

## ORIGINAL ARTICLE

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**Knee Flexors Maximum Effective Angle Variation after Anterior Cruciate Ligament Reconstruction with Hamstring Graft**<sup>1</sup>Hugues FRUYTIER, PT<sup>2</sup>Jean MAZEAS, PT<sup>3</sup>Maude TRAULLÉ, PT; M.Sc.<sup>4</sup>Amaury VANDEBROUCK, MD<sup>5</sup>Pascal DUFFIET, MD<sup>6</sup>Louis RATTE, MD<sup>\*7</sup>Florian FORELLI, PT, M.Sc.**ABSTRACT**

**Background:** During the anterior cruciate ligament reconstruction, the graft is taken from the distal hamstring tendon, which causes morphological and neurological changes in these muscles, particularly on the maximum effective angle of the knee flexors. The present study investigates changes in knee flexor following anterior cruciate ligament reconstruction with a hamstring graft.

**Methods:** Two populations participated in this study, a healthy group and a group that underwent anterior cruciate ligament reconstruction with a hamstring graft. First, the test group underwent two postoperative assessments on an isokinetic device at 3 and 6 months. Next, we compared the test group at 3 and 6 months with the control group to highlight the differences between the knee flexors maximum effective angle. And finally, we have compared the knee flexors maximum effective angle with the moment of maximum force to determine whether these two values are related.

**Results:** The maximum effective angle is decreased regardless of the duration of rehabilitation ( $\rho=0.0019$ ,  $\rho=0.037$ ). It does not change significantly during rehabilitation ( $\rho=0.29$ ). It does not depend on the strength gained during rehabilitation but on a neuromotor change due to the morphological changes caused by surgery.

**Conclusion:** The study results show that anterior cruciate ligament reconstruction with hamstring graft causes a decrease in knee flexor maximum effective angle.

**Keywords:** maximum effective angle, anterior cruciate ligament reconstruction, knee flexor, hamstring graft, variation.

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## INTRODUCTION

Because of the impact and many injuries in athletes, much research has been carried out to identify the risk factors to reduce the impact [1]. As a result, many of them have been identified [2] as having already injured the hamstrings, age, ethnicity, flexibility, or the lack of strength during an eccentric contraction [3].

One risk factor that has become popular is measuring the angle of maximum torque at knee flexion: the maximum effective angle (MEA) [4]. It is used as a measure following surgery, injury, or as a predictor of hamstring injury as it is considered a risk marker for hamstring strain injury (HSI) [5].

The angle of maximum efficiency is determined during a slow concentric contraction ( $60^{\circ}\cdot s^{-1}$ ) using an isokinetic dynamometer [6]. However, it could be determined at higher speeds or with different contractions (eccentric, isometric) [4].

These slow, concentric-mode contractions have been determined to be more reliable in determining the torque angle of maximum force than faster contractions or the use of the eccentric [7] and to minimize the development of the force-torque ratio.

HSI most commonly occurs during the oscillation phase of a high-speed run [1], when an eccentric contraction of the hamstrings is required to decelerate hip flexion and knee extension movements [8]. Thus, the interpretation of the force peak angle through a concentric contraction mode seems less representative than if the eccentric contraction mode or a higher speed in the concentric mode had been favored. Nevertheless, it has been proved that during an eccentric contraction carried out voluntarily, it is very difficult to obtain optimal recruitment of motor units, which causes problems of validity and reliability during an eccentric evaluation [9], and this slow contraction rate allowed better reproducibility of the evaluation [10].

Therefore, the maximum efficiency angle is determined using an isokinetic dynamometer at a speed of  $60^{\circ}\cdot s^{-1}$  concentrically to be as reliable as possible.

To date, no study has been able to link the measurement of the angle of maximum efficiency of knee flexion to a hamstring injury. Determining the cause and effect link between MEA and HSI would require a very well-conducted prospective study since retrospective studies would not be able to distinguish whether the MEA was already as it is before the injury and, therefore, if it was indeed caused by it [11].

Therefore, the interest of this study will be to compare the MEA of the knee flexors at 3 and 6 months after an anterior cruciate ligament reconstruction (ACLR) with hamstring graft and those of “healthy” knees not having benefited from this operation. The objective is to find out whether, because of the removal of the transplant from the hamstrings, the peak force angle of the patients who underwent the operation is significantly different from that of the control patients.

## MATERIALS AND METHOD

We favored research by prospective data collection through a protocol defined in advance to respond to the problem.

During the study, the measurements were carried out in the private clinic where the subjects in the test group were operated on, while their rehabilitation took place in private liberal practice.

The subjects participating in the study were not informed of the hypotheses or the data investigated. No feedback on the values or the protocol was given to the patients. However, it is impossible to exclude that they had no connection outside the sessions where the data were measured.

Therefore, the test group benefited from 2 measurements during the 3 and 6-month check-ups, the first at 3.37 months  $\pm$  12.6 days after the operation, the second at 6.21 months  $\pm$  12 days after the operation.

A file has been submitted to the CNIL and bears the number 2221587.

The subjects participating in the study are informed of the protocol's progress through an explanatory document serving as informed consent after signature.

The study subjects were divided into two groups:

- A test group of subjects who had ACLR with a hamstring graft.
- A control group of “healthy” subjects who have not benefited from ACLR.

The equipment used in this research consists only of an EasyTech Genu + <sup>®</sup> isokinetic machine. The test consisted of 4 repetitions of flexion and extension movements of the knee, with a dynamometer set to  $60^{\circ}\cdot s^{-1}$ .

The subjects are all aged a minimum of 18 and a maximum of 46 years. They all presented an ACLR with or without associated meniscal lesions (meniscectomy or meniscal suture). The ACLR took place about six months ago (average 6.21 months, plus or minus 0.4 months). Evaluations were performed at the clinic at 3.37 months ( $\pm$  0.42) and 6.21 months ( $\pm$  0.40) post-operation.

The subjects must not present on the knee tested any traumatic pathology (sprain, infiltration, fracture ...) and the rupture of the ligament must be the first, were excluded from the study people who underwent ACLR for the second time or more. People with central or peripheral cognitive or neurological pathologies and those with proven congenital malformations were also excluded. Any subject who presented with intra-articular effusion or hematoma was also excluded from the study.

The control group comprises subjects aged at least 18 and at most 36 years old, without anterior cruciate ligament injury. They should also not present with knee pathologies such as a sprain, bone fracture, immobilization, cognitive and neurological disorders (central or peripheral), or congenital malformations. These are people whose knees could be considered “healthy.”

The statistical analyzes were carried out after sorting the data recovered during the tests on the Excel<sup>®</sup> software. This processing made it possible to organize and read the raw results of the population studied for each question.

Statistical analyzes were carried out on the socscistatistics.com website using data sorted in Excel®.

Interference statistics have been carried out. The confidence level is predefined such that C = 95% and the significance level is  $\alpha = 0.05$ .

The study included 40 subjects, so we performed a normality test (Shapiro-Wilk) to analyze the distribution of populations.

The study of variances is carried out on each sample population using the Chi2 test, chosen for the qualitative values, and the Student's T-test for the quantitative values.

Thus, a Mann and Whitney test was used for quantitative variables such as body mass index and age and a Chi2 test for the qualitative variable which are sex and the knee studied, to ensure that there are no significant differences between the test and the control group.

- The comparison of MEA between the control group and the test group at 3 and then at 6 months is carried out with a Mann-Whitney test because they are quantitative values measured on 2 separate populations.
- The comparison of the MEA values of the test group at 3 and 6 months is done with a Student's T-test because they are paired variables.

Finally, to study whether the position of the maximum efficiency angle and the peak force are related, we will perform a Pearson correlation between the MEA and the maximum torque.

## RESULTS

The "control" and "test" groups did not show statistically significant differences in the characteristics of age, body mass index, sex, and the knee studied ( $\rho$ -value > 0.05).

The data collected during the balances are not distributed according to a normal distribution.

**Table 1:** Demographic table of test and control groups (mean  $\pm$  standard deviation)

	Control Group n=20	Test Group at 3 months n=20	Test Group at 6 months n=20	$\rho$ -value
Age (y)	27 ( $\pm$ 5,46)	26,25 ( $\pm$ 8,14)	26,50 ( $\pm$ 8,14)	(NS)
BMI (Kg/m <sup>2</sup> )	24,05 ( $\pm$ 3,57)	23,5 ( $\pm$ 3,30)	23,5 ( $\pm$ 3,30)	(NS)
Sex	Male : 10 Female : 10	Male : 10 Female : 10	Male : 10 Female : 10	(NS)
Side	Left : 9 Right : 11	Left : 9 Right : 11	Left : 9 Right : 11	(NS)
Postoperative delays (Months)	Ø	3,37( $\pm$ 0,42)	6,21 ( $\pm$ 0,40)	Ø

y : years – kg : kilograms – m : meter – BMI : body mass index kg/m<sup>2</sup> - Ø : no value

**Table 2:** Comparative table of the test group at 3 months and the control group.

	Average MEA $\pm$ SD (degree°) n=20	Average Peak Torque $\pm$ SD (Newton-meter) n=20
Test Group	26,25 ( $\pm$ 8,17)	55,4 ( $\pm$ 34,53)
Control Group	36,35 ( $\pm$ 11,98)	73,9 ( $\pm$ 36,68)
$\rho$ -value	0,0019	NS

SD: Standard Deviation

**Table 3:** Comparative table of the test group at 6 months and the control group.

	Average MEA $\pm$ SD (degree°) n=20	Average Peak Torque $\pm$ SD (Newton-meter) n=20
Test Group	27,85 ( $\pm$ 9,98)	80,3 ( $\pm$ 30,64)
Control Group	36,35 ( $\pm$ 11,98)	73,9 ( $\pm$ 36,68)
$\rho$ -value	0,037	NS

SD: Standard Deviation

**Table 4:** Comparative table of the test group at 3 months and at 6 months.

	Average MEA $\pm$ SD (degree°) n=20	Average Peak Torque $\pm$ SD (Newton-meter) n=20
3 months	26,25 ( $\pm$ 8,17)	55,4 ( $\pm$ 34,53)
6 months	27,85 ( $\pm$ 9,98)	80,3 ( $\pm$ 30,64)
$\rho$ -value	NS	0,0094

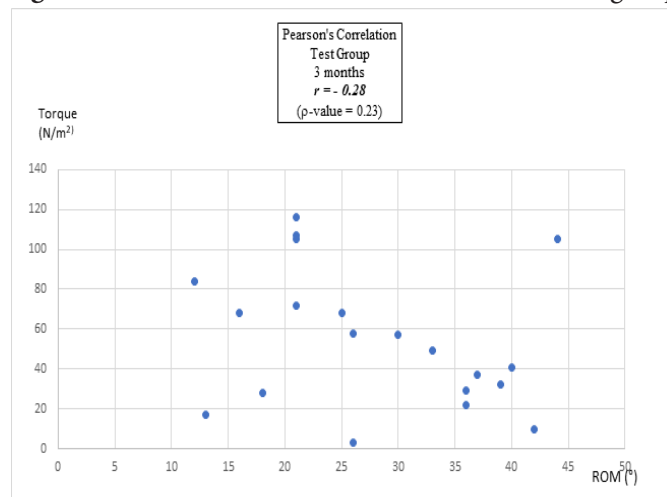
SD: Standard Deviation

The Mann-Whitney test allowing the comparison of the values of the MEA of the control group and those of the test group at 3 months is significant:  $\rho = 0.0019$  (<0.05)

The Mann-Whitney test, which compares the MEA values of the control group and those of the test group at 6 months, is significant at  $\rho = 0.037$  (<0.05)

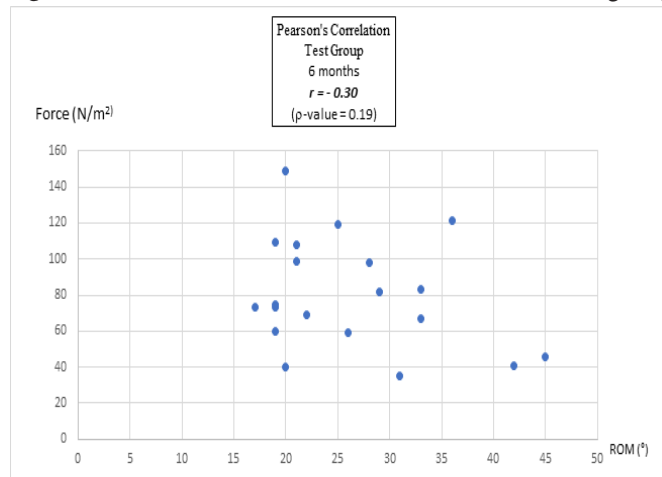
Student's T-test comparing the values of MEA at 3 and 6 months is not significant at  $\rho = 0.29$  (> 0.05).

**Figure 1:** Pearson's correlation for the 3-month test group



ROM: Range of Motion

**Figure 2:** Pearson's correlation for the 6-month test group



ROM: Range of Motion

With Pearson's correlation test, we observe that for a  $\alpha$ -value = 0.05, the two tests are not significant while the gain in strength is significant (see Table 4):

- For the 3-month balance sheet, the  $\rho$ -value is equal to 0.23 ( $> 0.05$ )
- For the 6-month balance sheet, the  $\rho$ -value is equal to 0.19 ( $> 0.05$ )

## DISCUSSION

The objective being to be able, if the results are conclusive, to adapt the rehabilitation as well as possible to readapt the hamstrings to functional work, to a specific sport, to effort, to everyday life, and to be able to prevent lesions or even a recurrence of anterior cruciate ligament injury.

From the results obtained, it can be observed that, contrary to what the studies by Proske et al. [6] and Brockett et al. [4] suggested that the MEA of the knee flexors in the test population is not greater than that of the control population, on the contrary, it tends more towards extension and therefore is inferior. These studies had shown that after an HSI, the MEA of the knee flexors was significantly higher than that of a "healthy" leg. We, therefore, started from the principle that after harvesting a tendon graft from the hamstrings (semi-tendinous), the puncture of the graft could be considered a full-fledged hamstring injury.

The consequences of an HSI are still visible 6 months after them [12], the eccentric and concentric force is affected, the angle of penetration of the fibers changed, and the MEA increased. In contrast, according to the results obtained in our study, the MEA of the knee flexors was not increased but indeed decreased at 3 and 6 months post-operation compared to a control group.

Therefore, it can be concluded that the removal of the graft from the semi-tendinous cannot be assimilated to an HSI.

These are the same data found in a 2019 study [13], which concluded that the MEA of the knee flexors after ACLR with hamstring graft to evolve towards extension. In addition, this study compared the evolution of MEA as a function of patient rehabilitation time (supervised rehabilitation of more than 6 months or less than 6 months). It concluded that regardless of the duration of rehabilitation, the MEA of these patients progressed towards extension compared

to a control group.

The nuance that this study was able to establish is that the limb symmetry index (LSI) increased with the duration of the rehabilitation and therefore that the MEA tended to increase slightly to approach that of the "healthy" contralateral leg.

A similar study demonstrated in 2018 [14] that the difference between knee flexor MEA patients who had ACLR was about 10° less (between 9° and 12° less) for the injured limb, regardless of the duration of rehabilitation.

Therefore, it is consistent that the MEA of the test group in our study is significantly smaller than that of the control group, regardless of the date of assessment (3 or 6 months). We also find data similar to those of the 2018 study [12] with concordant MEA differences:

- 10.10° difference between the 3-month assessment and the control group
- 8.5° difference between the assessment at 6 months and the control group

No precise explanation has been provided to date as to the reasons for this change in the MEA's position after an ACLR. Despite this, the most discussed and explored theory [13] brings into play the decrease in the activity of the semitendinous (ST) in favor of an increase in the activity of the Biceps Femoris (BF) especially during activities requiring intense efforts.

Hamstring morphology, strength [15], and neuromuscular activity [13] are altered after ACLR and may remain altered for up to 6 years after surgery. More particularly, BF and ST are the primary muscles affected by the operation [13].

The activity of BF after ACLR is increased, while that of ST is decreased [14]. The hypothesis put forward to explain this modification of the MEA is therefore that it is due to the change in the activity of these muscles, the increase in activity of BF to compensate for the loss of that of ST would cause a shift towards the MEA towards the extension because it would be more efficient in this area than the ST.

Studies could support this hypothesis by Proske et al. [6] and Brockett et al. [4], which show an increase in MEA after an HSI. Except during an HSI, the muscle suffering the lesion is the BF [15] most of the time, the activity of which declines in favor of the other hamstrings. Therefore, one might think that the involvement of the BF among the hamstrings helps regulate the MEA, and more precisely to make it tend towards the extension.

Pearson's correlation between MEA and the peak torque (PT) revealed that the PT did not influence the MEA. This is therefore not changed despite the gain in strength. However, it can be modified during rehabilitation, depending on the protocol used; for example, exercises based on eccentric contraction will decrease MEA [16]. These modifications are therefore not dependent on the architecture of the muscle but neuromotor changes.

In a study on the neuromuscular function of hamstrings after ACLR [17], it was shown that the electromyography amplitude of the hamstring was greater after ACLR and that their co-activation was better. A longer delay in hamstrings

activation has also been demonstrated in individuals with an ACLR with a hamstring graft.

Another study demonstrated under-activation of ST for up to 6 years after ACLR [9]. This under-activation could be explained by altered neuromuscular connections, which would justify the persistent hypotrophy of the ST after an ACLR.

Whereas the BF sees its muscular activity increased [14] to compensate for the under activation of the ST.

The results obtained during our trial are consistent with the data collected in the literature. The change in MEA after ACLR and during rehabilitation is due to neuromotor differences that influence the muscle contraction of the hamstring.

## LIMITS

We cannot say that the results obtained with this study represent a larger sample of subjects. For the experiment to be more representative, it would be interesting to carry it out with a larger number of participants while keeping an equivalent number of subjects in the two groups and keeping the same selection criteria for both groups to maintain a similar goal.

The subjects belonging to the test group carried out their follow-up assessments at 3 and 6 months, all on the same isokinetic machine. They all had ACLR at the same clinic with 3 different surgeons, all following a standard surgical protocol. They all received identical post-operative instructions and carried out their rehabilitation follow-up within the same practice to limit inter-subject variability.

Despite these parameters, the subjects were not all supervised by the same practitioner. In addition, the rehabilitation protocol was adapted during rehabilitation to the patient's progress and condition, so they did not all follow the same rehabilitation program, which could influence the variables studied during the study.

It is very difficult to know the actual effect of ACLR on the MEA because it is impossible to know at what angulation it was located before the ACLR. However, comparison with a healthy contralateral limb or even a control group can give us an idea of the change induced by reconstruction and graft harvesting. Still, without knowing the pre-rupture MEA, it is complicated to attribute the changes to the operation. This is explained by Bahr et al. [7] talking about HSI; without knowing the pre-lesion characteristics, it is complicated to state that the post-lesion characteristics were caused by it and were not already present before.

## CONCLUSION

Even though no study has been able to establish flexor MEA as a risk factor for myo-aponeurotic hamstring injury to date, it remains widely used as a marker for return to sport. During rehabilitation after ACLR, knowing its properties (such as its position and the MEA) allows the rehabilitation program to be best adapted to the patient's profile and expectations.

Knee flexor MEA is reduced regardless of the duration of rehabilitation. This change is due to architectural and neurological changes in the hamstrings after the operation.

It is essential to consider this during rehabilitation to adapt it to the patient's profile best.

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