ENDOSCOPIC FLEXOR HALLUCIS TENOLYSIS COMBINED WITH ACL RECONSTRUCTION ALLOWS BETTER FUNCTION AND RETURN TO HIGH SPORTING ACTIVITIES

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INTRODUCTION

Purpose

Endoscopic tenolysis of the Flexor Hallucis Longus (FHL) tendon was associated with Anterior Cruciate Ligament (ACL) reconstruction in a series of 136 patients operated by the same surgeon between 2002 and 2019. The aim of this study is to evaluate the benefit to combine both procedures. The study design is dual: there is a retrospective part, concerning the items "wellbeing" and "return to sport", based on answers to our patient questionnaire, and a prospective part regarding the pre- and post-surgery footprint and gait analysis, recorded on our footscan platform.

ACL injury mechanisms and Functional Hallux Limitus (FHLim) implication

ACL tears occur mostly in non-contact injuries and more in women than men. The mechanism is a quick pivotal movement that leads by a "corkscrew" mechanism to a "medial collapse" of the knee into valgus and internal rotation [1,2]. We identified Functional Hallux Limitus (FHLim) as a kinematic condition involved in this process. Indeed, the "corkscrew" mechanism is related by inter-articular synchronism to an abrupt transition from foot supination into exaggerated pronation during the support phase of the human gait cycle. [3-5] As this pronation is synchronized with internal tibial rotation, the knee is pulled in a spiral movement that it can't escape from.

FHLim: definition, anatomy and diagnosis

FHLim is defined by the inability of the hallux to extent dorsally during the course of the step when walking. In the propulsive phase, when the ankle is placed in dorsiflexion position, the 1st metatarso-phalangeal joint remains stiff and cannot be extended. This biomechanical condition is the consequence of a blockage (tenodesis effect) of the FHL tendon at the level of the hindfoot which prevents this tendon from sliding freely. [6] The impingement occurs in a tunnel located between the posterior medial and lateral tubercles at the posterior aspect of the talus and overlain posteriorly by a fibrous pulley that completes this tunnel. [7] Clinically it is possible to objectify this blockage due to the FHL inability to glide properly : this maneuver is the FHL stretch test. [8, 9]

Footprint changes and gait pattern related to FHLim and biomechanical consequences

In gait analysis, we noticed in FHLim patients the loss of support on the first metatarsal's head and a walking pattern on the outer edge of the foot. More, FHLim induces a desynchronized gait pattern characterized by an abrupt tilting of the foot in pronation at the end of the support phase when walking, running or landing from a jump. This kinematic disorder is a predisposing factor for a "medial collapse" of the knee and ACL injuries. In a previous prospective series of 200 ACL tears in non-contact injuries, we reported that FHLim was present in 98% of our patients. The attainment was bilateral in 2/3 of cases and when it was unilateral it concerned the injured side (unpublished data).

Indications for surgery

Indications for ACL reconstruction were ACL tears associated with instability, functional symptoms and/or damage to other intra-articular structures. Combination with FHL tenolysis was proposed in FHLim patients and in particular to those who had a high risk to develop a secondary instability including revision ACL reconstruction, bilateral ACL tears, significant meniscal or cartilage damage as well varus knees or complex injuries.

MATERIAL AND METHODS

1. Patients selection

Data were collected for a consecutive series of 106 patients operated between 2002 and 2019 who underwent combined ACL reconstruction and FHL endoscopic tenolysis in our institution (Clinique Bois-Cerf, Lausanne; CH). All ACL tears were due to non-contact injuries. The combined surgeries were performed by the same surgeon (Dr J Vallotton,MD) with the same surgical technique for both procedures.

4 patients were lost to follow-up creating a final cohort of 102 included patients, split up in 3 subgroups:

- **Group 1**: 70 patients with a completed questionnaire
- **Group 2**: 68 with a pre- and post-operative study
- **Group 3**: 23 patients with a long follow-up period

For the subjective part, our questionnaire was based on the Lysholm - Tegner score [10,11,12] and the International Knee Documentation Committee score (IKDC)

[13], adapted to our specific situation. As the majority of our patients are French speaking, we translated the English version into a French version, respecting each formulation as much as possible.

The original Tegner-Lysholm questionnaire is limited to the past 4 weeks, but we consider the postoperative period of an average of 6 years. Postoperative knee function was assessed by the answers at points 2 to 6 based on the Lysholm - Tegner score [10,11,12], pain by the answers to questions 2 and 3. A numeric pain rating scale from 0 to 10 was used, 0 for no pain to 10 for the worst pain experienced. The Lysholm scale calibrates pain as marked if the score is at 6 or above. Limping and Support weren't expressed in these terms in our questionnaire, but we extrapolated that the ability to run or jump excluded a positive answer to those items. An absence of answers in our questionnaire was considered as « none » in the original scale system since the answers couldn't be left blank. The score for all of the questionnaires was determined using the **orthopaedicscore.com** website.

Group 1

The questionnaires were sent by mail and by postal way to all the operated patients with valid contact data (99 patients). In this way, they could be filled out either online via a link or on paper. The obtained 65 responses of the French version and 5 of the English version, that were transferred into the online French Google Form to obtain an overview of the 70 completed questionnaires. 3 questionnaires were filled out anonymously. The missing data were due to non-responses or refusal to answer the questionnaire.

For the objective part, two footprints analysis were systematically recorded at our institution, one pre-operatively and the second one 6 months after surgery. The device used for the analysis was a foot pressure sensitive gateway dedicated to static, postural and gait analysis with total freedom in stance and motion acquisition (Win-Track medicaptors, Toulouse, Nice (France) and Atlanta (USA). The software was Win-Track V1.44 and Windows print-tool was used to convert the data into PDF.

Group 2

A total of 68 patients having both, a pre- and post-operative footprint, with a short term follow up (at 6 months after surgery), were available. Missing preoperative data (23 patients) were due to pain, limping and associated traumatic lesions or a too short interval between trauma and surgery.

Group 3

To expand the sample and for a long-term follow-up, we contacted all the patients who responded to the questionnaire but didn't have a postoperative footprint analysis. Out of 31 contacted patients, 23 answered and agreed to come to our medical center for a postoperative analysis. Therefore, we created an average follow-up of 87.6 months after surgery (range of 12-156 months). By this means, we were able to obtain 10 additional patient files with both, pre- and post-op records, and 13 with the postoperative record only. Thus, we collected a total of 91 post-op files and of these, we have 78 complete pre-and postoperative files (group 2). The data from group 2 were evaluated for any significant change in static and dynamic footprints. The short-term (group 2, at a median of 6 months follow-up) and long-term follow-up (group 3, at a median of 87.6 months follow-up) results were compared for post-op footprints. All footprints were examined separately by two qualified surgeons. In case of discordance, the decision about significance of the results was taken together.

2. Footprint analysis

FHLim can be suspected or diagnosed on static and dynamic footprints according to specific characteristics, shown in Table 1 & 2.

Table 1: static (postural) assessment with weight bearing on one foot, FHLim is suspected when we noted:

1. Displacement of the projection of the center of gravity towards the posterior (and lateral) part of the foot
2. Deleted loading on the 1st metatarsal head and simultaneous excessive loading of the big toe
3. Overloading of the posterior part of the foot (heel)

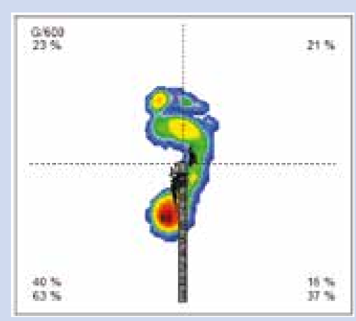
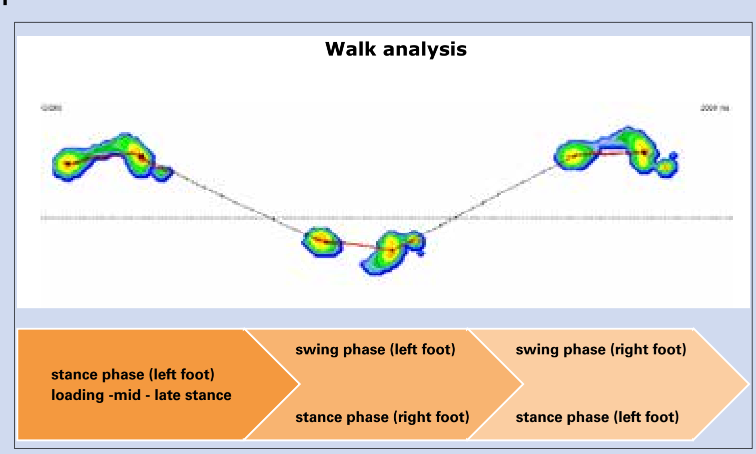


Table 2: dynamic assessment in gait, FHLim is suspected when we recorded:

1. Rolling motion to the outside edge of the foot during a step (supination)
2. Exaggerated and tardive switch over from supination into pronation in late stance
3. Deleted loading on the 1st metatarsal head



Significant changes were recorded as a return to physiologic gait after FHL tenolysis following several criteria. In static (postural) and dynamic assessments with weight bearing on one foot, significant changes were recorded in the postoperative podologic patterns (Table 3 and 4)

Changes were considered as significant when at least 2 of 3 criteria were fulfilled at the post-operative follow-up respectively for the static and the dynamic analysis. When one criterion only was fulfilled at the postoperative analysis, the result was considered as partially significant. In case of an analysis with none of the significant criteria, the result was considered as not significant. Finally, when the footprint or rolling motion was the same, it was considered as no change. For the dynamic analysis in gait, less loading on the 1st metatarsal distal phalanx and inflexion in supination at push-off were considered as secondary criteria and were not taken in account in the post-op evaluation. To validate the significance of the change between the pre-and postoperative footprints, they were reviewed independently by two experienced surgeons. This double check confirmed the reliability of the selected criteria. The combination of those characteristics leads to a pathognomonic footprint that is easy to identify. Our results concluded that if all the footprint criteria are fulfilled pre-operatively, significant changes can be expected in 100% of cases after surgery. Sensitivity and specificity are higher in the dynamic footprint than in the static. However, when only one criterion is present before surgery, the expectancy to find considerable footprint changes postoperatively is lower, and if no criteria are present, the footprint has remained the same.

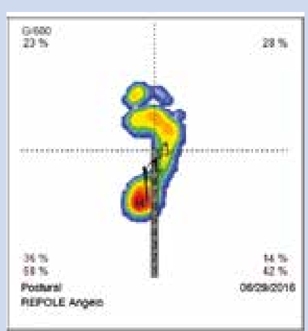
3. Surgical procedures

Both procedures were done in one session and are briefly described. FHL endoscopic tenolysis was carried out first on one or both feet, with the patient in prone position. Then, ACL reconstruction was performed by arthroscopy using a trans-tibial technique with an autologous 4-stranded semi-T tendon graft according to Rosenberg [14]. ACL reconstructions were primary or secondary and most of them are complex cases with multimodal interventions, including meniscus repairs and/or other ligamentous or tendinous repairs. The same technique was used for all the patients, besides for complex reconstructions (Figure 1).

Referring to our previous publication, FHL tenolysis consists to restore FHL tendon glide by sectioning the fibrous pulley at the posterior border of the retrotalar tunnel [15]. We also take care in correcting any bony conflict that could participate to the tendon entrapment until being sure of a free tendon glide. The foot on the side of the ACL injury was operated in all cases and since the benefits of operating both feet was proven by time, we ended up operating both feet consistently. In the series, 9 patients were operated on only one foot.

Table 3: postoperative podologic patterns

1. Forward displacement of the gravity center projection in the middle of the foot
2. No excessive loading of the big toe
3. Improved balance with less dispersion and concentration of the gravity center projection point



RESULTS

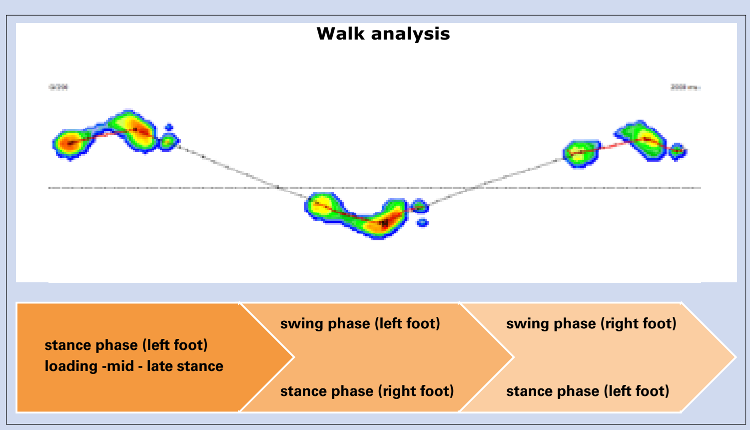
From a cohort of 102 patients, we obtained a total of 70 filled-out questionnaires (group 1) and 68 pre- and post-operative static and dynamic reports (group 2). Group 3 consisted of 23 patients who had a median follow-up of 87.6 months between post-op analysis and surgery, that is considerably long (Table 5).

1. Answers to the Questionnaire

Questionnaire results are presented for group 1 (n=70). The average time between surgery and answers to the questionnaire is 443.5 months and a standard deviation of 149 months.

Table 4: significant changes in dynamic assessment were recorded if the postoperative podologic pattern shows:

1. Less exaggerated supination between at heel strike and middle stance
2. Less brutal inflexion of the rolling motion in pronation in late stance
3. 1st metatarsal head reloaded



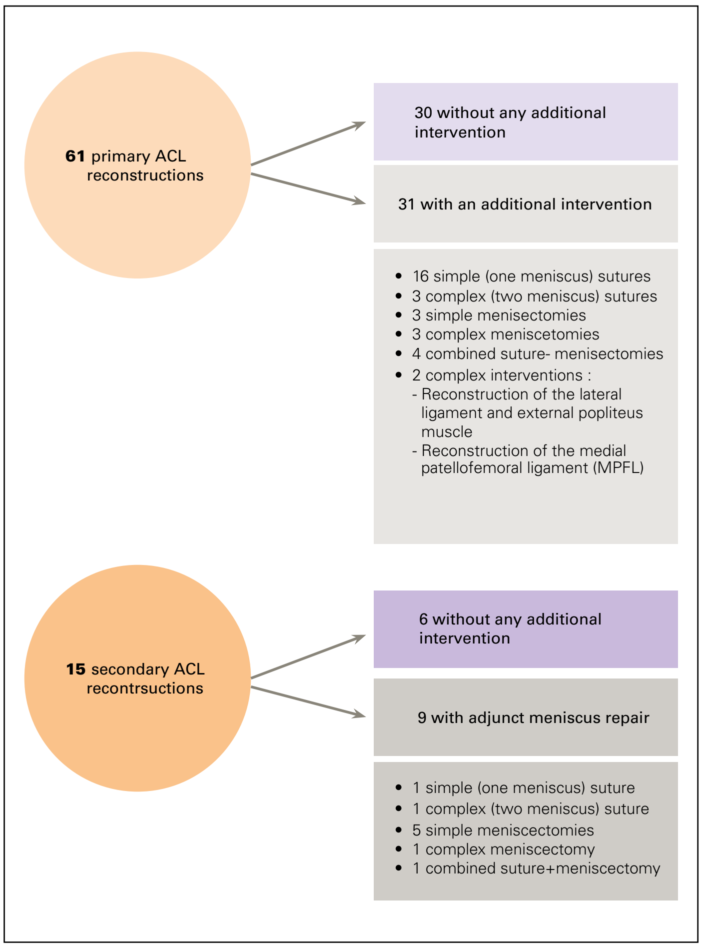


Figure 1: Type of ACL operations in group 2

Group	n	Female	Male	Age at surgery and standard deviation
1	70	31 (46%)	39 (58%)	443.5 months ± 149 months
2	68	33 (48%)	35 (52%)	452 months ± 126 months
3	23	9 (40%)	14 (60%)	87.6 months ± 51 months

Table 5: sex and age distribution of the 3 groups

Postoperative knee function

According to the Tegner-Lysholm score, the medium score is 87.16/100 and corresponds to good according to the established grading. Most of points were lost for squatting difficulties, locking or giving way episodes of the knee.

Painless activity level

More than 80% of the patients are able to return to their former activity level with a Tegner activity level of 6 corresponding to "strenuous activities (in orange) or 7 or more corresponding to very strenuous activites (in blue) [10-12] . Painless activity levels are presented in diagram 1.

Overall satisfaction results

87% of the patients were completely satisfied with both operations (diagram 2). 6% were not satisfied at all. 3% were satisfied only with the knee operation, because they didn't recognize any subjective benefit from the foot operation or felt a discomfort with the foot scar (see diagram 2). 4% did not answer this question. Of the 4 patients who weren't satisfied at all, 2 showed a significant change of pre- and postoperative footprint analysis, 1 showed partial significant changes and 1 showed no change.

2. Complications

6 revisions for post-operative complications were performed: two arthroscopic knee washouts, one motivated by an infection, and two arthroscopies for "cyclops" syndrome and one for partial meniscectomy. One patient had an revision ACL reconstruction. The revision took place 5 years after the first surgery and tearing happened in soccer.

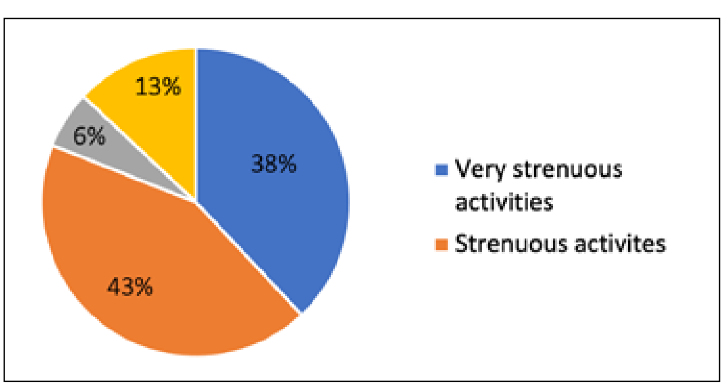


Diagram 1: Tegner score: Painless return to sport for group 1

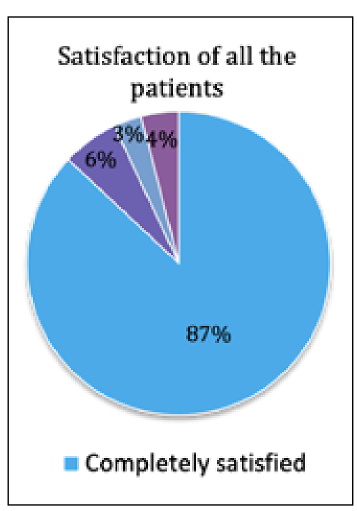


Diagram 2: Tegner-Lysholm score: Overall satisfaction for group 1

No revisions were required after surgical FHL tenolysis. 3 patients notified discomfort or residual pain at the foot scar.

3. Footprint assessments

Significant changes were observed in short-follow-up group 2 (n=68) for 80% of the patients. Static assessment was a bit less significant than the dynamic assessment. No changes at all were present in only 10% or less of the patients. (Table 6).

	Significant change	Partially significant	No significant change	No change
Static assessment	53 patients 80%	6 patients 9%	1 patient 1%	8 patients 10%
Dynamic assessment	56 patients 83%	6 patients 9%	1 patient 1%	5 patients 7 %

Table 6: Group 2: Significance of 68 compared pre-and postoperative footprint analyses

Factors that are not influenced by the FHLim as bony architecture and foot types can have some influence on the results, particularly stiff feet in static assessment with less significant changes [16,17]. In contrast, flat foot architecture can present dramatic changes after FHL tenolysis because of improved rolling motion. Clinical feet examination before surgery could help in some cases to determine the prognosis of changes after FHL tenolysis and focus on patients who will mostly benefit of the FHL tenolysis, which is 80% of cases in this series (significant changes of gait analysis).

In Group 3, for the 23 patients in with a mean post-op follow-up of 7 years, 87% showed significant changes between the pre-and postoperative exams. One patient's study was partially significant, and another patient's study was significant for the dynamic and partially significant for the static assessment. Only one patient showed no significant change. The comparison between groups 2 and 3 highly suggests that the results are stable in time after FHL tenolysis.

INTERPRETATION AND DISCUSSION

The most common mechanism involved in ACL tears is a medial collapse of the knee in late stance occurring in non-contact injuries [18-20]. The foot is firmly planted, the knee locks and twists or pivots at the same time. The landing from a jump or a sudden change of direction are the main causes of non-contact injuries [21-23]. As the lower kinetic chain is connected, meaning that the foot and the knee are interdependent, we concluded that the way of walking influences the knee positioning [24, 25]. FHLim induces a time lag in transition and a sudden tilt from supination into pronation in late stance. This kinematic disorder disrupts the knee alignment in rotation, as well as in varus-valgus. The result is a medial collapse of the knee in valgus induced by an aging corkscrew movement from the foot to the knee increased by a rapid deceleration.

The « pivot shift » test attempts to reproduce the functional combined rotary and translational instability in the ACL-deficient knee. Ron Losee reported this test when he took a sagittal X-ray picture of an ACL – deficient knee that showed an anterior subluxation of the lateral tibial plateau [26]. The clinical reported test was described as: « when I pivot the leg in internal rotation and valgus and bend the knee, the knee shifts ». This pathologic knee kinematics is similar to the foot kinematics generated by the FHLim in late stance. Its sudden transition from supination into pronation induces an internal tibial rotation and valgus at the knee level by inter-articular synchronism. Considering the stress applied to the ACL according to this movement sequence in an average of 5 millions of gait cycles per year, it is not surprising to observe a positive pivot-shift test in a high percentage of cases after ACL reconstruction [27].

We wanted to show in this study that the treatment of FHLim during the same surgical procedure as ACL reconstruction would yield better results concerning knee function and subjective satisfaction [28, 29]. If we extrapolate the high rate of significant gait changes after FHL tenolysis, we can explain the quality of the functional scores obtained with combined procedures. The results are not related only to the ACL surgical technique. Trans-tibial graft positioning is not a recommended technique nowadays but can be efficient in experienced hands. Our results of a high rate of return to sport in strenuous activities for 91% of the patients over a long period of time should be especially allocated to a comeback to a normal kinematics of the whole lower limb. This high percentage is related to significant postoperative changes in gait assessment for more than 80% in group 2 patients. It also explains the low number of re-ruptures (one case).

The cohort of patients in group 1 was small, but the average follow-up was approximately 6 years. When compared with literature [30, 31], our results show a better overall outcome, even regarding articles that describe other techniques such as quadriceps- or patellar tendon autograft [32, 33]. What highlights our study are sustainable results over a long-term follow-up, compared to other studies [34, 35]. The revision rate concerned only 8% of patients for the ACL reconstruction and 0% for the FHL tenolysis. At the beginning of the series, FHL tenolysis was proposed in complex cases more prone to develop secondary instability and/or recurrent or additional meniscal or cartilage lesions. Much of our analyzed patients of group 2 suffered from multiple lesions (9%), additional meniscal tears (43%) and 19% are ACL secondary reconstructions (first revision for 14 patients and second revision for 1). Nevertheless, most of the patients are satisfied over a long period of time, even after having resumed strenuous activities. This could be mainly related to improved stability. Body balance is influenced by multiple factors as muscle strength, proprioceptive information and bony foot anatomy [36], though the determinant factor seems the normal glide of FHL tendon and a free subtalar joint. By restoring normal kinematics in gait and a sustainable physiological rolling motion, FHL release seems the predominant factor to regain stability and avoid new injuries. Considering its biomechanical improvement in active patients, the effectiveness of the procedure and the low rate of complication, FHL tenolysis must be discussed and considered in any case of ACL injury.

The 23 patients of group 3 whose postoperative gait analysis took place 7 years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after surgery showed excellent results, with 83% of significant changes in the static assessment and respectively 87% in the dynamic assessment. These results are even better than those of group 2, which proves that excellent results are achieved and maintained over a long follow-up period. We can also see that the patients of group 1, that weren't satisfied of the intervention showed in 50% of the cases a partial or no change of the pre- and postoperative podologic analysis. This finding result supports our hypothesis that the FHL tenolysis is needed in order to provide sustainable changes of the foot's rolling motion during gait and therefore creating less pain, higher well-being and lower re-rupture and complication rates. A very recent article of Sonnery-Cottet shows not only a high re-rupture rate of the operated knee in ACL reconstruction but also a very high controlateral re-rupture rate of 26.7% (isolated ACL) and 17.4% after a combined ACL+ALL (anterolateral ligament) reconstruction, with a mean follow-up of 104.33±3.84 months [37]. These results confirm again, that FHLim creates a global dysfunction and imbalance that concerns the knee, foot and the entire lower limb. Gait and podologic analysis are helpful for a successful treatment in ACL tears. In case of knee ligament reconstruction only, conservative management of FHLim should be considered and included in rehabilitation protocols for physical therapy.

Most of the predisposing factors in ACL injuries are well documented [2] but few are related to a functional approach, balance, movement and gait. The hyper-specialization in orthopedics leads to focus more on ACL than on the predisposing factors for these injuries related for the majority of them to the same mechanism. Gait analysis is a neglected tool even if it gives crucial information in terms of kinematics [38]. Customized treatment is now the gold standard in knee arthroplasty, but why don't we use a simple podologic exam to understand the biomechanical problem in a patient with ACL lesion? Mini-invasive, often easy to perform before elective surgery, as for ACL reconstruction, this exam can also help the patient to understand her or his situation and to position her- or himself in a participative attitude for the rehabilitation. Should we still consider an ACL rupture as an unexpectedly or hazardous event? The arguments presented in the study tend to prove the contrary. One of the main issues in ACL pathophysiology is to identify the crucial factors for imbalance and functional impairment and FHLim seems for us to be the main factor.

Improvements in ACL reconstruction as double bundle techniques or additional extra articular ligamentous procedures are often proposed in complex cases in order to achieve sustainable results [39]. Unfortunately, many reports in the literature are not able to convince us: short-term results are often related to a delayed rehabilitation and stiffer knees and long-term results are presented with poor objectivity, having a high percentage of positive Lachman test (40%) [40].

Moreover, objective radiological measurements showed already at one year a pivot shift in 40% of patients and the rate of re-rupture is not negligible (10-15%) [41]. This means, that to associate a FHL tenolysis to an ACL reconstruction procedure seems to be the less invasive for successful sustainable results.

This holistic line of approach according to a personalized patient support is able to give the best chance to come back to strenuous activities with the lowest risk of recurrent injuries. In addition, balance and inter-articular synchronism are restored after FHL tenolysis and this global improvement of wellbeing could have a beneficial effect on performance.

The reliability of this study is given despite its polymorphic design. We combine a retrospective part through ACL reconstruction and a prospective one through our preoperative podologic analysis. As already described by previous literature, patient reported outcome measure (PROMS) are more significant for usefulness and value of a therapeutic intervention than patient reported experience measures (PREMS) [42]. This means, that even if we didn't include an objective clinical assessment for knees as a pivot shift or Lachmann test, patient-related results are relevant. The association of pro- and retrospective parts creates a good overview of sustainable results, even if it represents a particular study design.

CONCLUSION

Nevertheless, we hope that this article will open the eyes of our colleagues on the interdependence of the lower extremity joints and a functional approach based on gait analysis. ACL tear is not only a knee problem and has to be understood in a new way. Podologic examination gives useful and reliable tools to diagnose imbalance and/or FHLim. Recurrent ACL ruptures, meniscal tears or residual laxity are common after ACL and FHLim could partially explain this phenomenon. Complex cases could particularly benefit from FHL release or surgically or conservatively by specific exercises during the rehabilitation. This new trend holds promise for further improvements in terms of stability for ACL injuries as well for other pathologies. ■

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