Posterior Tibial Slope and Risk of Posterior Cruciate Ligament Injury

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Posterior Tibial Slope and Risk of Posterior Cruciate Ligament Injury

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Background: Recent biomechanical studies have identified sagittal plane posterior tibial slope as a potential risk factor for posterior cruciate ligament (PCL) injury because of its effects on the kinematics of the native and surgically treated knee. However, the literature lacks clinical correlation between primary PCL injuries and decreased posterior tibial slope.

Purpose/Hypothesis: The purpose of this study was to retrospectively compare the amount of posterior tibial slope between patients with PCL injuries and age/sex-matched controls with intact PCLs. It was hypothesized that patients with PCL injuries would have a significantly decreased amount of posterior tibial slope when compared with patients without PCL injuries.

Study Design: Case-control study; Level of evidence, 3.

Methods: Patients who underwent primary PCL reconstruction without anterior cruciate ligament injury between 2010 and 2017 by a single surgeon were retrospectively analyzed. Measurements of posterior tibial slope were performed with lateral radiographs of PCL-injured knees and matched controls without clinical or magnetic resonance imaging evidence of ligamentous injury. Mean values of posterior tibial slope were compared between the groups. Inter- and intrarater agreement was assessed for the tibial slope measurement technique via a 2-way random effects model to calculate the intraclass correlation coefficient (ICC).

Results: In sum, 104 patients with PCL tears met the inclusion criteria, and 104 controls were matched according to age and sex. There were no significant differences in age (P = .166), sex (P = .345), or body mass index (P = .424) between the PCL-injured and control groups. Of the PCL tear cohort, 91 patients (87.5%) sustained a contact mechanism of injury, while 13 (12.5%) reported a noncontact mechanism of injury. The mean ± SD posterior tibial slopes were 5.7° ± 2.1° (95% CI, 5.3°-6.1°) and 8.6° ± 2.2° (95% CI, 8.1°-9.0°) for the PCL-injured and matched control groups, respectively ($P < .0001$). Subgroup analysis of the PCL-injured knees according to mechanism of injury demonstrated significant differences in posterior tibial slope between noncontact (4.6° ± 1.8°) and contact (6.2° ± 2.2°) injuries for all patients with PCL tears (P = .013) and among patients with isolated PCL tears (P = .003). The tibial slope measurement technique was highly reliable, with an ICC of 0.852 for interrater reliability and an ICC of 0.872 for intrarater reliability.

Conclusion: A decreased posterior tibial slope was associated with patients with PCL tears as compared with age- and sex-matched controls with intact PCLs. Decreased tibial slope appears to be a risk factor for primary PCL injury. However, further clinical research is needed to assess if decreased posterior tibial slope affects posterior knee stability and outcomes after PCL reconstruction.

Keywords: posterior cruciate ligament; tibial slope; radiographs; posterior knee instability

As the primary restraint to posterior tibial translation (PTT), the posterior cruciate ligament (PCL) is susceptible to injury by posteriorly directed forces on the proximal tibia.[8,23] Although the mechanisms of isolated PCL injury have been well described, there is a paucity of literature regarding the anatomic geometry of the knee joint and its underlying association with the risk of PCL injury. Recent biomechanical and clinical investigations identified sagittal plane posterior tibial slope as a potential risk factor for anterior cruciate ligament (ACL) injury because of its substantial effects on the kinematics of the native and surgically treated knee.[11-14,27]

The mean native tibial slope was previously described as 7° to 10° posteriorly and suggested to have a significant effect on in situ forces experienced by the cruciate ligaments.[12,19,22] Increased posterior tibial slope was reported to alter the kinematics of the knee joint by anteriorly shifting the resting position of the tibia and subsequently increasing the in situ forces on the ACL.[5,9,20,30] Furthermore, increased posterior tibial slope was directly correlated to higher anterior tibial translation, predisposing patients to ACL injury.[7,9] In contrast, increased posterior tibial slope counteracts PTT and reduces the stress placed on the native PCL.[1,13,21] However, in PCL-reconstructed knees, a decreased posterior tibial slope is correlated with significantly higher residual PTT and lower reduction

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PTT.[13] Therefore, it is believed that there is a delicate "safe zone" regarding the optimal degree of posterior tibial slope to protect both cruciate ligaments from undesirable forces.

Although the association between tibial slope and ACL injury has been well studied, literature regarding the effect of decreased posterior tibial slope and its associated risk for primary PCL injury is limited. Evaluation of native anatomic factors and demographic factors may aid in determining the effect of decreased posterior tibial slope and the likelihood of sustaining a PCL tear. Therefore, the purpose of this study was to retrospectively compare the amount of posterior tibial slope between patients with PCL-injured knees and age/sex-matched controls with intact PCLs. It was hypothesized that patients with PCL injuries would have a significantly decreased amount of posterior tibial slope when compared with patients without PCL injuries.

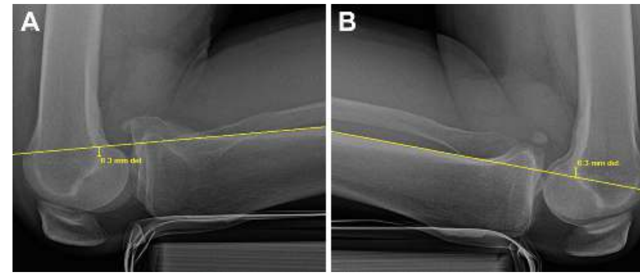

Figure 1. Posterior kneeling stress radiographs. (A) Lateral radiograph of the injured right knee reveals 6.3 mm of posterior tibial translation, as opposed to the (B) lateral radiograph of the uninjured left knee with 6.3 mm of anterior tibial translation, indicating a complete posterior cruciate ligament tear with a side-to-side difference of 12.6 mm of posterior tibial translation.

METHODS

Study Design

Following institutional review board approval (Steadman Philippon Research Institute), patients who underwent primary PCL reconstruction between 2010 and 2017 by a single surgeon (R.F.L.) and had plain radiographs available were retrospectively analyzed. Posterior kneeling stress radiographs were obtained for all patients, and indication for PCL reconstruction was a side-to-side difference in PTT $\geq$8 mm (Figure 1).[16,26] Inclusion criteria were any of the following, as confirmed at the time of examination under anesthesia: an isolated PCL tear according to posterior stress radiographs, combined PCL–fibular collateral ligament tears according to posterior and varus stress radiographs, combined PCL–medial collateral ligament tears according to posterior and valgus stress radiographs, or combined PCL–posterolateral corner injury according to posterior and varus stress radiographs. Exclusion criteria were failed previous PCL reconstruction, concomitant ACL and PCL injuries, and prior osteotomy. All patients were clinically examined preoperatively and underwent standardized preoperative imaging evaluation with plain and posterior knee stress radiographs and magnetic resonance imaging (MRI). In addition, the PCL-intact control group, matched by age and sex, was built to include patients without clinical history and MRI evidence of ligamentous injury and with a physical examination that indicated no evidence of ligament instability. Controls were excluded if they had any other pathologic or congenital condition known to affect tibial slope angulation, including but not limited to congenital genu recurvatum and rheumatoid arthritis. In addition, patients with previous surgery that may change their native bony geometry were excluded, including tibial osteotomy procedures.

Imaging Evaluation

Posterior knee stress radiographs, clinical examination, examination under anesthesia, and arthroscopic procedures were reviewed to determine the presence of a PCL tear and concomitant pathologies. Two independent raters (A.S.B. and N.N.D.) evaluated the preoperative lateral radiographs of the PCL-injured group (n = 104) and control group (n = 104) to measure the amount of posterior tibial slope according to a previously validated technique.[28] A third rater (B.T.D) was chosen to measure a random sample (n = 65) of the entire cohort to analyze interrater reliability among 3 raters. Tibial slope measurements were conducted by 2 fellowship-trained orthopaedic surgeons and 1 certified athletic trainer (A.S.B., B.T.D., N.N.D.). All raters were blinded to the existing knee pathology of all patients, thereby decreasing potential measurement bias.

Posterior tibial slope was measured by first marking points 5 and 15 cm distal to the joint line on the anterior and posterior tibial cortices. A line was drawn to connect the 2 points marked at 5 cm and again for the 2 points marked at 15 cm. The tibial proximal anatomical axis was drawn to intersect through both midpoints. The degree of posterior slope was then measured as the angle derived from the posterior inclination of the medial and lateral tibial plateaus and the perpendicular line drawn with respect to the tibial proximal anatomic axis. The slopes of the medial and lateral tibial plateaus were averaged to

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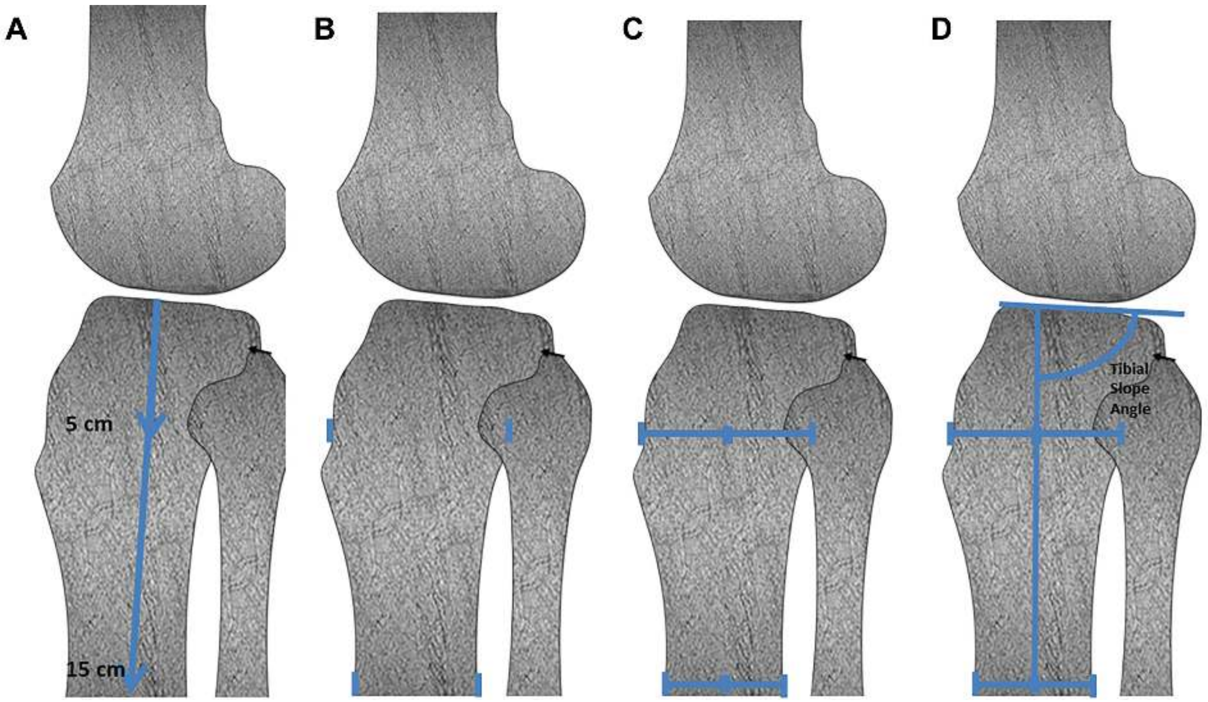

Figure 2. Schematic illustration demonstrating the described measurement technique for calculating sagittal plane tibial slope. (A) First, the tibial joint line was located, and a line was drawn 5 cm distal and a second line 15 cm distal. (B) Next, the anterior and posterior tibial cortices at both locations were marked. (C) A line was then drawn connecting the 2 points between the anterior and posterior tibial cortices at 5 cm distal and then at 15 cm distal, and the center point on the proximal tibia at both locations was calculated. (D) With an angle tool (or Cobb tool) on an imaging software system, a vertical line was drawn connecting the 2 center points on the proximal tibia, and a second horizontal line was drawn parallel to the joint surface. Last, the resultant angle was subtracted from 90 to determine the posterior tibial slope angle (in degrees).

produce the final calculated posterior tibial slope value (Figure 2).[28]

Statistical Analysis

Inter- and intrarater agreement was assessed for radiographic measurements with a 2-way random effects model to calculate the intraclass correlation coefficient (ICC). ICC values were interpreted as follows: ICC <0.40, poor agreement; 0.4 < ICC < 0.75, fair to good agreement; ICC > 0.75, excellent agreement.[10] Paired *t* tests were used to compare the mean posterior tibial slope and the mean difference in posterior tibial slope between the PCL-injured group and the control group. Additionally, independent samples *t* tests were performed for subgroup analysis comparing isolated and combined PCL injuries and noncontact and contact PCL injuries. All data were analyzed with SPSS Statistics (v 22; IBM), with an alpha level set at .05 for statistical significance.

RESULTS

Patient characteristics for the injured and control cohorts are presented in Table 1. In sum, 104 patients with PCL tears met the inclusion criteria, and 104 control patients were matched to the PCL-injured group according to age and sex. There were no significant differences in age (P = .166), sex (P = .345), or body mass index (P = .424) between the control and PCL-injured groups. Patient injury characteristics are presented in Figure 3.

Each patient with a PCL tear underwent an arthroscopic double-bundle reconstruction technique.[4,18] At the time of imaging and evaluation, 50 patients in the PCL-injured cohort had an acute injury (≤6 weeks), and 54 had a chronic injury (>6 weeks). Sixty-five patients had extra-articular ligament injuries with the PCL tear, while isolated PCL tears were identified in 39 patients. Whereas 78% of patients sustained their injuries during sports, 11% were injured in motor vehicle accidents or other high-energy mechanisms, and the remaining 11% sustained their injuries through non–high energy mechanisms (Figures 3A and B). The type of sport/activity during which patients were injured is presented in Figure 3. Sixty-five patients (62.5%) had extra-articular ligament injuries with the PCL tear, while isolated PCL tears were identified in 39 (37.5%). The majority of patients with a PCL injury (n = 91) reported a contact mechanism (eg, fall onto a flexed knee) at the time of injury (Table 2).

There was no significant difference in the mean ± SD slope of isolated PCL tears (6.4° ± 2.4°) versus combined PCL tears (5.7° ± 2.0°, P = .128). The mean posterior tibial

TABLE 1
Clinical Characteristics of Patients With PCL Injuries and Ligament-Intact Controls[a]

	Male	Female	Total
PCL tears			
Sex	80 (77)	24 (23)	104
Age, y, mean ± SD	30.6 ± 12.6	34.7 ± 12.5	31.5 ± 12.6
BMI, kg/m^2, mean ± SD	24.3 ± 2.7	25.5 ± 5.6	24.6 ± 3.6
Isolated PCL tear, n (%)	28	11	39
Combined injury, n (%)	52	13	65
Ligament-intact controls			
Sex, n (%)	74 (71)	30 (29)	104
Age, y, mean ± SD	32.3 ± 15.0	39.6 ± 18.2	34.4 ± 17.2
BMI, kg/m^2, mean ± SD	25.4 ± 4.3	23.9 ± 2.7	25.0 ± 3.9

[a]Controls were matched by age and sex to the PCL-injured cohort. BMI, body mass index; PCL, posterior cruciate ligament.

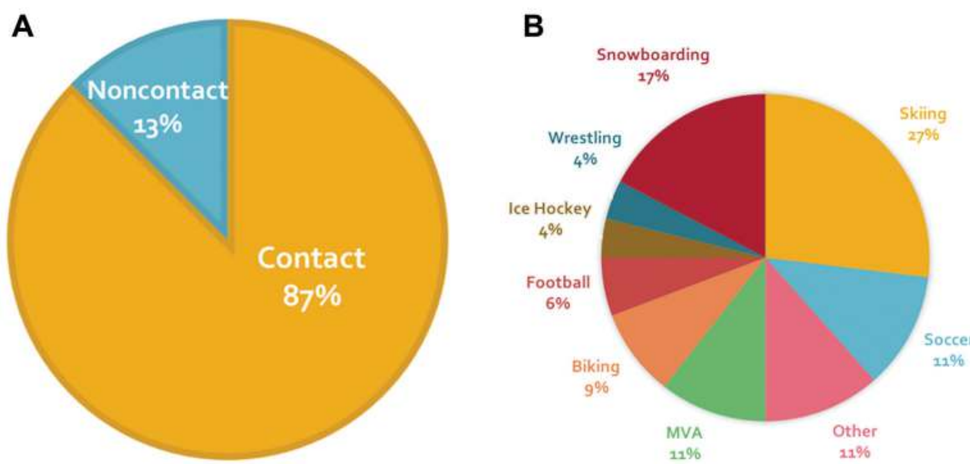

Figure 3. Injury characteristics for patients with a posterior cruciate ligament tear (n = 104). (A) Mechanism of injury and (B) type of sport/activity during injury. MVA, motor vehicle accident.

TABLE 2
Posterior Tibial Slope for Overall, Isolated, and Combined PCL Tears[a]

PCL Tear	Noncontact Injury (n = 13)	Contact Injury (n = 91)	*P* Value
Overall (n = 104)	4.6 ± 1.8	6.2 ± 2.2	.013[b]
Isolated (n = 39)	4.0 ± 0.8	6.6 ± 2.4	.003[b]
Combined (n = 65)[c]	4.8 ± 2.0	5.9 ± 2.0	.167

[a]Data reported as mean degrees ± SD, unless otherwise indicated. PCL, posterior cruciate ligament.
[b]$P < .05$.
[c]Combined PCL tear: PCL + medial collateral ligament, fibular collateral ligament, or posterolateral corner injury.

slopes were 5.7° ± 2.1° (95% CI, 5.3°-6.1°) and 8.6° ± 2.2° (95% CI, 8.1°-9.0°) for the PCL-injured and matched control groups, respectively ($P < .0001$) (Figure 4, Table 3). When the reliability of the tibial slope measurement technique was evaluated, interrater agreement and intrarater agreement were both excellent, with ICCs of 0.852 and 0.872, respectively. Additionally, subgroup analysis of PCL-injured knees according to mechanism of injury demonstrated a significant difference in posterior tibial slope between noncontact and contact injuries for all patients with PCL tears ($P = .013$) and among patients with isolated PCL tears ($P = .003$) (Table 2).

DISCUSSION

The main finding of this study was that decreased sagittal plane posterior tibial slope was associated with PCL tears as compared with cruciate ligament–intact controls. The majority of patients with PCL injuries sustained a contact mechanism with a posteriorly directed force to the proximal tibia. In addition, patients with noncontact PCL

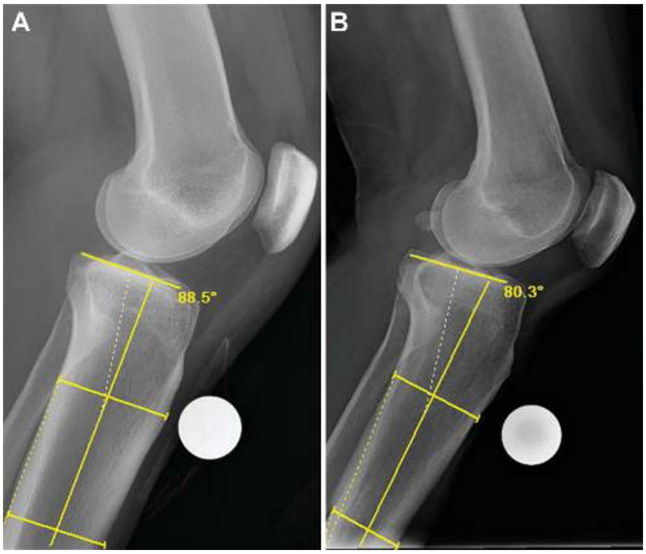

Figure 4. Tibial slope measurement comparison. (A) Left knee lateral radiograph of a patient with a posterior cruciate ligament (PCL) injury reveals a decreased posterior tibial slope measuring 1.5° as opposed to a (B) left knee lateral radiograph of a PCL-intact control with a normal posterior tibial slope measuring 9.7°. All controls were matched by age and sex to the patients with PCL injuries.

injuries had significantly decreased posterior tibial slope as compared with contact PCL injuries.

The findings of the current study suggest that a flattened tibial slope of approximately <6° may increase the force on the PCL and lead to a higher rate of PCL injury. Shelburne et al[24] modeled cruciate force and found that a 1° increase in posterior tibial slope decreased PCL force by 6 N, while noting an increase in PCL force when the slope was decreased during squatting. Giffin et al[11] reported that, at the tibial resting position, biomechanically increased tibial slope is beneficial for restoring PCL stability and decreasing PTT when applying axial loads and a simulated posterior drawer. The authors concluded that increased posterior tibial slope was protective for PCL-deficient knees, but they did not examine decreased slope and its effect on tibial sag or tibial position.

Biomechanical forces at the time of injury may help explain our finding of decreased posterior tibial slope for patients with noncontact and isolated PCL injuries as compared with contact and combined PCL injuries ($P < .01$). Patients with a normal tibial slope or increased tibial slope may require larger force at the time of injury to overcome the protective effect of posterior tibial slope on PCL injuries.[11,13] Previous laboratory research showed that increasing posterior tibial slope via tibial osteotomy in PCL-deficient knees reduces tibial sag by shifting the resting position of the tibia anteriorly.[11,12] Similarly, Singerman et al[25] conducted a biomechanical study and reported a significant increase in PCL strain with decreasing tibial slope from 10° to 5° after total knee arthroplasty with an opening wedge tibial osteotomy ($P < .0001$). In contrast, in a systematic review of ACL literature, Feucht et al[9] reported that an increased posterior tibial slope represents a risk factor for noncontact ACL injuries. This theory supports our findings of increased posterior tibial slope among patients with combined contact PCL injuries as compared with isolated noncontact PCL injuries.[15] This theory also supports our findings of increased posterior tibial slope among patients with contact PCL injuries versus noncontact PCL injuries.[15] Thus, patients with a decreased tibial slope who sustain a noncontact posteriorly directed moment (landing from a jump, running deceleration, etc) may be at higher risk of PCL injury based on their bony anatomy.[9,13,15] However, further research with larger sample sizes in both groups is needed to corroborate this clinical correlation.

TABLE 3
Posterior Tibial Slope for Patients With PCL Tears and Ligament-Intact Controls[a]

	PCL Tear (n = 104)	Control (n = 104)	*P* Value
Posterior tibial slope, deg, mean ± SD	5.7 ± 2.1	8.6 ± 2.2	.0001[b]
Standard error of the mean	0.20	0.22	—

[a]PCL, posterior cruciate ligament.
[b]$P < .05$.

The associated clinical findings of primary PCL injury among >100 patients with a decreased tibial slope appear to be unique and have yet to be fully investigated in the current literature. Although the association of sagittal plane tibial slope and ACL injury has been well studied,[6,15,19,30] literature regarding the effect of decreased posterior tibial slope and its associated risk for primary PCL injury is limited. Studies have highlighted the effect of increasing posterior tibial slope and the resultant increase in knee stability of PCL-deficient knees after high tibial osteotomy.[2,12,17,20] Furthermore, a recent study identified a decreased posterior tibial slope as a factor in increased PTT in single-bundle PCL reconstructions on follow-up kneeling PCL stress radiographs.[13] Additionally, the authors noted that these results were irrespective of patient sex and number of ligaments addressed during PCL reconstruction. No study to date has examined the loading experienced in a single- or double-bundle PCL graft when subjected to loading conditions at varying slopes and flexion angles, which could reveal an ideal slope or range of slopes that may be protective of a reconstructed PCL. Based on existing information, posterior tibial slope may affect PCL-reconstructed knees and should be closely examined perioperatively before PCL reconstruction.

We acknowledge some limitations to our study. The injury patterns in this cohort included isolated and combined PCL injuries, which could affect the interpretation of the tibial slope measurements. Furthermore, the use of plain radiographs, as opposed to the more recently described use of MRI to measure tibial slope incorporating the meniscus, may change the existing slope with regard to the soft tissues, and a perfect lateral of the knee is required to reliably determine the tibial slope via plain radiographs. However, the use of plain radiographs to measure tibial slope is clinically feasible and was shown to be highly reliable and reproducible.[28] Another limitation of the study was that matching patients by ethnicity was not possible, owing to the retrospective nature of the study design, although previous studies reported race-based differences in native tibial slope.[3,29]

CONCLUSION

A decreased posterior tibial slope was associated with patients with PCL tears as compared with age- and sex-matched controls with intact PCLs. Decreased tibial slope appears to be a risk factor for primary PCL injury. However, further clinical research is needed to assess if decreased posterior tibial slope affects posterior knee stability and outcomes after PCL reconstruction.

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