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### Supplementary material

Commentary and Perspective, data tables, additional images, video clips and/or translated abstracts are available for this article. This information can be accessed at <http://www.ejbs.org/cgi/content/full/88/10/2175/DC1>

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# CAUSES OF INTOEING GAIT IN CHILDREN WITH CEREBRAL PALSY

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**Background:** Intoeing is a frequent gait problem in children with cerebral palsy. It is essential to determine the cause(s) of intoeing when surgical intervention is being planned. The purpose of this study was to evaluate the prevalence of various causes of intoeing in children with cerebral palsy and to determine whether the causes differ between children with bilateral and those with unilateral involvement.

**Methods:** The cause of intoeing gait was examined retrospectively, with use of gait analysis, in 412 children with cerebral palsy (587 involved sides). The causes were evaluated separately for the children with bilateral involvement (diplegia or quadriplegia) and those with hemiplegia.

**Results:** Overall, the most common causes of intoeing were internal hip rotation (322 of 587 sides) and internal tibial torsion (296 of 587 sides). Pes varus contributed to intoeing of thirty-five of the eighty-two involved limbs of the patients with hemiplegia and of forty-two of the 505 limbs of the patients with diplegia or quadriplegia. Multiple causes of intoeing were noted in 215 of the 587 involved limbs, including 176 of the 505 limbs of the patients with bilateral involvement and thirty-nine of the eighty-two involved limbs of the patients with hemiplegia. The most common causes of intoeing in the subjects with bilateral involvement were internal hip rotation (288 of 505), internal tibial torsion (261 of 505), and internal pelvic rotation (ninety-two of 505). The most common causes in the hemiplegic children were internal tibial torsion (thirty-five of eighty-two), pes varus (thirty-five of eighty-two), internal hip rotation (thirty-four of eighty-two), and metatarsus adductus (twenty of eighty-two).

**Conclusions:** More than one-third of children with cerebral palsy have multiple causes of intoeing. Pes varus commonly contributes to intoeing by children with hemiplegic cerebral palsy but rarely contributes to intoeing by those with diplegia or quadriplegia. These findings should be carefully considered prior to surgical correction of the intoeing gait of these patients.

The prevalence of intoeing by children with cerebral palsy has been reported to be 64% (70% in quadriplegic children, 66% in diplegic children, and 54% in hemiplegic children)<sup>1</sup>. The reported causes of intoeing include spasticity of muscles (the hip internal rotators and adductors as well as the medial hamstrings), femoral anteversion, internal tibial torsion, metatarsus adductus, pes varus, and internal pelvic rotation<sup>2-5</sup>. We found no reports in the literature detailing the prevalences of specific causes of intoeing in children with cerebral palsy or examining the prevalences of those causes with respect to the pattern of cerebral palsy (hemiplegia, diplegia, or quadriplegia).

The purposes of this study were to evaluate the prevalences of various causes of intoeing in a large number of children with cerebral palsy and to determine if there are differences in causation between children with bilateral involvement and those with unilateral involvement. This information is important to help physicians understand the etiology of this common problem and to make informed treatment decisions.

## Materials and Methods

Institutional review board approval was obtained prior to initiation of the study. Reports on the findings of preoperative gait analyses of 412 subjects with cerebral palsy and intoeing gait patterns were reviewed retrospectively. The average age of the subjects was  $9.3 \pm 3.7$  years (range, 3.3 to 26.5 years). There were 213 male subjects and 199 female subjects. Intoeing was defined as internal foot progression of  $>0^\circ$  through  $>50\%$  of the gait cycle and was determined by examination of the kinematic gait data. Only the sides on which intoeing occurred were included in the data analysis. Three hundred and fourteen subjects had bilateral involvement (diplegic or quadriplegic cerebral palsy); 191 of them intoed bilaterally, and 123 intoed on one side only. There were ninety-eight hemiplegic subjects, forty-three of whom intoed bilaterally and fifty-five of whom intoed on one side only (on the hemiplegic side in thirty-nine subjects, and on the uninvolved side in sixteen). A total of 587 limbs affected by cerebral palsy and exhibiting intoeing were included in the analysis.

Gait analysis reports were reviewed to determine the cause of internal foot progression on the basis of the physical examination and three-dimensional kinematic and electromyographic data. The causes of intoeing, which were recorded for each subject, included internal rotation of the pelvis (the pelvis rotated internally, as seen on the kinematic graph, by more than one standard deviation from normal pelvic rotation, through >50% of the gait cycle), internal rotation of the hip (the hip rotated internally, as seen on the kinematic graph, by more than one standard deviation from normal hip rotation, through >50% of the gait cycle), internal tibial torsion (an internal thigh-foot angle of  $>0^\circ$ , measured statically, in the absence of foot deformity), pes varus (inversion of the hindfoot with or without forefoot supination during the stance and/or swing phase, as seen on the video record or as indicated by the foot-switch record), and metatarsus adductus (adduction of the forefoot without associated varus as assessed clinically). When internal hip rotation represented a primary gait deviation, it was associated with femoral anteversion (measured with use of the trochanteric prominence angle test<sup>6</sup>). However, when internal hip rotation was compensatory (such as to normalize foot progression in the presence of external pelvic rotation), it was not always associated with femoral anteversion. Therefore the term “internal hip rotation” will be used throughout this report and may indicate femoral anteversion in some limbs.

The contributors to intoeing were then determined. The internal foot progression angle was calculated from the kinematic data plots. Possible causes of the intoeing were then recorded on the basis of other transverse plane kinematic graphs (pelvic rotation and hip rotation); static examination measures (tibial torsion and metatarsus adductus); and video data, static examination measures, and electromyographic data (pes varus). For example, if a child had internal foot progression of  $>0^\circ$  but normal pelvic rotation, normal hip rotation, no pes varus, and no metatarsus adductus and had internal tibial torsion measured statically, the intoeing was attributed to internal tibial torsion. If a child had internal foot progression with internal hip rotation, normal tibial torsion, no pes varus, no metatarsus adductus, and normal or external pelvic rotation, the intoeing was attributed to internal hip rotation. If more than one of these contributors was present, intoeing was attributed to multiple causes (Figs. 1, 2, and 3).

### Statistical Methods

The number and percentage of intoeing sides attributed to each cause were calculated separately for subjects with bilateral involvement and those with unilateral involvement. The data were also examined to determine the prevalences of isolated versus combined causes of intoeing. They were further examined to determine the most common isolated causes as well as the most common combination of factors contributing to intoeing in the subjects with bilateral involvement and those with unilateral involvement. The prevalences of the various causes of intoeing were compared between bilaterally and unilaterally involved subjects with use of chi-square analysis. The significance level was set at  $p < 0.05$ .

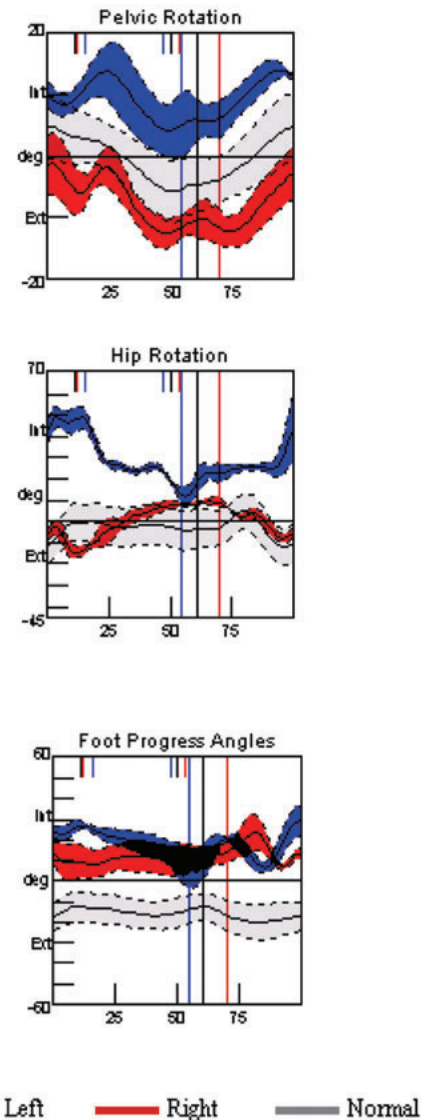


Fig. 1

Kinematic data for a child with quadriplegic cerebral palsy. On the left, internal foot progression was attributed to internal pelvic rotation and internal hip rotation (femoral anteversion measured  $60^\circ$ ). On the right, internal foot progression was attributed to internal tibial torsion (an internal thigh-foot angle of  $5^\circ$  with no foot deformity).

### Results

Overall, the most frequent contributors to intoeing were internal hip rotation and internal tibial torsion in both the subjects with cerebral palsy with bilateral involvement and those with unilateral involvement. Internal hip rotation was significantly more prevalent in subjects with bilateral involvement (288 of 505 limbs; 57%) than in patients with hemiplegia (thirty-four of eighty-two limbs; 41%). Pes varus was an equally common contributor to intoeing in the hemiplegic subjects (thirty-five of eighty-two limbs; 43%), whereas pes varus was rarely a contributor in either the diplegic or the

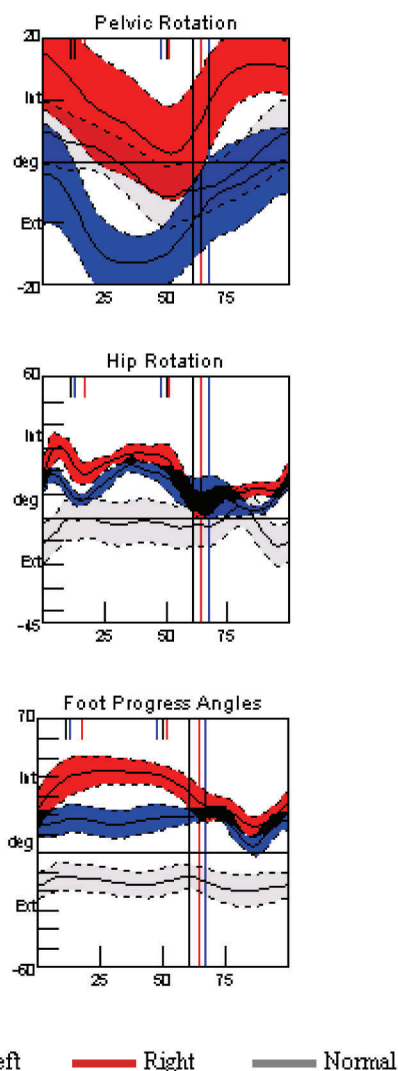


Fig. 2

Kinematic data for a child with diplegic cerebral palsy. On the left, internal foot progression was attributed to internal hip rotation (femoral anteversion measured 60°) and internal tibial torsion (an internal thigh-foot angle of 20° with no foot deformity). On the right, internal foot progression was attributed to internal pelvic rotation, internal hip rotation (femoral anteversion measured 45°), and internal tibial torsion (an internal thigh-foot angle of 20° with no foot deformity).

quadruplegic subjects (forty-two of 505 limbs; 8%) (Table I).

Isolated causes of intoeing were more prevalent in the subjects with bilateral involvement than in the hemiplegic subjects. Intoeing was due to a single factor in 65% (329) of the 505 limbs of the subjects with bilateral involvement and had a combination of causes in 35% (176) of the 505 limbs. The intoeing on the involved side of the hemiplegic subjects was as frequently caused by an isolated factor (forty-three of eighty-two limbs; 52%) as by multiple factors (thirty-nine of eighty-two limbs; 48%) (Table II).

When intoeing was due to a single factor, it was most of-

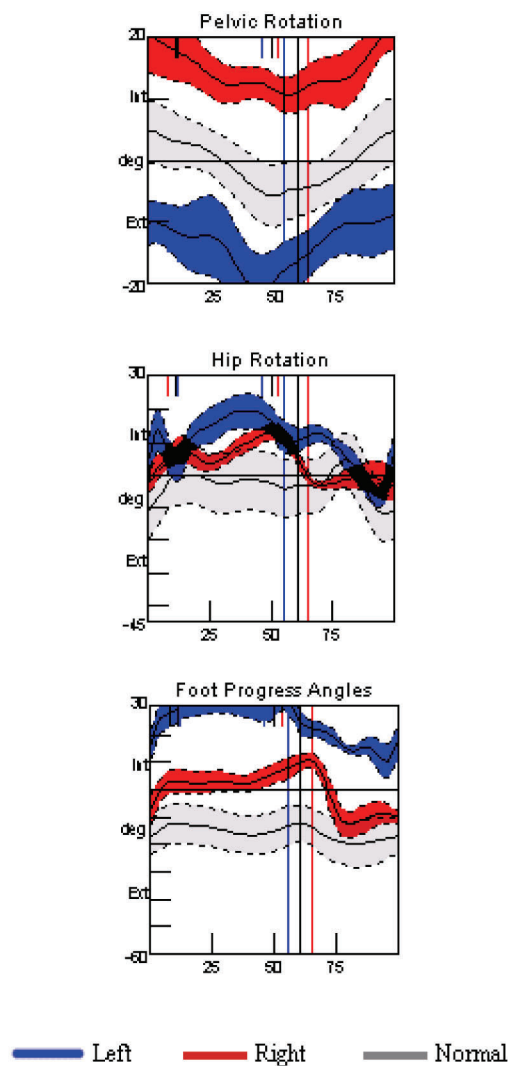


Fig. 3

Kinematic data for a child with left hemiplegic cerebral palsy. On the left, internal foot progression was attributed to pes varus (an external thigh-foot angle of 15°) and metatarsus adductus. On the right, internal foot progression was attributed to internal pelvic rotation.

ten caused by internal hip rotation or internal tibial torsion in both groups of subjects. In the hemiplegic subjects, internal tibial torsion (eighteen of forty-three limbs; 42%) was seen as an isolated cause more often than internal hip rotation (thirteen of forty-three limbs; 30%). Pes varus was the isolated contributor in 23% (ten) of the forty-three intoeing limbs with an isolated cause in hemiplegic subjects but in only 3% (eleven) of the 329 limbs with an isolated cause in the patients with bilateral involvement (Table III).

In the subjects with cerebral palsy affecting both lower extremities, the most common combination of factors contributing to intoeing was internal hip rotation with internal tibial torsion. This combination was seen in significantly fewer hemiplegic subjects (hemiplegic sides) ( $p \leq 0.01$ ). In the hemiplegic subjects, the most common combined causes

**TABLE I Contributors to Intoeing\***

	No. (%) of Limbs		P Value
	Diplegia/Quadriplegia (314 Subjects, 505 Limbs)	Hemiplegia (82 Subjects/Limbs†)	
Internal rotation of pelvis	92 (18%)	2 (2%)	≤0.001
Internal rotation of hip	288 (57%)	34 (41%)	≤0.01
Internal tibial torsion	261 (52%)	35 (43%)	≤0.2
Pes varus	42 (8%)	35 (43%)	≤0.001
Metatarsus adductus	27 (5%)	20 (24%)	≤0.001
Other	8 (2%)	2 (2%)	≤1.0

\*Isolated and combined causes in all intoeing limbs affected by cerebral palsy are included. †Only the hemiplegic sides are included.

**TABLE II Prevalence of Isolated and Combined Contributors**

	No. (%) of Limbs		P Value
	Diplegia/Quadriplegia (314 Subjects, 505 Limbs)	Hemiplegia (82 Subjects/Limbs*)	
Isolated cause	329 (65%)	43 (52%)	≤0.05
Combined causes	176 (35%)	39 (48%)	

\*Only the hemiplegic sides are included.

were pes varus with metatarsus adductus, followed by pes varus with internal hip rotation. The prevalences of these combinations of factors were significantly lower in the subjects with bilateral involvement ( $p \leq 0.001$ , and  $p \leq 0.01$ , respectively). The combination of internal pelvic rotation and internal hip rotation, with or without internal tibial torsion, was seen in 25% (forty-four) of the 176 intoeing limbs with a combination of causes in subjects with bilateral involvement. These combined factors were almost never seen in hemiplegic patients. All other combinations were seen in fewer than 10% of the limbs studied (Table IV).

Intoeing was caused by an isolated factor in 90% (fifty-three) of the fifty-nine uninvolved limbs in the hemiplegic subjects. It was due to isolated internal pelvic rotation in 64% (thirty-eight) of those fifty-nine limbs. Isolated internal tibial torsion contributed to intoeing in 19% (eleven) of the fifty-nine limbs.

### Discussion

Intoeing is a common problem interfering with function in children with cerebral palsy since it contributes to both lever arm dysfunction and tripping. The current study delin-

**TABLE III Prevalence of Isolated Contributors to Intoeing**

	No. (%) of Limbs		P Value
	Diplegia/Quadriplegia (329 Limbs)	Hemiplegia (43 Limbs*)	
Internal rotation of pelvis	27 (8%)	1 (2%)	≤0.2
Internal rotation of hip	146 (44%)	13 (30%)	≤0.1
Internal tibial torsion	141 (43%)	18 (42%)	≤1.0
Pes varus	11 (3%)	10 (23%)	≤0.001
Metatarsus adductus	1 (<1%)	1 (2%)	≤0.10
Other	3 (1%)	0	≤1.0

\*Only the hemiplegic sides are included.

TABLE IV Prevalence of Combined Causes

	No. (%) of Limbs		P Value
	Diplegia/Quadriplegia (176 Limbs)	Hemiplegia (39 Limbs*)	
Internal rotation of hip, internal tibial torsion	76 (43%)	7 (18%)	≤0.01
Pes varus, metatarsus adductus	7 (4%)	10 (26%)	≤0.001
Internal rotation of hip, pes varus	9 (5%)	8 (21%)	≤0.01
Internal rotation of pelvis, internal rotation of hip	25 (14%)	0	≤0.025
Internal rotation of pelvis, internal rotation of hip, internal tibial torsion	19 (11%)	1 (3%)	≤0.20
Internal rotation of pelvis, internal tibial torsion	13 (7%)	0	≤0.10

\*Only the hemiplegic sides are included.

ates the relative frequencies of various causes of intoeing in children with cerebral palsy.

An important finding in the current study is the frequency with which intoeing gait had multiple causes in children with cerebral palsy. Overall, there were multiple causes of intoeing in 37% of the affected limbs, with a prevalence of 35% in children with diplegia or quadriplegia and 48% in those with hemiplegia. Failure to correctly identify and treat those multiple causes may result in residual osseous deformity, intoeing, and lever arm dysfunction<sup>7</sup> after a child with cerebral palsy is operated on for intoeing gait.

The current study demonstrated that the most common contributors to intoeing, either alone or in combination with other factors, are internal hip rotation (55% of the intoeing limbs) and internal tibial torsion (50%). Pes varus is a frequent contributor only in hemiplegic subjects (43% of the limbs); it was present in only 8% of the intoeing limbs of patients with bilateral involvement. Therefore, pes varus should not be the first consideration for surgical correction of intoeing in children with diplegia or quadriplegia.

There are often other contributors to intoeing in children with hemiplegia and pes varus. The prevalence of metatarsus adductus (26%) and internal hip rotation (21%) in such children suggests that tendon transfers about the foot and ankle alone may not fully correct the intoeing.

There have been several reports on femoral derotational osteotomy to correct internal rotation gait of children with cerebral palsy<sup>8-12</sup>. However, there have been relatively few reports on the contribution of internal tibial torsion to intoeing by children with cerebral palsy. The results of the current study show that internal tibial torsion is often involved in intoeing and is a more frequent isolated cause of intoeing in hemiplegic children (42% of the limbs) than is internal hip rotation (30% of the limbs). Distal tibial derotational osteotomy has been shown to be safe and effective for correcting intoeing due to internal tibial torsion in children with cerebral palsy who are able to walk<sup>13,14</sup>.

Numerous reports in the literature have attributed the internal rotation gait of patients with cerebral palsy to spastic medial hamstrings and adductors<sup>2,4</sup> and to spastic gluteus me-

dius and minimus muscles<sup>3,5</sup>. However, more recent research involving cadavers and computer modeling<sup>15-17</sup> has shown that the hamstrings and hip adductors have either negligible internal rotation moment arms or have external rotation moment arms about the hip and are unlikely to contribute to internal rotation during gait. This finding is consistent with our experience. We noted that intoeing by these children is almost universally associated with osseous deformity rather than with simple muscle overactivity; therefore, we do not recommend soft-tissue surgery on the hamstrings, hip adductors, or internal rotators to correct internal rotation gait. However, such surgery may be indicated for other reasons.

Internal pelvic rotation was one of many contributors to intoeing in 32% (fifty-seven) of the 176 intoeing limbs of the patients with bilateral involvement. These subjects may have had external pelvic rotation on the contralateral side that normalized the contralateral foot progression, despite the internal hip rotation. These sides were excluded from the analysis in this study since only the intoeing sides (as measured by the foot progression angle) were evaluated. Therefore, the prevalence of internal rotation of the lower limb in subjects with bilateral involvement may be greater than indicated here. Internal pelvic rotation was rarely an isolated cause of intoeing in subjects with bilateral involvement (8% of the limbs) or on the involved side of hemiplegic subjects (2% of the limbs). However, internal pelvic rotation was an isolated cause of intoeing in 64% of the uninvolved limbs of the hemiplegic subjects. (In other words, children with left hemiplegia often had intoeing on the right side due to internal rotation of the right hemipelvis.) These findings are consistent with those reported in the literature<sup>9</sup>. Since internal pelvic rotation is compensatory to other factors, it is not treated surgically. However, internal pelvic rotation in both subjects with bilateral involvement and those with unilateral involvement has been shown to decrease after multilevel lower-extremity surgery with or without femoral derotational osteotomy<sup>9,11,18</sup>.

In summary, the cause of intoeing in children with cerebral palsy who are able to walk is often multifactorial. It is most often caused by internal hip rotation and/or internal tib-

ial torsion in both subjects with bilateral involvement and those with unilateral involvement. Pes varus is a frequent contributor (alone or in combination with other factors) to intoeing in hemiplegic subjects, but it is uncommon in diplegic and quadriplegic patients. Gait analysis was used to assess all patients in this study, and it often facilitates the identification of multiple causes of intoeing. However, by defining the common causes of intoeing in children with cerebral palsy, the findings of this study should prove helpful in cases in which gait analysis is not available. As more than one-third of children with cerebral palsy have multiple causes of intoeing, this possibility should be carefully considered prior to surgery to allow all sites of pathology to be addressed.

### Appendix

**eA** A video showing the gait analysis of one of the study subjects is available on our web site at [jbjs.org](http://jbjs.org) (go to the article citation and click on "Supplementary Material"). ■

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