STArt TUSYAD
Sports Traumatology & Arthroscopy
DOI: 10.14744/STA.2026.18786
Sports Traumatol Arthrosc 2026;3(2):47–51

Editorial

From Posterior Tibial Slope to Sagittal Knee Phenotypes: Personalizing ACL Surgery

Mahmut Enes Kayaalp,[1] Ozkan Kose[2]

[1]Department of Orthopedics and Traumatology, University of Health Sciences, Istanbul Fatih Sultan Mehmet Training and Research Hospital, Istanbul, Türkiye
[2]Department of Orthopedics and Traumatology, University of Health Sciences, Antalya Training and Research Hospital, Antalya, Türkiye

Anterior cruciate ligament (ACL) reconstruction has traditionally been approached as a soft-tissue solution to a ligament injury. The surgeon selects a graft, restores the anatomical footprints, secures fixation, addresses associated meniscal pathology, and guides the patient through rehabilitation. Nevertheless, graft failure and residual instability continue to occur despite technically satisfactory reconstruction. Contemporary ACL surgery is therefore moving beyond standardized reconstruction toward individualized risk stratification, graft selection, alignment assessment, augmentation, and rehabilitation.[1]

Posterior tibial slope (PTS) has become one of the most recognizable anatomical factors within this framework. A steeper tibial plateau increases the anterior shear generated during axial loading, promoting anterior tibial translation and increasing the mechanical demand on the native ACL or reconstructed graft.[2,3] Clinical evidence has consistently associated elevated PTS with ACL injury and reconstruction failure, with 12° frequently used as a high-risk radiographic threshold.[2,3] A recent review comprehensively summarized the measurement, biomechanics, indications, techniques, and outcomes of PTS-modifying osteotomies.[2] Rather than repeating that technical account, the present editorial addresses the next question: How should PTS be incorporated into personalized ACL surgery?

Greater recognition of PTS creates a new danger: replacing one oversimplification with another. ACL surgery should not evolve from performing the same reconstruction in every patient to performing an osteotomy whenever the slope exceeds a numerical threshold. A PTS of 12° is an important warning sign, but it is not, by itself, a diagnosis, an automatic surgical indication, or a universal correction target. The first challenge is measurement. PTS values vary according to imaging modality, tibial reference axis, plateau selection, visualized tibial length, and radiographic rotation.[2,3] Magnetic resonance imaging permits separate medial and lateral measurements but commonly references only the proximal tibia and may produce values that differ substantially from radiographic measurements. Thresholds established on lateral radiographs, therefore, cannot be directly transferred to magnetic resonance imaging or computed tomography. For clinical decision-making, PTS should be assessed on a strict lateral radiograph that adequately visualizes the proximal tibial shaft, preferably at least 15 cm. A consistent proximal anatomical axis and the medial tibial plateau should be used as the radiographic references.[2,3] Without methodological standardization, differences between 11°, 12°, and 13° may reflect technique rather than biology.

Risk also exists along a continuum. Radiographic medial PTS differentiated

Cite this article as:
Kayaalp ME, Kose O. From Posterior Tibial Slope to Sagittal Knee Phenotypes: Personalizing ACL Surgery. Sports Traumatol Arthrosc 2026;3(2):47–51.

Address for correspondence:
Ozkan Kose, Department of Orthopedics and Traumatology, University of Health Sciences, Antalya Training and Research Hospital, Antalya, Türkiye
E-mail:
drozkankose@hotmail.com

Available Online: 27.08.2026

Sports Traumatology & Arthroscopy – Available online at www.stajournal.com

successful primary reconstruction from multiple-revision ACL reconstruction more effectively than magnetic resonance imaging-based medial or lateral measurements. A radiographic medial PTS of at least 16° was associated with an approximately threefold increase in the odds of multiple revisions.[6] This does not establish 16° as a universal osteotomy threshold. Rather, increasingly extreme radiographic values identify increasingly hostile sagittal anatomy and should prompt more comprehensive assessment. Importantly, PTS may not always be a fixed constitutional characteristic. In skeletally immature patients with ACL injury, PTS can change during growth over long-term follow-up, a developmental observation that should not be extrapolated directly to adults.[4] Separately, in skeletally mature patients undergoing revision ACL reconstruction, radiographic medial PTS increased by a mean of 1.1° over approximately 9 years, with progression greater than 2° in one-quarter of patients; posterior medial meniscal resection was more frequent in this subgroup.[5] Although these distinct studies do not establish causality, together they challenge the assumption that PTS is invariably immutable. In selected adult revision knees, particularly those with recurrent instability and posterior medial meniscal loss, increasing PTS may represent a progressive sagittal deformity rather than simply the upper end of constitutional variation.

The second challenge is determining whether the anatomical risk factor has become functionally expressed. Two patients with the same PTS may demonstrate markedly different sagittal knee mechanics. One may maintain a relatively centered tibiofemoral resting position through intact menisci, preserved secondary stabilizers, constitutional soft-tissue stiffness, and neuromuscular control. Another may demonstrate substantial anterior tibial subluxation because the same osseous geometry is combined with chronic ACL deficiency, meniscal loss, hyperlaxity, or previous failed reconstructions. Static anterior tibial translation (sATT), assessed on a strict monopedal weight-bearing lateral radiograph, provides a measure of this functional expression. Unlike manual or instrumented laxity testing, which evaluates displacement under an externally applied force, sATT describes the tibia's position relative to the femur under physiological axial loading. It therefore represents the functional sagittal set-point produced by the combined effects of osseous geometry, ligamentous restraint, meniscal competence, soft-tissue compliance, neuromuscular control, hyperlaxity, and injury chronicity.[7]

Importantly, sATT is not merely another term for passive anterior laxity, nor should it be assumed to normalize after an otherwise successful ACL reconstruction. In same-patient measurements, ACL reconstruction reduced stress-induced anterior tibial translation from approximately 7–8 mm to 3–4 mm, whereas monopedal sATT remained essentially unchanged.[8] ACL reconstruction may therefore restore the passive displacement envelope without necessarily recentering the tibia to a normal resting position under physiological load. This distinction has important clinical consequences. Excessive weight-bearing anteriorization has been associated with ACL reconstruction failure, and recent studies have shown that elevated sATT remains associated with graft rupture even after lateral extra-articular tenodesis.[7,9,10] In a cohort with a minimum follow-up of 6 years, the graft-rupture rate was 19.4% among patients with PTS>12°, compared with 2.7% among those with PTS<12°. The highest rupture rate, 26%, occurred when PTS of at least 12° was combined with sATT of at least 5 mm.[9] In a larger contemporary cohort, patients sustaining graft rupture similarly demonstrated greater PTS and sATT than those without rupture.[10] These findings indicate that a reconstructed graft may remain exposed to an unfavorable weight-bearing sagittal set-point, even with restoration of conventional clinical stability. Instrumented laxity, stress-induced translation, and monopedal sATT should therefore be regarded as related but non-interchangeable measurements. The first two describe how far the tibia can be displaced; sATT describes where it rests when the limb accepts physiological load.

Elevated sATT may arise through at least three mechanisms. Osseous anteriorization is driven by a constitutionally steep or progressively increased PTS that continuously biases the tibia anteriorly. Acquired soft-tissue anteriorization develops through chronic ACL deficiency, posterior meniscal loss, repeated graft failure, and progressive insufficiency of the secondary stabilizers. Inherent soft-tissue anteriorization occurs in constitutionally hyperlax patients who may demonstrate high bilateral sATT without substantial pathological side-to-side asymmetry.[7] These mechanisms may converge on a similar radiographic appearance but require different treatment strategies. A unilateral, slope-driven anteriorized knee is not equivalent to symmetric bilateral anteriorization in a hyperlax patient. Likewise, a knee with moderate PTS but marked sATT after medial meniscal deficiency may be more compromised than a knee with a steeper slope but preserved meniscal containment.

Meniscal status is therefore a critical modifier. The meniscus should not be regarded merely as an associated lesion documented during arthroscopy; it is an essential component of sagittal stability. Biomechanical evidence indicates that ACL reconstruction combined with complete ramp repair may restore anterior translation across a range of PTS values. In contrast, following substantial medial meniscal deficiency, isolated ACL reconstruction may fail to restore normal translation at steeper slopes, and concomitant slope correction may become necessary.[11] Meniscal loss may therefore act as a biomechanical multiplier, converting tolerable osseous morphology into sagittal decompensation.

Several frameworks have attempted to move decision-making beyond isolated PTS thresholds. Ollivier et al. introduced the ACL + Slope Tracing Risk-Factor Algorithm (A+STRA) score, integrating previous revisions, meniscal deficiency, anatomical factors, and potential limitations to slope correction through weighted scoring.[12] This was an important attempt to incorporate the broader clinical context. However, its prescriptive arithmetic may suggest greater precision than is currently supported, particularly because biologically interdependent factors cannot necessarily be treated as independently additive. Schuster et al. approached the same problem through the Avalanche Concept, appropriately emphasizing that recurrent ACL failure usually results from an accumulation of interacting risk factors rather than from a single isolated measurement.[13] Its individualized philosophy is compelling, although the concept remains abstract and does not provide an objective method for quantifying sagittal decompensation or determining a patient-specific correction target.

The Assessment-Led Personalization (ALP) system offers a complementary, assessment-led framework for individualized decision-making.[14] It combines bilateral monopedal sATT, normalized sATT percentage, side-to-side sATT asymmetry, PTS laterality, meniscal status, injury chronicity, generalized hyperlaxity, and recurvatum to identify the dominant mechanism of sagittal anteriorization. Rather than deriving surgical necessity from a rigid point total, the ALP system uses the weight-bearing sagittal set-point to determine whether osseous morphology has become functionally expressed. The assessment applies to both primary and revision ACL reconstruction. Although overt sagittal decompensation is more commonly encountered in knees with markedly elevated PTS or after previous reconstruction, neither revision status nor an isolated slope threshold constitutes an indication for slope correction. Selected primary cases may already demonstrate an unfavorable combination of excessive PTS, pathological unilateral sATT, meniscal deficiency, and other evidence of sagittal decompensation. Within this framework, the contralateral knee serves as an internal reference rather than an unquestioned normal control. Bilateral differences in PTS and sATT should be considered while accounting for constitutional laterality and generalized hyperlaxity. Normalization of sATT to the sagittal dimension of the medial tibial plateau helps reduce magnification-related variability, while adjustment for PTS asymmetry may help distinguish osseous laterality from acquired soft-tissue decompensation.[14]

The operative strategy should follow the dominant pathology rather than the highest numerical measurement. A patient with moderately increased PTS, a centered weight-bearing sagittal position, intact menisci, and no generalized laxity may reasonably undergo isolated anatomical ACL reconstruction. A hyperlax patient with symmetric bilateral anteriorization may benefit more from graft optimization and selective extra-articular augmentation than from osseous correction. Conversely, a patient with elevated PTS, pathological unilateral sATT, chronic posterior meniscal deficiency, progressive slope, or repeated atraumatic graft failure may require slope-reducing osteotomy in addition to ligament reconstruction. Slope-reducing osteotomy is a powerful intervention, but the expanding recognition of sagittal risk should not justify indiscriminate expansion of its indications. Current clinical evidence is encouraging but remains predominantly retrospective.[2,3] The decision to correct the slope should therefore reflect the interaction between anatomy, weight-bearing sagittal position, meniscal competence, laxity phenotype, previous failures, and the expected demands on the reconstructed graft.

Correction must also remain proportional. The ideal postoperative PTS is unlikely to be identical in every knee. Planning should account for preoperative PTS, weight-bearing anteriorization, constitutional recurvatum, posterior cruciate ligament function, meniscal status, cartilage condition, coronal alignment, osteotomy level, and intended correction angle.[2,3,7,14] Wedge height should similarly not be selected through a universal millimeter-per-degree rule. The required resection depends on the individual osteotomy depth and planned correction angle. A depth-based planning method has demonstrated greater precision than fixed millimeter-per-degree ratios, which may produce clinically relevant undercorrection or overcorrection.[15] The correction angle should remain the principal target; wedge height is a patient-specific and technique-specific consequence of that target. Overcorrection may create a new biomechanical problem while attempting to solve the original one. Undercorrection may leave the graft exposed to the same anterior shear environment that contributed to failure. The objective should not be to produce a radiographically “normal” value at any cost, but to achieve sufficient sagittal recentering without creating an abnormal posteriorly directed knee phenotype.

Personalization in ACL surgery has often focused on graft choice, tunnel placement, lateral extra-articular procedures, rehabilitation, and return-to-sport testing.[1] Sagittal alignment adds another essential dimension. The clinically relevant questions are no longer limited to whether PTS is increased. How was it measured? Is it constitutional, growth-related, or progressively acquired? Is it expressed as pathological weight-bearing anteriorization? Does sATT remain elevated despite reconstruction? Is the contralateral knee similar? Are

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the menisci competent? Has chronic deficiency altered the secondary stabilizers? Does the patient have constitutional hyperlaxity or recurvatum?

PTS should therefore be viewed as the beginning of assessment rather than the end of decision-making. The next era of ACL surgery should not be defined by performing an osteotomy for every knee with an angle above 12°. It should be defined by identifying which steep slopes have become mechanically expressed, which moderate slopes have become dangerous through meniscal and soft-tissue decompensation, which slopes appear to be progressing, and which anteriorized knees represent constitutional laxity that should not be treated through bone.

The goal is not simply to reconstruct the ACL or to normalize a single radiographic angle. It is to restore a sustainable biomechanical environment in which the reconstructed ligament, menisci, cartilage, and neuromuscular system can function together. The essential transition is therefore not from ACL reconstruction to slope-reducing osteotomy, but from threshold-led surgery to assessment-led personalization.

DECLARATIONS

Ethics Committee Approval: Not applicable. This editorial does not involve human participants, patient data, or experimental procedures; therefore, ethics committee approval was not required.

Informed Consent: Not applicable. This editorial does not contain identifiable patient information or involve human participants.

Conflict of Interest: The authors declared no conflicts of interest.

Financial Disclosure: The authors declared that they have no relevant or material financial interests related to the content of this editorial.

Funding Disclosure: No funding was received for the preparation of this editorial.

Data Availability Statement: Not applicable. No datasets were generated or analyzed for this editorial.

Use of AI for Writing Assistance: Generative artificial intelligence was used for language editing and refinement during the preparation of this editorial. The authors critically reviewed and revised the content and take full responsibility for the final version.

Author Contributions: Both authors contributed to the conception and writing of this editorial, critically reviewed the manuscript, and read and approved the final version.

ABBREVIATIONS

ACL: Anterior cruciate ligament

ALP: Assessment-Led Personalization

A+STRA: ACL + Slope Tracing Risk-Factor Algorithm

PTS: Posterior tibial slope

sATT: Static anterior tibial translation

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