Rectus Femoris to Gracilis Muscle Transfer With Fractional Lengthening of the Vastus Muscles: A Treatment for Adults With Stiff Knee Gait
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Surena Namdari, Stephan G. Pill, Amun Makani, Mary Ann Keenan

**Background.** Stiff knee gait, which may be seen in patients with upper motor neuron injury, describes a gait pattern with a relative loss of sagittal knee motion. It interferes with foot clearance during swing, often leading to inefficient compensatory mechanisms and ambulatory dysfunction. Distal rectus femoris muscle transfers and fractional lengthening of the vastus muscles have been performed in adult patients.

**Objective.** The purpose of this study was to describe a unique surgical technique and report on initial outcomes.

**Design.** A retrospective case-series study design was used.

**Methods.** The patients were adults with stiff knee gait due to stroke or traumatic brain injury who underwent distal rectus femoris muscle transfer with fractional lengthening of the vastus muscles. The patients (19 men and 18 women) had an average age of 51 years at the time of surgery. Lower-extremity examinations, clinical gait analyses, and satisfaction levels were recorded preoperatively and postoperatively.

**Results.** At a mean follow-up time of 10 months, 36 (97%) of the 37 patients were satisfied with their clinical and functional results, and the average Viosca score improved from 3.1 to 3.5.

**Limitations.** Limitations of the study include use of a retrospective design, lack of a control group, and limited quantitative measures of gait.

**Conclusion.** Distal rectus femoris muscle transfer and fractional lengthening of the vastus muscles were found to be a possible treatment for adults with stiff-knee gait caused by stroke or traumatic brain injury.
A Treatment for Adults With Stiff Knee Gait

Stiff knee gait describes a gait pattern with a relative loss of sagittal-plane knee motion, which interferes with foot clearance during swing.\(^1\) It may be seen in patients with upper motor neuron injury, such as stroke or traumatic brain injury (TBI), and is commonly seen in children with cerebral palsy after hamstring muscle lengthening surgery. One proposed etiology of stiff knee gait is abnormal timing of the rectus femoris muscle. Instead of its normal brief action from terminal swing into mid stance and again in pre-swing, the rectus femoris muscle in patients with stiff knee gait has prolonged activity in the swing phase or is active throughout the entire gait cycle.\(^2\) This muscle activity leads to inadequate knee flexion during swing and poor foot clearance. Consequently, these patients often compensate with hip circumduction, pelvic elevation, and vaulting of the contralateral lower extremity. These compensatory mechanisms are inefficient and ineffective in these patients due to poor selective muscle control and co-spasticity of the hamstring and quadriceps muscles at mid-swing.\(^3\)

Increased vastus muscle activity and decreased iliopsoas muscle activity also have been proposed as potential causes of stiff knee gait. Perry\(^4\) demonstrated that the rectus femoris muscle often assumes the role of a primary hip flexor in these patients. In addition, there is inadequate activation of the sartorius and gracilis muscles and the short head of the biceps muscle during the swing phase.\(^4\) Surgery is considered if a patient with stiff knee gait has a reasonable ambulatory speed, because the amount of knee flexion during swing is directly related to walking speed. The patient also should have good strength (force-generating capacity) of the hip flexors, as forward momentum of the leg normally provides the inertial force to flex the knee. Dynamic electromyography (EMG) often demonstrates that the rectus femoris muscle displays dysynergistic activity from pre-swing through terminal swing, and surgical intervention is more likely to be effective if a block of the rectus femoris or vastus intermedius muscle improves knee flexion.

Numerous surgical procedures have been proposed to manage stiff knee gait, including proximal release of the rectus femoris muscle;\(^5\) fractional lengthening of the hamstring muscles;\(^6\) release of the distal rectus femoris muscle, with or without release of the vastus intermedius muscle;\(^6\) and distal rectus muscle transfer.\(^7\) Perry\(^7\) proposed transferring the distal rectus femoris muscle posterior to the knee axis in conjunction with hamstring muscle lengthening for treating children with cerebral palsy. This procedure allowed knee extension in stance, while augmenting knee flexion in swing for foot clearance.\(^7\)

We have been performing distal rectus muscle transfers in conjunction with vastus muscle lengthening in adult patients with stiff knee gait following stroke or TBI. Our study is unique in that previous studies on rectus muscle transfers have centered on a pediatric population with cerebral palsy. In addition, we include vastus muscle lengthening at the time of rectus muscle transfer, which, to our knowledge, has not been previously described. The purpose of this study was to determine whether rectus muscle transfer combined with vastus muscle lengthening improves ambulation.

Method

Study Sample

Patients who underwent rectus femoris muscle transfer and fractional lengthening of the vastus muscles for stiff knee gait related to stroke or a TBI from January 2003 to August 2008 were included in the study. All procedures were conducted by the senior surgeon (M.A.K.). Patients with cerebral palsy, spinal cord injury, heterotopic ossification, an equinovarus foot deformity, or less than 6 months of follow-up were excluded. Patients who were non-ambulatory and those who had multiple simultaneous surgical procedures also were excluded. Stiff knee gait was defined as delayed and decreased peak knee flexion in the swing phase and diminished knee range of motion throughout the gait cycle. Dynamic EMG was used preoperatively to assist in selecting surgical candidates. Continuous or prolonged activity of the rectus femoris muscle during the swing phase was considered a positive result. Patients with a positive dynamic EMG test, a positive Duncan-Ely test, and reduced knee flexion during the swing phase were considered surgical candidates. All methods were approved by the Institutional Review Board (IRB) of the Hospital of the University of Pennsylvania. This study was found to be IRB exempt, and a waiver of consent was obtained.

Surgical Technique

Each patient was positioned supine on an operating table, and a pneu-
A longitudinal incision measuring approximately 10 cm was made on the distal anterior thigh over the distal rectus femoris (Fig. 1A). The distal quadriceps muscle is exposed medially and laterally. The rectus femoris muscle is carefully dissected free from the other quadriceps muscles distally to the level of the mid-patella (Fig. 1B). A locking stitch (Krakow) of heavy, nonabsorbable suture is placed in the distal free end of rectus tendon. The rectus muscle is freed proximally to isolate it from the vastus muscles (Fig. 1C). The vastus intermedius muscle is identified beneath the reflected rectus femoris muscle. The tendon fibers over its muscle belly are incised. The myotendinous junctions on the undersurface of the vastus medialis and vastus lateralis muscles then are dissected. These muscles are lengthened by transecting the tendon fibers over the muscle belly (Fig. 1D). Photographs may not be used or reproduced without written permission from Dr Keenan.

A second incision was made on the posteromedial distal thigh (Fig. 2A). The gracilis muscle and tendon were identified and isolated. The gracilis tendon was released proximally from the muscle belly, but was left attached distally (Fig. 2B). A subcutaneous tunnel was created between the anterior and medial thigh incision.

Figure 1.
Surgical technique showing first incision. The patient is positioned supine on the operating table, and a pneumatic tourniquet is applied. A longitudinal incision measuring approximately 10 cm is made on the distal anterior thigh over the distal rectus femoris (Fig. 1A). The distal quadriceps muscle is exposed medially and laterally. The rectus femoris muscle is carefully dissected free from the other quadriceps muscles distally to the level of the mid-patella (Fig. 1B). A locking stitch (Krakow) of heavy, nonabsorbable suture is placed in the distal free end of rectus tendon. The rectus muscle is freed proximally to isolate it from the vastus muscles (Fig. 1C). The vastus intermedius muscle is identified beneath the reflected rectus femoris muscle. The tendon fibers over its muscle belly are incised. The myotendinous junctions on the undersurface of the vastus medialis and vastus lateralis muscles then are dissected. These muscles are lengthened by transecting the tendon fibers over the muscle belly (Fig. 1D). Photographs may not be used or reproduced without written permission from Dr Keenan.
The medial intramuscular septum was sharply divided for a distance of approximately 5 cm (Fig. 2C). The distal end of the rectus femoris tendon was passed subcutaneously through the tunnel to the posteromedial thigh incision. The rectus femoris and gracilis tendons were interwoven using a Pulvertaft technique and secured with multiple sutures of heavy, nonabsorbable suture (Fig. 2D). The tourniquet was released, and the incisions were irrigated. The wounds were closed in routine fashion.

**Postoperative Protocol**

A knee immobilizer was used postoperatively to allow healing of the tendon transfer. A continuous passive motion machine was used on the first day postoperatively, and physical therapy was instituted for gait training and knee passive range of motion exercises. Over the course of 1 to 2 weeks, patients were allowed to start full weight-bearing ambulation training, and they were weaned off of the knee immobilizer. Gait training emphasized hip and knee flexion during the swing phase. Marching exercises are helpful and were encouraged. Active knee extension exercises without ankle weights were started immediately to strengthen the quadriceps muscle. Hip flexor strengthening was started immediately after surgery. Electrical stimulation of the hip flexor or knee extensor muscles may be used 3 weeks after surgery if deemed appropriate by the treating therapist, physiatrist, or neurologist. Biofeedback techniques may be used immediately after surgery.
Data Acquisition/Analysis

Patient charts, including preoperative and postoperative office notes and surgical reports, were reviewed and data parameters were obtained. All patients were evaluated before and after surgery using a standard, detailed format. Data parameters included age, sex, duration from TBI or stroke to surgery, assistive device use, and ambulatory status using the Viosca score. The Viosca score represented the primary outcome measure in this study. The Viosca score is a validated instrument used to evaluate functional ambulatory capacity, which places patients into 1 of 6 categories: (0) unable to ambulate; (1) nonfunctional ambulation, (2) household ambulation, (3) neighborhood ambulation, (4) independent community ambulation, and (5) normal ambulation. The Viosca score was calculated retrospectively, based on descriptions of patients’ ambulatory status from detailed histories. As noted by Viosca et al., a patient is assigned to one of the functional walking levels after his or her gait is examined, and certain data are obtained by questioning the patient. These important data parameters include the degree of walking independence, agility, and safety, as well as information obtained directly from both patients and their relatives. Special attention is given to the patient’s ability to deal with different surroundings. Viosca et al. reported good interrater reliability of this instrument.

Secondary outcome measures included patient satisfaction, physical examination parameters, and observational gait analysis. Patient satisfaction was specifically addressed at each office visit by the senior author (M.A.K.) and was specifically documented in each office note. All physical examinations were conducted by the senior author. Gait analysis was a clinical measure by the senior author based on observational evaluation of ambulation. During the swing phase, knee flexion and knee range of motion were recorded as kinematic variables. Postoperative complications also were recorded. Statistical analysis was conducted using the Student t test for independent samples to compare preoperative and postoperative swing-phase knee flexion and Viosca functional ambulation level.

Results

Thirty-seven patients (19 men and 18 women) underwent rectus muscle transfer with vastus muscle lengthening during the study period. Their average age was 51 years at the time of surgery. Twenty-nine patients had a previous stroke, and 8 patients had a TBI. There was an average delay of 8 years between the stroke or traumatic injury and surgery. The mean follow-up was 10 months. Patient characteristics are shown in the Table.

The average Viosca score was 3.1 preoperatively and 3.5 postoperatively. This improvement was statistically significant (P<.001). Thirteen patients experienced an improvement in Viosca score, and 24 patients experienced no change in Viosca score. No patients had a decrease in Viosca score. Twenty-one patients used an orthosis preoperatively, which decreased to 13 patients at the time of latest follow-up. Similarly, 20 patients used an assistive device for ambulation preoperatively, which decreased to 15 patients at most recent follow-up. Thirty-six (97%) of the 37 patients were satisfied with their clinical and functional results. The patient who was dissatisfied had recurrence of deformity to near preoperative levels. Of the 21 patients with documented swing-phase knee range of motion, the average knee flexion during swing increased from 8 degrees (range=0°–15°) preoperatively to 33 degrees (range=20°–50°) at the most recent follow-up (P=.12).

Clinical gait analysis revealed an improvement in compensatory foot clearance strategies during gait, such as reduced hip hiking, vaulting, and circumduction; however, these variables were not consistently documented and were not formally evaluated. There were no reported deleterious effects on knee flexion during the stance phase, as no patients had knee instability or buckling during the stance phase. There were 4 complications (1 deep venous thrombosis, 1 superficial wound infection, and 2 hematomas).

Discussion

To our knowledge, this was the first study to evaluate the effects of distal rectus muscle transfer in an adult population with stroke or TBI and

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
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<tbody>
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<td>N (study sample)</td>
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</tr>
<tr>
<td>Male</td>
<td>19</td>
</tr>
<tr>
<td>Female</td>
<td>18</td>
</tr>
<tr>
<td>Mean age (range)</td>
<td>51 y (24–76)</td>
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<tr>
<td>No. poststroke</td>
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</tr>
<tr>
<td>No. post-traumatic brain injury</td>
<td>8</td>
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<tr>
<td>Mean duration between stroke/traumatic brain injury and surgery (range)</td>
<td>8 y (1.75–14.0)</td>
</tr>
<tr>
<td>Mean follow-up (range)</td>
<td>10 mo (6–31)</td>
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stiff knee gait. Simultaneous fractional lengthening of the quadriceps muscle also had not been described previously. Our results suggest that the combination of distal rectus muscle transfer with fractional lengthening of the vastus muscles improves knee flexion during the swing phase while not compromising knee stability during the stance phase. More importantly, patients reported excellent satisfaction postoperatively and an increased Viosca functional ambulation level. These outcomes may lead to fewer falls in this at-risk patient population. We believe that this procedure improves knee extension in stance while augmenting knee flexion in swing for foot clearance. Although a Viosca score increase from 3.1 to 3.5 may appear to lack clinical relevance, we believe that it demonstrates a promising trend toward improved ambulation after surgery. There is no minimal clinically important difference reported for the Viosca score; however, a linear correlation has been found between Viosca score and walking speed. Unfortunately, the Viosca score may not be a sensitive enough instrument to adequately assess walking efficiency, which is one of the primary goals of rectus muscle transfer surgery.

In order to offer appropriate surgical intervention for stiff knee gait, a clear understanding of knee kinetics and kinematics is essential. Although the knee has many functions during the gait cycle, its primary roles are to provide foot clearance during the swing phase and shock absorption during the loading response. The knee normally begins the stance phase in near full extension, flexes approximately 15 degrees during loading, and then gradually extends toward terminal stance. The vastus muscles counteract the ground reaction flexion moment during the loading response. After mid stance, knee extension is maintained by a plantar flexion and knee extension couple under control of the triceps surae muscle. The knee rapidly flexes approximately 40 degrees at pre-swing, which increases to approximately 60 degrees at initial swing. The rectus femoris muscle is active in pre-swing and initial swing and again from terminal swing to mid stance. It functions to accelerate the thigh and lower leg while restraining excessive knee flexion. Swing-phase sagittal knee motion is mostly passive at a normal walking cadence but requires increasing muscle activity as cadence increases. In stiff knee gait, the rectus femoris muscle has prolonged activity during the swing phase, thus disturbing the precise balance of knee motor activity.

In addition to abnormal activity during the swing phase, Goldberg et al. found that many patients with stiff knee gait have abnormally large knee extension moments during double support, which correlated with low knee flexion velocity at toe-off. A subsequent study by Reinbolt et al. confirmed that rectus femoris muscle activity during pre-swing is equally as important as early swing activity and may be more responsible for the loss of knee motion during the swing phase in some patients.

The evolution of surgical management for stiff knee gait started with proximal release of the rectus femoris muscle. In a series of 8 patients with cerebral palsy and spastic gait, Sutherland et al. found that proximal tenotomy of the rectus femoris muscle improved gait in patients with enough rectus muscle spasticity (reflex activity) to interfere with initiation of the swing phase and in patients with decreased knee flexion. However, they did not find any benefits from proximal tenotomy for improving hip or pelvic biomechanics. Perry proposed that a rectus muscle transfer would provide preservation of hip flexion while increasing knee flexion during swing. Rectus femoris muscle transfer has a greater influence on increasing knee flexion and improving postoperative knee range of motion compared with rectus femoris muscle release.

Gage et al. proposed transferring the rectus femoris muscle to the sartorius muscle in children with cerebral palsy and inadequate knee flexion during swing and an internal foot progression angle in stance. Similarly, they proposed rectus femoris muscle transfer to the posterior iliotibial band if there is inadequate knee flexion during swing and an external foot progression angle. Although they did not find a significant change in foot progression angle postoperatively, they observed an improvement in knee flexion during the swing phase in both groups. They concluded that the sartorius muscle is not an ideal recipient for the transfer because it inserts anteriorly on the tibia and thus has less rotation force. They also found the sartorius muscle to be of poor structural integrity, which may lead to transfer failure. Gage later emphasized the importance of a posterior transfer to better augment knee flexion and described transferring the distal rectus femoris muscle to either the semitendinosus muscle or the posterior iliotibial band.

Other authors have demonstrated similar success of the distal rectus femoris muscle transfer in children with cerebral palsy and a stiff knee gait. It is capable of developing a knee flexion moment during swing while preserving rectus femoris muscle activity at the hip, which may further contribute to knee flexion via dynamic coupling of a flexion moment about the hip. Sutherland et al. reported that knee flexion during the swing phase increased an average of 16 degrees after transfer of
the rectus femoris muscle. Transferring the distal rectus femoris muscle also prevents it from reattaching to the patella, which has been observed in rectus femoris muscle release. Ounpuu et al\(^{10}\) investigated the effect of transfer location site (sartorius, gracilis, semitendinosus, iliotibial band) on the outcome of the rectus femoris muscle transfer surgery and found no statistically significant difference among transfer sites in postoperative knee range of motion.

Similar to previous studies, we found the sartorius muscle to have inferior anatomic and biomechanical characteristics. The thin overlying fascia of the sartorius muscle often is too fragile to accept a transfer. In comparison, the gracilis tendon is stout and can withstand adequate tensioning. The gracilis tendon also is more posterior to the knee axis, thus providing an improved mechanical advantage for knee flexion.

Fractional lengthening often is done concurrently by the senior author, which has shown promising early results. Knee flexion depends on sufficient extensibility of the antagonists. Fractional lengthening of the quadriceps muscle improves knee flexibility without compromising its strength. Weakening of the quadriceps muscle also is a potential risk associated with a distal rectus muscle transfer because the rectus muscle comprises approximately 12% of the total quadriceps muscle mass.\(^{15}\) The combination of quadriceps muscle fractional lengthening with distal rectus muscle transfer theoretically may cause increased knee flexion during the stance phase, especially at weight acceptance, leading to either knee instability or crouch gait. However, this has not been observed in any of our patients. No patients reported knee instability or buckling postoperatively, which was confirmed with postoperative clinical gait analysis. It is likely that the vastus muscles retain sufficient strength to compensate for the loss of rectus muscle activity.

Limitations of the study include a retrospective study design without a control group. However, given that the patients had surgery at a mean of 8 years after TBI or stroke and that all patients had unsuccessful outcomes following nonsurgical interventions, we do not believe that these limitations detract considerably from our conclusions. Unfortunately, we were unable to determine adherence to physical therapy protocols postoperatively and could not separately analyze the interplay between surgery and therapy. However, we believe them to be intimately involved in providing a successful outcome. Additional weaknesses include the difficulty in conducting outcome evaluation in gait-related problems in patients with stiff knee gait. For example, we have noticed improved limb advancement and decreased foot dragging during follow-up gait analyses, but these variables are difficult to record and compare without expensive technology. We have noticed gait to be smoother as a result of the improved knee flexion, which has correlated positively with patient satisfaction levels. However, dynamic gains are difficult to measure and may not be necessary to reach a conclusion about the efficacy of the procedure. This was a retrospective review of patient data documented by the surgeon in an unblinded manner and thus is prone to both internal bias and confounding. Despite these limitations, we believe this study provides insight into the potential benefits of this type of surgery for stiff knee gait after TBI or stroke and develops a foundation for future, more rigorous studies.

Future directions include determining whether dynamic EMG results correlate with our clinical findings. As Perry\(^{7}\) demonstrated that the rectus femoris muscle has inconsistent action among patients with stiff knee gait, we agree that dynamic EMG testing is needed prior to surgery. However, we cannot justify the utility of routine postoperative dynamic EMG testing. Ongoing evaluation also is needed to determine whether any differences in muscle activity exist among patients with stiff knee gait due to stroke and TBI.

Conclusions

We have found that adults with stroke or TBI who develop stiff knee gait due abnormal rectus femoris muscle activity benefit from a distal rectus femoris muscle transfer with fractional lengthening of the vastus muscles. The results closely resemble outcomes following distal rectus muscle transfer for treating stiff knee gait in children with cerebral palsy. The gracilis tendon offers many anatomic and biomechanic advantages and is our preferred recipient tendon for the transfer. Simultaneous fractional lengthening of the quadriceps muscle offers improved knee flexibility without compromising knee stability.

All authors provided concept/idea/research design and data collection and analysis. Dr Namdari, Dr Pill, and Dr Keenan provided writing and consultation (including review of manuscript before submission). Dr Keenan provided project management, patients, and facilities/equipment.

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References

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