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Tibial slope and medial meniscectomy significantly influence short-term knee laxity following ACL reconstruction

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Abstract

Purpose To determine demographic, anatomic, and surgical factors associated with static and dynamic Anterior Tibial Translation (ATT) following ACL reconstruction. The hypothesis was that both static and dynamic ATT would be greater in knees with high tibial slope or that required meniscectomy.

Methods The authors prospectively enrolled 280 consecutive patients that had primary ACL reconstruction using hamstring autografts at one center for which preoperative tear type, meniscal tears, and medial tibial slope were documented. A total of 137 were excluded due to concomitant extra-articular tenodesis or surgical antecedents on either knee, and 18 were lost to follow-up, leaving 125 that were evaluated at a minimum of 6 months including: static ATT on monopodal weight-bearing radiographs, and dynamic ATT on differential stress radiographs using the Telos™ device.

Results Both postoperative static and dynamic ATT were strongly associated with preoperative static and dynamic ATT (respectively, $\beta = 0.068$ and $\beta = 0.50$, $p < 0.001$). Multivariable regression confirmed that postoperative static ATT increased with tibial slope ($\beta = 0.24$; CI 0.01–0.47; $p = 0.042$) and in knees that had partial medial meniscectomy ($\beta = 2.05$; CI 0.25–3.84; $p = 0.025$), while dynamic ATT decreased with age ($\beta = -0.11$; CI -0.16 to -0.05; $p < 0.001$), and increased with tibial slope ($\beta = 0.27$; CI 0.04–0.49; $p = 0.019$) and in knees that had partial medial meniscectomy ($\beta = 2.20$; CI 0.35–4.05; $p = 0.019$).

Conclusion Both static and dynamic ATT following ACL reconstruction increased with tibial slope and in knees that had partial medial meniscectomy. These findings could help surgeons tailor their techniques and 'à la carte' rehabilitation protocols, by preserving the menisci and sometimes delaying full weight-bearing and return to sport in patients at risk, and hence improve outcomes and prevent graft failures.

Study design Cohort study.

Level of evidence V.

Keywords ACL reconstruction · Anterior cruciate ligament · Tibial slope · Meniscal tears · Knee laxity

Introduction

Residual knee laxity after anterior cruciate ligament (ACL) reconstruction increases risks of meniscal tears [38, 50], tunnel widening [35], graft failure [41, 55], compromising clinical outcomes [43, 48] and patient satisfaction [23]. These complications are known to exacerbate risks of arthritic degeneration [31, 39, 44].

The main function of the ACL is to prevent anterior tibial translation (ATT) during the stance phase of gait [10]. 'Static' ATT is often measured on lateral monopodal weight-bearing radiographs [15], while 'dynamic' ATT quantifies knee laxity and is measured on instrumented stress radiographs using the Telos™ device or other laximetry tools such as the KT-1000 and Rolimeter™ [5, 36]. Several patient factors are known to influence anteroposterior knee stability in ACL-deficient knees: the posterior tibial slope [20, 32] is associated with primary [26, 54, 59] and recurrent ACL injuries [1]; meniscal tears can also compromise knee laxity and repair integrity [2, 18, 28, 47, 58], and their repair

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is recommended over meniscectomy during ACL reconstruction [29, 47, 52]. In a recent study [13], the authors investigated the factors that influence laxity and instability in ACL-deficient knees, but there are very few in vivo studies on prognostic factors of laxity and instability after ACL reconstruction. In 2016, Ahn and Lee [3] investigated the risk factors for knee laxity and instability after ACL reconstruction, but did not include tibial slope in their analysis.

The purpose of this study was therefore to determine demographic, anatomic and surgical factors associated with static and dynamic ATT at 6–8 months following ACL reconstruction, which is a critical time for complete graft integration [7] and when return to sports is usually allowed. The hypothesis was that, even following ACL reconstruction, both residual static and dynamic ATT would be greater in knees with high tibial slope and in those that required meniscectomy.

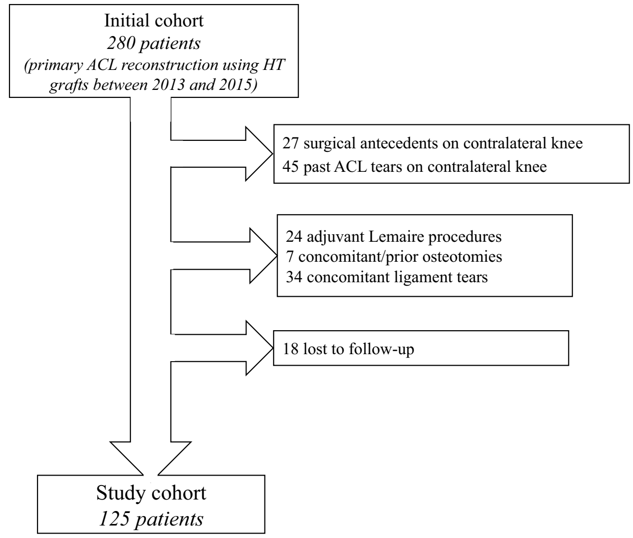

Fig. 1 Flowchart of the excluded patients

Materials and methods

A total of 280 consecutive patients that had primary ACL reconstruction using hamstring autografts by the same surgeon between 2013 and 2015 were prospectively enrolled. All patients had provided written informed consent for the use of their data and images for research and publishing purposes and the institutional review board approved the study in advance (Clinique de la Sauvegarde, Lyon, France, 2017–48013452 AQD). The inclusion criteria were patients aged over 16 years, full clinical and radiographic evaluation at a minimum of 6 postoperative months, including 'static' and 'dynamic' ATT, tibial slope and pivot-shift test, as well as strict adherence to a progressive nonaggressive rehabilitation protocol. The exclusion criteria were concomitant extra-articular tenodesis (modified Lemaire) ($n=24$), surgical antecedents on the contralateral knee ($n=27$), concomitant/prior osteotomies ($n=7$) or concomitant ligament tears on the ipsilateral knee ($n=34$), and history of ACL tears in the contralateral knee ($n=45$). Among the remaining 143 patients, 18 were lost to follow-up, leaving a study cohort of 125 patients evaluated at 6.9 ± 0.4 months (range 6.1–8.2) (Fig. 1).

Preoperative assessment

Anteroposterior knee laxity was assessed using 'static' and 'dynamic' measurements of anterior tibial translation (ATT) on 'true lateral view' radiographs, superimposing the posterior femoral condyles. The ATT was defined as the distance between two parallel lines and the posterior tibial cortex: the first tangent to the posterior aspect of the medial tibial plateau, and the second tangent to the posterior femoral condyles [11, 13]. Static ATT was measured on monopodal weight-bearing radiographs with the knee flexed by 20°. Dynamic ATT was measured using the Telos™ stress radiography device (Metax, Hungen, Germany) with a constant anterior force of 150N, and the side-to-side difference (SSD) between the injured knee and healthy knee was calculated. Rotational laxity was assessed using the pivot shit test (PST), by applying an anterior force to the tibia in internal rotation, while flexing the knee from full extension [16, 24]. The results were recorded, following the criteria of the International Knee Documentation Committee (IKDC), as none (0), glide (+1), clunk (+2), or gross (+3) [34]. The PST was considered of "high-grade" if it indicated clunk or gross pivot shift. The posterior tibial slope was also measured on 'true lateral view' radiographs, by calculating the angle between the perpendicular to the tibial diaphysis, and the tangent to the anterior and posterior edges of the medial tibial plateau [11, 13]. Meniscal and ligamentous tears were assessed on magnetic resonance images (MRI), acquired using a 1.5T magnet, using dual turbo spin echo or fast spin echo T1-weighted sagittal views.

Surgical technique and perioperative assessment

All operations were performed under general anesthesia with a tourniquet placed high on the thigh. The graft was harvested from the hamstrings to form a four-strand configuration using the gracilis and semitendinosus, which were left attached at their tibial insertions then doubled and sutured together to achieve appropriate length and thickness for the size of the patient. Meniscal tears and ligament status were further confirmed arthroscopically, by direct vision and palpation with a probe, at the time of ACL reconstruction. Medial meniscal tears were present in 47 knees (38%), and lateral meniscal tears were present in 39 knees (31%), of which 17 were bicompartmental (14%). The medial meniscal tears comprised 31 ramp tears, 9 degenerative tears, 4 radial tears without extension to the meniscal wall, and 3 bucket handle tears. The lateral meniscal tears comprised 17 longitudinal tears, 11 radial tears without extension to the meniscal wall, 6 degenerative tears, 4 root tears, and 1 bucket handle tear. ACL status was described as either 'complete tear' or 'partial tear', in which at least one bundle was still functional [12]. Meniscal treatments were performed when necessary, either by suture repair (Fast-Fix 360, Smith&Nephew, Memphis, TN) in stable lesions in red–red or red–white zones or by partial meniscectomy in unstable lesions or in white–white zone. The femoral tunnel preparation was performed using an outside-in guide for femoral tunnel placement. For the tibial tunnel, a standard 60° angulation guide was used. The graft was passed from the tibia to the femur and fixed with Ligafix interference screws (SBM, Lourdes, France), of 30% TCP on the femoral tunnel and of 60% TCP on the tibial tunnel.

Postoperative rehabilitation

Progressive nonaggressive rehabilitation was engaged immediately after surgery, avoiding hyperextension but with no restriction to flexion. Partial weight-bearing (50% body weight) was allowed during the first 3 postoperative weeks, and progressive full weight-bearing was allowed between 3 and 6 weeks. The rehabilitation protocol was identical for all patients, whether they had no meniscal treatment, meniscal repair, or menisectomy. Cycling and swimming were allowed after 6 weeks, and return to sports began at 6–8 months, depending on results of functional and isokinetic tests done at 4 and 6 months.

Postoperative assessment

The patients underwent clinical examination after 6–8 months, during which the authors recorded static ATT, measured on monopodal weight-bearing radiographs, and dynamic ATT measured on stress radiographs (SSD) using the Telos™ device.

Statistical analysis

Descriptive statistics were used to summarize the data. Shapiro–Wilk tests were used to assess the normality of distributions. For non-Gaussian quantitative data, differences between groups were evaluated using the Wilcoxon rank-sum test (Mann–Whitney U test). For non-Gaussian categorical data, differences between groups were evaluated using Fisher's exact test. Uni- and multivariable linear regression analyses were performed to determine significant associations of static and dynamic postoperative ATT with demographic and anatomic factors (gender, age, BMI, tibial slope, preoperative ATT, type of tear, preoperative PST, medial and/or lateral meniscal treatments). Due to high collinearity between preoperative ATT and postoperative ATT, the multivariable regression models were built excluding preoperative ATT, followed by backward selection of pertinent variables using the criterion $p<0.10$. With a sample size of 125, the regression models were deemed sufficiently powered, considering the recommendations of Austin and Steyerberg [4] of 10 Subject Per Variable (SPV). Statistical analyses were performed using R version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria). P values < 0.05 were considered statistically significant.

Results

The cohort of 125 patients comprised 80 men (64%) and 45 women (36%), aged 31.8 ± 10.8 years (range 16.3–61.9), with body mass index (BMI) of 23.8 ± 3.4 kg/m^2 (range 16.0–35.0) (Table 1). The ACL tears were partial in 34 knees (27%) and complete in 91 knees (73%). The average tibial slope was 9.6° ± 2.5° (range 3°−16°). The medial meniscal tears were sutured in 31 knees (25%),

Table 1 Patient demographics and surgical data ($n=125$)

	Mean ± SD	Cohort (range)
Age (years)	31.8 ± 10.8	(16.3–61.9)
Men	80 (64%)	
BMI (kg/m^2)	23.8 ± 3.4	(16.0–35.0)
Tibial slope (°)	9.6 ± 2.5	(3.0–16.0)
Type of tear		
Partial	34 (27%)	
Complete	91 (73%)	
Pivot-shift test		
Glide	103 (82%)	
Clunk/severe	22 (18%)	
Meniscal tear		
None	56 (45%)	
Isolated medial	30 (24%)	
Isolated lateral	22 (18%)	
Bicompartmental	17 (14%)	
Medial meniscal treatment		
None	80 (64%)	
Meniscal repair	31 (25%)	
Partial meniscectomy	14 (11%)	
Lateral meniscal treatment		
None	90 (72%)	
Meniscal repair	16 (13%)	
Partial meniscectomy	19 (15%)	

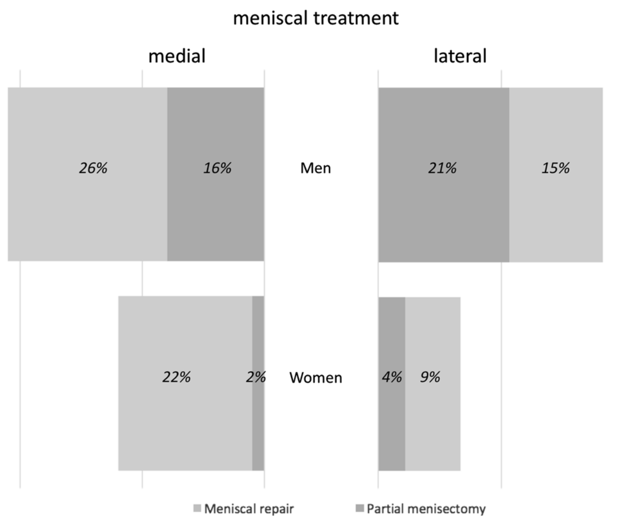

Fig. 2 Bar chart showing meniscal treatment regrouped by gender

Table 2 Knee laxity measurements ($n=125$)

	Mean ± SD	(Range)
Static ATT		
Preoperative	2.5 ± 2.9	(− 4.9 to 9.0)
Postoperative	2.3 ± 3.3	(− 4.6 to 17.8)
Net change[a]	− 0.2 ± 2.7	(− 5.5 to 10.4)
Dynamic ATT		
Preoperative	5.7 ± 3.8	(5.7–16.3)
Postoperative	2.7 ± 3.3	(− 6.0 to 10.4)
Net change[a]	− 2.9 ± 3.3	(− 11.0 to 5.0)

ATT anterior tibial translation

[a]Negative values indicate reduction in laxity

treated by partial menisectomy in 14 knees (11%), and left in place in two knees (2%). The lateral meniscal tears were sutured in 16 knees (13%), treated by partial menisectomy in 19 knees (15%), and left in place in 4 knees (3%). Compared to women, men had more partial meniscectomies on both the medial (2% vs 16%) and the lateral (4% vs 21%) menisci (Fig. 2).

The static ATT, measured on monopodal weight-bearing radiographs, was 2.5 ± 2.9 mm preoperatively and 2.3 ± 3.3 mm postoperatively (Table 2). Univariable regression showed that postoperative static ATT significantly increased with tibial slope ($p=0.011$), in knees with complete ACL tears ($p=0.041$) and those that had partial medial meniscectomy ($p=0.011$) (Table 3). In addition, postoperative static ATT was strongly associated with preoperative static ATT ($\beta=0.068$; $p<0.001$). Multivariable regression confirmed that postoperative static ATT significantly increased with tibial slope ($\beta=0.24$; CI 0.01–0.47; $p=0.042$) and in knees that had partial medial meniscectomy ($\beta=2.05$; CI 0.25–3.84; $p=0.025$).

The dynamic ATT, measured on stress radiographs (SSD) using the Telos™ device, was reduced from 5.7 ± 3.8 mm preoperatively to 2.7 ± 3.3 mm postoperatively (Table 2). Univariable regression showed that postoperative dynamic ATT significantly decreased with age ($p<0.001$) and increased with tibial slope ($p=0.032$) (Table 4). In addition, postoperative dynamic ATT was strongly associated with preoperative dynamic ATT ($\beta=0.50$; $p<0.001$). Multivariable regression confirmed that postoperative dynamic ATT significantly decreased with age ($\beta=-0.11$; CI − 0.16 to − 0.05; $p<0.001$), and increased with tibial slope ($\beta=0.27$; CI 0.04–0.49; $p=0.019$) and in knees that had partial medial meniscectomy ($\beta=2.20$; CI 0.35–4.05; $p=0.019$).

Discussion

The main finding of this study is that both static and dynamic ATT following ACL reconstruction increased with tibial slope and in knees that had partial medial meniscectomy, which confirms the authors' hypothesis. It is important to note, however, that ATT was only affected by medial meniscectomy, but not by lateral meniscectomy. Residual laxity was shown to increase the risks of tunnel widening [35], and graft failure [41, 55] and of developing osteoarthritis after ACL reconstruction [31, 39, 44], compromising clinical outcomes [43, 48] and patient satisfaction [23]. Interestingly, the present study found a strong linear relation between preoperative and postoperative ATT, which suggests that outcomes of ACL reconstruction could depend on preoperative laxity, and that high tibial slope and medial meniscectomy are aggravating factors.

In the literature, tibial slope has been reported to increase risks of ACL tear [54, 59] and graft failure [6, 26]. The present findings confirm that high tibial slopes increase postoperative knee laxity, which was also corroborated by recent studies [13, 21, 27], and could explain why knees with higher tibial slope are at greater risk of retear. In fact, multivariable analysis revealed that an increase of 5° in tibial slope could independently exacerbate postoperative static and dynamic ATT by 1.2 mm and 1.4 mm, respectively. It is for this reason that tibial deflexion osteotomy is considered for knees that had repetitive ACL graft ruptures and excessive tibial slopes (> 12°), as a means to protect the revised grafts [1, 14, 46]. A recent study also revealed that steep tibial slopes increase posterior tibial translation [42], so that tibial slope appears to have a global effect on anteroposterior knee laxity.

This study revealed that partial medial meniscectomy increased postoperative static and dynamic ATT by 2.05 mm and 2.20 mm, respectively. Therefore, the

Table 3 Uni- and multivariable regression to identify factor associated with static ATT (weight-bearing radiographs)

	$n=$	Univariable			Multivariable ($n=125$)[b]		
		Regression coefficient[a]	95% CI (range)	p value	Regression coefficient[a]	95% CI (range)	p value
Gender							
Female	45	REF					
Male	80	2.31	(− 1.27 to 1.14)	n.s			
Age	125	− 0.00	(− 0.06 to 0.05)	n.s			
BMI	125	− 0.09	(− 0.26 to 0.08)	n.s			
Tibial slope (°)	125	0.30	(0.07–0.53)	0.011	0.24	(0.01–0.47)	0.042
Preoperative static ATT	125	0.68	(0.52–0.84)	< 0.001			
Type of tear							
Partial	34	REF			REF		
Complete	91	1.33	(0.06–2.61)	0.041	1.23	(− 0.02 to 2.49)	n.s
Pivot-shift test (preop)							
Glide	103	REF					
Clunk/gross	22	1.20	(− 0.31 to 2.70)	n.s			
Medial meniscal treatment							
None	80	REF			REF		
Meniscal repair	31	− 0.32	(− 1.65 to 1.02)	n.s	− 0.29	(− 1.63 to 1.04)	n.s
Partial menisectomy	14	2.39	(0.56–4.21)	0.011	2.05	(0.25–3.84)	0.025
Lateral meniscal treatment							
None	90	REF					
Meniscal repair	16	0.62	(− 1.13 to 2.36)	n.s			
Partial menisectomy	19	1.31	(− 0.32 to 2.93)	n.s			

[a]Expected difference

[b]Backward selection was performed with criterion $p=0.10$

integrity of the medial meniscus appears to be important for anteroposterior knee stability after ACL reconstruction. This is in agreement with several authors [8, 9, 22] who report worse outcomes for patients who underwent medial meniscectomy. Meniscectomy is generally reported to affect knee stability and pain, as well as causing arthritic evolution [51, 57] and to lead to decreased outcomes after ACL reconstruction [52]. The role of the menisci in limiting ATT could also be explained considering their formation of a 'soft tissue slope', which increase coverage and reduce the bony slope [30]. The medial meniscus was shown to contribute to rotational knee stability in cadaveric [37] and clinical [47] studies, which emphasized that posteromedial meniscocapsular tears increase external and internal rotation of the tibia [47]. In this study, lateral meniscectomy did not affect postoperative ATT; this could be explained considering the role of the lateral meniscus in rotational knee stability [19, 45], which were not considered. Taken together, these results confirm that meniscal repair should be preferred over meniscectomy whenever possible [9, 13, 22, 57], and to consider rapid surgical repair of the ACL before the advent or deterioration of meniscal tears altogether [3, 33].

Age was found in this study to have a protective effect on postoperative ATT after ACL reconstruction. This can also be understood as a vulnerability of younger patients, who tend to exhibit greater joint laxity than older patients [39]. These findings are supported by studies which found that patients aged 18 or younger have greater risks of ACL retear [17, 39, 56]. However, adolescent patients may also exhibit differences in behavior or sport activity which could also correlate with increased risks of graft failure. Nevertheless, this group ought to be considered at risk when planning postoperative rehabilitation protocols. Finally, this study revealed an interesting but insignificant trend, that postoperative laxity may differ among men and women, which could be due to different incidences of medial meniscal tears and subsequent menisectomy (16% vs 2%) (Fig. 2) [40].

This study has several limitations. First, due to small sub-group sizes, the effects of type and location of meniscal tears, which may affect knee laxity in different ways, were not analyzed. Second, the mechanism of injury or the type of sport practiced at the time of injury was not considered, though this may be irrelevant when the type of ACL or meniscal tear is known. Third, while preoperative MRI were used to assess the extent of tear and presence of meniscal

Table 4 Uni- and multivariable regression to identify factors associated with dynamic ATT (SSD using stress radiographs)

	$n =$	Univariable			Multivariable ($n = 125$)[b]		
		Regression coefficient[a]	95% CI (range)	p value	Regression coefficient[a]	95% CI (range)	p value
Gender							
Female	45	Ref			Ref		
Male	80	− 0.91	(− 2.13 to 0.31)	n.s	− 1.09	(− 2.25 to 0.06)	n.s
Age	125	− 0.10	(− 1.48 to − 0.04)	< 0.001	− 0.11	(− 0.16 to − 0.05)	< 0.001
BMI	125	− 0.09	(− 0.26 to 0.09)	n.s			
Tibial slope (°)	125	0.32	(0.08–0.55)	0.008	0.27	(0.04–0.49)	0.019
Preoperative dynamic ATT	125	0.50	(0.37–0.63)	< 0.001			
Type of tear							
Partial	34	REF					
Complete	91	0.70	(− 0.62 to 2.02)	n.s			
Pivot-shift test (preop)							
Glide	103	REF					
Clunk/gross	22	0.97	(− 0.57 to 2.52)	n.s			
Medial meniscal treatment							
None	80	Ref			Ref		
Meniscal repair	31	− 0.06	(− 1.45 to 1.33)	n.s	0.82	(− 0.50 to 2.14)	n.s
Partial menisectomy	14	1.26	(− 0.64 to 3.17)	n.s	2.20	(0.35–4.05)	0.019
Lateral meniscal treatment							
None	90	REF					
Meniscal repair	16	0.50	(− 1.30 to 2.29)	n.s			
Partial menisectomy	19	0.13	(− 1.55 to 1.80)	n.s			

[a]Expected difference

[b]Backward selection was performed with criterion $p = 0.10$

tears, the tibial slope measurements were based solely on sagittal radiographs, which are quicker to obtain but do not permit measurement of lateral tibial slope. Fourth, while this study considered objective measurements of ATT, it used a subjective assessment of rotational laxity (the PST) instead of more objective instruments [49]. Last, the study lacks clinical scores to determine correlations between ATT and functional or subjective stability, and therefore cannot ascertain whether increased ATT has any adverse effects in the long term.

Due to the small size of the cohort, no positive residual pivot shift was observed so that the present study could not address factors leading to residual pivot shift after ACL reconstruction. Although a recent study did investigate risk factors for residual pivot shift after ACL reconstruction, they failed to consider potential effects of the tibial slope [53]. Nevertheless, this study has several strengths. First, all patients were operated by one surgeon, using the same surgical technique, the same graft type and the same rehabilitation protocol, thus reducing heterogeneity of treatment techniques. Moreover, postoperative knee stability is assessed only for the anteroposterior axis, an important element of knee stability during gait, using objective and easily accessible data and measurements. Finally, the study identified factors that could increase the risks of failure of ACL reconstruction and could guide surgeons when planning surgical or rehabilitation procedures. For example, patellar tendon grafts were recently shown to be associated with fewer graft failures than hamstring grafts [25] and could be indicated for patients at risk. These patients could also benefit from personalized rehabilitation procedures such as delayed weight-bearing or return to impact activities, although qualitative studies are still needed to assess potential benefits of more progressive rehabilitation protocols [60]. In the light of these findings, the authors no longer prescribe the same rehabilitation protocol to all patients, but instead delay partial weight-bearing for patients that had preoperative ATT > 5 mm, whether associated with high tibial slope, meniscal lesions, or inherent hyperlaxity, to secure early incorporation and prevent elongation of the graft.

Conclusion

The anterior laxity observed in some knees following ACL reconstruction could be attributed to graft elongation due to excessive tibial slope and/or meniscal deficiency. Surgeons should personalize their operative techniques and rehabilitation protocols—conserving the menisci if possible and delaying weight-bearing and return to sport if necessary—to prevent graft failures in patients with risk factors.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of our institutional research committee.

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