



## Proprioceptive Enhancement Hypothesis: Evaluating Early Joint Position Sense and Balance in Adults Receiving Remnant Preserving versus Standard ACL Reconstruction—A Single Center Pilot Trial

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### Abstract

**Background:** A torn anterior cruciate ligament (ACL) often forces active adults and athletes into lengthy rehabilitation, disrupted sports participation and a higher risk of early knee degeneration. Modern reconstruction aims to restore anatomy and promote biological graft incorporation and functional recovery. Preserving viable native ACL remnant tissue has been proposed because remnants can contain blood vessels, cellular elements and mechanoreceptor-like structures that might aid revascularization and sensory recovery. Patients value clear counselling about expected benefits and limitations, and surgeons must balance biological opportunity against technical accuracy in each case.

**Hypothesis:** Selective preservation of a viable ACL remnant during anatomic reconstruction will provide early benefits: improved instrumented laxity and enhanced subjective stability through immediate mechanical support and accelerated biological integration. Retained neural elements may aid proprioception and neuromuscular control, boosting confidence during rehabilitation. Crucially, when preservation does not hinder accurate tunnel placement, it will not increase complications such as symptomatic impingement or arthrofibrosis. Subgroup analyses will determine whether athletes, acute injuries or specific remnant patterns gain the most benefit.

**Clinical importance:** If confirmed, selective remnant preservation would offer surgeons an evidence-based option to modestly shorten early recovery, reduce tunnel-related bone reactions and improve patient confidence without adding morbidity. This information supports a patient-centred approach: preserve when the stump is viable and non-obstructive, and debride when landmarks or tunnel accuracy are compromised. Adoption should follow appropriate training so outcomes remain reproducible across different centres and experience levels.

**Future research:** Definitive answers require large, multicentre randomized trials with standardized surgical protocols, blinded assessment and at least five years of follow-up. Trials should include serial MRI to assess graft maturation, validated proprioception testing, return-to-sport metrics and subgroup analyses by remnant type, timing since injury and graft choice. Cost-effectiveness analyses and training reproducibility studies should accompany trials to understand adoption barriers and resource implications. Collaborative registries should track long-term outcomes across diverse populations, settings and surgical practices to ensure generalizability and implementation factors.

**Keywords:** ACL reconstruction; remnant preservation; ligamentization; proprioception; tunnel widening; arthrometer; cyclops lesion.



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## Background

A torn anterior cruciate ligament (ACL) changes lives. For many active adults and athletes it means months of rehabilitation, uncertainty about returning to sport and, for some, a risk of earlier joint degeneration. Surgery for ACL rupture has been refined over decades because simple mechanical replacement of a torn ligament does not by itself guarantee that the knee will feel or behave like it did before injury [1]. As surgeons learned more, the emphasis shifted from merely placing a strong graft to restoring anatomic relationships and creating conditions that favour biological healing of the graft inside the knee [2,3].

The process by which a tendon graft becomes a functioning ligament — commonly called “ligamentization” — depends on revascularization, cellular repopulation and remodeling of collagen within the graft and bone tunnels. Laboratory and clinical work has shown these processes are heavily influenced by the biological environment at the time of surgery and by how the graft is handled and fixed [3–5]. Against this background, the idea of preserving any remaining viable ACL tissue when reconstructing the ligament gained traction: why discard tissue that might help healing? Remnant tissue often contains blood vessels, fibroblasts and structures that look like mechanoreceptors. Leaving such tissue in place could offer a ready vascular scaffold to speed revascularization and, possibly, preserve proprioceptive elements that aid functional recovery [6–10].

A number of imaging, histologic and early clinical studies have documented features in remnants that make this hypothesis plausible [9, 10]. Building on that, investigators tested whether remnant-preserving techniques reduce tibial tunnel enlargement, improve early instrumented stability, or show more favourable graft appearance on MRI or at second-look arthroscopy [11–14]. Many of those studies reported modest gains in mechanical or imaging endpoints — less tunnel widening or slightly better arthrometer readings early after surgery — yet patient-reported outcomes at typical clinical checkpoints (for example one year) often ended up similar whether remnants were left or removed [14–16].

Interpreting the literature is not straightforward because “remnant preservation” describes a variety of technical approaches. Some surgeons retain most of the stump, others preserve only a bundle or perform minimal debridement. Those choices affect visualization and the surgeon’s ability to place tunnels anatomically; bulky remnants can obscure landmarks and increase the risk of non-anatomic tunnel positioning if not handled carefully [17–19]. Outcomes also vary with graft type (hamstrings, patellar tendon, and allograft), fixation method, rehabilitation strategy and the timing of surgery after injury — all potential confounders that make direct comparison across studies difficult [18–21].

Complications have been a concern. Early, indiscriminate attempts at remnant retention were sometimes linked with

symptomatic impingement (cyclops lesions) and stiffness, but more recent series using selective preservation — that is, keeping only tissue that does not block anatomic tunnel placement — report low rates of clinically significant arthrofibrosis when careful surgical judgment is applied [22–24]. Even so, systematic reviews emphasize the heterogeneity of the evidence and call for larger, multicentre randomized trials, longer follow-up and mechanistic substudies (imaging, proprioception testing, and biomarkers) to decide whether remnant preservation gives meaningful, durable patient benefit [25].

## Hypothesis

At its simplest: if a surgeon leaves viable native ACL tissue in place during reconstruction, will the patient do measurably better than if that tissue is removed? The question is practical and patient-centred — it asks whether preserving what is potentially helpful changes outcomes people care about: stability, function, return to activity and long-term joint health. From that central query come three linked hypotheses.

First, biologic augmentation. A preserved remnant brings vessels and cells to the graft environment and may serve as a scaffold for ingrowth. Faster revascularization and cellular repopulation could lead to more orderly graft remodeling, reduce micromotion at the graft–bone interface, and limit tunnel widening — mechanical and structural advantages that are plausible based on laboratory and imaging work [3–5,9,11]. Second, proprioceptive preservation. If remnants contain mechanoreceptor-like elements, keeping them could conserve some native sensory input. That preserved sensory scaffold might improve joint position sense and neuromuscular control during rehabilitation, translating to better subjective stability and perhaps safer, more confident return to activity — especially important for athletes who rely on fine sensorimotor control [6–8,10].

Third, early mechanical support. Before full biologic incorporation occurs, residual fibers could provide a degree of mechanical restraint. Clinically, that may show up as improved instrumented laxity in the early months after surgery and could help patients progress through rehabilitation with less apprehension [12–14].

Running in parallel is an essential safety hypothesis: when preservation is selective — performed only if the remnant does not obstruct accurate anatomic tunnel placement or compromise visualization — it will not increase clinically meaningful complications (e.g., symptomatic cyclops lesion, significant arthrofibrosis, infection). That boundary is critical because any biological advantage would be negated by higher procedural morbidity [22–24].

Operationally, these hypotheses translate into measurable endpoints: instrumented arthrometer readings and validated patient-reported outcome scores (Lysholm, IKDC) at defined early (3–6 months) and intermediate (12 months) windows;

radiographic or MRI indicators of tunnel change and graft appearance as mechanistic surrogates; and complication and reoperation rates as safety endpoints. Subgroup analyses by remnant type (bundle vs whole stump), time since injury, graft choice and activity level should illuminate who, if anyone, benefits most [15–20].

## Discussion

The debate over remnant preservation ultimately rests on a balance between biological opportunity and technical precision. Preserve viable tissue and you may help healing; preserve tissue that obscures landmarks and you may end up with a non-anatomic graft that performs poorly [20, 21]. That trade-off explains much of the variation we see in published reports.

Many studies that favour preservation report early, surrogate benefits — less tunnel widening on imaging, slightly better arthrometer values, or improved arthroscopic graft appearance. Those signals fit the biologic model: a vascularized remnant could speed graft maturation and curtail adverse bone-tunnel reactions [11–14]. But surrogate or mechanistic gains do not automatically translate into patient-centred improvements. By 12 months, the body's remodeling and structured rehabilitation often even out early differences, and validated functional instruments such as Lysholm and IKDC commonly show similar outcomes whether remnants were kept or removed [14–16]. Put simply, early mechanical or imaging advantages may be real but too small to change how patients feel or function in ordinary life at one year.

Technique and selection bias are central. The strongest evidence for benefit comes from series that practice selective preservation: the surgeon retains only tissue that is viable and not obstructive to precise tunnel drilling. That approach minimizes the risk of malposition and avoids leaving bulky tissue that could impinge and create a cyclops lesion. Earlier series that recommended wholesale stump retention reported higher rates of symptomatic impingement; modern selective approaches appear to avoid that hazard [21–24].

Measurement sensitivity is another issue. Standard patient-reported scores are valuable but blunt; they may miss subtle improvements in proprioception, neuromuscular coordination or high-level athletic tasks that matter to elite performers. To detect those differences, studies need specialized proprioceptive testing, instrumented gait or hop testing, and return-to-sport quality metrics. Equally, serial MRI or biomarker studies can more directly test whether remnant preservation accelerates graft ligamentization and reduces tunnel reactions [9,17].

Timing matters too. An acute remnant (hours or weeks after injury) is biologically different from a scarred, chronically retracted stump. The potential benefit of preservation is likely greater when remnants are biologically active and less when they are heavily scarred; therefore the same surgical policy may have different effects depending on how long the knee has been

unstable [18,19]. Graft choice and fixation also interact with these biology signals — a hamstring autograft in a vascular bed may behave differently than a less biologically active construct [18–20].

Long-term consequences remain an open question. Reduced tunnel widening or marginally better early stability are interesting, but do they lower revision risk, delay osteoarthritis or improve lifetime knee function? We do not know; answering these clinically meaningful outcomes requires multicentre randomized trials with long follow-up and embedded mechanistic work [25].

Finally, adopting remnant preservation in routine practice has practical implications. It requires surgical judgment, sometimes more operative time and good training to ensure the technique is reproducible and safe. Preservation should remain an option in the surgeon's armamentarium, not a universal rule applied regardless of intra-articular conditions [21].

## Clinical importance

For surgeons and patients the practical takeaway is simple: selective remnant preservation is a reasonable option when a viable stump exists and it does not prevent accurate anatomic tunnel placement. In experienced hands, it appears safe and may offer earlier arthrometric stability or less tunnel widening without increasing complications. But it must never compromise tunnel accuracy — if visualization is poor or landmarks are obscured, debridement is the safer route to guarantee an anatomically correct reconstruction. Patients should be counselled that preservation may provide modest early benefits but has not yet been proven to consistently improve one-year patient-reported outcomes or long-term joint health [21–24].

## Future Direction

To settle remaining uncertainty we need large, randomized, multicentre trials with standardized surgical protocols, blinded outcome assessment and follow-up of at least five years. Trials should include mechanistic substudies (serial MRI for graft maturation, validated proprioception and neuromuscular tests, return-to-sport quality metrics) and stratified analyses by remnant type, timing since injury and patient activity level. Training and reproducibility studies will help determine how safely the technique can be adopted in general practice [25].

## Conclusion

Remnant preservation in ACL reconstruction is biologically sensible and technically feasible when done selectively. Current evidence suggests it is safe and may confer early objective advantages, but—so far—has not demonstrated a consistent, reliable improvement in routine one-year functional outcomes. Careful surgical judgment and further rigorous research are required before universal adoption.

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