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Slope reducing osteotomy: The emerging gap between indication, safety and proportionality

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Abstract

Slope-reducing osteotomy (SRO) has emerged as a valuable risk-mitigation tool in the management of anterior cruciate ligament (ACL) injuries, particularly in high-risk patients and in revision settings. However, its rapid adoption has outpaced the evidence defining when, how and in whom it should be performed, raising important questions regarding proportionality, technical demand and patient selection. This editorial argues that SRO should be guided by integrated, individualised risk stratification rather than isolated numerical thresholds, and that clinical judgement and surgical experience remain the essential safeguards for its safe and effective application.

Level of Evidence: N/A.

KEYWORDS

anterior cruciate ligament reconstruction, posterior tibial slope, risk stratification, surgical indication, tibial slope–reducing osteotomy

INTRODUCTION

Slope-reducing osteotomy (SRO) has expanded from a highly specialised procedure reserved for extreme cases of anterior cruciate ligament (ACL) failure to one now considered even in selected primary ACL cases [26, 28, 37]. Compelling biomechanical rationale, promising early results and growing scientific evidence have driven this expansion [3, 16, 21, 31].

However, the speed of adoption prompts a necessary question: are we giving the same scrutiny to safety and proportionality as we are to clinical effectiveness?

In many patients, increased posterior tibial slope (PTS) represents only one component of a broader anatomical risk profile, which may also include unfavourable femoral morphology, such as a narrow intercondylar notch, along with meniscal deficiency increased posterior tibial plateau offset and other

Abbreviations: ACL, anterior cruciate ligament; PTS, posterior tibial slope; SRO, slope-reducing osteotomy.

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anatomical risk factors [29, 36]. Together, these elements may collectively contribute to graft overload, and as indications expand and surgical strategies become more complex, addressing multiple anatomical and biomechanical factors simultaneously raises important considerations regarding proportionality, technical demand and overall surgical risk.

A POWERFUL TOOL THAT REQUIRES EVEN MORE POWERFUL JUDGEMENT

SRO has meaningfully expanded the therapeutic armamentarium for managing complex ACL insufficiency [1, 16]. By directly addressing an important anatomical driver of graft overload, it provides a clinically effective option for carefully selected patients with excessive PTS-related instability [3, 13]. At the same time, SRO does not constitute a 'definitive solution' [19]. In contemporary practice, SROs are rarely performed in isolation and are most often combined with ACL reconstruction and frequently, additional stabilising procedures. In this setting, restoring the anteroposterior stability of the ACL-deficient knee depends not only on bony correction or ligamentous augmentation, but also on the integrity of key secondary stabilisers. The posterior horn of the medial meniscus plays a central role in resisting anterior tibial translation in ACL-deficient knees. Insufficient recognition or repair of posterior meniscal pathology, particularly ramp lesions, may compromise the stabilising effect of otherwise well-executed reconstructions, including extra-articular procedures [6, 32, 33].

This limitation helps explain why soft-tissue–based strategies alone may be insufficient in certain high-risk knees. While anterolateral procedures have proven effective in controlling rotational instability, they do not directly address excessive anterior tibial translation [23]. In contrast, SRO specifically targets the anterior tibial translation, highlighting the complementary, rather than interchangeable, roles of these approaches [4, 7]. These considerations further support viewing SRO as one component of an integrated stability strategy rather than as a stand-alone corrective solution. Its effectiveness remains closely linked to appropriate patient selection, precise planning and meticulous execution. As the influence of SRO on contemporary decision-making continues to grow, its value must be considered not only in terms of what it can achieve but also in terms of how reliably, proportionately and safely it can be applied in routine clinical practice [25].

Although there is no universal consensus on how failure should be defined after ACL reconstruction, reported rates remain substantial across the literature [12]. Following primary ACL reconstruction, reinjury or persistent instability has been reported in approximately 5%–25% of patients. Failure rates after revision surgery are consistently higher and more variable, reaching up to 20%–30% in some series [2, 9, 12]. The addition of anterolateral procedures may reduce this risk, in many cases bringing global failure rates into a lower range [30]. Importantly, its widespread adoption was followed by a phase of critical reassessment, during which indications were progressively refined as longer-term outcomes became available. A similar process appears to be ongoing for SRO, which has expanded rapidly but remains in a phase where its optimal indication is still being defined, making questions of safety, proportionality and risk tolerance particularly relevant at this stage.

This balance is particularly evident in patients with markedly increased PTS, in whom the resulting increase in anterior tibial translation under single-leg weight-bearing sustains a clinically relevant residual risk despite optimised soft-tissue strategies. In this subgroup, SRO has emerged as an additional risk-mitigating tool. However, even with SRO, contemporary series continue to report residual failure rates at mid-term follow-up [21]. These figures reinforce that SRO represents risk attenuation rather than risk elimination, underscoring the need for careful judgement when selecting patients in whom the expected benefit justifies the added surgical complexity.

FIRST, DO NO HARM

The contemporary interest in SRO has been largely driven by its reported ability to reduce graft failure, particularly in the setting of revision ACL reconstruction, and by the apparent reproducibility of sagittal plane correction [16]. These advantages are supported by a growing body of biomechanical and clinical literature. However, much of the available clinical evidence originates from centres with established expertise in both osteotomy techniques and complex ACL revision surgery [8, 26, 28]. While these series provide valuable insight into outcomes achieved under experienced practice conditions, they also frame procedural safety within a specific and highly controlled context [8, 10, 21, 26, 31].

Growing technical refinement and contemporary data have clarified that several early concerns, such as clinically relevant alterations in patellar height, unintended coronal plane changes or hinge fractures, no longer represent defining limitations of slope-modifying osteotomies [5]. This evolution, however, should not be interpreted as the absence of clinically meaningful risk [5, 21]. Even in modern cohorts, reported failure rates may approach 10%, with complications including residual medial laxity, delayed union, symptomatic hyperextension and a nontrivial rate of secondary procedures, most commonly for implant

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removal [21, 22]. What remains less clearly defined is how this risk profile evolves during the early phases of adoption, a period characterised by gradual acquisition of technical familiarity, which is difficult to define, inconsistently captured in published series and rarely addressed through structured training pathways. While most published series reflect experienced practice patterns, it is uncertain whether complication and failure rates remain stable when SRO is incorporated earlier in a surgeon's learning curve. As seen with other technically demanding procedures in knee surgery, it is reasonable to anticipate that complication profiles may differ during initial experience, warranting careful attention as indications broaden [20].

This consideration becomes particularly relevant in a clinical landscape where other, less technically demanding procedures, such as anterolateral procedures, have consistently demonstrated reductions in ACL graft failure [11, 14, 27, 30]. Although these approaches address different biomechanical mechanisms, they offer reliable clinical benefit with lower technical complexity. This observation is not intended to prioritise one strategy over another, especially given that in selected cases these techniques may be complementary, but rather to emphasise the importance of carefully weighing the risk–benefit profile of each surgical option.

Taken together, these considerations reinforce that SRO should be regarded as a powerful but demanding risk-modifying strategy rather than a definitive solution with zero failure. Its indication requires a thoughtful balance among anticipated benefit, procedural complexity, learning-curve considerations and the availability of alternative or adjunctive strategies to mitigate failure risk.

INDICATIONS ARE EXPANDING FASTER THAN THE EVIDENCE BEHIND THEM

As awareness of PTS as a relevant risk factor has grown, the field has understandably moved away from earlier under-recognition. However, as often occurs with emerging concepts, there is a possibility that the pendulum may now be swinging toward overindication. The challenge has shifted from recognising the relevance of PTS to defining the clinical scenarios in which surgical correction translates into a meaningful clinical benefit. In patients with clearly elevated failure risk, SRO may be justified. In more moderate-risk profiles, however, exposing multiple patients to a major corrective procedure, sometimes involving combined corrections across more than one anatomical plane, raises essential questions about proportionality. Careful patient selection is therefore critical to ensure that the expected benefit justifies the surgical complexity.

This evolution has been accompanied by the development of integrated conceptual frameworks that move beyond isolated PTS thresholds, combining slope with multiple patient- and knee-specific risk factors to better reflect the multifactorial nature of ACL failure [19]. These approaches reinforce that PTS should not be interpreted as a binary indication for osteotomy, but rather as one variable within a broader constellation of contributing factors [12, 38] Figure 1.

While this represents a significant step forward, it also underscores a critical and often underappreciated reality: as decision-making becomes more complex and individualised, it increasingly depends on surgical experience, judgement and familiarity with osteotomy principles. This distinction becomes particularly

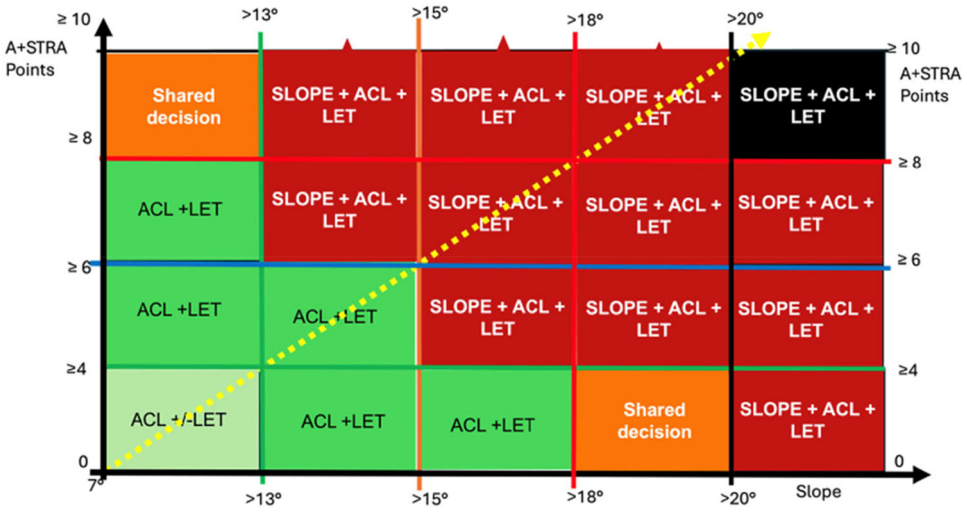


FIGURE 1 Proposed scoring matrix guiding the indication of slope-reducing osteotomy according to posterior tibial slope and cumulative instability risk factors (A + STRA points), a weighted score derived from patient-specific risk and limiting factors. Reproduced with permission from Ollivier et al. [19].

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relevant in the setting of primary ACL reconstruction. Although increased PTS is a recognised risk factor across different clinical scenarios, the baseline risk profile in primary ACL injury is substantially lower than in revision cases, often characterised by better meniscal status and fewer concomitant risk factors. As a result, applying the same surgical thresholds across these fundamentally different contexts risks disproportionate intervention. In primary ACL reconstruction, slope correction may therefore be reasonable only in the presence of clearly extreme values and additional high-risk factors, rather than as a response to isolated or borderline increases in PTS [19].

Recent evidence from large primary ACL reconstruction cohorts further supports a cautious interpretation of PTS as a surgical indication [34]. While an increased PTS has been associated with higher objective laxity and an increased risk of graft failure, this does not necessarily translate into inferior patient-reported outcomes or higher revision rates in the short to mid-term [34]. These findings highlight an important distinction between structural or biomechanical risk and clinically meaningful failure, suggesting that PTS should primarily inform risk stratification and patient counselling rather than serve as a stand-alone trigger for SRO.

Within this framework, commonly cited cut-offs, most often around ~12°, should be interpreted with caution rather than used in isolation to guide surgical decisions [26, 31, 35]. Risk associated with PTS exists along a continuum, and such values do not represent a real inflection point [24]. Indeed, different studies report varying cut-off values and no universal threshold has been established, as these figures typically reflect statistically defined population distributions where the probability of failure is considered to exceed a tolerable level. Notably, a radiographic medial PTS of 16° or greater has been specifically associated with multiple revision episodes after ACL reconstruction, suggesting that truly extreme values may carry a distinct, clinically meaningful risk profile [15].

Furthermore, such values are frequently applied in isolation, disregarding not only the broader clinical context, patient characteristics, meniscal status, cumulative ACL reconstructions, but also the functional manifestation of an increased PTS, particularly anterior tibial translation while weight bearing. Moreover, the way PTS is measured plays a nonnegligible role in how these thresholds are interpreted. Even on standardised lateral radiographs, different reference axes and measurement techniques yield systematically different slope values, suggesting that a single numerical cut-off may not carry the same clinical meaning across different patient populations, and that risk thresholds may vary rather than converge to a universal value [35].

Equally unsolved is the question of what postoperative slope represents an optimal target. Suggested ranges, commonly 4°–6°, are derived from retrospective outcome studies, and optimal targets remain to be formally established [7, 26]. More importantly, the notion of a universal target is undermined by the lack of standardised measurement, as different imaging protocols and reference axes yield systematically different slope values.

Regarding the osteotomy level, available evidence suggests that both supra- and infra-tubercle slope osteotomies can achieve comparable clinical outcomes. A recent study by Patel et al. [21] did not identify clinically relevant differences in functional results or overall complication rates between techniques. Although supra-tubercle osteotomy was associated with slightly higher residual anterior laxity and more unstable coronal-plane behaviour, these differences were small and unlikely to translate into a meaningful clinical advantage. In contrast, infra-tubercle osteotomy was associated with a higher likelihood of subsequent hardware removal and a greater wedge resection, resulting in increased cortical mismatch [17]. Rather than defining superiority between approaches, these observations suggest that the level of osteotomy is ultimately a technical variable, whose implications should be considered only after the indication for PTS correction itself has been carefully established.

Consequently, determining when, how, and to what extent an SRO should be performed relies more on clinical judgement than on clearly defined numerical thresholds. While this is not unusual in orthopaedic practice, where nuance and individualised assessment are often essential, the combination of technical demands and uncertainty regarding both indication and target correction inevitably raises the threshold for safe application [18]. In this setting, experience, procedural familiarity and thoughtful patient selection become central in determining whether PTS correction fulfills its intended role or introduces avoidable risk.

CONCLUSION

SRO has earned an important place in contemporary ACL surgery. It provides a biomechanically meaningful correction for selected patients, and in expert hands, its outcomes are compelling. At the same time, its rapid and widespread adoption has outpaced our certainty about when to perform it, how much to correct, and which postoperative PTS represents the most favourable biomechanical state.

Ultimately, discussing SRO requires first understanding where instability may be originating. Careful evaluation of PTS and its functional expression, particularly anterior tibial translation under physiologic loading, should precede any decision to correct. The decision to perform slope modification ultimately rests with the surgeon's clinical judgement. What must be

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avoided is overlooking a relevant risk factor when it is clearly present.

The true strength of SRO lies not only in its biomechanical effectiveness but also in the judgement used to apply it. Clinical judgement and experience, rather than enthusiasm alone, remain the safeguards that keep this procedure both effective and safe.

AUTHOR CONTRIBUTIONS

Tomas Pineda: Writing—review and editing. **Romain Seil**: Writing—review and editing. **Bertrand Sonnery-Cottet**: Writing—review and editing. **David H. Dejour**: Writing—review and editing. **Michael T. Hirschmann**: Writing—review and editing. **Matthieu Ollivier**: Writing—review and editing.

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The authors have nothing to report.

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