The objective of this study was to identify the predictors of outcome of distal rectus femoris transfer in cerebral palsy. Preoperative and postoperative gait data for 81 patients were examined, focusing on knee flexion/extension range. Outcome was ‘good’ for 46 patients and ‘poor’ for 35. The poor outcome group had no improvement in knee range because of increased crouch postoperatively. Outcome was unrelated to quadriceps strength, crouch, velocity, or type of cerebral palsy. Gross Motor Function Classification System was predictive of outcome, with poor results in all level IV patients (P < 0.008). In conclusion, Gross Motor Function Classification System IV patients may not benefit from distal rectus femoris transfer because of increased postoperative crouch.

Introduction

Stiff-knee gait is one of the most common gait deviations seen in ambulatory children with cerebral palsy (CP) [1] and is thought to result from an overactive rectus femoris during the swing phase of the gait cycle [2]. A stiff-knee gait decreases foot clearance during swing, which can result in an increased amount of work during ambulation and increased energy expenditure [3]. Distal rectus femoris transfer (DRFT), as described by Perry [4], is a well-established procedure to improve this gait abnormality, allowing increased knee flexion during swing phase. DRFT involves transferring the distal end of the rectus femoris to one of the hamstring tendons (usually semitendinosus or sartorius). DRFT is recommended in patients with decreased and/or delayed peak knee flexion in swing phase, or a range of knee motion from stance to swing phase of less than 80% of able-bodied participants [5–7]. These factors should exist in conjunction with prolonged rectus femoris activity in swing phase as determined by electromyography. The aim of DRFT is to maintain or improve peak knee flexion in swing, while concomitant hamstring lengthening is presumed to improve knee extension in stance. Together, these surgical procedures improve the excursion or range of knee motion from stance to swing (Fig. 1).

Most of the research on DRFT show improvements in knee motion during gait postoperatively [5–11]. However, a few studies have noted poor outcome in some patients.

Gage et al. [5] found that of 21 participants who had DRFT, the patients with the poorest outcome had residual knee flexion in stance, and excessive internal or external foot rotation resulting in lever arm dysfunction. In routine postoperative assessments of patients, Yngve et al. [10] noted less positive outcome of DRFT in lower-functioning patients, and conducted a retrospective study on the topic. Though improvements were seen in all patients of varying functional levels, the independent ambulatory patients had the greatest improvement in knee range of motion from stance to swing postoperatively, because of their maintenance of peak knee flexion in swing phase.

In our clinic and motion analysis laboratory, we have also noted that some patients respond better than others to DRFT. We have hypothesized that this may be related to the degree of preoperative crouch, or differences in preoperative quadriceps strength, postulating that patients in greater crouch or with weaker quadriceps might be less able to tolerate any loss of knee extensor strength post-DRFT. We have also debated the role of walking velocity, type or distribution of CP, and functional level of the patients in the outcome of DRFT. The purpose of this study was to elucidate the factors that predict outcome of DRFT in ambulatory children with static encephalopathy.

Methods

Patients

A retrospective review of gait studies was conducted for all participants presented to the Motion Analysis...
Laboratory at the authors’ institution between 1 October 1992 and 1 December 2005 for preoperative and postoperative gait analysis tests, having undergone multi-level surgery including DRFT between the two studies. All participants had static encephalopathy because of a variety of causes such as CP (71 patients), traumatic brain injury (four patients), cerebrovascular accidents (three patients), near drowning (one patient), or viral etiology (two patients). The involved limb in hemiplegics was selected for analysis. The right side was arbitrarily used for all participants with bilateral involvement except for two participants for whom only left DRFT had been performed, in which case the left side was used. A total of 81 patients (81 limbs) were included in the analysis. There were 45 males and 36 females in the group. Age at the time of surgery averaged 9.3 ± 3.8 years (range 3.7–20.6). Surgery included unilateral or bilateral DRFT in all cases. Indications for DRFT was a stiff-knee gait, which was defined as decreased knee range of motion from stance to swing and/or delayed peak swing knee flexion (Fig. 1) with associated prolonged activity of the rectus femoris muscle as determined by electromyography. Concurrent surgery was performed in all but three cases (Table 1).

Procedures

Surgery

Rectus transfer surgery was performed by various surgeons. Whenever possible, the rectus femoris was transferred to the semitendinosus. If the semitendinosus was not available, the rectus was generally transferred to the sartorius. This occurred in cases of previous semitendinosis tenotomy, or when no concomitant hamstring lengthening was to be performed, leaving no distal limb of the semitendinosus available to receive the transfer.

Gait study

Gait analysis studies were repeated an average of 1.9 ± 1.3 years after surgery (range 0.8–9.8 years). The gait analyses were performed with an eight camera VICON 3-D motion system (Lake Forest, California, USA). Three-dimensional joint motion (kinematic) data were collected for multiple strides, averaged and used for analysis.

Classification and evaluation methods

Outcome variables

The kinematic variables analyzed for this study included preoperative and postoperative maximum knee extension in stance, peak knee flexion in swing, and the range of knee motion from stance to swing. (Fig. 1) Knee range of motion from stance to swing was used to assess the outcome of DRFT. Knee range of motion was analyzed instead of peak knee flexion in swing, as participants with greater than normal peak knee flexion in swing can have a ‘stiff-knee’ gait pattern if there is excessive knee flexion in stance. Use of peak knee flexion in swing as the sole outcome measure in such participants would yield erroneous positive results.

The patients were placed in one of two outcome groups based on the postoperative range of knee motion from stance to swing (Fig. 1). Outcome was rated ‘good’ if knee range was within the normal range ± 2SD (60 ± 12.8°, based on laboratory normative data collected from 33 able-bodied children), or if the postoperative knee range was less than the normal range, but had improved by more than 1SD (6.4°) toward the normal range. Outcome was rated ‘poor’ if postoperative knee range was less than the normal range and had improved less than 1SD or had worsened as compared with the preoperative value. In some cases, knee range was within the normal range both preoperatively and postoperatively, but DRFT was recommended because of a significant delay.
in timing of peak swing knee flexion limiting foot clearance. In these cases, the outcome was rated 'good' regardless of whether knee range increased or decreased postoperatively. This judgment was felt to be appropriate as, based on the literature, it is likely that peak swing knee flexion (and knee range of motion) would have decreased in these cases had DRFT not been performed [12–14].

**Predictive variables**

Variables assessed as possible predictors of outcome of DRFT included:

1. Preoperative gait velocity and degree of crouch (indicated by preoperative maximum knee extension in stance) – derived from the kinematic data.
2. Quadriceps muscle strength – rated using the traditional 0–5 scale.
3. Type or distribution of static encephalopathy (hemiplegia, diplegia, or quadriplegia) – recorded from the gait analysis test report.
4. Ambulatory functional level – determined using the Gross Motor Function Classification System (GMFCS) [15]. The GMFCS has only been validated and standardized for use in CP, and therefore it was used only for the 71 patients with that diagnosis in this study.

**Statistics**

Between-group comparisons of kinematic variables and gait velocity were made using *t*-tests. Quadriceps strength was compared between groups using the Mann–Whitney *U* test. Chi-square analysis was used to determine relationships between GMFCS level and outcome of DRFT. Statistical significance was set at a *P* value of less than 0.05. For the χ² analysis that involved multiple comparisons between the different GMFCS levels, the Bonferroni correction was applied resulting in an adjusted significance level of a *P* value of less than 0.008.

**Results**

The result of DRFT was rated 'good' for 46 out of 81 patients (57%), and 'poor' for 35 out of 81 patients (43%). There was no significant difference in age at the time of surgery between groups (8.6 ± 4 years for the good outcome group, 10 ± 4 years for the poor outcome group, *P* = 0.09). The amount of time between surgery and follow-up gait analysis was equivalent between groups (22.7 ± 12 months for the good outcome group, 21.6 ± 20 months for the poor outcome group, *P* = 0.76).

The groups were equivalent for preoperative maximum knee extension in stance, peak knee flexion in swing, and knee range of motion from stance to swing. Preoperative gait velocity was also equivalent between groups. The lack of significant differences between groups for preoperative maximum knee extension in stance (crouch) and preoperative gait velocity indicate that they are not predictors of outcome of DRFT (Table 2).

Postoperatively, the groups showed statistically significant differences in maximum knee extension in stance, and knee range of motion from stance to swing, suggesting that the rating system used was sensitive enough to detect between-group differences. The good outcome group had significantly greater maximum knee extension in stance and knee range of motion from stance to swing than the poor outcome group. The good outcome group also showed a significantly higher gait velocity than the poor outcome group after surgery (Table 2).

Sixty-six out of 81 patients were able to comply with manual muscle testing, and thus had recorded quadriceps strength measurements. Preoperative quadriceps strength was not a predictor of outcome (*P* = 0.46) (Table 3).

Patients with hemiplegia had a good outcome 50% of the time and poor outcome 50% of the time. A slightly higher percentage of diplegic patients had good outcomes than...
Table 4  Type or distribution of static encephalopathy

<table>
<thead>
<tr>
<th>Type</th>
<th>n</th>
<th>Good outcome, n (%)</th>
<th>Poor outcome, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemiplegia</td>
<td>16</td>
<td>8 (50)</td>
<td>8 (50)</td>
</tr>
<tr>
<td>Diplegia</td>
<td>55</td>
<td>34 (61)</td>
<td>21 (38)</td>
</tr>
<tr>
<td>Quadriplegia</td>
<td>10</td>
<td>4 (40)</td>
<td>6 (60)</td>
</tr>
</tbody>
</table>

Table 5  Statistical significance values for GMFCS level comparisons (statistical significance set at $P \leq 0.008$, to adjust for multiple comparisons)

<table>
<thead>
<tr>
<th>GMFCS Level Comparison</th>
<th>$\chi^2$</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMFCS II vs. I</td>
<td>0.002</td>
<td>0.96</td>
</tr>
<tr>
<td>GMFCS III vs. I</td>
<td>0.4</td>
<td>0.51</td>
</tr>
<tr>
<td>GMFCS IV vs. I</td>
<td>10.5</td>
<td>0.001</td>
</tr>
<tr>
<td>GMFCS III vs. II</td>
<td>0.6</td>
<td>0.44</td>
</tr>
<tr>
<td>GMFCS IV vs. II</td>
<td>11.5</td>
<td>0.0007</td>
</tr>
<tr>
<td>GMFCS IV vs. III</td>
<td>9.6</td>
<td>0.002</td>
</tr>
</tbody>
</table>

GMFCS, Gross Motor Function Classification System.

Table 6  Distribution of GMFCS scores versus outcome group

<table>
<thead>
<tr>
<th>GMFCS Level</th>
<th>n</th>
<th>Good outcome, n (%)</th>
<th>Poor outcome, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMFCS I</td>
<td>14</td>
<td>10 (71)</td>
<td>4 (29)</td>
</tr>
<tr>
<td>GMFCS II</td>
<td>18</td>
<td>13 (72)</td>
<td>5 (28)</td>
</tr>
<tr>
<td>GMFCS III</td>
<td>31</td>
<td>19 (61)</td>
<td>12 (39)</td>
</tr>
<tr>
<td>GMFCS IV</td>
<td>8</td>
<td>0</td>
<td>8 (100)</td>
</tr>
<tr>
<td>Total</td>
<td>71</td>
<td>42 (59)</td>
<td>29 (41)</td>
</tr>
</tbody>
</table>

GMFCS, Gross Motor Function Classification System.

The outcome of multilevel surgery including DRFT varies depending on ambulatory functional level. Patients functioning at GMFCS levels I and II seem to benefit in more than 70% of cases, whereas those at GMFCS level III benefited in 61% of cases. However, patients with limited ambulatory ability (GMFCS level IV) do not seem to benefit from DRFT as a part of multilevel surgery. The only other study, of which we are aware, to examine relationships between outcome of DRFT and functional level was by Yngve et al. [10] who found that patients of all functional levels had improved knee range of motion during gait at 1-year follow-up, because of increased stance phase knee extension. However, only independent ambulatory patients maintained their peak knee flexion in swing, whereas the dependent ambulators lost significant amounts of peak swing knee flexion postoperatively. In this study, patients in both outcome groups maintained their peak swing knee flexion, whereas the patients with poor outcome lost knee extension in stance phase. This finding is consistent with that of Gage et al. [5] who found that patients with the poorest outcome after DRFT had residual knee flexion in stance of 15° (compared with 0.34° for the best outcomes), and internal or external foot rotation greater than 8° from normal. Saw et al. [11] found similar results in a study of long-term outcome of DRFT. In their study, peak swing knee flexion was maintained or increased at a mean of 4.6 years after surgery, but knee range of motion decreased because of a significant loss of stance phase knee extension over time. Progressive crouch over time may be a consequence of the natural history of CP in some patients (diplegic patients, or those of lower functional level) [1,16]. Time to follow-up was, however, not a predictive factor in this study, as it was equivalent in both outcome groups.

GMFCS level was recorded for the 71 patients who had CP. GMFCS level was the only preoperative variable which showed a statistically significant relationship with outcome of DRFT, with GMFCS level IV having a significantly different distribution of outcome from all other levels. (Table 5) All patients in GMFCS level IV had a poor outcome. GMFCS levels I and II had higher percentages of patients with good outcome than GMFCS level 3, but these differences did not reach the level of statistical significance (Tables 5 and 6).

Discussion

The outcome of multilevel surgery including DRFT varies depending on ambulatory functional level. Patients functioning at GMFCS levels I and II seem to benefit in more than 70% of cases, whereas those at GMFCS level III benefited in 61% of cases. However, patients with limited ambulatory ability (GMFCS level IV) do not seem to benefit from DRFT as a part of multilevel surgery. The only other study, of which we are aware, to examine relationships between outcome of DRFT and functional level was by Yngve et al. [10] who found that patients of all functional levels had improved knee range of motion during gait at 1-year follow-up, because of increased stance phase knee extension. However, only independent ambulatory patients maintained their peak knee flexion in swing, whereas the dependent ambulators lost significant amounts of peak swing knee flexion postoperatively. In this study, patients in both outcome groups maintained their peak swing knee flexion, whereas the patients with poor outcome lost knee extension in stance phase. This finding is consistent with that of Gage et al. [5] who found that patients with the poorest outcome after DRFT had residual knee flexion in stance of 15° (compared with 0.34° for the best outcomes), and internal or external foot rotation greater than 8° from normal. Saw et al. [11] found similar results in a study of long-term outcome of DRFT. In their study, peak swing knee flexion was maintained or increased at a mean of 4.6 years after surgery, but knee range of motion decreased because of a significant loss of stance phase knee extension over time. Progressive crouch over time may be a consequence of the natural history of CP in some patients (diplegic patients, or those of lower functional level) [1,16]. Time to follow-up was, however, not a predictive factor in this study, as it was equivalent in both outcome groups.

The reason for lack of improvement in stance phase knee extension in our participants with poor outcome could not be elucidated from the data collected. It could not be explained by recurrent hamstring tightness, as popliteal angle was equivalent between groups postoperatively. (Table 2) The percentage of patients who underwent concomitant hamstring lengthening was similar between groups (38 out of 46, 83% in the good outcome group and 23 out of 35, 66% in the poor outcome group, $P = 0.08$). The lack of improvement in knee extension during stance in the poor outcome group could not be attributed to calcaneal gait due to surgical lengthening of the triceps surae. Surgery to the triceps surae was performed concomitantly in equal percentages of participants in both outcome groups (18 out of 46, 39% in the good outcome group and 13 out of 36, 36% in the poor outcome group). Dorsiflexion in stance phase was not assessed as part of this study.

Quadriceps strength (as measured by manual muscle testing) was equivalent between groups preoperatively, and there was no difference between groups in the number of participants who gained or lost quadriceps strength postoperatively ($P = 0.34$). Of patients in the good outcome group, six out of 40 (15%) had increased, and one out of 40 (3%) had decreased quadriceps strength by $\geq 1$ grade. In the poor outcome group, six out of 26 (23%) had increased, and three out of 26 (12%) had decreased quadriceps strength by $\geq 1$ grade postoperatively. Hip extensor weakness has also
been identified as a potential contributor to crouched gait [17]. In this study, however, hip extensor strength was also equivalent between groups both preoperatively and postoperatively, and essentially unchanged in both groups after surgery (average 3+ for both groups, preoperatively and postoperatively).

Traditional manual muscle testing, as used in this study, may not be sensitive enough to measure functional muscle strength in patients with CP. It is possible that more subtle differences in quadriceps strength could have been detected if more sophisticated equipment had been used, such as an isokinetic dynamometer. Traditional manual muscle testing assesses concentric contractions rather than eccentric contractions, such as are produced by the quadriceps in the early stance phase of gait. Manual muscle testing does not measure a muscle’s ability to maintain a certain level of strength through repeated contractions, such as during walking. In addition, impaired motor control in patients with CP often limits their ability to perform a maximal contraction during muscle testing, potentially affecting the validity of strength assessment in this patient population.

A ‘poor’ outcome was seen in 28–29% of participants at GMFCS levels I and II, and in 39% of participants at level III. We were unable to elucidate the predictive factors of outcome in these participants. Outcome does not seem to be related to amount of crouch or preoperative gait velocity. The measures of selective control and strength used in this study were not sensitive enough to detect differences between groups. Further study is needed in this area.

The limitations of this study are similar to other retrospective studies involving children with CP. The participants underwent multilevel surgery, and therefore we could not control for the impact of other surgical procedures on outcome at the knee. For statistical purposes, we included only one side in the analysis, even for participants who had surgery performed bilaterally. It is possible that gait deviations on the other side impacted gait kinematics on the side analyzed. In addition, many of the patients were seen postoperatively because of their potential need for further surgical intervention. Thus, this study may have excluded many patients with good surgical outcomes, and the results may be skewed toward a more involved patient population.

Length of follow-up was not consistent among patients, and it is possible that patients with longer follow-up could have had poorer outcome because of deterioration of gait over time. However, there was no significant difference in time to follow-up between the ‘good’ and ‘poor’ outcome groups, therefore this did not seem to influence outcome. Very few studies have evaluated the outcome of orthopedic surgery based on functional ability level of the patient. These results may not be isolated to rectus transfer surgery. The outcome of other surgeries may also be related to GMFCS level in CP patients. Further study is recommended, as this information may be valuable to clinicians when counseling patients and families regarding the need for surgery and prognosis for postoperative improvement.

Acknowledgement
None of the authors received financial support for this study.

References