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Influence of hamstring stiffness on anterior tibial translation after anterior cruciate ligament rupture

Djaffar Mouhli ^a, Théo Cojean ^{b,*}, Sébastien Lustig ^{a,b}, Elvire Servien ^{a,c}

^a Département de Chirurgie Orthopédique et de Médecine du Sport, FIFA Medical Center of Excellence, Hôpital de la Croix Rouse, Centre Hospitalo-Universitaire de Lyon, France

^b Univ Lyon, Univ Gustave Eiffel, Univ Claude Bernard Lyon 1, LBMC UMR_T 9406, F-69622 Lyon, France

^c LIBM – EA 7424, Laboratoire interuniversitaire de la Biologie du Mouvement, Université Claude Bernard Lyon 1, Lyon, France



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ABSTRACT

Background: There is a correlation between the hamstring stiffness and the decrease of anterior tibial translation in athletic patients with healthy knees. This observation could question the clinical reliability of the Lachman-Trillat test to detect complete ACL ruptures in patients with an important hamstring stiffness. This study aims to determine if anterior tibial translation is correlated with hamstring stiffness in patients with complete ACL rupture.

Methods: This is a prospective study including patients with unilateral complete ACL rupture confirmed by MRI. The arthrometer GNRB[®] was used to measure anterior tibial translation on both knees at 134 N and compute the side-to-side difference. The hamstring stiffness was assessed with the eccentric peak torque using the isokinetic dynamometer CON-TREX. Linear regressions were done between these two parameters on two study groups: one included all patients (GR1), and the other included only isolated ACL injuries without associated lesions (GR2).

Results: Fifty-two patients were included (29 men, 23 women) with an average of 34.9 years old. The mean eccentric peak torque of the hamstrings for pathological knees was 94.9Nm for GR1 and 91.7Nm for GR2. The mean side-to-side difference was 2.42 mm for GR1 and 1.99 mm for GR2. No significant correlations were identified for GR1 ($p = 0.66$) and GR2 ($p = 0.105$).

Conclusion: No significant linear correlation was found between side-to-side difference measured by GNRB[®] and hamstring stiffness for pathological knees with complete ACL rupture. These results lead to believe that the Lachman-Trillat clinical test is not influenced by hamstring stiffness.

Level of evidence: Prospective study, level of evidence IV.

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1. Introduction

The function of the anterior cruciate ligament (ACL) is to prevent anterior tibial translation (ATT) as well as providing tibial internal rotational stability [1]. Each year, nearly 3% of amateur athletes suffer an ACL injury. In high performance

* Corresponding author at: Laboratoire de Biomécanique et Mécanique des Chocs, 25 Avenue François Mitterrand, 69500 Bron, France.
E-mail address: theo.cojean@etu.univ-lyon1.fr (T. Cojean).

athletes, this percentage can reach 15% [2]. The overall incidence rate of ACL rupture in athletes is 1.5 per 10,000 [3]. This risk varies according to age, sex and the type of sports practiced [3–8].

Clinically, ACL injuries are detected with an excessive ATT on patient during muscle relaxation. The Lachman-Trillat is the most commonly used clinical test and presents high performances with a sensitivity of 85% and a specificity of 94% [9]. The patient is lying on an examination table with the leg at 20°–30° knee flexion. The examiner places one hand behind the tibia and the other on the patient's thigh in order to create a translational movement by pulling the tibia anteriorly. Magnetic Resonance Imaging (MRI) is often used as a complementary exam to confirm a diagnostic with a sensitivity of 87% and a specificity of 93% [10]. In 2008, the design of an automated arthrometer, the GNRB[®],¹ allowed to quantify objectively ATT with increasing thrust forces applied on the upper section of the calf. Thus, according to Klouche et al., a complete ACL tear can be confirmed with a sensitivity of 92.2% and a specificity of 96.3% if the side-to-side difference (SSD) of laxity at 134 Newtons (N) between both knees is superior to 1.5 mm [11]. Several other studies have validated the interest of using the GNRB[®] as a diagnostic aid for ACL tears detection [12–15].

Isokinetic has also become essential in the management of these ligament injuries [16,17]. It is possible with this technique to identify and assess muscle ratios between hamstrings and quadriceps in order to improve the rehabilitation work [18–20]. Some meta-analyses, such as the one of Hewett et al., showed the primary role of the hamstring muscles in knee stability and the control of ATT [21–24]. Stiffness is defined as the ratio between the change in force and change in length. With a constant given forward force on the tibia, an anterior drawer is created, inversely proportional to the knee stiffness. As the hamstring belongs to the knee flexor group, the stiffer it is, the more it will prevent tibial translation. Simulated hamstring force reduces ATT, ACL strain and ACL loading [25]. Thus, during a Lachman-Trillat test, all these structures are stressed. However, only few studies analysed the influence of hamstrings at rest on ATT. Blackburn et al. in 2011 were interested to this question and found a correlation between the hamstring stiffness and the reduction of the ATT on athletes with healthy knees [25]. Thus, this study questions the clinical reliability of the Lachman-Trillat test and the higher rate of false negatives in subjects with an important hamstring stiffness.

The main objective of this study is to highlight on pathological patients with a complete ACL tear a linear correlation between the hamstring stiffness of the injured knee assessed with the eccentric peak torque (PT) using the isokinetic dynamometer CON-TREX, and the SSD of laxity at rest measured with the GNRB[®].

Our hypothesis is that SSD at rest between the healthy and the pathological knee is getting lower when the hamstring stiffness is high.

2. Method

2.1. Participants

It is a prospective and single-center study. All participants were informed of the use of their data for experimental purposes. The Scientific and Ethical Committee of the Hospices Civils de Lyon (France) approved the realization of this study on February 04, 2021 (N° 21_332) and a declaration of conformity MR-004 was obtained from the Commission Nationale Informatique et Liberté (CNIL) (N°21_5332).

Data collection was performed between May 2020 and April 2021. Inclusion criteria were as follows: consulted for an acute or chronic ACL tear diagnosed clinically by a senior physician in the department (sports medicine physician or orthopaedic surgeon) and confirmed by MRI. Patients with homolateral ACL rupture (graft rupture) could be included as the contralateral knee remained healthy. 56% of the database reports associated meniscal injuries and 17% associated ligament injuries. According to several studies, meniscal injuries associated with ACL injuries range from 16% to 82% for acute injuries, and can go up to 96% for chronic ligament tears [26–29]. Considering that in most cases, meniscal injuries are highly prevalent in conjunction with ACL injuries, all these patients were included. Exclusion criteria were: patients with a partial rupture, a bilateral rupture, who have already undergone a ligamentoplasty on the contralateral knee and lack of patient consent.

2.2. Method and protocol

Two study groups were created: the first group included all patients, without differentiate associated injuries in order to reflect the clinical reality (GR1). It is demonstrated in literature that meniscus tears could increase ATT [26,29–31]. A second group included only isolated ACL tears to overcome this bias (GR2).

The protocol was exactly the same for all included patients. GNRB[®] tests performed before isokinetic tests in order to not increase the ATT resulting from hamstring or quadriceps muscle fatigue [32,33]. When both tests could not be performed the same day, a 30-day period was acceptable between the tests.

The automated device GNRB[®] was used to measure the laxity of anteroposterior tibial translation at 20° knee flexion, reproducing the Lachman test position. The device used for this study did not have the “Biodeefback” option, able to detect

¹ Genourob[®], Bâtiment 60, Rue du Chef de Bataillon Henri Gêret, 53,000 Laval – France.

muscle contraction of hamstrings. Before each test, a palpation of the knee joint was performed to identify properly the lower limit of the patella and then place accurately the different supports on the leg (Figure 1).

Measurements were performed first on the healthy knee to allow the patient to become familiar with the device and sensations. A posteroanterior force calibrated at 134 N was applied on the upper part of the calf to allow tibial translations. The same procedure was then performed on the pathological limb. The patellar clamping force was measured for the healthy and pathological sides. At the start of each measurement, patients were asked to relax as much as possible and not to voluntarily contract the hamstring or quadriceps muscles. If the patient felt pain during the measurements, results were excluded. When the ATT measurements were performed for both knees, the SSD at 134 N was calculated and expressed in millimeters.

Isokinetic tests were carried out using a CON-TREX[®] isokinetic dynamometer, where Maffiuletti et al. demonstrated a good reliability and reproducibility [34]. The analysis software “Human Kinetics 1.7.5 Filter V 1.7.3” was used to record all force data. All knee flexion and extension movements were between -15° and -100° from the horizontal. The procedure was standardized: first, familiarization and warm-up on the isokinetic machine by performing ten concentric/concentric movements at an angular velocity of $240^\circ/s$ followed by ten concentric/concentric movements at an angular velocity of $60^\circ/s$. A test always started with the healthy limb. After, data were recorded on three concentric/concentric repetitions at $60^\circ/s$ angular velocity, followed by three concentric/concentric repetitions at $240^\circ/s$ angular velocity and finally two eccentric/passive repetitions at $30^\circ/s$ angular velocity. During the different sets, we used verbal stimuli to encourage the patient to produce maximum effort. A rest period of 30 seconds was allowed between each set. Two parameters were used: the first was the maximal eccentric PT of the hamstrings of the pathological lower limb at an angular speed of $30^\circ/s$. This value is used to estimate the hamstring stiffness according to Pousson et al.[35]. The second parameter is the mixed ratio

$\frac{\text{Maximal hamstring PT in eccentric at } 30^\circ/s}{\text{Maximal quadriceps PT in concentric at } 240^\circ/s}$ defined by Croisier et al. [36].

2.3. Statistics

A linear regression was performed on both groups between the SSD at 134 N measured by the GNRB[®] and the maximal PT of the hamstring in eccentric at $30^\circ/s$ of the pathological lower limb. The correlation coefficient Pearson was computed for GR1. As the sample size for GR2 was too small, the correlation coefficient Spearman was used.

Several studies suggested that the difference of the patella tightening between both knees of a patient and the mixed ratio hamstring/quadriceps of the lower pathological limb could directly impact ATT measurements [36,37]. That is why a second linear regression including these two variables was done. This was possible only for GR1 because of the sample size. The remaining potential adjustment variables were entered into a penalized Least Absolute Shrinkage and Selection Operation (LASSO) regression model. The penalty coefficient (lambda) was chosen to provide an estimation error less than one standard deviation from the minimum error obtained by 10-fold cross-validation, while being as parsimonious as possible. No variable had a coefficient other than 0 with this lambda coefficient. The remaining potential adjustment variables were entered into a penalized Least Absolute Shrinkage and Selection Operation (LASSO) regression model. The penalty coefficient (lambda) was chosen to provide an estimation error less than one standard deviation from the minimum error obtained by cross-validation 10 times, while being as parsimonious as possible. No variable had a coefficient other than 0 with this lambda coefficient.

For all statistical analyses, significance was accepted at $p < 0.05$. All statistical analyses were performed with the open access software pvalue.io based on R software.

2.4. Management of missing data

No variable entered in the model had more than 20% missing data. For variables with less than 5% missing data, imputation method with median was used for quantitative variables, and by the mode for qualitative variables.

3. Results

Fifty-two patients (twenty-nine males and twenty-three females) with unilateral complete ACL rupture were included in this study. All patient characteristics are summarized in Table 1. The patients ranged in age from 15 to 60 years with an average age of 34.9 years. Most of the patients were amateur athletes. Soccer and skiing were the most represented sports. Twenty-nine patients had at least one associated meniscal lesion, including two with a posteromedial meniscal ramp lesion. Nine patients had a moderate sprain (maximum grade 2 on MRI) of the medial collateral ligament. Seven patients reported a history of homolateral ACL rupture, operated or not, and five patients had associated bone oedema.

Only two patients did not perform both tests on the same day (14 and 28 days delay). The minimum delay between the ACL rupture and the GNRB[®] tests was 45 days, the average was 148 days. The different parameters of the two tests are summarized in Table 2 for both groups. No significant differences were found between GR1 and GR2 for the patellar tightening delta ($p = 0.58$), the maximal eccentric PT ($p = 0.45$), the mixed ratio ($p = 0.32$) and the SSD at 134 N ($p = 0.69$).

With an alpha risk of 5%, no significant linear correlation was found between the SSD of laxity measured with the GNRB[®] and the maximal eccentric PT of the hamstring of the pathological lower limb for GR1. It exists a poor correlation which is not significant for GR2 where the ATT increases with the maximal eccentric PT (Table 3 and Figure 2).



Figure 1. Patient position for GNRB® laxity measurements.

The second adjusted analysis considers the absolute value of the patellar tightening difference between the two knees and the mixed ratio of the pathological lower limb. It was performed only on GR1 and presented no statistically significant linear correlation at the 5% risk (Table 4).

4. Discussion

The most important finding of this study is that no linear correlation was found between the SSD of laxity at 134 N measured with the GNRB® and the maximal eccentric PT of the hamstring measured with the isokinetic dynamometer CON-TREX in patients with unilateral ACL rupture. The hypothesis is then not confirmed.

To our knowledge, this is the first study which evaluates the impact of hamstring torque on TTA in patients with ACL rupture. With this measurement, hamstring stiffness could be approximated using the method described in the work of Pousson

Table 1
Characteristics of the included population.

Age	Mean (standard deviation)	Median [Q25-75]	Min	Max	n
	34.9 (12.3)	33.5 [25.5; 44.2]	15.0	60.0	52
Sex			n (%)		
	Male		29 (56%)		
	Female		23 (44%)		
Main sport practiced					
	Football		16 (31%)		
	Ski		13 (25%)		
	Other sports		6 (12%)		
	Running		6 (12%)		
	None		5 (9.6%)		
	Bike		3 (5.6%)		
	Rugby		2 (3.8%)		
	Judo		1 (1.9%)		
Reported orthopaedic history					
	None		43 (83%)		
	Iterative homolateral ACL rupture		7 (13%)		
	Partial Meniscectomy		1 (1.9%)		
	Internal meniscal suture		1 (1.9%)		
Side of the ACL rupture					
	Right		26 (50%)		
	Left		26 (50%)		
Associated meniscus lesions					
	No		23 (44%)		
	Internal meniscus		16 (31%)		
	External meniscus		6 (12%)		
	Internal and external meniscus		4 (7.7%)		
	« RAMP lesion »		2 (3.8%)		
	Bucket handle		1 (1.9%)		
Associated ligament lesions					
	No		43 (83%)		
	Medial collateral ligament		9 (17%)		
Associated oedema					
	No		47 (90%)		
	Yes		5 (9.6%)		

Table 2
GNRB[®] and isokinetic results.

Group	Parameter	Mean (standard deviation)	Median [Q25-75]	Min	Max	n
GR1	Maximal eccentric PT at 30°/s of the PH (Nm)	94.8 (39.3)	87.5 [68.5; 114]	19.0	223	52
	Mixed ratio of the PLL	1.43 (0.713)	1.25 [1.06; 1.54]	0.654	5.20	51
	Absolute value of tightening difference (N)	5.4 (5.00)	4.00 [2.00; 7.25]	1.00	25.0	52
	SSD of laxity at 134 N (mm)	2.42 (1.84)	2.30 [1.15; 3.23]	0.600	7.40	52
GR2	Maximal eccentric PT at 30°/s of the PH (Nm)	91.7 (37.1)	85.0 [68.0; 108]	17.0	173	23
	Mixed ratio of the PLL	1.49 (0.572)	1.37 [1.15; 1.78]	0.654	3.14	22
	Absolute value of tightening difference (N)	4.83 (3.33)	4.00 [2.00; 6.50]	1.00	12.0	23
	SSD of laxity at 134 N (mm)	1.99 (1.50)	1.70 [1.00; 2.45]	0.200	6.10	23

GR1: All patients with associated injuries, GR2: Patients with isolated ACL tears, PT: Peak Torque, PH: Pathological Hamstring, PLL: Pathological Lower Limb, SSD: Side-to-Side Difference (Pathological – Healthy), N: Newton, Nm: Newton-meter.

et al. [35]. They were the first to demonstrate an increase in muscle stiffness after six weeks of eccentric training of the arm flexor muscles. In their study, they showed that eccentric muscle work decreased muscle compliance and increased active muscle stiffness. Some authors have questioned this measurement technique [38,39]. In the study of Blackburn et al., the

Table 3
Correlation between the SSD of laxity and the maximal eccentric PT of the hamstring of the pathological lower limb.

Group	Correlation coefficient [IC 95%]	n	p	Test
GR1	0.0633 [-0.213; 0.331]	52	0.66	Pearson
GR2	0.207 [-0.159; 0.486]	23	0.105	Spearman

GR1: All patients with associated injuries, GR2: Patients with isolated ACL tears.

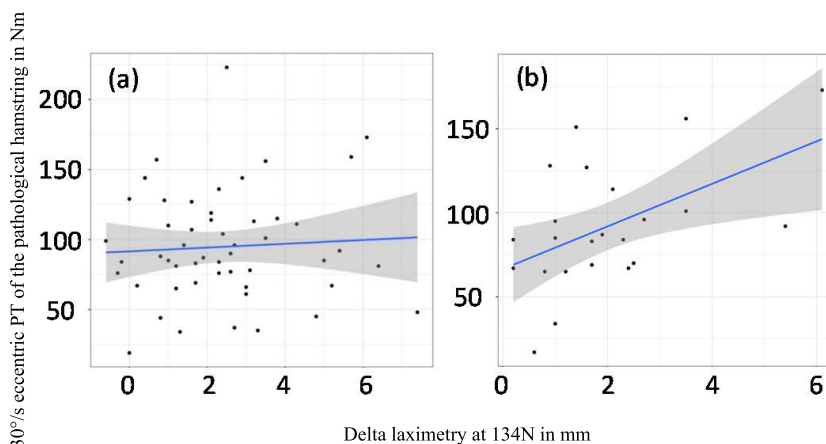


Figure 2. Curves showing correlation between ATT side to side difference and pathological hamstring eccentric PT for GR1 (a) and GR2 (b).

Table 4

Correlation between the SSD of laxity and the maximal eccentric PT of the hamstring of the pathological lower limb adjusted with the difference of the patellar tightening and the mixed ratio.

Group	Correlation coefficient [IC 95%]	n	p	Test
GR1	0.0329 [-0.103; 0.168]	52	0.63	Pearson

GR1: All patients with associated injuries.

measurement of hamstring stiffness was performed using the “damped oscillation” [25]. This method is more accurate but not very accessible in the current practice. This is why we thought it would be more appropriate to evaluate stiffness using the eccentric muscle torque.

Stiffness corresponds to the resistance of a muscle to its own elongation [40]. This muscular stiffness varies and can be modified chronically by training its muscular strength in isometric, isotonic and plyometric modes. Thus, changes in muscle stiffness of the order of 29–71% have been demonstrated after this type of training [39,41]. According to Howell et al., even a single session of eccentric exercise is sufficient to observe an increase in musculo-articular stiffness [42].

Particular attention was paid to the value of patellar tightening when performing GNRB® tests. Alqahtani et al. showed that a difference in patellar tightening between the two knees of a patient greater than 11 N induced a significant difference in ATT [37]. In our study, the average patellar tightening delta was only 5.4 N. The mixed hamstring/quadriceps ratio defined by Croisier et al. was also incorporated into our analyses to limit the bias of an overly strong quadriceps compared to the hamstring muscle.

The mean SSD of laxity measured with the GNRB® in our study was 2.42 mm. This result confirms the work done by Klouche et al., who stated that a diagnosis of ACL rupture can be made beyond a differential of 1.5 mm at 134 N [11]. Thus, the sensitivity of the GNRB® in the diagnosis of an ACL rupture does not seem to be influenced by hamstring stiffness.

A limitation of this study is the bias that could be induced by involuntary hamstring contraction during GNRB® measurements. The work of Barcellona et al. had already shown in 2014 that in patients with an ACL rupture, initial hamstring muscle activity had a greater effect on reducing anterior tibial translation compared with patients with a healthy knee [43]. Dale et al. confirmed these results and observed that the large number of false negatives in the KT-1000 measurements was largely attributed to involuntary contraction of the hamstring [44]. We can therefore reasonably transpose these results to the automated dynamic arthrometer GNRB®, especially since the device used in our study was not equipped with the “Biofeedback” option for detecting hamstring muscle contractions.

Two study groups were created to provide different approaches. GR1 included all patients to obtain results to better capture the clinical reality with the use of the Lachman-Trillat test, providing more holistic approach with the frequent associations between ACL and meniscal injuries, and offering a more comprehensive perspective. GR2 included only isolated ACL tears to assess specifically the relationship between the hamstring stiffness and the ATT independently of other factors. Indeed, referring to the literature, meniscal injuries increase ATT, especially medial meniscus injuries such as longitudinal tears or ramp lesions [26,29–31]. However, the sample size was a limitation for GR2. A poor correlation could be observed but it was not significant. In light of the foregoing, it implies that our study lacks the statistical power necessary to draw definitive conclusions regarding the correlation between isolated ACL tears and hamstring stiffness. It would be interesting to conduct a new study with a larger number of patients and thus create several distinct groups.

The study of Barcellona et al. demonstrated a logarithmic relation between voluntary contraction at different levels of hamstring muscle strength and the measurement of anterior tibial laxity by KT-2000 device at 133 N [43]. It is therefore possible that we did not find a significant correlation because it was not linear in nature.

5. Conclusions

In patients with a complete ACL rupture, there was no linear correlation between the anterior tibial laxity differential measured with the GNRB[®] at 134 N and the maximal eccentric peak torque of the hamstring of the pathological lower limb. These results lead us to believe that the Lachman-Trillat clinical test is not influenced by hamstring stiffness, but should prompt a new study allowing the control of hamstring contraction using a GNRB[®] device equipped with the “Biofeedback” option with a larger number of patients.

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CRedit authorship contribution statement

Djaffar Mouhli: Data curation, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Théo Cojean:** Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sébastien Lustig:** Supervision, Validation, Resources. **Elvire Servien:** Resources, Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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