Tibial Slope Strongly Influences Knee Stability After Posterior Cruciate Ligament Reconstruction

A Prospective 5- to 15-Year Follow-up

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Background: The reported failure rate after posterior cruciate ligament (PCL) reconstruction remains high. Previous studies have shown that the tibial slope (TS) influences sagittal plane laxity. Consequently, alterations of TS might have an effect on postoperative knee stability after PCL reconstruction.

Hypothesis: We hypothesized that flattening of TS is associated with increased posterior laxity after PCL reconstruction.

Study Design: Cohort study; Level of evidence 3.

Methods: This study consisted of 48 patients who underwent PCL reconstruction in a single-surgeon series. Eight patients underwent an isolated PCL reconstruction, 27 patients underwent an additional posterolateral corner reconstruction, and 13 patients underwent a combined reconstruction of the PCL, anterior cruciate ligament, and posterolateral corner. Three blinded observers measured TS and the side-to-side difference (SSD) of posterior tibial translation (PTT) before and after PCL reconstruction using standardized stress radiographs. The minimum follow-up was 5 years.

Results: At a mean follow-up of 103 months (range, 65-187), the mean SSD of PTT was significantly reduced (10.9 ± 2.9 vs 4.9 ± 4.3 mm; $P < .0001$). The mean TS was 8.0° ± 3.7° (range, 1°-14.3°) for the operated knee and 7.9° ± 3.2° (range, 2°-15.3°) for the contralateral knee. There was a statistically significant correlation between TS and PTT ($r = –0.77$ and $R^2 = 0.59$; $P < .0001$). In addition, there was a significant correlation between TS and the postoperative reduction of PTT ($r = 0.74$ and $R^2 = 0.55$; $P < .0001$). Subgrouping according to the number of operated ligaments showed no significant differences regarding TS or the mean reduction of PTT.

Conclusion: Flattening of TS is associated with a significantly higher remaining PTT as well as a lower reduction of PTT. Notably, these results are irrespective of sex and number of ligaments addressed. Thus, isolated soft tissue procedures in PCL deficiency may only incompletely address posterior knee instability in patients with flattening of the posterior slope.

Keywords: posterior cruciate ligament; tibial slope; ligament reconstruction; posterior tibial translation

Posterior cruciate ligament (PCL) injuries are among the most devastating injuries affecting the knee joint and have the potential for long-term sequelae, including persistent instability, decreased activity levels, and early degenerative changes, particularly in the patellofemoral and medial compartments.[10,18,29]

Clinical outcomes of both surgical and nonsurgical treatment remain inconsistent.[27] Despite advancements in PCL reconstruction, current approaches have been ineffective at consistently restoring knee stability to its original state irrespective of the surgical technique.[30,34] The reported failure rate remains high despite improved clinical parameters after PCL reconstruction.[6,31,32,41] A relative paucity of studies

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exists regarding influencing factors that can contribute to a favorable outcome after PCL reconstruction.

A wide range of possible influencing factors are discussed in the current literature, such as tunnel placement,[11,26] graft choice,[28] single- versus double-bundle techniques,[4] or involvement of the peripheral structures.[2-5] Appraisal of the literature is complicated because of the wide range of treated injuries, differing surgical techniques, and after-treatment protocols in relatively small patient series.

Recent studies have shown that the underlying geometry of the tibial plateau, especially the tibial slope (TS), affects the load transmission of the knee joint and the anterior-posterior translation of the tibia.[1,17] Thus, the in situ strain of the cruciate ligaments during weightbearing activities is altered. This has prompted growing scientific interest because increased TS results in an anteriorly shifted resting position of the tibia and thus in an increased risk for anterior cruciate ligament (ACL) injuries.[12,13,16,21,47] Conversely, patients with increased TS may also avoid mechanical overload of the graft after PCL reconstruction, which might be beneficial for knee stability in the long term.

To our knowledge, no study has yet evaluated the effect of TS on knee laxity after PCL reconstruction. This study aimed to examine whether there is a correlation between TS and posterior laxity after PCL reconstruction as measured by stress radiographs. We hypothesized that increased TS will be associated with a higher reduction in posterior tibial translation (PTT) after PCL reconstruction.

METHODS

All PCL surgeries were performed at our institute by a single surgeon (A.W.). Inclusion criteria were minimum symptomatic grade 2 laxity (>5 mm of side-to-side difference) on clinical examination and bilateral posterior stress radiographs (GA II stress device; Telos). Only patients with a primary reconstruction of the PCL with use of autologous hamstring tendon grafts were included. The minimum follow-up was 5 years.

Exclusion criteria comprised bilateral injuries, combined lower extremity fractures, or previous surgery to the uninvolved knee. Furthermore, we excluded patients whose radiographs did not include a true lateral view as determined by proper superimposition of the femoral condyles. In addition, patients without digital data sets of the radiographs were excluded to decrease the number of confounding variables.

An institutional ethics commission approved this study (EA1/003/16), and all patients signed informed consent forms.

Surgical Technique

All PCL reconstructions were performed by a single surgeon in a single-bundle (anterolateral) technique using autologous ipsilateral 5-folded semitendinosus and gracilis tendons. If needed, reconstruction of the ACL or posterolateral corner was performed with use of the contralateral hamstring tendon grafts.

Femoral tunnel creation was achieved through a low anterolateral portal in an inside-out fashion using a dedicated femoral drill guide (Karl Storz GmbH) centered at the anterolateral bundle of the PCL. Remnants of the PCL complex such as the meniscofemoral ligaments or the posteromedial bundle were preserved whenever possible. Tibial tunnel creation was performed via direct arthroscopic visualization using an additional posteromedial portal and standardized calibrated drill guides.

Femoral and tibial fixation was performed in a hybrid manner using a biodegradable interference screw (MegaFix; Karl Storz GmbH) and the EndoPearl device (Linvatec Corp) on the femoral site and sutures tight over a bony bridge on the tibial site.[20,46] Maximum manual pretension in approximately 90° of flexion was performed as per our clinical routine.

Rehabilitation

The posttreatment protocol included immobilization for 6 weeks in a straight posterior tibial support (PTS) splint (Medi). Partial weightbearing and gradual passive mobilization in the prone position were performed during this period to prevent knee stiffness. Subsequently, weightbearing was gradually established and the PTS splint was changed to a dedicated functional PCL brace.

Radiological Assessment

Radiographic imaging studies included posterior stress radiographs of both knees. Three blinded observers evaluated TS and PTT using a picture archiving and communication system workstation (Centricity RIS-I 4.2 Plus; GE Healthcare). Both parameters were measured separately, without the assessor having knowledge of clinical history, as a means of controlling intraobserver reliability. To ensure that assessors were appropriately blinded, an independent study participant who did not take part in reading of the selected images performed the randomization of all radiographs. The mean values for TS and PTT were then calculated.

TS, defined as the angle between the posterior inclination of the tibial plateau and a line perpendicular to the diaphyseal shaft axis (Figure 1), was determined according to the technique of Dejour and Bonnin.[15] The diaphyseal shaft axis was measured using 2 midpoints between the anterior and posterior tibial cortex at 5 cm below the tibial tuberosity and 15 cm below the tibial joint line. Subsequently, TS was determined between the tangent to the medial tibial plateau and perpendicular to the established diaphyseal shaft axis. Although the best available radiographs were chosen, not all included enough tibial shaft to determine the width of the shaft at a distance of 15 cm distal to the joint line. In these instances, the most distal width was measured based on the above-mentioned values.

PTT was measured on conventional stress radiographs at 90° of flexion with a posteriorly directed force of 150 N at the level of the tibial tubercle, using the Telos stress device. PTT was determined according to the technique

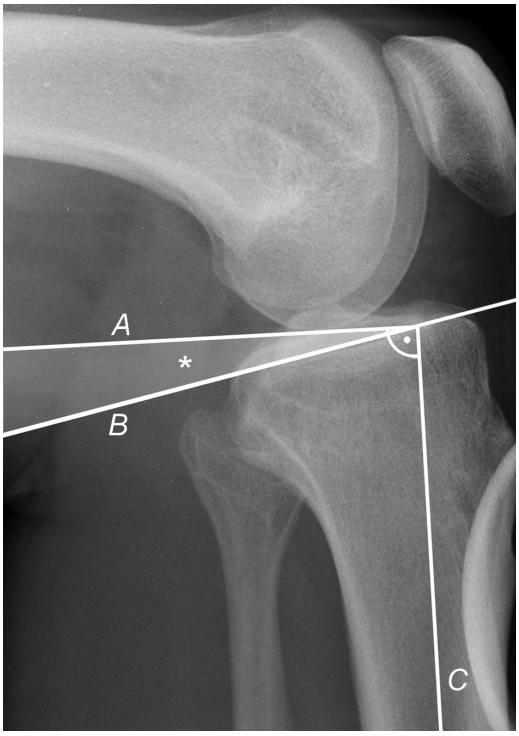

Figure 1. Lateral stress radiograph depicting the measurement of the tibial slope. The tibial slope (asterisk) is defined as the angle between *A* and *B* with respect to *C*, a line perpendicular to the longitudinal axis of the tibia.[15]

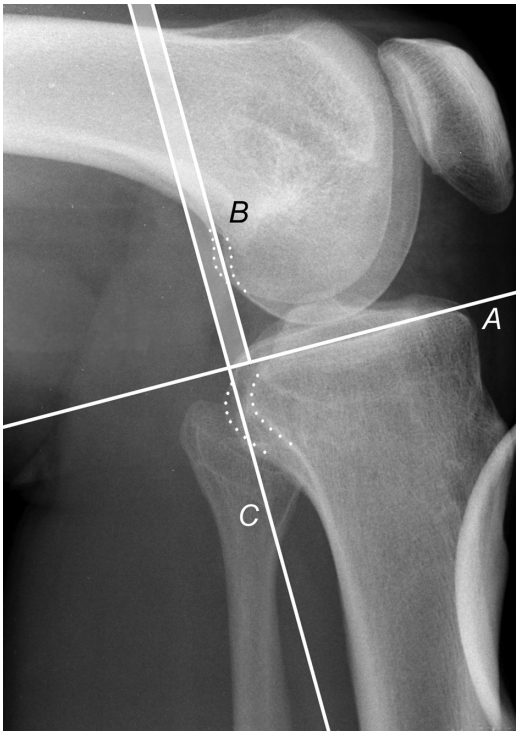

Figure 2. Measurement of posterior tibial translation using a posterior force, which is applied to the proximal tibia by a Telos stress device, as described by Jacobsen[23] and Stäubli and Jakob.[42] Perpendicular to the tangent of the tibial plateau (*A*), the midpoints between the most posterior contours of the medial and lateral femoral condyles (*B*) and tibial plateaus (*C*) were established. The distance between these 2 points is regarded as the posterior tibial translation and is subsequently assessed in relation to that of the uninjured contralateral knee.

described by Jacobsen[23] and Stäubli and Jakob.[42] Perpendicular to the tangent of the tibial plateau, the midpoints between the most posterior contours of the medial and lateral femoral condyles and tibial plateaus were established. The distance between these 2 points was regarded as the PTT (Figure 2) and was subsequently assessed in relation to that of the uninjured contralateral knee.

Statistical Analysis

Subgrouping between female and male patients was conducted to examine sex-based differences. An additional subgrouping according to the number of operated ligaments was performed as follows: isolated PCL reconstruction (group A) versus reconstruction of the PCL and the posterolateral corner (group B) versus reconstruction of the ACL, PCL, and posterolateral corner (group C).

Statistical analysis was performed using GraphPad Prism software (version 6; GraphPad Software Inc). Continuous data are expressed as the mean ± SD and/or median (interquartile range) according to their distribution. D'Agostino and Pearson omnibus normality tests were used to test normal distribution. A *t* test was performed to compare parametric data and the Mann-Whitney test was used for nonparametric data. To establish an association between TS and PTT, Pearson correlation was performed assessing *r* and R^2. The intraclass correlation coefficient (ICC) was used to evaluate interobserver agreement.

RESULTS

A total of 66 patients were enrolled in this study, 18 of which were excluded as a result of injuries of the contralateral side (n = 9), revision surgery (n = 6), or use of allografts (n = 3), respectively. Therefore, 48 patients (10 women and 38 men) aged 30 years (range, 18-47 years) at the time of surgery met our inclusion criteria and were included in this study. Eight patients (17%) underwent an isolated PCL reconstruction, 27 patients (56%) had a combined PCL and posterolateral corner reconstruction, and 13 patients (27%) underwent an ACL, PCL, and posterolateral corner reconstruction. All patients had a radiological examination both preoperatively and at a final follow-up of 103 months (range, 65-187 months). ICCs between the observers were 0.78 for TS and 0.86 for PTT, indicating high interobserver agreement.

The mean side-to-side difference of PTT significantly improved from preoperative values to the final follow-up (10.9 ± 2.9 vs 4.9 ± 4.3 mm; $P < .0001$), thus leading to a mean reduction of PTT (ΔPTT) of 6.0 ± 3.5 mm. The mean TS was 8.0° ± 3.7° (range, 1°-14.3°) for the operated

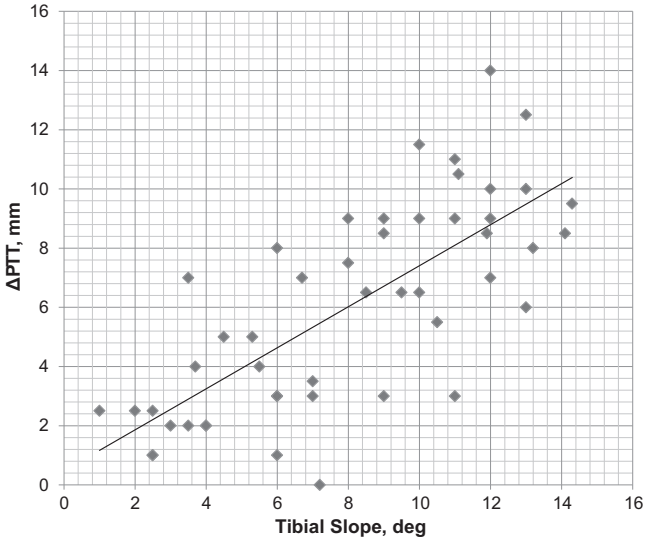

Figure 3. Regression plot showing the association between tibial slope (TS) on the x-axis and reduction of posterior tibial translation (ΔPTT) on the y-axis. The central line is the calculated regression line, indicating a significant correlation between TS and ΔPTT (r = 0.74 and R^2 = 0.55; $P < .0001$).

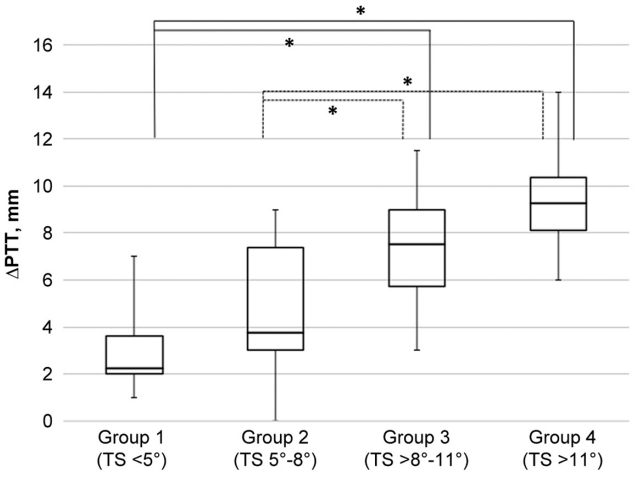

Figure 4. Subgrouping of the patient cohort according to their tibial slope (TS) showed a significantly lower reduction in posterior tibial translation (ΔPTT) for group 1 compared with groups 3 and 4 and for group 2 compared with groups 3 and 4, respectively. *$P < .05$ (statistically significant difference between groups).

knee and 7.9° ± 3.2° (range, 2°-15.3°) for the contralateral knee.

In addition, we compared TS and PTT in women (n = 10) and men (n = 38). There were no significant differences in both preoperative PTT (9.4 ± 3.3 vs 11.3 ± 2.7 mm; P = .06) and postoperative PTT (3.7 ± 5.0 vs 5.2 ± 4.1 mm; P = .34). Likewise, there was no statistically significant difference in TS between women and men (8.1° ± 3.4° vs 8.0° ± 3.9°; P = .98).

Pearson correlation revealed a significant correlation between postoperative PTT and TS (r = –0.77 and R^2 = 0.59; $P < .0001$) and between TS and postoperative ΔPTT (r = 0.74 and R^2 = 0.55; $P < .0001$) (Figure 3).

To improve comparability, we conducted a subgroup analysis of the patient cohort according to their TS. There were 4 groups with 12 patients each (group 1, TS < 5°; group 2, TS of 5°-8°; group 3, TS > 8°-11°; and group 4, TS > 11°). Group 1 showed a significantly lower ΔPTT compared with groups 3 and 4 (2.8 ± 0.5 vs 7.4 ± 0.8 mm [group 3] and 9.5 ± 0.6 mm [group 4]; $P < .0001$ for both comparisons). Accordingly, group 2 had a significantly lower ΔPTT compared with groups 3 and 4 (4.5 ± 0.8 vs 7.4 ± 0.8 mm [group 3] and 9.5 ± 0.6 mm [group 4]; P = .02 and $P < .0001$, respectively) (Figure 4). No statistically significant differences were noted between groups 1 and 2 (2.8 ± 0.5 vs 4.5 ± 0.8 mm; P = .09) or between groups 3 and 4 (7.4 ± 0.8 vs 9.5 ± 0.6 mm; P = .06).

We performed additional subgrouping according to the number of operated ligaments as follows: isolated PCL reconstruction (group A; n = 8), reconstruction of the PCL and posterolateral corner (group B; n = 27), and reconstruction of the ACL, PCL, and posterolateral corner (group C; n = 13). There were no statistically significant differences in TS and ΔPTT between groups A and B (TS: 8.1° ± 3.9° vs 7.9° ± 3.7°, P = .89; ΔPTT: 5.5 ± 3.5 vs 5.5 ± 3.1 mm, P = .99), groups A and C (TS: 8.1° ± 3.9° vs 8.2° ± 3.1°, P = .92; ΔPTT: 5.5 ± 3.5 vs 7.6 ± 2.9 mm, P = .17), and groups B and C (TS: 7.9° ± 3.7° vs 8.2° ± 3.1°, P = .76; ΔPTT: 5.5 ± 3.1 vs 7.6 ± 2.9 mm, P = .054).

DISCUSSION

This investigation aimed to evaluate the effect of TS on postoperative knee stability after PCL reconstruction. We hypothesized that increased TS is associated with a higher reduction of PTT after PCL reconstruction. Our findings clearly indicate that flattening of TS correlates with both higher remaining PTT as well as a lower reduction of PTT. Consequently, these patients are at risk of a higher degree of postoperative instability after PCL reconstruction. This might be attributable to repetitive overloading and subsequent elongation of the PCL graft during the postoperative course.

As an implication of this, TS could be used as a risk stratification, which could lead to a modification of the treatment algorithm of these patients and could range from more conservative posttreatment and return-to-activity criteria to a careful consideration of an additional correction of TS. Consequently, our data suggest that isolated soft tissue procedures for PCL deficiency may only incompletely address posterior instability in patients with flattening of TS.

Of note, the initial injury pattern and the consecutive number of operated ligaments did not show any significant influence on the amount of reduction of PTT, which further underlines the importance of the slope on postoperative knee stability.

Previous research has indicated that sex-based differences after PCL surgery exist and that TS plays a greater role

in female patients with ACL injuries.[9,24] Although patient sex was tested accordingly, this association could not be established in our patient series.

Despite advancements in PCL surgery, knee kinematics is not fully restored and a considerable number of patients fail to recover from their injuries.[30,34,45] This may be attributable to covariables that affect outcome parameters. Prior research has mainly focused on femoral and tibial tunnel placement,[11,26] graft choice, single- or double-bundle reconstruction, tibial tunnel or tibial inlay approaches, and involvement of peripheral structures, especially the posterolateral corner.[4,27] However, the underlying geometry of the operated knee may have an even greater effect on patient outcomes.

The linear relationship between TS and tibial translation during weightbearing has been acknowledged in cadaveric models[39,44] and in clinical studies.[8,15] Dejour and Bonnin[15] concluded that a higher degree of slope results in a significantly higher anterior translation of the tibia. Accordingly, every 10° increase of TS in a monopodal stance test results in an anterior tibial shift of 6 mm. Taking this into consideration, several authors have concluded that a higher degree of TS can increase the in situ forces of the ACL and thus the likelihood of ACL injuries.[12,13,16,21,47] Conversely, the anterior shift of the resting position of the tibia would decrease postoperative in situ forces of the healing graft after PCL reconstruction and thus may be beneficial for postoperative knee stability.

Notably, the degree of TS is shown to vary substantially among individuals,[14,19,33] which may explain the heterogeneous clinical outcomes within patient cohorts and the reported minor effect of surgical technique on clinical outcomes. This would further explain the subset of patients who are better able to cope with PCL deficiency during normal daily activities.

Within the past few decades, correction of osseous malalignment of the knee has become popular not only in the coronal plane but also in the sagittal plane, such as in chronic instability of the PCL.[35]

Agneskirchner et al[1] were the first to suggest in a cadaveric study that an increase in TS could be used to counteract pathologically increased PTT in patients with chronic PCL insufficiency. These results were echoed by Petrigliano et al,[34] who concluded that increasing TS in a PCL-deficient knee can dampen the posterior drawer.

Giffin et al[17] stated that increasing TS (ie, via an anterior opening wedge osteotomy) would shift the resting position of the tibia anterior relative to the femur. Consequently, the tibiofemoral point of contact was altered and a decrease of PTT was noted. Although the authors did not note a modification of the in situ forces of the cruciate ligaments, one must take the applied tibiofemoral compression forces into consideration, which were only one-tenth of the peak force present during normal walking.[37,38,43]

The findings of the current clinical study complement the work of the aforementioned biomechanical studies. Nevertheless, our patient series has several limitations. The relatively wide range of concomitant injuries within our patient cohort must be taken into consideration because it limits the ability to draw firm conclusions. To our knowledge, this study is the first to evaluate the association between TS and PTT in a clinical setting. Notably, no statistically significant differences could be established between pre- or postoperative values with regard to the number of operated ligaments. PCL tears rarely exist in isolation, and recent literature has helped to elucidate that the majority (up to 79%[7]) of grade 3 PCL tears are associated with multiligament knee injuries.[27]

Although there were no statistically significant differences between women and men in this study, the power to compare the sexes may be limited because the number of female participants was relatively small.

A missing clinical correlation is another drawback of this study. We chose to rely solely on objective parameters. The use of posterior stress radiographs has increasingly been acknowledged, because they provide high accuracy for an objective quantification of PTT in relation to the uninjured contralateral knee.[22,25,36] We aimed to set strict inclusion criteria, such that the same surgeon performed all PCL reconstructions using the same technique.

Finally, we measured TS on a lateral view of standard radiographs, thereby potentially ignoring a possible asymmetry of the medial and lateral aspects of the tibial plateau as well as of the chondral or meniscal surface.[13] Simon et al[40] reported that increased lateral TS relative to the medial TS might result in an internal rotation and anterior tibial translation, which increases strain on the ACL. Because lateral radiographs are not sufficient to differentiate exactly between the medial and lateral slopes and thus to detect rotational movements between the femur and tibia, future studies are needed to further address this issue.

CONCLUSION

Flattening of TS is associated with significantly higher remaining PTT as well as a lower reduction of PTT. Consequently, our data indicate that isolated soft tissue procedures in PCL deficiency may only incompletely address posterior knee instability in patients with flattening of the posterior slope. As an implication of this, correction of a pathological slope might offer an additional option to improve outcomes. Although this possibility was not directly tested in our study, it might be the subject of future studies.

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