




# Lateral meniscal slope negatively affects post-operative anterior tibial translation at 1 year after primary anterior cruciate ligament reconstruction

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## Abstract

**Purpose** The aim of this study was to assess the correlation between posterior tibial slope and meniscal slope over postoperative anterior tibial translation during the first 18 months after primary anterior cruciate ligament (ACL) reconstruction. The main hypothesis was that PTS and MS would be positively correlated with post-operative ATT-SSD after ACL reconstruction.

**Methods** Patients (28 males and 15 females) with confirmed ACL tears were selected from an in-house registry and included if they were over 16 years old, had primary ACL-reconstruction and healthy contralateral knee. Patients meeting one of the following criteria were excluded: previous knee surgeries, intraarticular fractures, associated ligamentous lesions, previous or concomitant meniscectomy or extraarticular procedures. Lateral posterior tibial slope, medial posterior tibial slope, lateral meniscal slope and medial meniscal slope were measured using preoperative MRIs. The side-to-side-difference in anterior tibial translation was evaluated 9–18 months postoperatively.

**Results** Forty-three patients were included, (28 males/15 females; mean age  $25 \pm 8$  years). Mean postoperative anterior tibial translation was  $1.0 \pm 1.1$  mm at a mean time of  $12 \pm 1$  months. Mean slope values were: lateral posterior tibial slope  $4.7^\circ \pm 2.2^\circ$ , medial posterior tibial slope  $4.0^\circ \pm 2.8^\circ$ , lateral meniscal slope  $3.0^\circ \pm 2.2^\circ$  and medial meniscal slope  $2.0^\circ \pm 2.8^\circ$ . The anterior tibial translation was significantly correlated with lateral meniscal slope ( $r=0.63$ ;  $p<0.01$ ). For each  $1^\circ$  increase in lateral meniscal slope, a 0.3 mm 95% CI [0.2, 0.4] ( $p<0.01$ ) increase in anterior tibial translation was observed. A lateral meniscal slope greater or equal to  $4.0^\circ$  was estimated as optimal threshold for increased risk of abnormal side-to-side difference in postoperative anterior tibial translation ( $\geq 1.2$  mm).

**Conclusion** The lateral meniscal slope was positively correlated to side-to-side difference in anterior tibial translation after primary ACL reconstruction. A lateral meniscal slope greater or equal to  $4.0^\circ$  was detected as threshold for an increased risk of abnormal side-to-side difference in postoperative anterior tibial translation in patients who underwent primary ACL reconstruction. This confirms that soft tissue slopes have an impact on the outcomes after reconstructive surgery.

**Level of evidence** III.

**Keywords** ACL reconstruction · Posterior tibial slope · Meniscal slope · Anterior tibial translation · Laxity

## Introduction

Bony and soft tissue slopes of the knee joint have recently been reported to have an impact on the incidence of anterior cruciate ligament (ACL) injuries as well as on the outcomes after reconstructive surgery. A steeper posterior tibial slope

(PTS) has been related to a higher rate of non-contact ACL injuries and an increased failure rate after reconstructive surgery [8, 9, 25]. Both have also been associated with an increased ACL loading stress [1, 6, 19, 29] and a higher anterior tibial translation (ATT) in ACL-injured knees [4].

Aside from the bony geometry of the tibia, the impact of the menisci on both anterior and rotational knee laxity has also been highlighted [20, 24, 33, 34]. The wedge-like shape of the menisci in the sagittal plane, represented by a thicker posterior than anterior horn [2, 13], might influence the effect of the tibial bony slope and thereby affecting the

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ATT [9]. The meniscal slope (MS) has been defined as the angle between the tangential line to the superior meniscosynovial borders and the tibial axis and quantifies the obliquity of the meniscus in relation to the anterior and posterior horn. An increased meniscal slope has been advocated as a risk factor for sustaining non-contact ACL injuries [9, 31]. To the best of our knowledge, the effect of the MS over the post-operative ATT has not been considered in the literature so far. In the first months after ACL reconstruction the graft undergoes a remodeling process [12]. A steeper PTS and/or MS may thus increase loading stress on the graft, affecting graft healing and, therefore, post-operative ATT [4].

The impact of bony and soft tissue slopes of the knee joint on the outcomes after ACL reconstruction is still under investigation. The main purpose of this study was thus to assess the correlation between both PTS and MS (medial and lateral) and post-operative ATT in a group of patients who underwent primary ACL reconstruction with bone–patellar tendon–bone (BPTB) or hamstring (HT) tendons. The main hypothesis was that PTS and MS would be positively correlated with post-operative ATT-SSD after ACL reconstruction. The secondary purpose of the study was to identify a possible slope threshold value that could predict an increased risk of abnormal post-operative ATT-SSD.

## Materials and methods

Between 2011 and 2017, 317 patients who underwent ACL reconstruction were retrospectively screened for eligibility from an in-house registry including patients with confirmed ACL tears using Magnetic Resonance Imaging (MRI) [28]. The study protocol underwent approval by the National Ethics Committee for Research (N°201101/05). All patients signed an informed consent to participate in the study. They were included if they were above 16 years of age, had a primary ACL reconstruction with a single-bundle technique and a healthy contralateral lower limb without musculoskeletal disorders affecting the knee joint. Furthermore, patients were included if the following exams were performed within our institution: pre-operative MRI of the injured knee and anterior knee laxity measurement at a minimum of 9 months and a maximum of 18 months after the ACL reconstructive surgery. Patients were excluded if they met one of the following exclusion criteria: previous knee surgeries, a concomitant posterior cruciate ligament (PCL) lesion, ipsilateral medial and/or lateral collateral ligament lesions, meniscectomy at the time of the surgery, associated extra-articular procedures or intraarticular fractures of the knee.

According to these inclusion–exclusion criteria, 43 patients (28 males and 15 females) were selected. The demographic characteristics of the population and the post-operative ATT-SSD values are presented in Table 1.

**Table 1** Demographic characteristics of the studied population and post-operative ATT-SSD values

|  | Total<br><i>n</i> = 43 |
|--|------------------------|
| Gender, male/female ( <i>n</i> )           | 28/15                  |
| Age at the injury, (years)                 | 25 ± 8                 |
| Injured side, right/left ( <i>n</i> )      | 26/17                  |
| Age at the surgery (years)                 | 26 ± 8                 |
| Mechanism of injury (non-contact/contact)  | 31/12                  |
| Time from the injury (months)              | 4.6 (2.7–9.1)          |
| BMI (kg/m <sup>2</sup> )                   | 23.5 ± 2.7             |
| Lesion to the medial meniscus (Yes/No)     | 19/24                  |
| Lesion to the lateral meniscus (Yes/No)    | 19/24                  |
| Graft (BPTB/DIDT)                          | 22/21                  |
| Post-operative ATT-SSD evaluation (months) | 12 ± 1                 |
| Mean post-operative ATT-SSD (mm)           | 1.0 ± 1.1              |

Normally distributed variable reported as mean ± standard deviation; non-normally distributed data are reported as median (interquartile range)

ATT-SSD anterior tibial translation side-to-side difference, BPTB bone patellar tendon bone, HT hamstring tendons

## Surgical technique

All patients underwent a primary single-bundle ACL reconstruction by the same senior surgeon using a quadrupled HT (21 patients) or a BPTB (22 patients) autograft. During surgery, the knee was evaluated using a standard anterolateral portal to assess the status of the menisci, the articular cartilages and the ACL remnant (partial or total rupture). In all patients, meniscal stability was assessed through probe palpation and the arthroscope was advanced into the posterior compartment using a transnotch approach to assess the presence of ramp lesions. When required and possible, meniscal tears, including ramp lesions, were sutured using an all-inside or out-in technique. Then, the graft harvesting was performed through a 4 cm anteromedial incision or through two 3 cm median incisions if the HT or BPTB were required, respectively [11]. After the notch preparation, the femoral tunnel was drilled through the anteromedial portal, with the knee at 120° of flexion, in the central zone of the original ACL femoral footprint. The tibial tunnel was drilled in the center of the original ACL footprint preserving the stump. The graft was fixed with a biodegradable screw at both tibial and femoral level with the knee at 20° of flexion.

## Data collection

Anamnestic and injury-related data of all ACL injured patients were prospectively collected in the in-house

registry. They included: age, sex, height, weight, previous knee trauma and surgeries and injury mechanism. In patients undergoing ACL reconstruction, intra-operative findings and surgical procedures were systematically recorded by the surgical team, including: type of ACL rupture (partial or complete), PCL and ACL remnant status, meniscal lesions type and localization according to Cooper et al. [3], cartilage defects, their localization and grading according to Outerbridge classification [26], graft type and size, associated intra-articular and extra-articular procedures.

### PTS and MS MRI measurement

All patients underwent a preoperative MRI evaluation. The images were acquired using a 1.5 T MRI scanner (1.5 T Optima MR450w, GE Healthcare©). The PTS and MS slope values were measured for both the lateral and medial compartment according to the “circle method” described by Hudek et al. [9, 10] using Osirix® freeware DICOM viewer ([www.osirix-viewer.com](http://www.osirix-viewer.com)). Measurement accuracy was  $0.1^\circ$ .

To determine the tibial axis, the central sagittal image in T1 sequence including the PCL tibial attachment, the spine eminence, the anterior and posterior tibial cortex in a concave shape, was selected. A circle tangent to the proximal, anterior and posterior border of the tibia was drawn; a second lower one, centered on the circumference of the first one, was drawn tangent to the anterior and posterior tibial cortex. The centres of these circles were connected to determine the tibial sagittal axis, then the line was overimposed in a fixed position (Fig. 1a). In the absence of a well-defined

tibial cortex, the middle of the grey zone was considered as the reference point for the marker's placement.

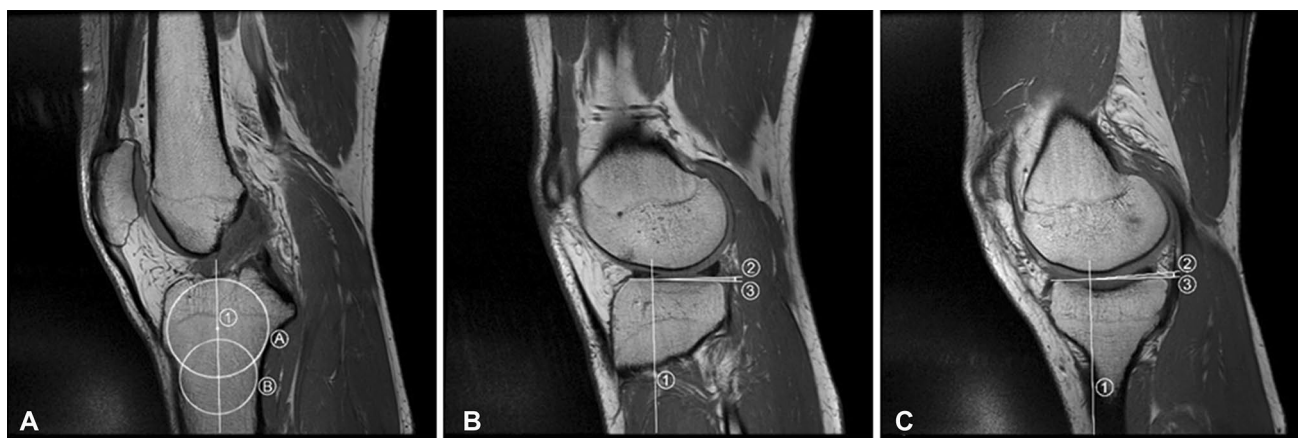
The mediolateral centered slices of both lateral and medial tibial plateau were selected and for each of them a line tangent the uppermost superior-anterior and posterior cortex edges was traced. The complementary angles between the tibial longitudinal axis and the tangent to the lateral and medial plateau were measured to determine respectively the lateral-PTS (Fig. 1b) and medial-PTS (Fig. 1c) values.

In a similar way, the lateral and medial MS were determined on a sagittal T2 slice. In this case, the line tangent to the most superior-anterior and posterior part of the meniscosynovial border was used (Fig. 2).

Two blindsided authors independently performed image selections and slope measurements considering the same set of MRI slice. After 6 weeks, the same set of images was reevaluated by one author who repeated the entire measurement process (image selections, landmark estimations and angle measurements).

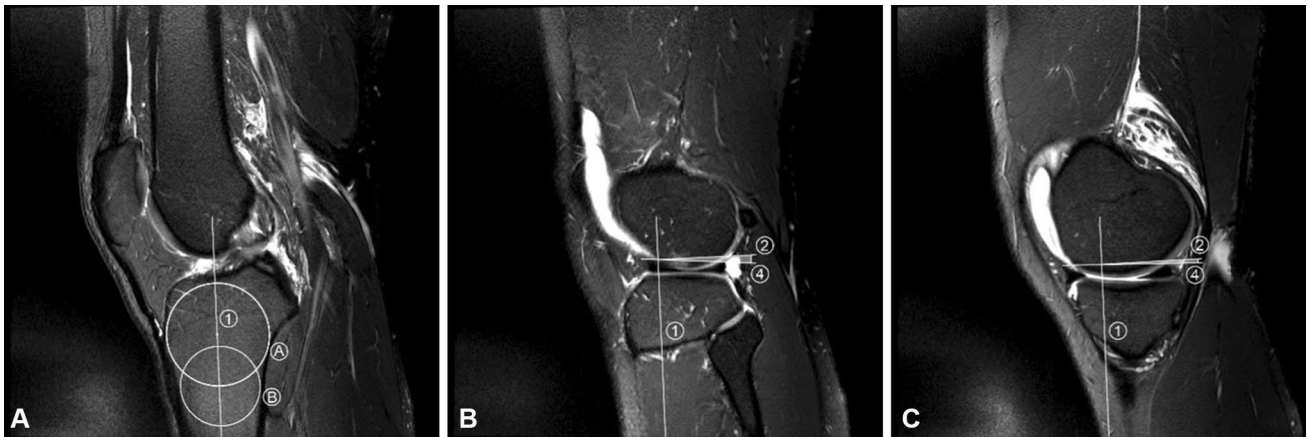
### Anterior tibial translation measurement

Anterior knee laxity was measured with a motorized laximeter (GNRB®, Laval, France) [27]. This device allows for standardized and reproducible anterior tibial translation measurements using a sensor with a precision of 0.1 mm. Standardized patient positioning and testing protocols were used as previously described [21]. A 200 N posterior to anterior directed force was applied to the proximal part of the calf. The test was repeated three times and the average of the last two trials was considered.



**Fig. 1** **a** The central MRI slice including the tibial PCL insertion, the tibial eminence and the anterior–posterior cortex in a concave shape is selected. A circle tangent to the articular surface and both the anterior and posterior cortex is drawn ①. A second circle ② is determined in a lower position, tangent to the cortex borders and centred on the circumference of the first one. The line connecting the two centres ①

is considered as the MRI longitudinal tibial axis, **b, c** The medio-lateral centred slice of both lateral and medial plateau is selected. A line tangent to the uppermost superior-anterior and posterior tibial plateau cortex is traced ③. The angle between this line and the one perpendicular to the tibial axis ② is measured in order to determine the PTS value of the lateral and medial compartment



**Fig. 2** **a** The longitudinal tibial axis of the tibia ① is determined as aforementioned using the MRI T2 slices. **b, c** The medio-lateral centred images of lateral and medial tibial plateau are chosen. The tangent to the most superior part of both anterior and posterior meniscal

horns is traced ④ for each compartment. The angle between this line and the perpendicular to the tibial longitudinal axis ② is determined to quantify the MS

As an ATT-SSD at 200 N greater or equal to 1.2 mm was reported to allow detecting ACL ruptures with a specificity of 95% [22], a postoperative ATT-SSD lower than 1.2 mm was considered as “normal” (ATT-SSD is expected to be lower than 1.2 mm in 95% of healthy subjects). Patients presenting values equal or higher than the selected threshold were defined as having an abnormal post-operative ATT-SSD.

### Statistical analysis

The analyses were performed using SPSS software for Windows v.20.0. The normal distribution of the following continuous variables was verified using the Kolmogorov–Smirnov test: age at the injury, time from the injury (TFI), age at the surgery, BMI, post-operative ATT-SSD, lateral and medial PTS, lateral and medial MS.

The average slopes as determined twice by the same observer were considered for all analyses. The Pearson’s correlation coefficient was determined to assess the correlation between post-operative ATT-SSD and PTS or MS. The correlations were considered negligible if  $r \leq 0.30$ , weak if  $0.30 < r\text{-value} < 0.50$ , moderate if  $0.50 \leq r\text{-value} < 0.70$ , strong if  $0.70 \leq r\text{-value} < 0.90$  and very strong if  $r \geq 0.90$  [23].

For significant correlation(s): (1) a linear regression analysis was computed to predict ATT-SSD based on PTS and MS, (2) a binary logistic regression was used to estimate the risk of abnormal ATT-SSD in relation to increasing degrees of PTS and MS (3) a receiver operating characteristic (ROC) curve was elaborated to determine a slope threshold the could lead to an increased risk of abnormal post-operative ATT-SSD. Based on the area under the curve (AUC), the predictive values were defined as poor ( $< 0.5$ ),

moderate ( $0.5 \leq \text{AUC} < 0.75$ ), good ( $0.75 \leq \text{AUC} < 0.90$ ) or excellent ( $\geq 0.90$ ). The optimal threshold was according to the Youden index [7].

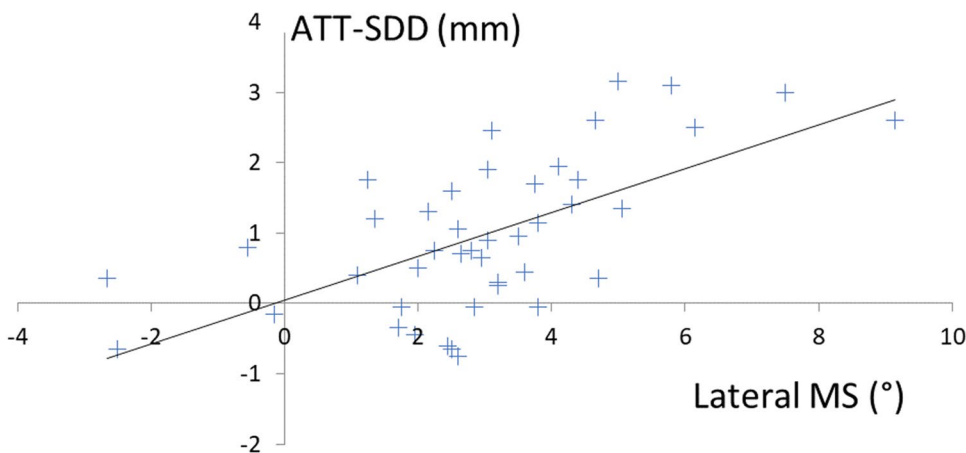
For each measured variable of the slope, the intra- and interobserver reliability was estimated using the intraclass correlation coefficient (ICC) using an absolute-agreement, two-way mixed-effects model. According to the ICC values, the reliability was defined as poor ( $< 0.5$ ), moderate ( $0.5 \leq \text{ICC} < 0.75$ ), good ( $0.75 \leq \text{ICC} < 0.90$ ) or excellent ( $\geq 0.90$ ) [15]. To evaluate the reproducibility of measurements the Standard-Error-Measurement (SEM) related to PTS and MS was determined using an ANOVA analysis for repeated measures. All data were expressed as means  $\pm$  standard deviation (SD). For all analyses, statistical significance was set at  $p < 0.05$ .

### Results

All variables were normally distributed except for TFI. The mean PTS values were  $4.7^\circ \pm 2.2^\circ$  and  $4.0^\circ \pm 2.8^\circ$  for the lateral and medial compartment, respectively. The mean lateral-MS was equal to  $3.0^\circ \pm 2.2^\circ$  and the medial-MS to  $2.0^\circ \pm 2.8^\circ$ . The bony and meniscal slopes were neither affected by the presence or absence of a meniscus injury, nor by its laterality.

A positive correlation existed between postoperative ATT-SSD and lateral-MS ( $r = 0.63$ ;  $p < 0.01$ ) (Fig. 3). No correlation was determined between post-operative ATT-SSD and lateral-PTS, neither medial-PTS nor medial-MS. For each  $1^\circ$  increase in lateral-MS, an increase of 0.3 mm postoperative-ATT-SSD (95% CI [0.2; 0.4]) could be observed. A 2.3 95% CI [1.2; 4.2] ( $p < 0.01$ ) times increased risk of abnormal ATT-SSD was associated with every  $1^\circ$  of

**Fig. 3** Relationship between lateral-MS and ATT-SSD. ATT-SSD: anterior tibial translation side-to-side difference; Lateral-MS: lateral meniscal slope



increase in lateral-MS. Since the lateral-MS was the only variable which was positively associated with an increasing risk of abnormal ATT-SSD, the ROC curve analysis was determined for this variable only. The AUC value for the lateral-MS was 0.78 IC 95% [0.63; 0.94]. A lateral-MS greater or equal to 4.0° was determined as the optimal threshold for an increased risk of abnormal post-operative ATT-SSD (Sensibility 60%; Specificity 96%; Positive Predictive Value 94%; Negative Predictive Value 70%).

A good to excellent intraobserver reliability (range of ICC 0.84–0.90) was assessed using ICC for all the considered measurements. The SEM ranged from 0.8° to 1.1°. A moderate-to-good reliability was determined between tester (range of ICC 0.57–0.83). The SEM ranged from 1.4° to 1.7°. The mean values of the slope measurements and the ICC along with their corresponding 95% IC values and SEM values are reported in Table 2.

**Discussion**

The main finding of the study was the positive correlation between lateral-MS and post-operative ATT-SSD at 1 year after primary ACL reconstruction. The lateral-MS was the only studied slope value which was related to the risk of

having an abnormal postoperative ATT-SSD. A 2.3 times increased risk of abnormal ATT-SSD was associated with every 1° of increase in lateral-MS. A lateral-MS higher or equal to 4.0° was determined as the optimal threshold for an increased risk of abnormal post-operative ATT-SSD.

To the best of our knowledge, only two researchers reported data related to PTS and postoperative ATT-SSD in a group of ACL reconstructed patients. Zaffagnini et al. [32] reported a positive correlation between medial PTS and post-operative ATT in a group of 32 patients undergoing ACL reconstruction with associated closing wedge high tibial osteotomy. Their results may, however, have been affected by a possible slope reduction of the closing wedge technique as well as by the inclusion of patients undergoing ACL revision surgeries. Therefore, it is difficult to extend their findings to a population of primary ACL reconstructed patients. Li et al. [16] analyzed the relationship between the medial and lateral PTS and the ATT-SSD measured with a KT-1000 arthrometer in 40 patients with a primary ACL reconstruction after a non-contact injury. The authors reported a moderate correlation between postoperative ATT-SSD and both lateral-PTS ( $r=0.40$ ) and medial-PTS ( $r=0.41$ ) [16]. Unlike those findings, no association was found between postoperative ATT-SSD and medial PTS in the present study. None of

**Table 2** Mean slope values, intra and interobserver ICC and SEM values were reported for each considered variable along with their 95% CI

|             | Mean slope (°) | ICC [95% CI]      |                   | SEM (°)       |               |
|-------------|----------------|-------------------|-------------------|---------------|---------------|
|             |                | Intraobserver     | Interobserver     | Intraobserver | Interobserver |
| Lateral-PTS | 4.7 ± 2.2      | 0.94 [0.89, 0.97] | 0.72 [0.49, 0.85] | 0.8           | 1.4           |
| Medial-PTS  | 4.0 ± 2.8      | 0.95 [0.90, 0.97] | 0.82 [0.66, 0.90] | 0.9           | 1.7           |
| Lateral-MS  | 3.0 ± 2.2      | 0.92 [0.86, 0.96] | 0.57 [0.20, 0.76] | 0.9           | 1.7           |
| Medial-MS   | 2.0 ± 2.8      | 0.91 [0.84, 0.95] | 0.83 [0.70, 0.91] | 1.1           | 1.5           |

For each slope variable the mean value, intraobserver and interobserver ICC and SEM were reported along with their 95% CIs

PTS posterior tibial slope, MS meniscal slope, ICC intraclass correlation coefficient, SEM standard error of measurements

the aforementioned studies considered the meniscal slope in their analysis.

The mean value for the lateral and medial-PTS of  $4.7^\circ \pm 2.2^\circ$  and  $4.0^\circ \pm 2.8^\circ$  were similar to the lateral and medial-PTS values of  $4.9^\circ \pm 3.2^\circ$  and  $4.1^\circ \pm 2.8^\circ$ , respectively, which were reported by Hudek et al. [9] in a group of 55 patients with patellofemoral pain syndrome. The added value of the present study is the measurement of the slope of the soft tissues as the meniscus slope, reaching  $3.0^\circ \pm 2.2^\circ$  for the lateral and  $2.0^\circ \pm 2.8^\circ$  for the medial compartment. In a series of 101 patients with anterior knee pain, Lustig et al. [18] reported a mean lateral and medial-MS of  $-0.1^\circ \pm 5.7^\circ$  and  $1.8^\circ \pm 4.3^\circ$ , respectively. In a recent study, Elmansory et al. [5] compared the meniscal slope of 100 ACL-injured patients to a control group. The authors reported lateral-MS values of  $4.7^\circ \pm 4.7^\circ$  and  $0.9^\circ \pm 4.8^\circ$  and medial-MS values of  $6.0^\circ \pm 3.4^\circ$  and  $3.7^\circ \pm 3.6^\circ$ , respectively, in the ACL-injured and control group [5]. It remains unclear how such discrepancies in MS values can be explained. Further studies are needed to determine whether this is due to the measurement methods or the diversity of the studied populations in terms of pathologies, anatomical variability of the meniscal structures or even degenerative changes of the menisci related to the aging process (i.e. meniscal extrusion and root lesions).

A steeper PTS has been shown to be associated with the presence of posterolateral meniscus root tears [14] and an increased medial meniscal slope with a greater risk of a medial meniscus ramp lesion in non-contact ACL injuries [30]. Bony and meniscal slopes may thus differ between patients with or without a meniscal lesion, a finding which could not be confirmed in the present study. This may be explained by the fact that the present cohort included several types of meniscal lesions (including ramp lesions of the medial meniscus and root tears of the lateral meniscus amongst many other types of meniscal tears).

PTS and MS values were determined by two independent examiners using the circle method, introduced by Hudek et al. [10] and validated by Lipps et al. [17]. Excellent intraobserver reliability (95% CI [0.91; 0.95]) and moderate to good interobserver reliability (95% CI [0.57; 0.83]) were achieved. The intraobserver and interobserver SEM values for the lateral-MS were, respectively,  $0.9^\circ$  and  $1.7^\circ$ . The precision of the measurement performance is in agreement with the values obtained by Lustig et al. [18], who reported examiner-dependent measurement errors for the lateral-MS varying from  $0.9^\circ$  to  $1.4^\circ$ . Despite a moderate-to-good interrater reliability, the established threshold of  $4.0^\circ$  for lateral-MS to detect an increased risk of abnormal ATT-SSD difference is much higher than the precision of the present measurements.

The findings of this study indicate that, based on the MRIs that are routinely performed after ACL injury, it is possible to efficiently identify patients with a high lateral-MS

in clinical practice. A patient with a lateral MS above  $4.0^\circ$  would have a Positive Predictive Value of 94% to have an increased postoperative ATT-SSD. Although the optimal treatment to provide to these patients remains to be determined, lateral meniscal slope should be taken into account in the setting of ACL reconstruction. The clinical relevance of this study is related to the fact that it confirms previous findings showing that bony and soft tissue slopes of the knee joint have an impact on the outcomes after reconstructive surgery [9, 25]. In this case, it was shown that meniscal tibial slope was related to an increased laxity occurring within the first year after primary ACL reconstruction. Future studies will need to identify patients at risk of such an early laxity increase, find ways to prevent it and eventually show if it may lead to an increased rate of recurrent injuries, graft failure or joint degeneration in the long term.

The current study is not without limitations. First of all, it was performed retrospectively, although data were prospectively collected. It does not allow concluding on causal relationship between the lateral MS and the postoperative ATT-SSD. Furthermore, other factors, such as graft or age, may have a confounding effect on postoperative ATT-SSD, although this effect was not considered in the present study. Although patients with meniscectomies at the time of the ACL reconstruction were excluded from this study, patients with meniscal repair were not and the influence of such repair on the meniscal slope or postoperative ATT-SSD may be considered. Finally, all slope measurements were determined using MRI imaging in static non-weight-bearing conditions. It may not reflect the real dynamic in-vivo conditions as the meniscal shape may differ with weight conditions. The measurement of slope in the latter condition may thus be considered.

## Conclusion

Lateral meniscal slope was positively associated with postoperative anterior tibial translation side-to-side difference. A lateral meniscal slope greater or equal to  $4.0^\circ$  was detected as threshold for an increased risk of abnormal post-operative ATT-SSD in patients who underwent primary ACL reconstruction.

**Author contributions** All authors contributed equally to the study.

**Funding** None.

## Compliance with ethical standards

**Conflict of interest** The authors' declare that they have no conflict of interest.

**Ethical approval** National Ethics Committee for Research (N°201101/05).


**Informed consent** All patients signed an informed consent to participate in the study.

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