Changes in Pelvic Rotation After Soft Tissue and Bony Surgery in Ambulatory Children With Cerebral Palsy

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Abstract: The authors performed a retrospective review of pelvic rotation in 59 children with cerebral palsy who underwent lower extremity surgery and pre- and postoperative gait analysis. Two groups were studied: a femoral derotation osteotomy (FDRO) group and a soft tissue surgery only (no FDRO) group. Both groups exhibited abnormal pelvic rotation preoperatively and normalization of this abnormal pelvic rotation postoperatively. Though the mean change in pelvic rotation was small (3.3° ± 6.0°), some patients demonstrated postoperative changes as large as 21°. Variability in pelvic rotation was greater in the no FDRO group than in the FDRO group. Improvement in pelvic rotation occurred both in children with unilateral (hemiplegic) involvement and in those with bilateral (diplegic or quadriplegic) involvement. Surgeons planning lower extremity surgery in children with cerebral palsy should expect improvement in abnormal pelvic rotation in both hemiplegic and diplegic patients, whether or not bony surgery is planned in addition to soft tissue surgery.

Key Words: gait analysis, pelvic rotation, kinematics, transverse plane, cerebral palsy

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The goals of surgery in ambulatory children with cerebral palsy (CP) often include the normalization of foot progression and the correction of "lever arm disease."[1] Foot progression is affected by hip rotation (as in the case of femoral anteversion) and rotation below the level of the knee (caused by tibial torsion, forefoot adductus or supination), as well as rotation of the pelvis in the transverse plane. When planning a femoral rotational osteotomy to treat intoeing due to femoral anteversion, the surgeon must decide how much intoeing is due to femoral anteversion and how much is due to internal pelvic rotation or other factors. The surgeon must also decide whether any abnormal pelvic rotation is primary (due to spinal deformity) or secondary (a compensation to equalize foot progression) to determine whether pelvic rotation asymmetry can be expected to resolve postoperatively. In the case of a primary deviation, pelvic rotation would not be expected to change after derotational osteotomy of the femur. However, in the case of a compensatory pelvic rotation asymmetry, pelvic rotation would be expected to normalize once the rotational deformity of the femur is corrected.

Recent studies have reported contradictory results regarding the change in pelvic rotation following femoral derotation osteotomy (FDRO) in subjects with CP.[2–4] Saraph et al reported improvement in abnormal pelvic rotation in hemiplegic but not in diplegic children with CP.[4] Ounpuu et al reported no significant change in pelvic rotation in one study that included mostly bilaterally involved patients.[2] In another study that included only hemiplegic patients, they found significant improvement in pelvic rotation after femoral derotation osteotomy.[3] Because all subjects in these studies had soft tissue surgeries and some had concomitant rotations of the tibia at the time of FDRO, the postoperative change in pelvic rotation may not be attributable solely to femoral derotation. We are not aware of any previous reports regarding pelvic rotation before and after surgery in subjects who have asymmetric pelvic rotation in the absence of femoral anteversion.

The purposes of the current study were to determine the effect of surgery on pelvic rotation in subjects undergoing soft tissue surgery both with and without FDRO and to compare the results in subjects with unilateral versus bilateral involvement. This information will help orthopaedic surgeons predict which patients are likely to have a change in pelvic rotation postoperatively, thus facilitating the planning of bony derotation. In addition, this will enhance preoperative counseling of patients and their families.

MATERIALS AND METHODS

Subjects

A retrospective review of patients with static encephalopathy who had undergone soft tissue surgery with or without

Study conducted at Children's Hospital Los Angeles, Los Angeles, California.
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TABLE 1. Surgeries Performed (Excluding FDRO)

	FDRO		No FDRO	
	Hemi (n = 3)	**Di/Quad (n = 16)**	**Hemi (n = 15)**	**Di/Quad (n = 25)**
Gastrocnemius recession	0	7	8	8
Tendo Achilles lengthening	0	1	4	3
Adductor lengthening	1	5	3	8
Psoas lengthening	0	6	6	12
Hamstring lengthening	2	9	5	16
Rectus transfer	3	9	7	17
Posterior tibial tendon lengthening	0	0	2*	0
Flexor digitorum longus lengthening	0	0	2*	0
Flexor hallicus longus lengthening	0	0	1*	0
Plantar fasciotomy	0	0	1*	0
Tibial epiphyseodesis	0	0	1	0

*These procedures were done for extreme equinocavus in the absence of ankle varus.
FDRO, femoral derotation osteotomy.

TABLE 2. Subject Demographics

	FDRO		No FDRO		
	Hemi (n = 3)	**Di/Quad (n = 16)**	**Hemi (n = 15)**	**Di/Quad (n = 25)**	**Total (n = 59)**
Age at surgery (yr)	8.7 ± 1.0	8.2 ± 2.5	11.2 ± 5.5	9.5 ± 4.8	9.7 ± 4.4
Sex	2 M, 1 F	4 M, 12 F	10 M, 5 F	11 M, 14 F	27 M, 32 F
Time to follow-up (mo)	19.2 ± 9.2	17.5 ± 7.6	15.5 ± 4.5	18.1 ± 9.3	17.4 ± 7.7
Ambulatory level	0 aided, 3 unaided	8 aided, 8 unaided	1 aided, 14 unaided	13 aided, 12 unaided	22 aided, 37 unaided
# soft tissue surgeries on side analyzed	2.0 ± 0.0	2.3 ± 1.6	2.7 ± 1.3	2.6 ± 1.3	2.5 ± 1.4

FDRO, femoral derotation osteotomy.

TABLE 3. Kinematic Parameters

	FDRO		No FDRO		
	Preop	**Postop**	**Preop**	**Postop**	**Normal**
Pelvic rotation	−3.4 ± 6.2*	−0.2 ± 5.5†	**−6.4 ± 6.4**	−3.1 ± 6.2†	−0.4 ± 1.9
Hip rotation	**10.7 ± 10.3**	0.2 ± 16.0†	2.6 ± 18.6	1.8 ± 13.9	−2.8 ± 7.7
Foot progression	**14.1 ± 15.6**	**1.8 ± 22.4†**	−8.4 ± 18.5	−13.1 ± 14.2†	−10.8 ± 5.5

Data are given as mean ± SD.
Negative values indicate external rotation and positive values indicate internal rotation. Bold indicates significant difference from normal ($P < 0.05$).
*$P = 0.053$.
†Significant change from preoperative based on paired *t* test.
FDRO, femoral derotation osteotomy.

simultaneous femoral derotation osteotomy was conducted. Subjects who had concomitant tibial osteotomies or foot surgery that could affect foot progression were excluded. This left 59 patients for review, 18 with unilateral (hemiplegic) and 41 with bilateral (diplegic or quadriplegic) lower extremity involvement. For the subjects who underwent bilateral lower extremity surgery, the limb with more external pelvic rotation was selected for primary analysis. For the subjects undergoing unilateral procedures, the operative side was evaluated. Of the limbs evaluated, 19 had undergone multilevel orthopedic surgery including femoral derotational osteotomy (FDRO group) and 40 had undergone multilevel soft tissue surgery without FDRO (no FDRO group) (Table 1). Secondary analysis was also conducted for the contralateral limbs of the diplegic and quadriplegic subjects (16 with FDRO on the primary side, 25 with no FDRO on the primary side), excluding one subject for whom there were no contralateral data. The groups did not differ significantly with respect to age, sex, ambulatory level, number of soft tissue surgeries, or time between surgery and follow-up (Table 2).

Procedures

All subjects underwent computerized gait analysis both before and after surgery. Follow-up assessments took place an average of 17.4 ± 7.7 months postoperatively. The gait analysis used a seven-camera VICON (Oxford Metrics, Oxford, England) three-dimensional motion analysis system. This system uses a set of 15 to 19 passive retroreflective markers attached over specific bony landmarks of the pelvis and lower extremities. Subjects made several passes down a 15-meter path with the markers in place. Kinematic data from at least three trials were averaged, and the averaged data were used for statistical analysis. The parameters analyzed were pelvic rotation, hip rotation, and foot progression averaged over the stance phase of gait.

Statistics

Analysis of variance (ANOVA) was performed to study the influence of femoral derotation osteotomy (FDRO or no FDRO) and involvement (unilateral or bilateral) on average hip rotation, pelvic rotation, and foot progression during the stance phase of gait. Unpaired t tests were used to compare measurements from the study subjects with measurements from 18 able-bodied children. Paired t tests were used to compare the pre- and postoperative measurements for the study subjects. The significance level was set at $P < 0.05$.

RESULTS

No differences were found between unilaterally and bilaterally involved subjects, before or after surgery. The only parameters that differed between the FDRO and no FDRO groups were postoperative pelvic rotation ($P = 0.04$), preoperative ($P = 0.001$) and postoperative ($P = 0.01$) foot progres-

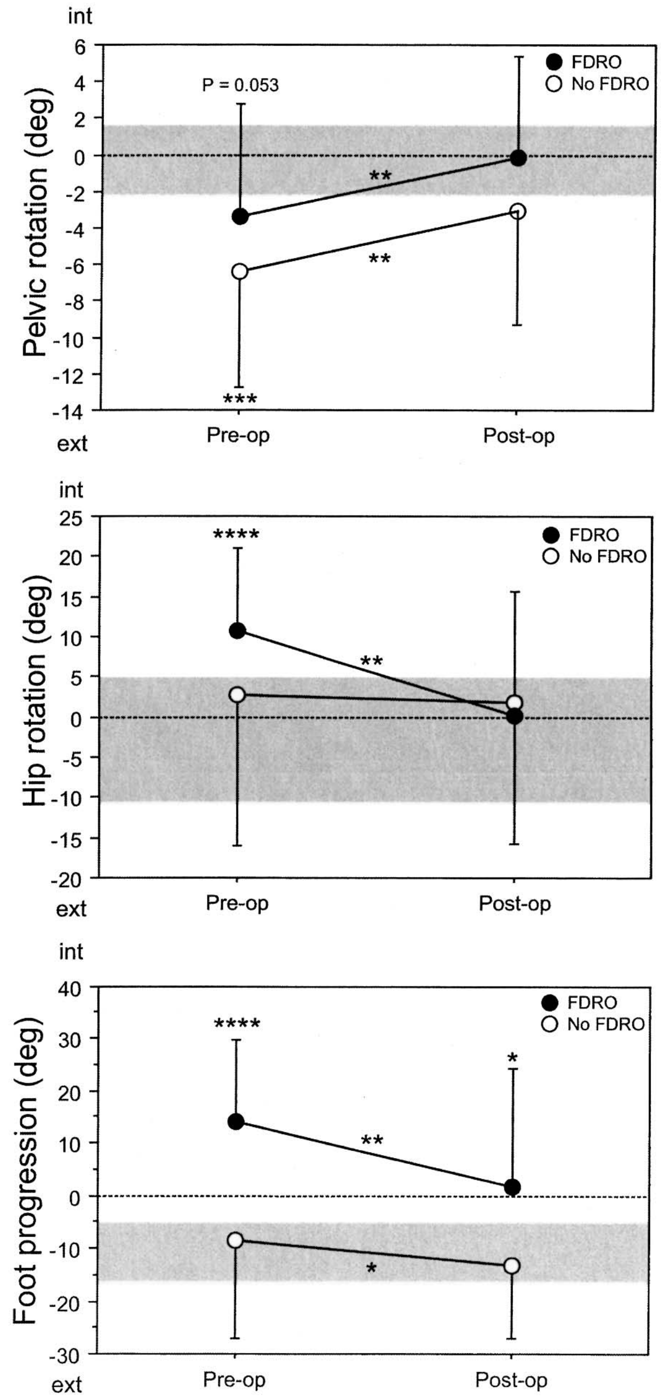

FIGURE 1. Kinematic results (mean ± SD). Shaded area is normal range (mean ± 1 SD). Asterisks indicate statistically significant differences (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ***$P < 0.0001$) versus normal (above data points) or from pre- to postoperative (above lines between data points). FDRO, femoral derotation osteotomy.

sion, and the pre- to postoperative change in hip rotation (P = 0.01).

Preoperatively, subjects in both the FDRO group (P = 0.053) and the no FDRO group (P = 0.0002) exhibited abnormal external pelvic rotation, although this difference was statistically significant only in the no FDRO group (Table 3). The FDRO group had abnormal internal hip rotation ($P < 0.0001$) and internal foot progression ($P < 0.0001$), while the no FDRO group had normal hip rotation (P = 0.24) and foot progression (P = 0.60) preoperatively (Fig. 1). The abnormal pelvic rotation (P = 0.007), hip rotation (P = 0.009), and foot progression (P = 0.002) all changed significantly toward normal after surgery in the FDRO group. Pelvic rotation (P = 0.003) changed significantly toward normal in the no FDRO group, and foot progression became significantly more external (P = 0.04), although it remained within the normal range (see Fig. 1). Hip rotation did not change (P = 0.71) in the no FDRO group. Though the mean postoperative change in pelvic rotation was comparable for the two groups, the range was greater in the no FDRO group (−11° to +21°) than in the FDRO group (−4° to +13°). Postoperatively, only foot progression in the FDRO group (P = 0.03) differed significantly from normal.

For the contralateral limbs (side of forward hemipelvis) of the bilaterally involved subjects, preoperative pelvic rotation was more internal than normal in both the FDRO (P = 0.002) and no FDRO ($P < 0.0001$) groups (Table 4). The FDRO group also exhibited abnormal internal rotation of the contralateral hip (P = 0.006) and foot ($P < 0.0001$) preoperatively. The no FDRO group had normal hip rotation (P = 0.98) and foot progression (P = 0.08) preoperatively on the contralateral side. Contralateral pelvic rotation (P = 0.03), hip rotation ($P < 0.0001$), and foot progression (P = 0.0007) changed significantly toward normal in the FDRO group after surgery. Contralateral pelvic rotation (P = 0.002) also changed toward normal in the no FDRO group, while hip rotation (P = 0.16) and foot progression (P = 0.07) did not change significantly in this group. Postoperatively, the forward pelvis remained more internally rotated than normal in the no FDRO group (P = 0.02) and tended to remain internally rotated in the FDRO group (P = 0.07). Hip rotation (P = 0.34 for FDRO group, P = 0.20 for no FDRO group) and foot progression (P = 0.42 for FDRO group, P = 0.41 for no FDRO group) did not differ significantly from normal in the contralateral limbs postoperatively.

DISCUSSION

Pelvic rotation has been recognized as a contributing factor to abnormal transverse plane kinematics in children with CP. Recent studies have investigated the effects of femoral derotation on pelvic rotation in children with CP.[2–4]

Unlike previous studies, the current study evaluates pelvic rotation in children undergoing only soft tissue surgery, as well as in those undergoing FDRO. In both the FDRO and no FDRO groups, abnormal preoperative pelvic rotation improved postoperatively. In fact, the improvement in pelvic rotation in the children undergoing soft tissue surgery alone was comparable to the improvement in the children who underwent both soft tissue surgery and concomitant femoral rotational osteotomy. This calls into question the etiology of the abnormal pelvic rotation. Clearly, this asymmetric pelvic rotation cannot solely be attributed to compensation for abnormal femoral anteversion and abnormal hip rotation. If pelvic rotation were only compensatory to femoral anteversion, one would not expect it to improve after soft tissue surgery alone.

The current study demonstrates improvement in pelvic rotation for both unilaterally and bilaterally involved children. These results differ from those of Ounpuu et al,[2] who found no significant change in pelvic rotation following femoral osteotomy in a group of primarily bilaterally involved patients, and from those of Saraph et al,[4] who noted improvement in pelvic rotation in hemiplegic but not diplegic patients. If pelvic rotation were simply compensatory in these children, one would expect the hemiplegic children to be able to normalize pelvic rotation better than bilaterally involved children.

One possible explanation for the differences between our results and those of Ounpuu et al[2] and Saraph et al[4] may be related to differences in subject selection and data analysis. For the bilaterally involved subjects in the current study, we analyzed the side with more external pelvic rotation. This provides

TABLE 4. Kinematic Parameters for Contralateral Limbs of Bilaterally Involved Subjects

	FDRO		No FDRO		
	Preop	Postop	Preop	Postop	Normal
Pelvic rotation	**5.3 ± 6.9**	2.7 ± 6.7*	**6.9 ± 5.5**	**2.6 ± 5.1***	−0.4 ± 1.9
Hip rotation	**7.9 ± 13.1**	−6.2 ± 13.0*	−2.7 ± 15.5	1.2 ± 10.8	−2.8 ± 7.7
Foot progression	**11.2 ± 14.2**	−6.8 ± 19.9*	−1.5 ± 21.0	−7.2 ± 17.5	−10.8 ± 5.5

Data are given as mean ± SD.
Negative values indicate external rotation and positive values indicate internal rotation. Bold indicates significant difference from normal ($P < 0.05$).
*Significant change from preoperative based on paired t test.
FDRO, femoral derotation osteotomy.

consistency with analysis of the involved side in hemiplegic subjects, since the involved limb in hemiplegics is almost always the trailing side. When analysis includes two limbs from the same subject, as in the studies of Ounpuu et al[2] and Saraph et al,[4] internal rotation of one hemipelvis tends to cancel external rotation of the other in the overall results. The inclusion of subjects with concomitant tibial rotations and foot procedures also affects the results. Subjects who underwent these types of surgeries were included in the previous studies but were excluded from the current study.

Most (13 of 16) of the bilaterally involved children in the FDRO group underwent bilateral FDROs. In the group who underwent bilateral FDROs, hip rotation tended to be undercorrected on the side with external pelvic rotation preoperatively and overcorrected on the side with internal pelvic rotation preoperatively. The recent report by Ounpuu et al suggests that such corrections would be expected to be long-lasting.[2] As the data in the current study demonstrate, pelvic rotation improved toward normal postoperatively for both sides of the pelvis in these patients. The postoperative change in pelvic rotation in these patients resulted in significant asymmetry in postoperative foot progression angles.

This study showed an improvement in pelvic rotation for bilaterally and unilaterally involved CP patients both with and without FDRO. Though the mean postoperative change in pelvic rotation was small, 10 of 59 sides (17%) had changes exceeding 10°, and some patients showed dramatic changes (up to 21°) postoperatively. Postoperative changes in pelvic rotation were more variable in the no FDRO group (range −11° to +21°) than in the FDRO group (range −4° to +13°).

When planning lower extremity surgery for these children, the surgeon should be aware that the trailing hemipelvis will be less externally rotated postoperatively than preoperatively. Consequently, if the amount of femoral derotation is based on only the preoperative hip rotation and foot progression data, then the patient may have residual intoeing due to the postoperative change in pelvic rotation. For patients undergoing soft tissue surgery alone, both the pelvic and foot progression angles can be expected to change postoperatively.

REFERENCES

1. Gage JR. *Gait Analysis in Cerebral Palsy.* London: Mac Keith Press, 1991:118–131.
2. Ounpuu S, DeLuca P, Davis R, et al. Long-term effects of femoral derotation osteotomies: an evaluation using three-dimensional gait analysis. *J Pediatr Orthop*. 2002;22:139–145.
3. Ounpuu S, Michalak RE, Romness MJ, et al. The effects of the femoral derotation osteotomy on pelvic motion in children with cerebral palsy spastic hemiplegia. *Gait Posture*. 2002;16:S34–S35.
4. Saraph V, Zwick EB, Zwick G, et al. Effect of derotation osteotomy of the femur on hip and pelvis rotations in hemiplegic and diplegic children. *J Pediatr Orthop B*. 2002;11:159–166.

