since it would not be adherent to the underlying muscles. **Questions/purposes** We therefore determined whether rectus femoris distal tendon resection improves knee ROM and kinematic characteristics of stiff-knee gait in patients with spastic diplegia.

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Each author certifies that his or her institution waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research. This work was performed at Robert Debre Hospital and Motion Analysis Laboratory at Bois Larris Rehabilitation Center.

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Patients and Methods We studied 45 patients who underwent rectus femoris distal tendon resection as a part of multilevel surgery. Rectus femoris procedures were indicated based on kinematic characteristics of stiff-knee gait. All patients were walkers and had a mean age at surgery of 13 years (range, 6–22 years). We obtained gait analyses before surgery and at mean 2-year followup. We based postoperative assessment on clinical evaluation and gait analysis data.

Results At followup, rectus femoris distal tendon resection was associated with improved knee ROM and timing of peak knee flexion in swing, and the absolute values of peak knee flexion became normal for those patients who showed abnormal preoperative values.

Conclusions Kinematic parameters of stiff-knee gait improved after rectus femoris distal tendon resection. Given the preliminary nature of our report, we intend to study the same patients to assess outcomes at a longer followup.

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

Introduction

Children with spastic diplegia frequently have reduced knee motion in the sagittal plane (stiff-knee gait). This gait pattern was described by Sutherland and Davids [17] as an excessive knee extension throughout swing phase with variable alignment in stance. Prolongation of phasic, late stance, rectus femoris (RF) activity into swing phase constitutes an EMG pattern commonly associated with stiff-knee gait [13, 17, 18, 20]. RF proximal or distal release is said to improve knee flexion in patients with stiff-knee gait

and abnormal RF activity in swing phase [18, 20]. According to Sutherland et al. [18], RF surgery does not influence pelvic alignment or hip ROM. They concluded RF release reduces the extensor properties of the muscle and facilitates passive knee flexion in swing. Since patients with cerebral palsy tend to walk slower than normal, hip flexion moment in preswing often diminishes. For that reason, Perry [13] suggested abandoning proximal RF release and recommended transferring the RF posterior to the axis of knee flexion to enhance active knee flexion. Several studies compared the outcomes of RF release (proximally or distally) versus transfer [4, 10, 11, 19]. Although the results were controversial in terms of amount of variation in peak knee flexion (PKF) and time to PKF in swing, these studies confirmed there was a tendency toward more normal values after the RF transfer. This tendency could be explained by the notion that the RF, transferred posterior to the axis of knee flexion, would generate a knee flexion moment in swing. The choice of the transfer site did not influence PKF, knee ROM, or transverse plane kinematics values [4, 10].

Recent studies have attempted to explain the action of the RF muscle after distal tendon transfer. Riewald and Delp [14] investigated whether the RF converts to a knee flexor after being transferred to the semitendinosus muscle or to the iliotibial band. Rectus femoris EMG activity showed the muscle generated an extensor moment in all of their subjects. Based on cine phase-contrast MRI, Asakawa et al. [1] examined RF motion in vivo after tendon transfer surgery. In the tendon transfer group, the RF moved in the direction of the knee extensors and fiber excursions were reduced compared to vastus intermedius. These authors concluded the RF is not converted to a knee flexor after its distal tendon is transferred to the posterior side of the knee, but its capacity for knee extension is diminished by the surgery. They suggested scar tissue could form after RF transfer, making the RF adhere to the underlying muscles. They also examined three-dimensional (3D) MRI of patients who had RF transfer [2, 5] and observed abnormal, low-signal intensity images that could represent scar tissue between the transferred muscle and the underlying vasti in each of the patients. Three-dimensional (3D) models showed the transferred muscles followed angular, deviated paths to their new insertions, suggesting RF tendons were probably constrained by adhesions to the underlying muscles.

Clinical followup studies showed improvement in PKF values were maintained after RF transfer, but improvements in knee ROM tended to decrease over time [9, 16]. Moreau and Tinsley [8] compared the outcomes of a group of patients who had RF transfer as part of multilevel surgical procedures to another group of patients who did not undergo any RF procedure. They found the transfer helped maintain knee ROM and PKF values over time, after a

minimum followup of 3 years. Hemo et al. [6] compared the outcomes of two different techniques: RF distal release as described by Öunpuu et al. [11] and RF transposition to the iliotibial band. They found similar improvement in knee ROM, PKF, and time to PKF after 1-year followup. These authors concluded the benefit of RF procedure was related to the distal tendon release from the patella. After a review of the literature, we believed there was insufficient evidence supporting transferring the RF, rather than performing a distal release. We also thought a complete tendon resection would reduce adhesions and prevent relapses.

We therefore assessed the outcome of patients with spastic diplegia after RF distal tendon resection as a part of multilevel surgery to (1) evaluate the improvement of knee ROM during gait, (2) measure changes in PKF and time to PKF during swing phase, and (3) compare our results with those reported in the literature after RF distal release or transfer, since we are not aware of any previous reports on RF distal tendon resection.

Patients and Methods

We retrospectively reviewed 45 patients with cerebral palsy who underwent 80 RF distal tendon resections to treat stiff-knee gait between January 2003 and December 2005. The indications for RF surgery were (1) kinematic characteristics of stiff-knee gait; (2) abnormal EMG activity of RF; and/or (3) RF contractures on physical examination. Patients who showed prolonged RF EMG activity without kinematic characteristics of stiff-knee gait did not undergo RF procedures. To be included in the study, patients had to (1) be diagnosed with spastic diplegia related to prematurity; (2) be a functional walker, whether with or without the use of assistive devices; and (3) have had a 3D gait analysis performed before and after surgery. During the study period, we performed RF distal tendon resections on 109 patients. Forty-five patients met the selection criteria and were included in the study. The remaining patients had spastic familiar paraparesis or congenital hemiplegia or were not able to walk enough to obtain a 3D gait analysis. Thirty-five patients underwent bilateral RF procedures, for a total of 80 RF procedures. None of these patients had previous RF surgery. Gender distribution was 27 males and 18 females. Mean age at the time of surgery was 13.3 years (range, 6.1–22.6 years). The minimum followup was 1.5 years (mean, 2.2 years; range, 1.5–3 years). Our hospital institutional review board gave expedited approval and waived the need to obtain written informed consent.

Preoperatively, all patients were functional walkers: 33 patients walked without any assistive devices and 12 patients walked with crutches and used manual wheelchairs for long distances (Table 1). We graded function

Table 1. Patient data

Patient	GMFCS level	Side	Age (years)	Concurrent surgical procedures*
1	II	Bilateral	9.2	Hip, Add, Tri, FRO (L)
2	II	Bilateral	8.6	Hip, Add, Tri
3	I	Unilateral	16.5	Hip, Add, Tri, FRO
4	III	Bilateral	22.6	Add, TP (L), TA (L)
5	III	Bilateral	13.9	Hip, Add, Per, FRO, TRO
6	II	Bilateral	10.3	Hip, Add, FRO, TP (R)
7	II	Unilateral	13.2	Hip, Add, FRO
8	II	Bilateral	19.3	Hip, Add, Per, FRO, TRO
9	II	Bilateral	11.9	Add, Tri, TA (L), FRO (L), Foot (L)
10	III	Bilateral	15.2	Add, Tri
11	I	Unilateral	15.8	Add, FRO
12	II	Bilateral	12.5	Add, Tri, Foot (R)
13	II	Unilateral	12.7	Per, TRO, Foot
14	III	Bilateral	12.2	Add, Tri, TP (L), TA (L), TRO (L)
15	III	Unilateral	17.3	Add, Tri, Foot
16	II	Bilateral	9.6	Add, Tri, TP(R), TA(R)
17	II	Bilateral	15.4	Add, TP (L), TA (L), Per (R), TRO
18	II	Bilateral	16.1	Add, Tri, FRO
19	I	Unilateral	9.4	Tri
20	II	Bilateral	8.9	Hip (R), Tri, Per, TRO
21	III	Bilateral	17	Hip, Add, Tri, FRO
22	II	Bilateral	14.9	Add, Tri, FRO
23	II	Unilateral	16	Add, Per, TRO
24	II	Bilateral	9.7	Hip (R), Add, Tri, TRO
25	III	Bilateral	14.4	Add, Tri, FRO
26	II	Bilateral	8.3	Hip, Add, Tri, FRO
27	II	Bilateral	6.9	Add, Tri, FRO
28	III	Bilateral	17.1	Tri, Foot
29	III	Bilateral	16	Add, Per, TRO, Foot
30	II	Bilateral	12.2	Hip (R), Add, Tri, TA, Per (R), FRO
31	III	Bilateral	15.4	Add, Per, FRO
32	II	Bilateral	12.1	Hip, TA, Foot
33	II	Bilateral	12.4	Hip, Add, Per, TRO
34	III	Bilateral	15.3	Hip, Add, FRO
35	II	Bilateral	6.1	Add
36	II	Bilateral	12.4	Add, Tri
37	II	Unilateral	10.3	Tri, Foot
38	II	Unilateral	14.3	Add, TP, TA, TRO
39	II	Bilateral	11.8	Add, Tri (R)
40	II	Bilateral	12.6	Add, Tri, FRO (R)
41	II	Unilateral	9.5	Add, Tri
42	II	Bilateral	13.2	Add, Tri, Foot

Table 1. continued

Patient	GMFCS level	Side	Age (years)	Concurrent surgical procedures*
43	III	Bilateral	13	Hip, Per, TRO
44	II	Bilateral	12.8	Add, Tri
45	II	Bilateral	14.5	Per, TRO (L)

* All patients had hamstrings lengthening associated with rectus femoris release; GMFCS = Gross Motor Function Classification System [12]; Hip = psoas release; Add = gracilis/adductor longus release; Tri = gastrocnemius/soleus release; FRO = femur osteotomy; TRO = tibia osteotomy; Foot = subtalar arthrodesis or lateral column lengthening. Per = peroneus brevis lengthening; TP = tibialis posterior lengthening; TA = tibialis anterior split tendon transfer; R = right side; L = left side; the procedure was performed on both sides if unspecified.

using the Gross Motor Function Classification System (GMFCS) [12]. We used the GMFCS level as a criterion of inclusion but did not perform a functional assessment to evaluate the functional benefits of the procedure. Similarly, we recorded preoperative EMG, but since EMG studies were not consistently included in postoperative gait analysis, we did not have adequate information regarding changes in RF electrical activity. For each operated limb, we preoperatively determined RF contractures, knee extension in stance, PKF in swing, time to PKF, and knee ROM, as well as patients' walking velocity and cadence. We estimated RF degree of contracture by measuring the angle of hip flexion, with the patient lying prone with both lower limbs over the edge of the table to bring the pelvis to a neutral position and the knee of the tested limb bent at 90°.

We currently use RF distal tendon resection to treat patients who exhibit kinematic characteristics of stiff-knee gait or RF contractures. Since 2003, this has been the preferred technique at our institution to treat stiff-knee gait. The same two surgeons (GFP, AP) performed the procedure for all patients. The approach for the RF distal tendon resection procedure was similar to that described for RF transfer [19]. Through a longitudinal anterior approach, proximal to the patella, the muscle was dissected as if a transfer were to be performed. The RF tendon was then released from the patella, proximally transected at the muscular junction, and completely removed (Fig. 1). Contrary to the transfer technique description, we paid particular attention to avoid any tendon fibers being left between the muscle and the patella because we have operated on RF transfer relapses and found fibrous tissue causing reattachment of muscle fibers to the patella.

We performed all the RF procedures as a part of multilevel surgery (Table 1). All limbs in this series had medial hamstrings aponeurotic lengthening. Adductor releases (gracilis myotomy with or without adductor longus

Fig. 1 A photograph shows how the RF is dissected from the underlying vasti and transected at the musculotendinous junction.

lengthening) were performed in 67 of the 80 procedures. The third most common soft-tissue procedure was gastrocnemius/soleus lengthening (48 sides). Peroneus brevis lengthening was performed in 20 sides; tibialis anterior transfer was performed in 10 procedures and tibialis posterior lengthening in five. Twenty-seven hips underwent psoas lengthening over the brim of the pelvis. Twenty-eight limbs underwent femoral derotation osteotomy, 21 underwent tibial derotation, and 11 underwent foot surgery (subtalar arthrodesis or lateral column lengthening).

After surgery, the patients followed a standardized rehabilitation program, including two physical therapy sessions a day. The program started the day after surgery and extended for an average of 4 months if only soft-tissue surgery was performed or for 6 months when bony procedures were part of the multilevel surgery.

The patients were seen 6 weeks, 3 months, 6 months, 12 months, and 18 months after surgery. Thereafter, the patients were seen once a year until they were 18 years old. A physical examination including ROM, force, and spasticity assessment was performed at every visit. Video recording and temporal spatial parameters were obtained at 3 and 6 months postoperatively. Full 3D gait analysis was performed at 18 months' and 3 years' followup (a few years ago, gait analysis timing was more variable, and thus, these patients had the analyses performed at an average of 2 years' followup). If bony procedures were performed, radiographs were taken 3 months and 1 year after surgery.

We reviewed patients' medical records to collect the following clinical data: cerebral palsy pattern, gender, level of motor function (GMFCS), age at surgery, number and type of concomitant surgical procedures, presence of RF contractures, and surgical complications.

The gait analysis data we collected were date of preoperative and postoperative gait analysis, walking velocity

and cadence, values of peak knee extension in stance, PKF in swing, knee ROM (defined as the difference between the two last values), time to PKF in swing (measured as percentage of the gait cycle), and presence of RF abnormal EMG pattern in swing.

We based postoperative assessment on physical evaluation and gait analysis data. All patients were available for postoperative gait analysis and final followup visit. The gait analyses included videotaping, 3D kinematics, kinetics, dynamic EMG, and clinical assessment. Postoperative gait analysis did not systematically include EMG recording. Examinations followed the Helen Haynes protocol [7]. The motion of body segments was recorded in 3D with a six-camera Vicon™ 612 (Oxford Metrics Ltd, Oxford, UK) infrared motion analysis system, at a sampling rate of 50 Hz. Respecting the Vicon™ Plug-in Gait™ biomechanical model (Oxford Metrics Ltd), 13 passive reflecting markers were positioned on various parts of the body. We filtered the data using a second-order Butterworth filter and calculated the Euler angles for the hips, knees, and ankles. We digitized kinetics force plates (Advanced Mechanical Technology, Inc, Watertown, MA) and MA300 EMG system (Motion Lab Systems, Inc, Baton Rouge, LA) data and synchronized them using a 16-bit A/D card with a sample frequency of 1000 Hz. We acquired the EMG signals with MotionLab sensors (Motion Lab Systems, Inc) consisting of two circular stainless steel dry button electrodes. We collected data from five superficial muscles: RF, vastus lateralis, medial hamstrings, tibialis anterior, and lateral gastrocnemius. As the patient walked along a walkway at a self-selected cadence, we collected data from multiple strides; we selected one representative stride for analysis. Preoperatively, all patients showed characteristics of stiff-knee gait (insufficient knee flexion during swing and/or delayed PKF), an overall decrease in knee ROM, RF prolonged activity in swing, and some degree of RF contracture. PKF values were less than 45° in 12 patients (16 sides) and within normal limits for the rest of the patients. Values of gait velocity and cadence were below average for all patients.

The results after operation for knee ROM, peak knee extension in stance, PKF, and time to PKF during swing, temporal spatial parameters, and degree of RF contracture were compared for all patients using paired *t* tests. The pre- and postoperative PKF values were also compared using paired *t* tests for the 12 patients with preoperative PKF values of less than 45°.

Results

Mean ($\pm$ SD) values of sagittal plane knee ROM during gait increased ($p < 0.001$) from $30^\circ \pm 13^\circ$ preoperatively to $41^\circ \pm 12^\circ$ postoperatively (Table 2). Overall knee

motion during gait cycle was calculated by the difference between the values of peak knee extension during stance phase and PKF during swing phase. Average values of peak knee extension improved ($p < 0.001$) from $28^\circ \pm 15^\circ$ preoperatively to $15^\circ \pm 13^\circ$ postoperatively. An example of knee kinematics correction after RF release and hamstrings lengthening is shown (Fig. 2).

For the whole group of patients, PKF values decreased ($p = 0.122$) from $59^\circ \pm 12^\circ$ to $57^\circ \pm 10^\circ$ after surgical treatment (Table 2). In the 12 patients (16 sides) with PKF values of less than 45° (mean, $43^\circ \pm 4^\circ$), the postoperative PKF increased ($p = 0.011$) to $53^\circ \pm 10^\circ$. The other 23 patients showed a preoperative PKF of $62^\circ \pm 9^\circ$ and a postoperative PKF of $58^\circ \pm 9^\circ$ ($p = 0.058$). Preoperative time to PKF averaged $83\% \pm 7\%$ of the gait cycle and this value diminished ($p < 0.001$) to $77\% \pm 5\%$ postoperatively. Expressed as percentage of swing phase, time to

PKF improved from an average of 52.2% to 35.7%. Stance phase length increased ($p = 0.038$) postoperatively from a mean of 63.3% to 64.8% of gait cycle.

The mean degree of RF contracture diminished ($p < 0.001$) from $30^\circ \pm 12^\circ$ to $6^\circ \pm 7^\circ$ after surgery (Table 2). Walking velocity increased ($p = 0.053$) from 0.7 m per second to 0.9 m per second and cadence increased ($p = 0.103$) from 108 steps per minute to 116 steps per minute after surgery.

Minor postoperative complications were recorded for 14 patients: eight patients presented with hematomas, either with RF or hamstrings approach, and six patients showed inflammatory signs related to suture rejection on one or more of the surgical wounds. None of the patients required further surgery to treat these complications. No major complications were recorded.

Discussion

Patients with spastic cerebral palsy commonly present with limited knee ROM, ie, stiff-knee gait. RF prolonged activity into swing phase is reportedly the most common cause of stiff knee in children [13]. Waters et al. [20] found improvement after RF tendon release in patients with an EMG pattern of isolated RF activity during swing. Perry [13] recommended transferring the RF to the hamstrings to generate a knee flexor moment. Several studies from the last decade focused on understanding the action of the RF after distal tendon transfer [1, 2, 5, 14]. These studies showed the RF did not generate a flexor moment after being transferred to the posterior side of the knee. Three-dimensional MRI models showed the transferred muscles followed angular paths to their new insertions, suggesting RF tendons were constrained by adhesions to the underlying tissues. Thus, the observed improvement in knee flexion would be related to a diminished extensor power after distal RF release [2, 5]. We believed there was insufficient evidence supporting transferring the RF and we started performing distal tendon resections in 2003. In this preliminary report, we therefore assessed the outcome of patients with spastic diplegia after RF distal tendon resection as a part of multilevel surgery by (1) evaluating the improvement of knee ROM during gait, (2) measuring changes in PKF and time to PKF during swing phase, and (3) comparing our results with those reported in the literature after RF distal release or transfer, since we are not aware of any previous reports on RF distal tendon resection.

We recognize limitations to our study. First, the mean followup was 2 years. We believed it was crucial to analyze our preliminary results since we have changed the surgical technique to assess patients' gait improvement after treatment. Second, we decided not to compare this

Table 2. Comparison of pre- and postoperative knee kinematics, degree of RF contracture, and spatial temporal parameters

Parameter	Preoperative	Postoperative	p Value
Knee ROM ($^\circ$)	30 ± 13	41 ± 12	< 0.001
Knee extension in stance ($^\circ$)	28 ± 15	15 ± 13	< 0.001
PKF in swing ($^\circ$)*	43 ± 4	53 ± 1	0.011
Time to PKF (% gait cycle)	83 ± 7	77 ± 5	< 0.001
RF contracture ($^\circ$)	30 ± 12	6 ± 7	< 0.001
Walking speed (m/second)	0.7 ± 0.3	0.9 ± 0.2	0.053
Cadence (steps/minute)	108.6 ± 24	116.3 ± 14	0.103

Values are expressed as mean $\pm$ SD; * group of patients who had abnormal preoperative PKF values; RF = rectus femoris; PKF = peak knee flexion.

Fig. 2 A graph shows an example of knee kinematics correction after RF release and hamstrings lengthening.

Table 3. Comparison of knee kinematics outcomes after RF surgery from our study and others in the literature

Study	Number of patients/sides CP pattern	Mean age at surgery (years)	Other procedures/ number of hamstrings lengthenings	RF surgery type (number of limbs)	Mean followup GA	Pre/post knee ROM	Pre/post PKF	Pre/post time to PKF	Difference between groups
Hemo et al. [6]	13/25 Diplegia (9) Quadriplegia (4)	13.8	No	Transfer (13)	12 months	31/37 ($p < 0.010$)	29/42 ($p < 0.010$)	52/39* ($p < 0.010$)	PKF ($p < 0.050$)
Moreau and Tinsley [8]	41/72 Hemiplegia Diplegia	10.9 (transfer) 8.4 (no RF surgery)	Multilevel surgery/?	Transposition to ITB (12) Transfer (50) No RF surgery (22)	3 years (3–4.5 years)	31/36 ($p < 0.010$) 17/28 ($p < 0.001$) 28/33 ($p = \text{no data}$)	37/49 ($p < 0.010$) 47/56 ($p < 0.008$) 54/50 ($p = \text{no data}$)	55/38* ($p < 0.010$) 81/79 ($p < 0.005$) 78/76 ($p < 0.005$)	ROM ($p < 0.001$) PKF ($p < 0.031$) Time to PKF ($p < 0.003$) None
Önupuu et al. [11]	98/136 Hemiplegia (4) Diplegia	10 (transfer) 8 (release)	Multilevel surgery/119	Transfer (105) Release (31)	12 months	30/46 ($p < 0.001$) 37/43 ($p = 0.147$) 40/50 ($p < 0.001$)	55/55 ($p = 0.971$) 64/57 ($p = 0.047$) 55/58 ($p = 0.059$)	50/43* ($p < 0.001$) 57/52* ($p = 0.131$) No data	None
Saraph et al. [15]	25/46 Diplegia	13.6	Multilevel surgery/56	Transfer	3 years	26/29 ($p = 0.647$)	37/47 ($p < 0.001$)	No data	
Saw et al. [16]	18/26 Hemiplegia (5) Diplegia (9) Quadriplegia (4)	11.7	Multilevel surgery/7	Transfer	4.6 years (3.3–7.8 years)				
Sutherland et al. [19]	22/42 Hemiplegia (1) Diplegia (17) Quadriplegia (4)	12.6 (release) 11.3 (transfer)	Previous hamstrings (33) Simultaneous hamstrings (1)	Proximal release (13) Transfer (19)	22 months 12 months	38/46 ($p = 0.006$) 41/54 ($p = 0.002$)	42/51 ($p = 0.003$) 44/60 ($p < 0.001$)	36/37* ($p = 0.900$) 56/43* ($p = 0.010$)	PKF ($p = 0.02$) ROM ($p = 0.2$)
Presedo et al.	45/80 Diplegia	13.3	Multilevel surgery/80	Distal tendon resection	24 months (18–36 months)	30/41 ($p < 0.001$)	59/57 ($p = 0.011$)	52/35* ($p < 0.001$)	Time to PKF ($p = 0.07$)

* Expressed as a percentage of swing time; RF = rectus femoris; CP = cerebral palsy; GA = gait analysis; pre = preoperative; post = postoperative; PKF = peak knee flexion in swing; ITB = iliotibial band.

cohort to a larger series of patients who had undergone RF tendon transfer before 2003 because the time those patients had a postoperative gait analysis was variable and this fact made it difficult to compare the groups at the same followup time. We intend to report on the current series of patients with a long-term followup. Third, the RF procedures were always performed as part of a multilevel surgery. This type of surgery has been the gold standard at our institution for the last 10 years to treat gait problems in patients with cerebral palsy. The convenience of this type of surgical treatment has been well documented in the literature [3].

Overall knee ROM improvement after RF surgery has been consistently reported by short-term followup studies [6, 11] (Table 3). The type of RF procedure (transfer, proximal or distal release) and the presence of concomitant hamstrings lengthening did not appear to influence the knee ROM outcomes [6, 19]. Öunpuu et al. [11] observed patients with a knee ROM greater than 80% of normal did not show any improvement after RF surgery. All patients in our study had preoperative knee ROM less than 80% of normal. We found an 11° improvement in this parameter 2 years after surgery. These results are similar to those of Öunpuu et al. [11] and Sutherland et al. [19] who reported an average 10° improvement in overall knee ROM. Moreau and Tinsley [8] and Saraph et al. [15] reported an increased knee ROM 1 year after RF transfer, which remained stable at 3 years' followup. Saw et al. [16] observed a deterioration of the postoperative improvement in knee ROM after a mean followup of 4.6 years. Since knee ROM values are related to both maximum knee flexion in swing and minimum knee flexion in stance, outcomes are influenced by the effect of RF procedures and hamstrings lengthening as well. Hemo et al. [6] observed a progressive increase in minimum knee flexion in stance. They explained this by the combined influence of the natural tendency of crouch to increase over time and the fact that their patients had not undergone hamstrings lengthening surgery.

Sutherland et al. [19] reported a greater degree of improvement in PKF after RF transfer, compared to proximal release. Hemo et al. [6] reported a postoperative improvement in PKF during swing from 33° to 45°. Although the PKF improved in all patients, they observed greater improvement after RF transposition to the iliotibial band, compared to RF transfer to the sartorius. Öunpuu et al. [11] found improvement in PKF in patients with preoperative knee ROM less than 80% of normal after RF transfer. These authors hypothesized, in the RF release group, some tethering effect secondary to scarring may resist knee flexion in swing. In our study, all patients had a preoperative knee ROM less than 80% of normal. The PKF improved after RF distal tendon resection for patients who had abnormal preoperative PKF values. As clearly stated

by Moreau and Tinsley [8], the average PKF values in actual degrees can be misleading due to the presence of different gait patterns at the knee. Whereas we found no changes in PKF for the whole group of patients, we observed improvement in PKF in swing for patients who had preoperative PKF values of less than 45°.

Several short-term followup studies reported improvements in time to PKF after RF transfer [6, 11, 19]. Whereas Öunpuu et al. [11] did not find an improvement in this parameter after RF distal release, Hemo et al. [6] reported an improvement after distal RF transposition. We also observed an increase in PKF after surgery with postoperative values closer to normal than in the aforementioned studies.

To conclude, we observed an improvement in knee kinematic parameters after RF distal tendon resection with a short followup time. Our results are similar to those reported in the literature after RF transfer, but we found more improvement in PKF than what has been reported after distal tendon release. To confirm these preliminary results, we intend to report outcomes at a longer followup.

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