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Review article

[Translated article] Tibial slope in ACL reconstruction: When should it be corrected?

Pendiente tibial en reconstrucción de ligamento cruzado anterior: ¿cuándo debe corregirse?

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ABSTRACT

The tibial slope has been identified as a key anatomical factor influencing anteroposterior knee stability. Increased slope values have been linked to greater anterior tibial translation, higher stress on the anterior cruciate ligament and an elevated risk of graft failure following reconstruction. This review aims to examine the current evidence and ongoing controversies regarding the clinical relevance of tibial slope, measurement methods, and surgical correction indications.

Palabras clave:
Pendiente tibial
Ligamento cruzado anterior
Translación tibial anterior
Osteotomía tibial
Falla de injerto

RESUMEN

La pendiente tibial (PT) ha sido reconocida como un factor anatómico clave en la estabilidad anteroposterior de la rodilla. Valores aumentados se asocian con una mayor translación tibial anterior, mayor carga sobre el ligamento cruzado anterior (LCA) y un riesgo aumentado de falla luego de una reconstrucción. Esta revisión tiene como objetivo analizar la evidencia disponible y las controversias sobre la importancia clínica de la PT, los métodos de medición y su indicación de corrección.

Introduction

Tibial slope (TS) has been identified as a key factor in the risk of failure following anterior cruciate ligament (ACL) reconstruction.[1–6] Although numerous studies demonstrate its association with increased anterior tibial translation and greater force on the graft, this factor has not been systematically assessed in clinical practice.[7,8] This can be attributed, in part, to heterogeneity in measurement methods, a lack of clarity regarding clinically significant thresholds, and the absence of standardisation in surgical recommendations. The aim of this paper is to review the available evidence and provide recommendations based on the lead author's experience.

Clinical evidence

TS has been recognised in recent years as one of the main risk factors for failure of ACL reconstruction.[1–4] Systematic measurement of TS allows patients at higher risk of re-injury to be identified, enabling the surgical strategy to be adjusted accordingly.[6,9,10]

Clinical studies have confirmed this association. Salmon et al.[1] reported, in a 20-year follow-up after ACL reconstruction, that adolescent patients with a TS $\geq 12^\circ$ had a survival rate of 22%, with this variable being the strongest predictor of reconstruction failure. Similarly, Lee et al. demonstrated that patients with a TS $>12^\circ$ have an odds ratio of failure of 4.52 compared to patients with a TS $<12^\circ$.[11]

A steeper TS causes anterior displacement of the tibia relative to the femur when subjected to axial loads, thereby increasing the force on the native ACL or on the graft following reconstruction.[7] This effect can be objectively assessed radiologically on single-stance lateral knee radiographs; recently, Cance et al. observed that in patients with ACL injury, static anterior tibial translation (SATT) increased by .5 mm for every 1° of increase in TS.[8]

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Although pure anterior translation (without axial load) is effectively reduced by ACL reconstruction, SATT is not normalised by this procedure, and increased postoperative values have been shown to indicate a higher risk of failure.[4]

Recent findings by Romandini et al.[12] suggest that a three-week postoperative protocol of non-weight bearing in patients with increased preoperative SATT could be beneficial, although this approach requires further validation. Meanwhile, other interventions such as adding an anterolateral procedure to ACL reconstruction, increasing the graft diameter, or performing early reconstruction have not been shown to have an impact on SATT.[13,14]

Although a steep slope is associated with an increased risk of graft re-injury, it does not appear to compromise mid-term functional outcomes, which emphasises the importance of balancing mechanical risk with the patient's functional expectations before indicating aggressive anatomical correction.[6] In this context, Ollivier et al. propose an integrative approach that goes beyond considering TS as the sole risk factor, introducing the ACL + Slope Tracing Risk-factor Algorithm (A + STRA).[10] This model combines the medial TS value with relevant clinical variables, such as medial meniscal injury, SATT, and a history of previous failures or multiple reconstructions, with the aim of generating personalised recommendations on the need for corrective osteotomy, in both primary and revision contexts. Although this tool allows the surgical indication threshold to be adapted according to the cumulative risk burden, offering a more precise decision-making framework, its clinical use has yet to be prospectively validated.

Finally, some authors have suggested optimising other technical factors to compensate for the steeper TS and thus avoid an osteotomy. For example, using a patellar tendon autograft has been promoted as a strategy to reduce subsequent tear rates compared to hamstring grafts. However, even in these patients, a steeper TS remains a significant risk factor.[15] Similarly, anterolateral procedures have been shown to reduce the rotatory load on the ACL, but do not alter the sagittal vector caused by a high TS.[6,13] Subgroup analysis of the STABILITY study demonstrated that, whilst anterolateral procedures reduce the absolute risk of re-injury, the relative risk continues to increase in patients with high TS, highlighting the need to directly address this anatomical abnormality.[2] Currently, only slope-reducing tibial osteotomy has been shown to have a substantial effect on reducing SATT.[16]

Measurement of the tibial slope

Lateral knee radiography remains the most widely used method for assessing TS. However, there is considerable variability in measurement techniques and the type of radiograph to be used.

An optimal radiograph for this assessment should, firstly, show the femoral condyles in superimposition, as rotation could underestimate the actual TS measurement.[17] Secondly, the radiograph should show at least 15 cm of visible tibia in order to obtain a valid reference[18,19] (Fig. 1). Additionally, this radiograph could be taken under axial loading during single-leg stance to objectively assess the SATT.[12–14,20]

Some authors argue that using short knee radiographs may underestimate the true extent of the TS by excluding the tibial diaphysis from the assessment. They therefore prefer to use images that include the entire tibia. Recent studies have observed differences in the values obtained between these two techniques of between 1° and 3°.[18,21] Furthermore, there is variability in how the reference point for the tibial axis is determined. Some authors suggest using the centre of the tibia, while others use the anterior or posterior cortex. This could potentially lead to greater variability and result in a different normal TS value.

More recently proposed imaging methods for this measurement include magnetic resonance imaging (MRI) and computed tomography (CT).[21–23] These methods have the advantage of enabling more accurate assessment of the slope of both plateaus; however, they do not permit measurement under axial loads. While measurements obtained using these imaging methods have shown a correlation with radiograph measurements, it must be recognised that the former have lower reproducibility and their values are not interchangeable, potentially resulting in TS values being overestimated.[21–23]

Fig. 1. Lateral knee radiograph showing measurement of the tibial slope (TS). The TS is the angle formed between a line (B) perpendicular to the tibial diaphyseal axis (A) and the line (C) tangent to the uppermost points of the anterior and posterior margins of the medial tibial plateau.

One of the main challenges in assessing TS today is the lack of standardisation in its measurement, and the fact that available evidence is primarily based on knee radiographs where the entire tibia is not visible. It is important to bear in mind that the method used influences the diagnosis, the indication for correction, and the definition of the postoperative objective. For this reason, we recommend adhering to a single measurement method and its corresponding cohort values, as values obtained using different methods are not interchangeable.[19]

Static anterior tibial translation

SATT is quantified on lateral knee radiographs during single-leg stance. Traditionally, this has been defined as the distance between two lines that are both parallel to the posterior cortical surface of the tibia: the first line is tangent to the posterior margin of the medial tibial plateau, and the second is tangent to the posterior femoral condyles[20] (Fig. 2). This measurement has been proposed as a complementary method for assessing knee stability in patients with an ACL injury. It has been shown to correlate well with the functional status of the ligament in both acute and chronic injury scenarios.[20,24]

While cadaveric studies have demonstrated a direct correlation between TS and force on ACL grafts,[7] clinical studies suggest that there

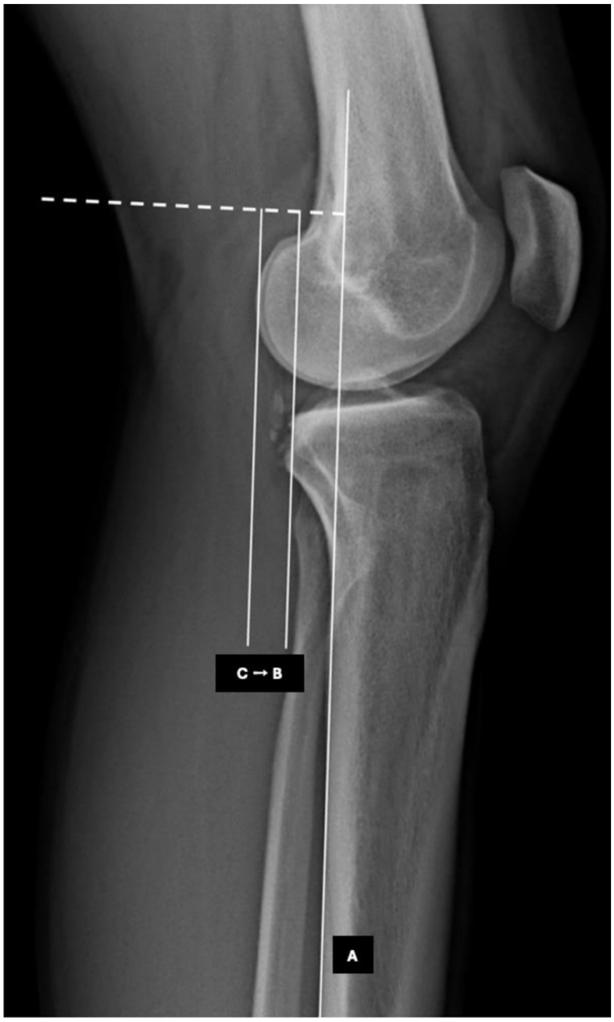

Fig. 2. Lateral knee radiograph showing the measurement of static anterior tibial translation (SATT). The posterior cortical bone of the tibia is used as a reference (A line). Two lines are drawn parallel to line A and tangent to the posterior aspect of the medial tibial plateau (line B) and to the femoral condyles (line C). SATT corresponds to the distance between lines B and C.

is a linear correlation between increased TS and increased SATT.[8] Based on this, this measurement tool has recently been used to propose a postoperative target value in cases of surgical correction.[16]

The combined use of TS and SATT enables more rational surgical decision-making, avoiding overtreatment or inappropriate indications based on a single anatomical parameter. However, this has been mainly reported in short knee radiographs, and there is limited evidence to account for its variability and define normal values. Therefore, greater efforts are needed to validate its use in different populations.[8,20,24]

When should the tibial slope be corrected?

The first key point in establishing the surgical indication is to understand that the 12° TS threshold, frequently cited in the literature, is based on the proximal anatomical method applied to short lateral knee radiographs, and not on full-leg radiographs.[15,25] This methodological difference must be taken into account when interpreting the threshold values.

The available evidence for assessing the indication and, above all, the outcome of this type of osteotomy comes exclusively from case series.[25] In these, the vast majority of authors suggest correction in cases of ACL revision associated with a TS of ≥12°, while others also consider the measurement of SATT in their therapeutic decision.[25]

Recently, the possibility of performing this correction in selected primary reconstructions has been suggested.[26,27] Wang et al.[26] described a cohort of patients with ACL injury and a TS ≥15° measured on full-leg radiographs, associated with excessive tibial subluxation (≥6 mm) as measured on MRI, in whom a slope-reducing tibial osteotomy with primary ACL reconstruction was performed. The results showed a significant reduction in tibial translation and a lower rate of residual laxity in the osteotomy group. Following a stratified analysis, the authors suggest that a TS ≥16° with tibial subluxation ≥6 mm would be a good indication for this procedure in primary cases.

Surgical technique

We use the supra-tuberosity osteotomy technique, as this allows us to act directly on the region where the anatomical abnormality is located without compromising the anterior tibial tuberosity.[28–30]

First, the femoral and tibial tunnels are created arthroscopically, with the trajectory planned in relation to the future osteotomy. Next, a supra-tuberosity biplanar deflection osteotomy is performed, preserving the posterior cortex. This is achieved using four guide pins: two converging medially and two laterally. The osteotomy is closed by extending the knee under fluoroscopic guidance, with the aim of achieving a postoperative tibial slope of between 4° and 6°. Before passing the graft, the integrity and patency of the tibial tunnel are inspected following closure. Fixation is then achieved using two metal staples, without the need for a graft or any other fixation method. This technique has been shown to be both reproducible and safe, enabling early rehabilitation without weight-bearing restrictions.

Our recommendation

In light of the consistent evidence in the literature regarding the negative impact of increased TS on the outcomes of anterior cruciate ligament (ACL) reconstruction surgery, we recommend that the TS be systematically measured in all patients undergoing primary or revision surgery. This should be performed using properly taken lateral knee radiographs with superimposed femoral condyles and including at least 15 cm of the proximal tibia, to ensure reliable measurements.

In the context of primary reconstructions, we suggest considering surgical TS correction in patients with a slope >14°, which corresponds to more than two standard deviations, especially if accompanied by a SATT >5 mm. In cases of ligament revision, we suggest a more conservative threshold of ≥12°.

Finally, where the indication is debatable, combining TS and SATT measurements can help determine the actual effect of the TS more accurately, thereby avoiding over-indication.

Conclusion

TS and SATT are key variables in the assessment of sagittal knee stability, particularly in the context of failed ACL reconstruction. The available evidence suggests that they should be routinely measured and corrected in selected cases. However, there is still no consensus on clinical thresholds or when correction is indicated. This is exacerbated by the heterogeneity in the measurement methods used and therefore, standardisation of the diagnostic method - including the radiographic technique and measurement criteria – is essential to ensure the correct interpretation of the values obtained and allow valid comparisons between studies.

Level of evidence

Level of evidence: V.

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Conflict of interests

The authors have no conflict of interests to declare.

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