Correction of Tibial Torsion in Children With Cerebral Palsy by Isolated Distal Tibia Rotation Osteotomy: A Short-term, In Vivo Anatomic Study

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Background: Excessive internal or external tibial torsion is frequently present in children with cerebral palsy. Several surgical techniques have been described to correct excessive tibial torsion, including isolated distal tibial rotation osteotomy (TRO). The anatomic changes surrounding this technique are poorly understood. The goal of the study was to examine the anatomic relationship between the tibia and fibula following isolated distal TRO in children with cerebral palsy.

Methods: Twenty patients with 29 limbs were prospectively entered for study. CT scans of the proximal and distal tibiofibular (TF) articulations were obtained preoperatively, at 6 weeks, and 1 year postoperatively. Measurements of tibia and fibula torsion were performed at each interval. Qualitative assessments of proximal and distal TF joint congruency were also performed.

Results: The subjects with internal tibia torsion (ITT, 19 limbs) showed significant torsional changes for the tibia between preoperative, postoperative, and 1 year time points (mean torsion 13.21, 31.05, 34.84 degrees, respectively). Measurement of fibular torsion in the ITT treatment group also showed significant differences between time points (mean -36.77, -26.77, -18.54 degrees, respectively). Proximal and distal TF joints remained congruent at all time points in the study. Subjects with external tibia torsion (ETT, 10 limbs) showed significant differences between preoperative and postoperative tibial torsion, but not between postoperative and 1 year (mean torsion 54, 19.3, 23.3 degrees, respectively). Measurement of fibular torsion in the ETT treatment group did not change significantly between preoperative and postoperative, but did change significantly between postoperative and 1 year (mean torsion -9.8, -16.9, -30.7 degrees, respectively). Nine of 10 proximal TF joints were found to be subluxated at 6 weeks postoperatively. At 1 year, all 9 of these joints had reduced.

Conclusions: Correction of ITT by isolated distal tibial external rotation osteotomy resulted in acute external fibular torsion. The fibular torsion alignment remodeled over time to accommodate the corrected tibial torsional alignment and reduce the strain associated with the plastic deformity of the fibula. Correction of ETT by isolated distal internal TRO resulted in acute subluxation of the proximal TF articulation in almost all cases. Subsequent torsional remodeling of the fibula resulted in correction of the TF subluxation in all cases. Acute correction of TT by isolated distal TRO occurs by distinct mechanisms, based upon the direction of rotational correction.

Level of Evidence: Level II—Diagnostic.

Key Words: tibial rotation osteotomy, cerebral palsy, anatomy

(*J Pediatr Orthop* 2016;36:743–748)

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The authors did not receive any outside funding or grants in support of their research for or in preparation of this work.

The authors declare no conflicts of interest.

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Excessive internal or external tibial torsion is a frequent problem in children with cerebral palsy (CP). It can lead to an abnormal gait pattern secondary to "lever arm dysfunction," compromise shock absorption and stability in stance, and contribute to abnormal frontal plane knee moments.[1–7] Additional clinical concerns include swing clearance difficulties; knee, ankle, and foot pain, and poor gait cosmesis.[7–12]

A variety of surgical techniques have been utilized to treat excessive tibial torsion.[13–23] Proximal tibial osteotomies are no longer favored when correcting for a transverse plane deformity because of increased neurological complications.[24–26] Casting alone, staples, and suture fixation have been replaced by crossed K-wires, Steinman pins, or plate osteosynthesis. Improved internal fixation has decreased loss of reduction and prevented iatrogenic malunions.[16] The current standard of care when correcting abnormal torsion includes a distal tibial rotational osteotomy (TRO) with or without a concomitant fibular osteotomy. There continues to be controversy surrounding the need for a fibula osteotomy.[27–29]

Proponents of the tibia-alone technique claim that the ankle joint and fibula can accommodate acute torsional correction by plastic deformation. Avoiding a fibula osteotomy adds stability to the leg. There is also decreased morbidity associated with a second surgical site and little risk of a cross-union complication and subsequent ankle valgus during growth.[16,20,27–31] Proponents of a combined distal osteotomy (ie, tibia and fibula) argue it allows for a stress-free rotation during correction, greater magnitude of torsional correction, decreases ankle joint incongruity, and lowers the risk of recurrence.[14,23]

The anatomic changes following an isolated distal TRO are not yet fully understood, and to our knowledge no advanced diagnostic imaging studies have been performed to look at the anatomic changes associated with this procedure. Our purpose was to use computed tomography (CT) to examine the changes seen between the tibia and fibula following isolated distal TRO in children with CP.

METHODS

The study design was prospective case series and was approved by our institution's research review board. Patients were enrolled prospectively after their excessive tibial torsion was confirmed quantitatively during preoperative motion analysis laboratory testing. Inclusion criteria were a diagnosis of CP and recommendations for surgical correction of functionally significant excessive tibial torsion. Abnormal torsion was defined through a comprehensive gait assessment that included a clinical history (ie, frequent trips and falls or pain), physical examination (ie, thigh-foot angle, transmalleolar axis in extension and flexion), and abnormal kinematics (knee rotation and foot progression angles) as determined in the gait laboratory.

Twenty patients with 29 limbs met the inclusion criteria. Thirteen patients with 19 limbs were treated for excessive internal tibial torsion (ITT, by externally rotating the distal tibial segment). Seven patients with 10 limbs were treated for external tibial torsion (ETT, by internally rotating the distal tibial segment). There were 14 males and 6 females. The average age at the time of surgery was 8.2 years (range, 6.4 to 11.0 y) in the ITT group. The average age at the time of surgery was 15.5 years (range, 12.6 to 18.9 y) in the ETT group. CP types included spastic diplegia (14 subjects), hemiplegia (4 subjects), and triplegia (2 subjects). The Gross Motor Functional Classification System (GMFCS) identified 9 patients with level I, 8 patients with level II, and 3 patients with level III involvement. There were 13 right limbs and 16 left limbs. Twenty-three of the 29 limbs had concurrent multilevel surgery, including hamstring lengthening in 14, gastrocnemius soleus recession in 14, rectus femoris transfer in 8, foot skeletal reconstructions in 6, and femoral rotational osteotomies in 2 extremities. All of the surgeries were performed by 2 surgeons, who utilized identical surgical techniques (4 to 6 hole compression plates, depending on patient size; and proximal/distal k wires to determine the magnitude of correction required to correct the supine thigh-foot angle to approximately 5 degrees external).

Study subjects underwent limited radiation axial plane CT scans of the proximal and distal tibia and fibula [to include the tibiofibular (TF), articulations] at 3 time points: preoperatively, 6 weeks, and 1 year postoperatively. The tibial and fibular torsion at each time point was separately measured by 2 different examiners to establish intraobserver and interobserver reliability. Strength of agreement was categorized as poor (< 0.00), slight (0.00 to 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), good (0.61 to 0.80), or excellent (0.81 to 1.00).[32] Assessment of tibial and fibular torsion was performed using the previously described techniques by Widjaja et al[33] and Vasarhelyi et al,[34] respectively (Figs. 1, 2). The more positive (+) the numerical angular measure, the more externally rotated the distal tibial segment (foot end) was in relation to the proximal tibial segment (knee end). Qualitative assessment of proximal and distal TF joint congruency was also performed. In 3 of the 29 limbs,

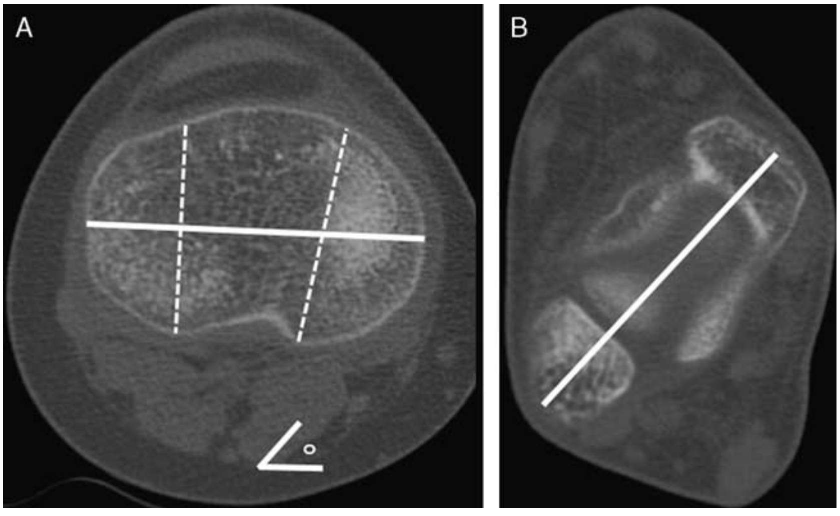

FIGURE 1. CT measurement of tibial torsion. A, The axis line of the proximal tibia is obtained just proximal to the physis by drawing a line between the middle of the widest anteroposterior diameter of the medial and lateral tibial condyles. B, The axis line of the distal tibia is calculated at the level of the syndesmosis just distal to the physis. The proximal and distal axis lines are combined to determine the degree of torsion [bottom of (A)]. External rotation of the distal axis line relative to the proximal axis line is denoted by a positive (+) number.

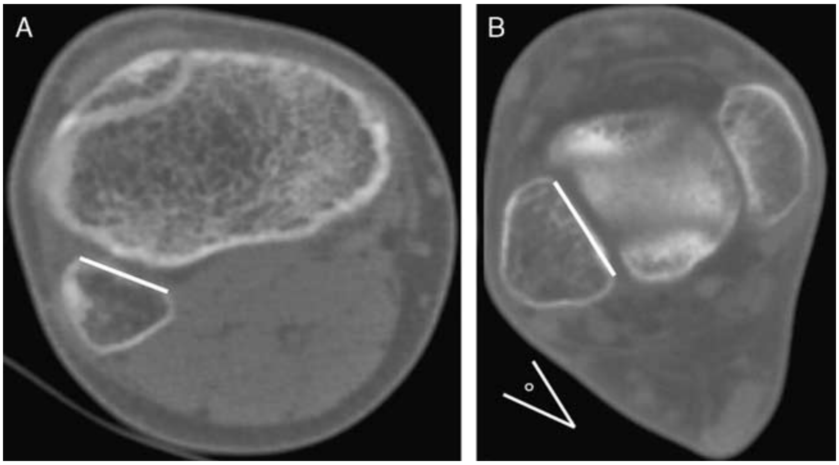

FIGURE 2. CT measurement of fibular torsion. A, The axis line of the articular surface of the proximal fibula is obtained at the level of the proximal tibiofibular joint. B, The axis line of the articular surface of the distal fibula is obtained at the level of the distal tibiofibular joint. The proximal and distal axis lines are combined to determine the degree of torsion [bottom of (B)]. Internal rotation of the distal fibular articular surface relative to the proximal fibular articular surface is denoted by a negative (–) number.

the CTs incompletely captured the proximal TF joint, making assessment of fibular torsion and proximal TF joint congruency impossible. In addition, 3 CTs of the proximal TF joint revealed a ball and socket type anatomy, making measurement of fibular torsion impossible.[35–37] Tibia torsion and distal TF joint congruity was assessed for all 29 extremities. Fibular torsion was calculated for 23 of 29 extremities. Proximal TF joint congruity was determined for 26 of 29 extremities.

Statistical analysis included variance (ANOVA) testing as well as post hoc comparisons. Adjustments were made for multiple comparisons and the mean significant difference was set at a 0.05 level.

RESULTS

Reliability

Intraobserver reliability for the measurement of tibial and fibular torsion was excellent (99.3% and 96.4%, respectively). Interobserver reliability for the measurement of tibial torsion was excellent (99.6%). Interobserver reliability for the measurement of fibular torsion was also excellent (86.0%), but slightly lower than the other measures of reliability.

Changes in Torsion

Torsional changes for the ITT treatment group are summarized in Table 1. Mean acute correction of tibial torsion was 18 degrees (range, 2 to 30 degrees). The change in tibial torsion was significant between preoperative and 6 weeks postoperative ($P < 0.000$), as well as between 6 weeks postoperative and 1 year time points ($P = 0.007$). The former is interpreted as clinically significant; the latter is not. The acute mean change in fibular torsion was 10 degrees (range, -8 to 21 degrees). The change in fibular torsion was significant between preoperative and 6 weeks postoperative ($P = 0.001$), as well as between 6 weeks postoperative and 1 year time points ($P = 0.04$).

Torsional changes for the ETT treatment group are summarized in Table 2. Mean correction of tibial torsion was -35 degrees (range, -20 to -55 degrees). The acute change in tibial torsion was significant between preoperative and 6 weeks postoperative ($P < 0.000$), but was not significantly different between 6 weeks postoperative and 1 year time points ($P = 0.291$). The acute mean change in fibular torsion was -7 degrees (range, 9.5 to -30 degrees). The change in fibular torsion was not significant between preoperative and 6 weeks postoperative

TABLE 1. Internal Torsion Treatment Group Measures

	Mean (deg.)	SD	N	P*
Tibia				
Preoperative	13.21	6.917	19	
6 wk postoperative	31.05	9.812	19	< 0.000
1 y postoperative	34.84	12.397	19	0.007
Fibula				
Preoperative	−36.77	11.226	13	
6 wk postoperative	−26.77	12.015	13	0.001
1 y postoperative	−18.54	12.804	13	0.040

Mean difference set at 0.05 level.
*P-value between time points (ie, preoperative to 6 wk, 6 wk to 1 y).

TABLE 2. External Torsion Treatment Group Measures

	Mean (deg.)	SD	N	P*
Tibia				
Preoperative	54.00	11.363	10	
6 wk postoperative	19.30	10.166	10	< 0.000
1 y postoperative	23.30	15.283	10	0.291
Fibula				
Preoperative	−9.80	8.954	10	
6 wk postoperative	−16.90	11.493	10	0.147
1 y postoperative	−30.70	10.089	10	0.003

Mean difference set at 0.05 level.
*P-value between time points (ie, preoperative to 6 wk, 6 wk to 1 y).

($P = 0.147$). The mean change in fibular torsion between 6 weeks postoperative and 1 year postoperative was -14 degrees (range, 13 to -25.5 degrees), which was significant ($P = 0.003$).

Proximal and Distal TF Joint Congruity

For the ITT treatment group, the proximal and distal TF joints remained congruent at all measured time points. For the ETT treatment group, the proximal TF joint was noted to be subluxated in 9 of 10 extremities following surgery. All cases with subluxation showed a similar pattern of posterior gapping, which subsequently resolved by the 1 year postoperative follow-up imaging study (Fig. 3). For the ETT treatment group, the distal TF joint remained congruent at all measured time points.

For the ITT treatment group, the acute change in fibular torsion, in the absence of change in either proximal or distal TF joint congruity, suggests torsional plastic deformity of the fibula to accommodate the surgically induced change in tibial torsion. Subsequent change in fibular torsion (between 6 wk and 1 y postoperatively) suggests torsional remodeling to further accommodate the stresses associated with correction of the tibial torsion.

For the ETT treatment group, the lack of change in fibular torsion at the time of the surgically induced acute change in tibial torsion, in association with subluxation of the proximal TF joint, suggests that the torsion stress associated with the isolated distal TRO is accommodated through the proximal TF joint. Subsequent change in measured fibular torsion and realignment of the proximal TF joint (between 6 wk and 1 y postoperatively) suggests torsional remodeling of the fibula to further accommodate the stresses associated with correction of the tibial torsion.

DISCUSSION

Significant controversy exists with regards to the preferred surgical technique for the correction of excessive tibial torsion in children with CP who are ambulatory. Although distal tibial osteotomy is generally favored over proximal tibial osteotomy, the role for concomitant distal fibular osteotomy is not clear.[27–29] The anatomic mechanism(s) by which isolated distal TRO is accommodated by the conjoined tibia-fibula (through the proximal and distal TF articulations and the interosseus membrane) has not been previously determined.

This study shows that correction of excessive ITT or ETT by isolated distal TRO in children with CP occurs by distinct anatomic mechanisms based on the direction of rotational correction. Correction of excessive ITT results in acute external fibular torsion. This accommodation occurs through plastic deformation of the fibula, and there are no changes in either the proximal or distal TF articulations. The acutely increased fibular torsion remodels over time to further accommodate the corrected tibial torsional alignment and reduce the strain associated with the plastic torsional deformity. The concept of the fibula accommodating for torsional forces of the tibia and lower leg is not a new one, but it has not, to our knowledge, been demonstrated in vivo through CT imaging. In an anatomic study, Close[38] observed that there was rotation of the fibula with respect to the tibia as the leg was rotated medially and laterally with the foot in a fixed position. Ogden[39] applied moderate lateral rotatory forces thru a Steinmann pin placed in the fibula with the knee in full extension thereby tightening the lateral collateral ligament and biceps femoris, 2 large dynamic stabilizers of the proximal TF joint. Failure of this maneuver to dislocate the proximal end of the fibula was interpreted to suggest acute plastic torsional deformation to accommodate the applied stress. Lucas and Cottrell[20] noted that following tibia-alone osteotomy the fibula adapted itself very rapidly to the new position without undue strain on the ankle joint. It seems reasonable to presume that there are limits to the amount of acute torsional load that the fibula can acutely accommodate. Ryan et al[29] was able to reliably correct up to 35 degrees of tibial torsional deformity by isolated tibial osteotomy. In the current study, acute surgical correction of tibial torsion averaged 17.8 degrees in the ITT group and 34.7 degrees in the ETT group. Clinical experience and review of the literature suggest that between 30 and 40 degrees of tibial rotation can be achieved by distal TRO without concomitant fibular osteotomy.

Correcting ETT did not result in significant acute torsional changes in the fibula. Instead, acute surgical correction of external torsion resulted in subluxation of the proximal TF articulation in almost all cases (9 of 10). Because tibial torsional correction was maintained during the same time interval, we presume that subsequent torsional remodeling of the fibula (in the direction of the surgical tibia rotation correction) occurred between 6 weeks and 1 year postoperative. This resulted in correction of the proximal TF joint subluxation in all cases. Studies of the pathomechanics of ankle fractures suggest that when the foot segment is internally rotated the pathway of energy transmission is not the same as when the foot segment is externally rotated. This is likely due to the osseous architecture at the ankle and the orientation of the fibers of the interosseus membrane.[40] These factors may also provide insight into the different mechanisms of accommodation between the tibia and fibula for isolated distal internal versus external TRO identified in the current study.

Clinical experience suggests that torsional remodeling that occurs following fractures is limited in both those with open and closed physes. The widely held consensus is that one should expect very little rotational remodeling.[41–45] However, animal studies suggest that forces applied obliquely across the physis can lead to torsional deformity with growth.[46,47] The documented torsional remodeling seen in this study may occur by multiple mechanisms. The ETT group included 3 of 7 patients (ie, 5 of 10 limbs) who were presumably skeletally mature (ages 18.9, 18.0, and 16.9). In the older patients rotational remodeling response may be related to persistent plasticity in the skeletally mature fibula. In the younger patients the physeal response to in vivo stresses most likely occurs. It seems reasonable to conclude that

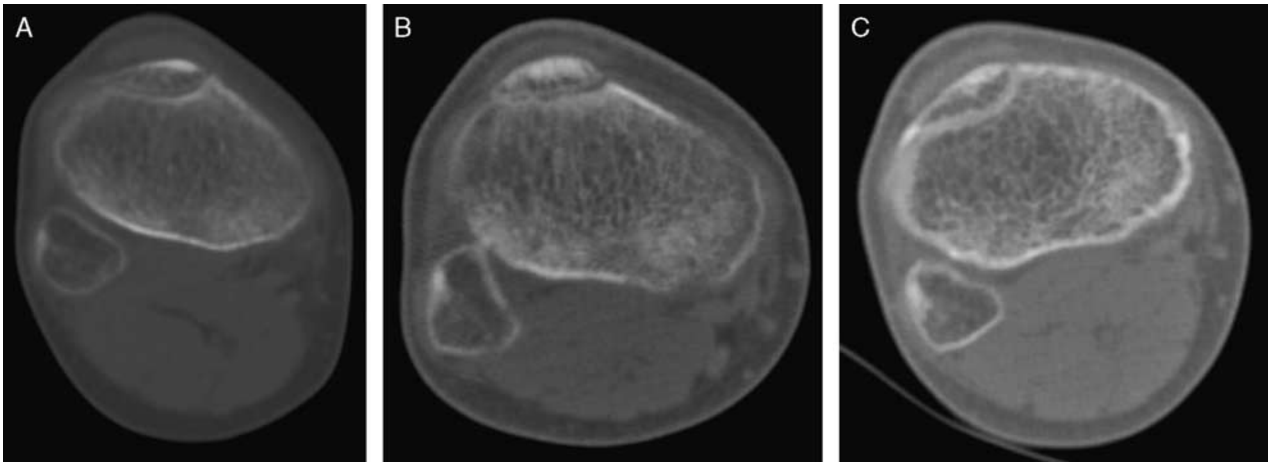

FIGURE 3. Axial CT scan of the proximal tibiofibular joint in a patient with excessive external tibial torsion. A, The joint is congruent at the preoperative assessment. B, At 6 weeks following isolated internal rotation distal tibia osteotomy the joint is subluxated. C, At 1-year follow-up the joint congruent alignment has been restored.

both mechanisms may contribute to the realignment seen following surgery. This is the first study, to our knowledge, that quantitatively documents in vivo torsional remodeling in response to prolonged application of a torsional load. In addition, it is the first time, to our knowledge, that rotational remodeling has been shown to realign a joint derangement.

The clinical significance of the proximal TF joint subluxation following isolated distal TRO in the ETT treatment group is not clear. The study design was retrospective, and patient-reported outcomes were not available. The literature suggests that subjects with subluxation of the proximal TF joint most commonly report pain on the lateral side of the knee that is exacerbated by direct pressure over the fibular head. Instability is worse when the knee is in flexion as the biceps femoris and lateral collateral ligament are relaxed stabilizers.[39,48] The proximal TF joint subluxations that occurred in the current study may not have been symptomatic as the subjects were immobilized in extension during much of the rehabilitation phase following the single-event multilevel surgery. However, if more focused future studies show that proximal TF joint knee symptoms are of clinical significance, then consideration should be given to a combining distal tibia and fibula osteotomies when surgically correcting excessive ETT. When correcting ITT up to 30 degrees, a concomitant fibula osteotomy is not necessary given the plastic accommodation documented. Finally, 1 year follow-up after surgery is short, and the possibility of further changes in torsional alignment and deformity recurrence with growth will require longer follow-up.

In summary, this study sheds light upon the mechanisms by which isolated distal TRO corrects excessive tibial torsion. On the basis of CT scans of tibial and fibular torsion, and proximal and distal TF joint congruity, we have determined that correction of excessive ITT or ETT by isolated distal TRO in children with CP occurs by distinct anatomic mechanisms based on the direction of rotational correction. Correction of excessive ITT relies on acute fibular torsion to accommodate for the surgical correction. Correction of excessive ETT causes acute subluxation of the proximal TF joint, which resolved (presumably due to rotational remodeling) in all cases over the course of a year.

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