Long-term changes in femoral anteversion and hip rotation following femoral derotational osteotomy in children with cerebral palsy

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**Abstract**

**Background:** Excessive femoral anteversion is common in cerebral palsy (CP), is often associated with internal hip rotation during gait, and is frequently treated with a femoral derotational osteotomy (FDO). Concerns exist regarding long-term maintenance of surgical outcomes. Past studies report varying rates of recurrence, but none have employed a control group.

**Methods:** We conducted a retrospective analysis examining long-term (≥5 years) changes in anteversion and hip rotation following FDO in children with CP. We included a control group that was matched for age and exhibited excessive anteversion (≥30°) but did not undergo an FDO. Anteversion, mean stance hip rotation, and rates of problematic remodeling and recurrence were assessed (≥15° change and final level outside of normal limits).

**Results:** The control group was reasonably well matched, but exhibited 9° less anteversion and 3° less internal hip rotation at the pre-time point. At a five-year follow-up, the FDO group had less anteversion than the control group (20° vs. 35°, p < 0.05). The mean stance phase hip rotation did not differ between the groups (4° vs. 5°, p = 0.17). Over one-third of limbs remained excessively internal in both groups (FDO: 34%, Control: 37%). Rates of problematic recurrence and remodeling were low (0%–11%).

**Conclusions:** An FDO is an effective way to correct anteversion in children with CP. Long-term hip rotation is not fully corrected by the procedure, and is not superior to a reasonably well matched control group. Rates of problematic recurrence and remodeling are low, and do not differ between the groups.

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1. Introduction

Excessive femoral anteversion is a common bony torsion present in cerebral palsy (CP) \cite{1-4}. The natural history of anteversion remodeling in typically developing children is a decrease from approximately 40° at birth to 15° at skeletal maturity \cite{3}. The etiology of excessive anteversion is speculative, but delayed or attenuated remodeling is the primary suspect. This hypothesis is supported by cross-sectional data; though longitudinal studies are lacking \cite{1}. Skeletal loading plays a causal role in femoral morphology remodeling, and may result in atypical anteversion \cite{5}. Greater anteversion is observed in the more-affected side of individuals with hemiplegia, again implicating muscle tone, neurological control, and skeletal loading \cite{4}.

Excessive anteversion in CP is often considered problematic for various reasons. If not accompanied by internal hip rotation, it may decrease coronal plane hip abductor moment arms (lever arm dysfunction), which may result in insufficient hip abductor moment generation, and thus lead to gait pathologies \cite{6-8}. Internal hip rotation and concomitant in-toeing is also cosmetically undesirable and generally follows excessive anteversion. In-toeing may also increase the risk of trips and falls, though no clear evidence exists to confirm this.

The accepted treatment to address excessive anteversion and its associated gait problems is a femoral derotational osteotomy (FDO). Many studies have reported positive short-term improvements in anteversion and hip rotation (Table 1). McMulkin compared two groups of CP patients who underwent surgery, either with or without an FDO, and noted that the FDO group had favorable improvements in hip rotation during stance while the other group did not \cite{9}. However, several studies have also reported instances of over- or under-correction of hip rotation. For instance, an FDO performed on a limb with mean stance hip rotation less than 15° may lead to an external hip rotation and out-toeing \cite{10,11}.

Long-term evaluations of FDO outcomes show varying levels of surgical correction maintenance (Table 1). Recurrence has been
reported in 0–33% of patients [12–17]. In general, recurrence refers to the regression of anteverision or hip rotation to baseline levels, or some threshold beyond normal limits. The mechanism behind recurrence is unclear, although various risk factors have been proposed, including patient age, greater plantarflexion, decreased hip abductor impulse and work, decreased ankle joint impulse, greater hamstrings and adductor spasticity, and reduced preoperative walking speed [12,14,15,17,18].

One shortcoming of existing long-term outcomes studies is that none of them include a control group. This makes it difficult to separate the effects of the FDO from those of bony remodeling that accompanies growth. Additionally, past studies have failed to report excessive changes resulting in retroversion or external hip rotation, thereby giving an asymmetric picture of post-FDO changes. The primary aim of this study was to examine long-term changes in anteverision and hip rotation following FDO in children with CP compared to a control group. We hypothesized that at the long-term follow-up, all limbs would have decreased anteverision and hip rotation compared to baseline. We further hypothesized that the FDO group would have less anteverision and internal hip rotation at long-term compared to controls.

2. Methods

This was a retrospective longitudinal cohort study. We started by identifying individuals with longitudinal gait and physical examination data before and after an FDO, and identifying a matched control group who did not undergo an FDO (Fig. 1). At our center, there are no set indications for an FDO, although previous statistical analysis has shown that age, prior FDO, anteverision, and hip rotation during gait are the primary factors influencing the
decision [11]. Additionally, anteversion, independent of hip rotation during gait, is viewed as a significant indication by some surgeons due to its effect on proximal muscle lever arms. The FDO is performed proximally in a vast majority of limbs.

Step 1 of the search enforced the following criteria:

- Diagnosis of CP
- Underwent an FDO
- Had gait data acquired prior to the FDO ("pre" time point)
- Femoral anteversion >30° at pre
- Had gait data after an FDO ("short-term" time point)
- Had gait data at an additional time point after the short-term ("long-term" time point)

We then found the 10th and 90th percentiles for age of the FDO group at the pre time point. These data were then used to identify a control group for Step 2 of the search, using the same criteria with the following exceptions:

- Did not undergo an FDO
- Age at "pre" time point within the 10th–90th percentile range of the FDO group

We also identified a sub-set of both groups who had gait data prior to the pre time point ("first" time point), in order to track antecedent anteversion and hip rotation progression.

The trochanteric prominence test was used to measure anteversion. For typically developing children 7–8 years old (mean of our FDO group at pre), anteversion is approximately 23 ± 7° [1]. Our anteversion criterion of 30° therefore represents 1 SD above normal.

Mean stance phase hip rotation was derived from three-dimensional gait analysis. For gait analyses acquired prior to January 2004, kinematics were calculated using the Vicon Plug-In-Gait model (Vicon, Oxford, UK). Kinematics acquired after 2004 were based on a modified version of the Plug-In-Gait model that used a functional hip center and knee axis [19–21]. Only data acquired entirely prior to or entirely after January 2004 were included in our sample. This allowed us to avoid combining data from different models.

We examined distributions of anteversion and hip rotation at each time point and categorized these measures as external, within normal limits (WNL), or internal. Categories were based on the 10th to 90th percentiles for typically developing individuals. For anteversion norms, we used age-based means from a meta-analysis [3]. We assumed a constant standard deviation of 10°, which is similar to 9.7° for children age 2–16 with CP [1]. For hip rotation, normative values were acquired from gait data of 83 typically developing children previously evaluated in our center [19]. The 10th and 90th percentiles for mean stance phase hip rotation were –12.8° (external) to 9.4° (internal).

We calculated bony remodeling (changes in femoral anteversion) and gait adaptations (changes in mean stance phase hip rotation) between the short- and long-term gait evaluations. An anteversion increase >15° was defined as excessive ante-directed remodeling (i.e., recurrence of anteversion). Excessive retro-directed remodeling was defined as anteversion decreasing by >15°. Excessive internal hip rotation during gait (i.e., recurrence of hip rotation) was defined as hip rotation change by >15° in the internal direction. Alternatively, excessive external hip rotation was defined as hip rotation change by >15° in the external direction. Both internal and external bony remodeling and gait adaptations were deemed “problematic” if, in addition to the >15° change, the long-term value fell outside of the 10th to 90th percentile of normative data.

Statistical tests were conducted in Matlab (2015b, Natick, Mass., USA). Changes from first to pre, pre to short-term, and short- to long-term were compared for each group using a two-tailed paired samples t-test. Long-term anteversion and mean stance hip rotation were compared between the FDO and control group using a two-tailed independent samples t-test. Differences in rates of bony remodeling or gait adaptation beyond 15° were evaluated using Chi-square test. We assessed how well groups were matched at the pre time point by also using two-tailed independent samples t-tests and Chi-square tests. Significance was set at p < 0.05 for all tests.

3. Results

Pre, short-, and long-term gait analyses were available for 163 limbs (108 individuals) in the control group and 131 limbs (86 individuals) in the FDO group. Typical surgeries included in a SEMLS at our institution have been published previously [11]. Topographical classification was similar between groups. Cases were 94% bilaterally (di-, tri- or quadriplegic) and 6% unilaterally (hemiplegic) involved. Controls were 95% bilaterally and 5% unilaterally involved. Of the identified limbs, 61 (40 individuals) in the FDO group and 26 (22 individuals) in the control group also had a first time point. The groups were reasonably matched for age, pre hip rotation, and pre anteversion; although the FDO group was one year older and had 9° more anteversion. There was a significant discrepancy in sex distribution between the groups (Table 2).

At the pre time point, 81% of limbs in the control group and 98% in the FDO group exhibited excessive anteversion based on age-based norms (Table 3). At the short-term time point, most of the limbs in the FDO group were corrected, with only 6% remaining excessively anteverted. Among the control limbs, the change was much less pronounced, with 70% of limbs remaining excessively anteverted. There was a modest rate of “over-correction” in the FDO group, with 13% of limbs excessively retroverted at the short-term time point. At the long-term time point, excessively anteverted limbs in the FDO group increased from 6% to 18%, while the number of excessively anteverted limbs in the control group continued to decline from 70% to 53%. Excessively retroverted limbs in the FDO decreased from 13% to 7% at the long-term time point.

At the pre time point, 52% of limbs in the control group and 66% in the FDO group exhibited excessive internal hip rotation (>9°) (Table 3). At the short-term, 24% of the limbs in the FDO group remained internal. Among the control limbs, the change was

Table 2

<table>
<thead>
<tr>
<th>Group</th>
<th>Age [yr] (Pre)</th>
<th>Age [yr] (Short-Term)</th>
<th>Age [yr] (Long-Term)</th>
<th>Sex [F:M:U]</th>
<th>Hip Rot. [°] (Pre)</th>
<th>Anteversion [°] (Pre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>7.3 (1.8)</td>
<td>9.1 (2.1)</td>
<td>12.6 (2.1)</td>
<td>84:78:1</td>
<td>11 (7.3)</td>
<td>47 (11.2)</td>
</tr>
<tr>
<td>FDO</td>
<td>8.3 (1.8)</td>
<td>9.8 (2.0)</td>
<td>13.1 (2.3)</td>
<td>47:83:1</td>
<td>14 (8.7)</td>
<td>56 (10.5)</td>
</tr>
</tbody>
</table>

Data expressed as mean (sd).
F: female, M: male, U: unknown.
* Statistically different between groups (p < 0.05).
Table 3
Anteverision and Hip Rotation Outcomes.

<table>
<thead>
<tr>
<th>Anteverision</th>
<th>Pre [%]</th>
<th>Short-Term [%]</th>
<th>Long-Term [%]</th>
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<tr>
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<td>3</td>
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<tr>
<td></td>
<td>FDO</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>Within Normal Limits</td>
<td>Control</td>
<td>19</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>FDO</td>
<td>2</td>
<td>81</td>
</tr>
<tr>
<td>Excessive Anteverision</td>
<td>Control</td>
<td>81</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>FDO</td>
<td>98</td>
<td>6</td>
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<table>
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<tr>
<th>Hip Rotation</th>
<th>Pre [%]</th>
<th>Short-Term [%]</th>
<th>Long-Term [%]</th>
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<td>External</td>
<td>Control</td>
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<td>3</td>
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<tr>
<td></td>
<td>FDO</td>
<td>0</td>
<td>5</td>
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<tr>
<td>Within Normal Limits</td>
<td>Control</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>FDO</td>
<td>34</td>
<td>70</td>
</tr>
<tr>
<td>Internal</td>
<td>Control</td>
<td>52</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>FDO</td>
<td>66</td>
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</table>

<table>
<thead>
<tr>
<th>Short- to Long-Term</th>
<th>Recurrence [%]</th>
<th>Retro-Directed [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute</td>
<td>Problematic</td>
<td>Absolute</td>
</tr>
<tr>
<td>Excessive Retroversion</td>
<td>Control</td>
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<td>13</td>
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<tr>
<td>Within Normal Limits</td>
<td>Control</td>
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<tr>
<td></td>
<td>FDO</td>
<td>7</td>
</tr>
<tr>
<td>Excessive Anteverision</td>
<td>Control</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>FDO</td>
<td>12</td>
</tr>
</tbody>
</table>

Note: percentages may not add to 100 due to rounding
Absolute, change greater than 15°.
Problematic, final value lies beyond 10th–90th percentile.
*Statistically different between groups (p < 0.05).

minimal, with 49% of limbs remaining intact. At the long-term time point, the number of internally rotated limbs in the FDO group increased to 34%, while the number in the control group continued to decline, reaching a final level of 37%. The rates of external, WNL, and internal limbs were nearly identical between the two groups at the long-term time point.

The amount of anteverision changed significantly with time in both groups (Fig. 2a). In the control group, anteverision decreased from mean = 47° (standard deviation = 11°) (pre) to 42° (14°) (short-term) to 35° (16°) (long-term). Pre to short-term and short- to long-term changes were statistically significant. Anteverision did not change between the first and pre time point (p = 0.86). In the FDO group, from pre to short-term, there was a large and statistically significant change in anteverision from 56° (11°) to 17° (11°). There was a small and statistically significant increase in anteverision to 20° (13°) between the short- and long-term. Anteverision did not change between the first and pre time point (p = 0.90). The control group had significantly more anteverision than the FDO group at long-term.

Hip rotation changed significantly with time in both groups (Fig. 2b). In the control group, hip rotation decreased from 11° (17°) (pre) to 8° (9°) (short) to 5° (12°) (long). Pre to short-term and short- to long-term changes were statistically significant. Hip rotation did not change between the first and pre time point (p = 0.29). In the FDO group, between the pre and short-term time points, there was a large and statistically significant change in hip rotation from 14° (9°) to 3° (10°). There was no statistically significant change in hip rotation between the short- and long-

Fig. 2. (a, b) (a) Changes in anteverision and (b) changes in hip rotation over time. Individual patient trajectories are plotted as thin lines. The mean is shown by the circles connected by the heavy line; with 1 SD error bars. Dashed lines represent normal limits (10th–90th percentile) for hip rotation, and for mature anteverision. Time is measured from the pre time point. The control group is plotted on top. The groups are reasonably well matched at the pre time point; though the FDO group is slightly more anteverved (9°) and slightly more internally rotated (3°). At the long-term time point, anteverision in the FDO group is 15° lower than in the control group (p < 0.05), but hip rotation in the groups is equal (p = 0.17).
term time points (3° to 4°). Hip rotation did not change between the first and pre time point for the FDO group (p = 0.44). The long-term decrease in hip rotation was larger in the FDO group compared to controls (10° vs. 6°). The two groups had statistically equal hip rotation at the long-term time point (p = 0.17).

Rates of significant bony remodeling and associated gait adaptations were low in both groups, reaching problematic levels in only 6%–11% of limbs overall (Table 3). There were no statistically significant differences in the prevalence of antedirected bony remodeling or internal directed gait adaptations between the groups. This was true for both the absolute and problematic levels. The absolute rates of retro-directed bony remodeling and external directed gait adaptations were higher in the control group, reflecting normal anteverision remodeling. The problematic levels were the same between groups (anteverision: Control 0%, FDO 2%, p = 0.11, hip rotation: Control 7%, FDO 6%, p = 0.67).

4. Discussion

An FDO is an effective means for correcting femoral anteverision at the long-term time point, both compared to preoperative levels, and compared to a matched control group. This supports our hypotheses. Limbs in the FDO group had significant excessive anteverision at the preoperative time point, with a mean of 56° and 98% of limbs exceeding the 90th percentile of anteverision for age-matched norms. At the long-term time point, the mean anteverision in the FDO group was 20°, and only 18% exhibited excessive anteverision. Anteverision also improved in the control group, from a mean anteverision of 47° and 81% beyond the 90th percentile, to 35° and 53% at the long-term time point. This too supports our hypothesis that significant changes in anteverision can be attributed to bony remodeling, which, although delayed and perhaps attenuated in children with CP, is still significant.

Problematic recurrence of anteverision was relatively uncommon in the FDO group and was statistically equal in frequency to the rate observed in control limbs. Problematic retro-directed bony remodeling was virtually non-existent, with only 2% of control limbs and no FDO limbs exhibiting this response. Retro-directed remodeling largely matched expected age-dependent changes. Some cases of excessively external hip rotation post-FDO may be a result of performing the FDO on limbs with less internal hip rotation; a practice which previous studies have warned against [10,11].

Short- to long-term bony remodeling differed between the control and FDO group. In the FDO group, there was a small but significant increase in anteverision, while limbs in the control group continued remodeling as expected. It is not clear whether this difference is partly attributable to the FDO, or reflects some pre-selection of individuals for FDO surgery who have abnormal remodeling rates.

An FDO is not effective at correcting internal hip rotation at the long-term time point, compared to a control group. This fails to support our second hypothesis. Both groups significantly decreased their hip rotation, and the decrease for the FDO group was larger. However, at the long-term time point, the difference between the groups was less than 3° and was not statistically significant (p = 0.17). Participants were approximately 13 years old at the long-term time point. This is prior to skeletal maturity in many children, so it is unknown what additional remodeling and gait adaptation may occur. Of concern for both groups is that, at the long-term time point, over one-third of participants were outside the 90th percentile for internal hip rotation. If internal hip rotation is truly problematic for efficiency, safety, or cosmetic reasons, additional treatment may be necessary to achieve a desired final result.

Internal hip rotation recurred in 12% in the FDO group. Of those 12%, only half were considered problematic; a distinction that has not been made previously, but seems appropriate for identifying negative outcomes from surgeries. Unique to this study design, we were able to show that the rate of recurrence of internal hip rotation was the same in the control group as it was in the FDO group. Problematic external hip rotation occurred at an approximately equal rate as problematic internal rotation for both groups. These findings suggest that gait adaptations over time may not be significantly influenced by the FDO.

The data exhibit a tremendous amount of between-subject heterogeneity. Some heterogeneity is attributable to experimental error. We have estimated our inter-observer errors in anteverision measurement to be approximately 15°. This magnitude of error is not only a limitation for clinical decision-making, but also confounds some of the findings of this study. Measurement of hip rotation is more precise, but there is still some uncertainty, which may be exacerbated by changes in soft tissue artefact with time, growth, acetabular morphology, and changes in anteverision [20,21]. Another source of variability may be asymmetry. Previous studies have found that patients who are asymmetrically involved may demonstrate greater pelvic retraction and internal hip rotation on the more affected side [22–25]. Correcting excessive anteverision with an FDO on both sides of asymmetrically involved patients does not significantly decrease hip rotation on the less affected side [24].

This study improves upon previous studies by the inclusion of a control group, allowing the impact of the FDO to be assessed independent of bony remodeling that occurs naturally in growing children. However, the retrospective design also allows for a possible biasing influence of patient selection, since both groups had at least one clinically-initiated long-term follow-up visit. We have not examined why some limbs underwent an FDO, while seemingly matched limbs did not. Most likely, this is due to the slightly older, more antverted, and more internally rotated status of the FDO group, combined with typical variability in clinical decision making [26]. Specifically, some surgeons may choose to correct bony malalignment based on the principles of lever arm deformity correction; because excessive anteverision presumably limits function or requires compensations. Alternatively, other surgeons only correct bony malalignment if it is accompanied by evidence of aberrant dynamic function. There is also a pronounced difference in female to male ratios between the two groups. Further work is needed to understand the impact and cause of these differences, and if they influence surgical decisions and outcomes.

The results of this study suggest that a model is needed to predict who should receive an FDO, when the surgery should be performed, and by how much the femur should be derotated, in order to obtain a predictable and desirable long-term outcome. The ability to forecast the rate and amount of remaining anteverision remodeling for an individual appears to be the key factor in such a model. Currently, anteverision measures may not be accurate enough to provide this guidance. Finally, a careful re-evaluation and weighting of treatment goals is needed. While correcting hip rotation is a primary reason for performing an FDO, other reasons may be equally important (e.g., hip dysplasia, functional abductor weakness, or other gait deviations).

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Conflict of interest

The authors have no financial or personal relationships with other people or organizations that could inappropriately influence (bias) their work.

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