Rectus femoris transfer in multilevel surgery: Technical details and gait outcome assessment in cerebral palsy patients

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KEYWORDS
Cerebral palsy; Stiff knee; Rectus femoris transfer; Surgical procedure; Gait analysis

Summary
Introduction: In children with cerebral palsy the abnormal activity of the rectus femoris (RF) during the swing phase results in ''stiff-knee gait''. Transferring the RF to a knee flexor tendon improves this stiffness. The effect may be limited by adhesions from scar tissue or from angular deviations along the surgically created muscle tendon route.

Hypothesis: The goal of this study was to assess the effect on gait of a single event multilevel surgery protocol, and provide a detailed description of the transfer technique.

Patients and methods: Forty-eight RF transfers were studied in 26 children and adolescents 12 ± 3 years old after a follow up of 25 ± 10 months. Quantified gait analysis was performed pre- and postoperatively to calculate spatiotemporal variables, 3D kinematics, the Gait Deviation Index (GDI) and a knee stiffness score (Goldberg index). A standardized surgical procedure was followed: RF release, gracilis tendon preparation as well as the transfer and suture techniques are described.

Results: Step length improved. Gait velocity and cadence were not modified. Gait quality improved (+13 ± 11GDI) with an inverse relationship between the preoperative GDI and its improvement. Improvement of the preoperative Goldberg index in 74% of the cases was due to modifications of knee ROM from toe-off to peak flexion (+7°), total knee ROM (+16°) and timing of peak knee flexion in percentage of swing (from 51 to 40% of swing).

Discussion: The surgical protocol presented here is discussed in relation to the results.

Level of evidence: IV, retrospective study.

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Introduction

During normal gait the rectus femoris (RF) is activated during the transition between the stance and swing phases to control knee flexion [1]. In children with cerebral palsy, RF hyperactivity results in excessive prolonged contraction during the swing phase. This abnormal activity limits knee flexion during swing [2–8] contributing to a gait anomaly called "stiff knee gait". Different treatments have been proposed for this gait anomaly: chemical paralysis by botulin injections, distal release or resection of the RF muscle or its transfer to a flexor tendon of the knee. Although the muscle is still spastic once it has been transferred it preserves its function as flexor rather than an extensor of the knee [4,5].

Numerous studies have investigated the results of this transfer. All of them used kinematics [3,4,6,7,9–27]. Certain have associated kinetic measurements [19,27], electromyographic recordings [11,17,20] and functional results [13,15]. All of these studies concluded that the results of transfer of the RF were positive.

The potential flexion effect of transfer on moment arms has been validated. How the moment arm will be modified can also be predicted by computer models [28]. However, in vivo, it has been observed that RF transfer generates a knee extension moment during electric stimulation [29]. Other studies [30,31] have noted the presence of scar tissue between the RF and adjacent structures. This paradox between the potential action and in vivo reality suggests that transfer does not act as a knee flexor.

Scar tissue and angular deviations along the entire RF muscle-tendon tract are potential complications, which could explain the above-mentioned paradox. These are highly dependent upon the surgical technique.

The aim of this study was to evaluate the overall effect of multilevel surgery associated with a specifically described technique of surgical transfer of the RF muscle. A retrospective longitudinal study was performed by evaluating the effect of surgery on different parameters.

Patients and methods

Patients

Twenty-six children and adolescents participated in this study (12 ± 3 years old). Children and parents gave their informed consent. All participants underwent a clinical examination and quantified gait analysis before surgery and 25 ± 10 months after surgery.

Surgical procedure

A specific surgical procedure was developed to ensure appropriate management of RF transfer and fixation. A longitudinal incision was made on the distal femur beginning at the superomedial pole of the patella extending 10 cm proximally. The intervals between the RF muscle, the vastus medialis, the vastus lateralis and the vastus intermedius were first identified proximally. The RF was separated from the three vastes at this point. The RF muscle and tendon were completely released until half way up the thigh so that the direction of transfer would be straight (Fig. 1A). Dissection was continued distally to 2 cm above the proximal side of the patella. The RF tendon was then separated from the quadriceps tendon and resected without penetrating the knee joint. The gap between the vastus medialis and the vastus lateralis was closed by pulling together these two muscles along the median line therefore covering the vastus intermedius, with the knee flexed at 90° (Fig. 1B).

Hamstring lengthening was often performed with a second incision beginning above the popliteal fossa and extending 10 cm proximally medially and in front of the medial hamstrings. Intramuscular lengthening was performed on the semitendinosus and semimembranosus tendons. The belly of the gracilis tendon was dissected proximally then released distally (Fig. 2A).

At the initial incision, the fascia of the vastus medialis was separated from the underlying muscle creating a subfascial interval leading to the medial intramuscular septum. This was then divided longitudinally to shift the gracilis tendon from the posterior compartment to the anterior compartment of the thigh (Fig. 2B).

The gracilis tendon was sutured to the RF tendon on the medial and distal side of the thigh wrapped in the large RF tendon. Tension necessary for transfer was controlled with the knee in 20° of flexion. This was obtained by 2 U stitches placed at the beginning and end of the juxtaposition of the two tendons (Fig. 3A–C). A continuous suture was then performed burying the gracilis in the RF tendon (Fig. 3D, E). Finally the path of pull of the entire muscle-tendon transfer was as direct as possible (Fig. 4).

Associated surgical procedures and techniques

The procedures and techniques are as follows:

- in the presence of patella alta, a third incision was made on the lateral side of the patella extending distally to the tibial tuberosity. The patellar ligament was identified. A patella alta may be lowered by transferring distally the tibial tubercle or by a rectangular transpatellar and tibial wired frame protecting the patellar ligament, which is divided and shortened;
- if the gracilis tendon thickness was not sufficient, the semitendinosus could be used with the same transfer technique;
- if lengthening of the hamstrings was not necessary, dissection was limited to the gracilis tendon.

This study included 48 RF transfers. Associated surgical procedures included: 44 intramuscular lengthening of the medial hamstrings, lowering of the patella [16], femoral derotation osteotomies [19], lengthening of the adductors and/or the psoas [10], surgery of the leg and/or foot [32].

Quantified gait analysis

Gait analysis was performed pre- and postoperatively using a modified Helen Hayes [32,33] model with anatomical markers on the femoral condyles and the medial malleolus (Biogesta™ SAGA3RT then Vicon™ 8xMX20).
The spatiotemporal parameters (mean speed, cadence, right and left step length, duration of single and double stance), kinematics and kinetics were recorded. Preoperative electromyographic (EMG) recordings were obtained (MotionLabs™ device then Aurion™ Zero-Wire). Surface electrodes were positioned on the RF and the vastus laterals according to SENIAM guidelines [34]. Specific tests were performed to confirm placement of these electrodes [35].

Overall gait quality was calculated by the Gait Deviation Index (GDI) [36]. The GDI provides linear quantification of the difference between the patient’s gait and “normal” gait. Thus a score of 100 indicates a normal gait and any reduction of this score by 10 units indicates one standard deviation from a normal gait.

The Goldberg index [19] was calculated in relation to knee kinematics (peak knee flexion, knee flexion ROM from toe-off to peak flexion, total knee range of motion, timing of peak knee flexion as a percentage of swing) to determine whether the 44 lower limbs were “stiff”, “borderline” or “non stiff”. If one of these variables differed from the norm, the index increased by one point. The index for a “stiff knee” was 4 or 3. An index of 2 indicated a “borderline knee”. The index for “non stiff knees” was 1 or 0.

Statistical assessment of the influence of surgery was performed using the paired Student t-test. The correlation between surgery and knee stiffness was evaluated by the Stuart-Maxwell test. The effects of independent variables and associated surgery except for hamstring lengthening (lowering of the patella, femoral derotational osteotomies, lengthening of adductors and/or psoas and leg and/or foot surgery) on the kinematic parameters of the knee were evaluated by multifactorial linear ANOVA. Based on these ANOVA, the estimated mean differences and 95% confidence intervals were calculated by post-hoc Tuckey tests. A P-value under 0.05 was considered to be significant.

Figure 1  Anteromedial intraoperative view of the left thigh (patella is to the right). A. Exposure of the quadriceps. The rectus femoris muscle (RF) is dissected free from the vastus lateralis (VL), vastus intermedius (VI) and vastus medialis (VM) beginning proximally. The RF tendon is divided (dark line) above the patella. B. The defect between the VM and VL is repaired by approximating in the mid line these two muscles.

Figure 2  A. Posteromedial intraoperative view of the distal left thigh. The tendon of the Gracilis (Gr) is dissected inside its muscle belly and divided. B. Anteromedial view of the left thigh (patella is to the right). The Medial Intermuscular Septum (MIS) is divided longitudinally allowing the Gr tendon to migrate from the posterior to the anterior compartment of the thigh. SM: semimembranosus; ST: semitendinosus.
**Clinical evaluation**

A complete pre- and postoperative neuro-orthopedic examination that was specific for children and adolescents with cerebral palsy was performed including, in particular, the Duncan/Ely test. Patient function was classified by the Gross Motor Function Classification System (GMFCS) [37].

**Indications for surgery**

Criteria for the indication of RF transfer were the presence of a positive Duncan/Ely test, a significantly prolonged EMG in swing, and kinematic disturbances such as a reduced and/or delayed knee flexion peak in swing.

**Results**

The Duncan/Ely test was positive and the EMG was significantly prolonged in swing in all patients. The preoperative distribution of the GMFCS was I:7, II:11, III:6 and IV:1.

Table 1 shows the changes in spatiotemporal parameters and the GDI. Step length increased (+0.04 ± 0.1 m). Overall gait quality according to the GDI improved in all patients except two (P < 0.05). Pre- and postoperative gait was $62 \pm 9$ (min = 38; max = 80) and $75 \pm 8$ (min = 47; max = 88) respectively. Mean improvement was $+13 \pm 11$ (min = −13; max = 41).

There was an inverse correlation between the preoperative GDI and its increase (Fig. 5). Thus the greater the initial gait disturbance was, the greater the postoperative improvement (Pearson coefficient = −0.66; P < 0.05).
Table 1  Spatiotemporal parameters before and after surgery (mean and standard deviation [SD]). Significant modifications are indicated in the Student t-test column by P < 0.05.

<table>
<thead>
<tr>
<th></th>
<th>Presurgery</th>
<th></th>
<th>Post-surgery</th>
<th></th>
<th>Student t-test (P)</th>
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</thead>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
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<tr>
<td>Mean velocity</td>
<td>0.85</td>
<td>0.31</td>
<td>0.84</td>
<td>0.33</td>
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<tr>
<td>Cadence</td>
<td>117</td>
<td>24</td>
<td>106</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Step length</td>
<td>0.41</td>
<td>0.12</td>
<td>0.45</td>
<td>0.12</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>GDI</td>
<td>62</td>
<td>9</td>
<td>75</td>
<td>8</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

GDI: Gait Deviation Index.

Table 2  Sagittal plane knee parameters before and after surgery (mean and standard deviation [SD]). Significant modifications are indicated in the Wilcoxon test column by P < 0.05.

<table>
<thead>
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<th>Wilcoxon test (P)</th>
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<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
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<tr>
<td>Peak Knee Flexion in swing (°)</td>
<td>59</td>
<td>15</td>
<td>59</td>
<td>10</td>
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</tr>
<tr>
<td>Knee ROM from toe-off to peak flexion (°)</td>
<td>14</td>
<td>7</td>
<td>21</td>
<td>10</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Knee ROM total (°)</td>
<td>32</td>
<td>13</td>
<td>48</td>
<td>13</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Timing of peak knee flexion (% swing)</td>
<td>51</td>
<td>14</td>
<td>40</td>
<td>7</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

Changes in the sagittal kinematic parameters of the knee and the associated surgical procedures are presented for each lower limb in Supplementary data, Table. Table 2 presents a summary of the change in these parameters. Knee flexion ROM from toe-off to peak flexion (+7°), the total knee ROM (+16°) and the timing of peak knee flexion in percentage of swing (51–40% of swing) all improved.

The preoperative Goldberg index showed 8 "stiff knees" and 27 intermediate knees. There were 35 postoperative "non stiff" knees and 10 borderline. Twenty-six legs had improved in at least one category (6 in two categories). The Goldberg Index improved in 74% of patients who presented with preoperative swing disturbances (P < 0.05) (Table 3).

Adductor and/or psoas lengthening influenced improvement in peak knee flexion (F = 5.14; P < 0.05) (+13°; 95% CI: 1°, 25°). Also, surgery of the leg and/or foot influenced improvement in total knee flexion range of motion (F = 5.44; P < 0.05) (+10°; 95% CI: 1°, 18°). Except for hamstring lengthening, the other associated surgical procedures did not influence kinematic parameters (Supplementary data).

Discussion

This study describes a technique for RF transfer and evaluates the results in relation to multilevel surgery of the lower limbs. This assessment is based on changes in spatiotemporal parameters, kinematics, and certain indices (GDI, Goldberg) of gait analysis data. Gait quality improved significantly (+13 ± 11 GDI) and there was also an inverse relationship with the preoperative GDI. Thus the more the gait was disturbed before surgery, the greater the improvement following surgery. These results support a recent study showing that the efficacy of transfer is dependent upon initial swing disturbances [38].

![Figure 5](image_url)  Negative correlation between the presurgery Gait Deviation Index (GDI) and the improved GDI.
The Goldberg index summarizes sagittal kinematic anomalies of the knee and showed an improvement in knee stiffness in 74% of cases. This corresponds to improvements in knee flexion from toe-off to peak flexion, total knee range of motion and the timing to peak flexion. A lack of improvement in peak knee flexion in swing has already been reported [12,13,39] with different interpretations. We explain it in our study by the low limitations of this preoperative parameter.

These kinematic results must be assessed in relation to the specific surgical techniques. For some, the choice of techniques is based on scientific evidence, for others on the surgeon’s preferences. In this series the choice of RF transfer to the gracilis was unequivocal. Certain surgeons transfer the RF to the semitendinosus because it results in a larger peak knee flexion moment arm than other potential transfer sites (gracilis or sartorius) [28]. Although the reported results have been similar [6,7,9,11,20], and because a choice had to be made without objective evidence, transfer to the semitendinosus was not performed to prevent disturbing the sagittal balance of the pelvis. Lateral transfer to the iliotibial tract is much less common than other medial transfers. This was not chosen because theoretically it does not produce a knee flexion moment [28] although a few studies have reported comparable results [20,23].

Subcutaneous transfers have been described [11,30,40]. Our choice of deep dissection under the fascia covering the vastus medialis [41] prevents a residual stump under the skin while exposing the medial intermuscular septum. A large window is created in the septum to facilitate a direct path for the transfer. It should be noted that angular deviations and the presence of tissue adhesions have been reported during subcutaneous transfers [30] but not subfascial transfers.

Two different anastomotic techniques have been described to suture a small (gracilis) to a large (RF) tendon: the Pulvertaft tendon weave technique and the running/continuous suture, which buries the gracilis tendon in the RF. With the first technique the gracilis is weaved through the RF several times increasing the risk of injury to both tendons. The second technique was chosen because it facilitates adjustment of tension and allows stable, rigid anastomosis.

The gap between the vastus medialis and the vastus lateralis should be repaired by approximating in the midline these two muscles in front of the vastus intermedius. A suture with the knee in 90° flexion should be performed to avoid extension contracture of the knee. The goal of this procedure is to preserve the extension lever arm of the vastus medialis and lateralis muscles which would be diminished if they were left to slide laterally. This hypothesis requires further biomechanical studies.

In this series, improvement in total knee range of motion was influenced in particular by improvement in extension in stance. Associated surgical procedures played a role such as hamstring lengthening as well as the potential effect of approximating the vasti.

The results of this retrospective series depend upon all of the associated surgical procedures as well as clinical criteria for surgery. These criteria were similar to those that have been frequently described in other studies [8,11,42]. Improving and standardizing these criteria is an important topic of future studies [27]. Thus modifications in the Duncan Ely Test have already been made, and its predictive value is a subject of debate [20,43] especially in cases of excessive femoral antetorsion [44]. The diagnostic and prognostic value of EMG recording is also a topic of debate [11,17,20]. The kinematic criteria were a reduction in peak knee flexion and/or a delayed flexion in swing. Despite those criterion, the retrospective results of the Goldberg index in certain legs (n = 13) were ‘‘non-stiff’’ as this index additionally includes total and swing knee flexion range of motion. It should be noted that this study does not compare the different surgical procedures to treat ‘‘stiff knee’’ gait (different RF transfer procedures, tenotomies or resection of the distal tendon) [45,46].

All patients underwent associated orthopedic procedures that could influence the results of RF transfer. It has been shown that transfer results are independent of associated surgeries when at least an hamstring lengthening was performed [24]. This was the case in our series except in four legs. Comparable results were found in our series between most of the other associated procedures, except hamstring surgery, and the variables of ‘‘stiff knee’’ gait. The only relationships found were between an improvement in peak knee flexion and adductor and/or psoas lengthening and between improved total knee flexion range of motion and leg and/or foot surgery. These surgical procedures were associated in 10 and 32 lower limbs respectively. However, it should be noted that no relationship of the associated orthopedic procedures was found with an improvement in the time to peak flexion or in the knee flexion range of motion in swing. Thus these two results in our series are due to RF transfer (associated with lengthening of the hamstrings).

This study of the specific role of RF transfer is timely. The randomized study by Dreher et al. [47] confirmed the effect of RF and also specified its indication in patients presenting with limited flexion range of motion in affected knees.

In conclusion, our study confirms that overall gait quality and knee ‘‘stiffness’’ were improved after multi-level surgery of the lower limbs including RF transfer. It must be emphasized that the more the gait is disturbed preoperatively, the greater the improvement following surgery.

Disclosure of interest
The authors declare that they have no conflicts of interest concerning this article.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.otsr.2012.10.017.

References