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Benefit of the Early Open Kinetic Chain on the Quadriceps Strength after Anterior Cruciate Ligament Reconstruction in Male Soccer Players in a Context of Return to Running

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ABSTRACT

Background: The objective of this study is to determine whether the early association of the open kinetic chain (OKC) and the closed kinetic chain (CKC) allows an improvement in the strength and functional qualities of the quadriceps in the context of soccer rehabilitation after anterior cruciate ligament reconstruction.

Materials: A collection of prospective data on two groups of 15 subjects who all suffered an after anterior cruciate ligament (ACL). Each subject is assigned to a group according to the type of rehabilitation they have undergone within the center, with only CKC rehabilitation and mixed OKC and CKC rehabilitation. The protocols were introduced four weeks after ACL reconstruction. The measurements were carried out at three months on an isokinetic dynamometer to measure the peak torque (PT) and to be able to determine limb symmetry index (LSI) and the PT concerning the body weight, the relative peak torque (PT/WB).

Results: After testing the LSI and the PT/WB between the two groups, there was a significant difference ($p < 0.05$) between the LSI of the two groups and a very significant difference between the PT/WB ($r=0.817$; $p<0.001$). We have also shown a significant positive correlation between these two parameters.

Conclusion: The study suggests an interest in the early association of OKC and CKC in correcting quadriceps strength deficits and improving its functional quality after ACL reconstruction.

Keywords: anterior cruciate ligament reconstruction, peak torque, open kinetic chain, early rehabilitation, limb symmetry index, soccer players.

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INTRODUCTION

In soccer, an anterior cruciate ligament (ACL) injury is one of the most common and problematic injuries, both amateur and professional. One of the most frequent options following the injury is a surgical treatment with ACL reconstruction, followed by rehabilitation, re-athletic training, and re-training to regain a level and competitive practice. However, the process of returning to competition can take a long time to hope for a return to the initial level of performance and presents iterative injury risks.

At a high level, such unavailability entails considerable costs for the clubs, whether they are sporting (impossibility of integrating one or more convalescent players into the rotation over a long period) and financial (payment of salary despite unavailability, the cost of the operation, and rehabilitation, etc.). Beyond these costs and despite rehabilitation, athletic training, and retraining, some affected athletes and whatever the level never return to competition or to their original sport due to an ACL injury. Indeed, among professionals, the rate of return to competition considered successful (return to the initial performance level) is around 85% [1], while it is only 55 to 60% at the leisure level [2]. Moreover, beyond sporting and financial issues, a failure to resume sports practice has a pathological dimension by inducing a sedentary lifestyle that will promote other long-term ailments, in particular cardiovascular.

The sine qua non-conditions for a triumphant return to competition lie partly in the quality of the surgical procedure and the patient's clinical management, and the quality of rehabilitation and re-athletic training. It is in this second part that we can act. Generally, the return to sport (RTS) is based on temporal criteria. The decision to return to sport is made at the end of the rehabilitation process [3]. It is done by obscuring many other factors, sensorimotor parameters, etc.) because it follows a temporal frame that does not allow individualizing the decision-making. One of the criteria, if not the criterion considered central in decision-making during rehabilitation, is muscle strength in its different modalities [4].

In rehabilitation, it is the closed kinetic chain (CKC) work that is the most used at a stage early. Conversely, open kinetic chain (OKC) work usually happened later. Few studies have been shown the effects of the OKC on muscle strength. Still, Mikkelsen et al. [5] showed that the use of the OKC significantly increases the strength (torque) of the quadriceps without inducing more significant knee laxity. However, this is one of the few studies examining the effects on muscle strength, and it is not the most recent.

Therefore, it appears essential to support, monitor, and above all optimize the process of returning to competition following such an injury to partly limit the consequences on future practice (return to a level performance before the injury) and attempt to stem or at least limit a total withdrawal from practice among the soccer player. He should more particularly feel the effects of the early introduction of an OKC work within the framework of the RTS because this method is little used at such a stage of rehabilitation. After reviewing the associated literature, the objective of this thesis will be to test the interest of this method at an early stage of rehabilitation on variables considered to be decisive in rehabilitation to optimize the return to competition for soccer.

MATERIALS AND METHOD

To respond to the problem, we favored research by collecting data. However, the method of data collection is prospective.

The study performed is a multicenter study. It was executed in a private clinic as well as in a liberal rehabilitation center in Domont.

The population is presented here in a demographic table of the test and control groups.

The study was carried out on 30 soccer players of varying levels of practice, randomly assigned to two groups of 15 depending on the nature of the protocol they followed (Table 1). All are monitored and evaluated by the structure as part of their rehabilitation following an ACL reconstruction.

All underwent a similar type of surgery (hamstring graft) following their ACL injury to be included in the study. All were injured while practicing their activity, and those whose rehabilitation follows a recurrence of an ACL injury are excluded. To be able to be included and to carry out the assessments, all had to meet the primary criteria conditioning the return to running (RTR), namely: an amplitude of movement of the injured leg equal to at least 95% of that of the healthy leg, a score of the Visual Analogue Scale less than 2 (VAS), as well as an absence of intra-articular effusion (6).

The study is prospective, so, once selected based on the inclusion criteria defined above, the athletes are divided into two groups according to the rehabilitation protocol they followed. Concretely, within the rehabilitation center, the modalities and protocols of rehabilitation vary from one practitioner to another, some systematically implementing mixed OKC and CKC protocols with their patients, others using the CKC exclusively.

The subjects are therefore assigned to two groups, a CKC control group (CKC exclusively) and an OKC test group (mixed OKC and CKC rehabilitation) according to the type of rehabilitation they have undergone as part of their training RTR.

The OKC group followed a mixed protocol with muscular work in OKC and CKC. For the OKC group, work in OKC was initiated from 4 weeks after surgery (29.7 days ± 8.4) [7]. In addition to the exercises mentioned above for the CKC group, the rehabilitation process of the second group included various exercises in OKC, for example, sessions with knee extensions against resistance on an isokinetic dynamometer (the protocols, number of repetitions, and the angular speeds applied to be progressive throughout

the two months, with work at an angular speed of 120 °.s^{-1} at the start and maintained over the two months by gradually adding series on lower angular speeds, 90 ° s^{-1}, 60 ° .s^{-1} then 30 °.s^{-1}), leg extensions coupled with electrostimulation at the edge of the table, leg extensions on a quadriceps machine.

Rehabilitation of the two groups is standardized between the surgery and the end of the first month preceding the start of the protocol and, therefore, OKC for the test group.

The evaluation of the two groups was carried out three months after the operation (99.9 days ± 14.5; Table 1), the time being variable between each individual but without significant difference between the two groups, because the time is not an absolute decision criterion and the deadlines had to be individualized based on other objective variables [6]. Therefore, the achievement of the isokinetic assessment coincides with the RTR following it (based on the objective criteria evaluated) [6].

The assessment of all individuals was performed on the same EasyTech Genu Plus Concentric / Eccentric isokinetic dynamometer available at the clinic, and data was collected on the computer software interface attached to the machine

The purpose of these checkups was to measure the peak torque (PT, given in Newton meters, Nm) of the quadriceps on knee extension movements. The values of PT were then related to the weight (PT/WB) of the subjects to obtain relative maximum torque values for each of the subjects, as an indicator of the functional quality of the quadriceps, [8] but also related to the PT of the leg healthy to be able to determine the limb symmetry index (LSI) between the two legs [9].

Before proceeding with the isokinetic assessments, each of the subjects followed a standardized warm-up comprising 10 minutes of walking.

Once the warm-up was completed, and the positioning was carried out on the machine, each of the subjects carried out a protocol of 1 series of 4 knee extensions per leg at 60 °.s-1 [10], over an angular range of 100 ° flexion at 0 ° (full extension). The series was carried out first on the injured leg and then on the healthy leg.

The angular range was chosen, and the angular velocity corresponds to the standards in the literature in terms of isokinetic evaluation of the PT of the quadriceps in the context after ACL reconstruction follow-up [11]. This is justified by the fact that the maximum measured torque values are obtained in 0 and 60 °.s^{-1} and an evaluation at a higher angular speed would, on the one hand, decrease the values of the PT but would also decrease the sensitivity of a comparison of PT between two legs or two distinct groups, thus skewing decision making under RTS.

The statistical processing of the data was carried out on the Jamovi software (The jamovi project (2021). Jamovi (Version 1.6) [Computer Software]).

The objective of this statistical treatment was to identify or not significant differences between the LSI on the OKC group and the CKC group and the PT/WB (Nm.kg^{-1}) of the injured leg between the two groups to be able to confirm or not our hypotheses suggesting the benefits of an early association of muscular work in OKC and CKC.

We consider here two distinct groups of people; these are independent variables that must be tested with a Student T test if the following conditions are true. We, therefore, first determined the normality of the data using a Shapiro-Wilk test. Then, the distribution being normal, we were able to carry out the T-test.

We also tested the epidemiological data (age, height, weight, postoperative delays) between the two groups to identify or not significant differences between them and to be able to identify or eliminate bias.

A Pearson correlation test was also performed between the groups' symmetry index and the maximum relative torque to show or not a correlation between the two variables considered.

RESULTS

Table 1: Demographic data

Population (mean + SD)		
n	**30**	
Age (y)	26,5 ± 5	p=0,868 (NS)
Size (cm)	178,5 ± 6	p=0,901 (NS)
Weight (kg)	79,2 ± 10,1	p=0,56 (NS)
Post-operative deadline (days)	99,9 ± 14,5	p=0,271 (NS)
Testing Group (mean + SD)		
n	**15**	
Age (y)	26,3 ± 5,3	NS
Size (cm)	26,3 ± 5,3	NS
Weight (kg)	77,8 ± 10,2	NS
Post-operative deadline (days)	97,9 ± 17,5	NS
Control group (mean + SD)		
n	**15**	
Age (y)	26,7 ± 4,9	NS
Size (cm)	178,9 ± 6,3	NS
Weight (kg)	80,5 ± 10,2	NS
Post-operative deadline (days)	101,8 ± 10,9	NS

The two groups do not present a statistically significant difference (Table1) between them looking at the epidemiological data of age, height, weight, and time between the operation and the assessment (p> 0.05).

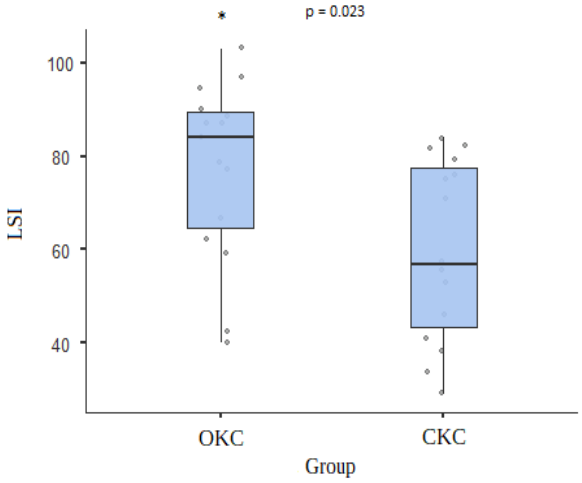

Figure 2: LSI comparison between OKC group and CKC group

The statistical analysis revealed a statistically significant difference (Figure 2) between the percentages of LSI of the two groups (p = 0.023).

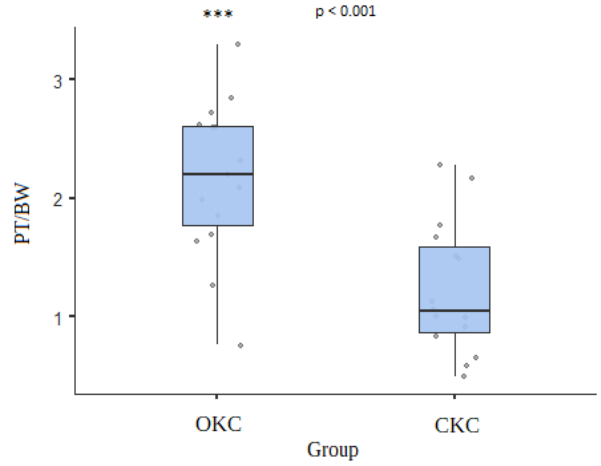

Figure 3: PT/WB (Nm.kg-1) comparison between OKC group and

The statistical analysis carried out revealed a very significant statistical difference (figure3) between the PT/WB values of the two groups (p <0.001).

Table 2: Mean value of LSI and PT / WB

Group	LSI	PT/BW
OKC	77,2 ± 19,3	2,16 ± 0,66
CKC	60,2 ± 19,2	1,23 ± 0,56
	%	Nm.kg^{-1}

Table 2 summarizes the mean values of the symmetry index and the PT/WB for the two groups. The average LSI of the OKC group is 77.2%, and 60.2% for the CKC group. Thus, it can be seen that the LSI of the CKC group is 22% lower than that of the OKC group.

The average PT/WB of the OKC group is 2.16 Nm/kg and 1.23 Nm/kg for the CKC group, i.e., a difference of 43% between the two groups.

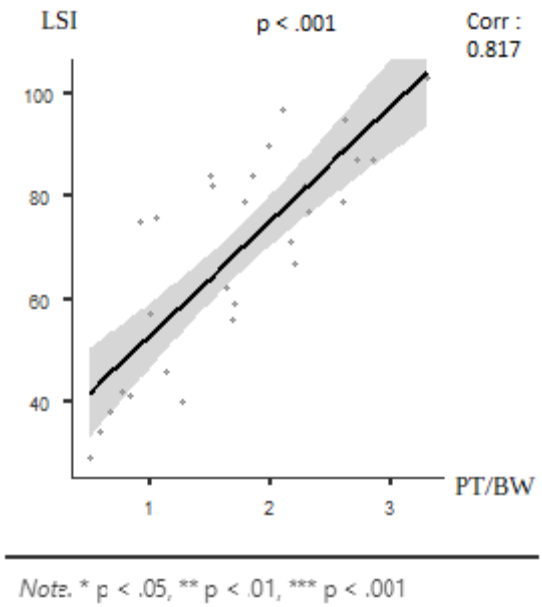

Figure 4: Pearson's Correlation between LSI and PT / WB (Nm.kg-1)

The Pearson test applied to the data of LSI and PT/WB show a very significant positive correlation (r = 0.817) (p <0.001) between the LSI and the PT/WB (figure 4)

DISCUSSION

The objective set by this study was to show the benefits of the early introduction of a rehabilitation protocol combining OKC with CKC, both on the correction of the quadriceps strength deficits inherent in ACL injury and on its functional quality. To meet this objective, two hypotheses were defined. First, combining OKC and CKC at an early stage improves LSI, and the combination of OKC and CKC at an early stage improves the functional qualities of the quadriceps. Second, to meet this objective, we identified two parameters to be studied, namely the LSI, an index of force symmetry between the leg having undergone the ACL injury and the surgery and the healthy leg, as well as the PT/WB control of the quadriceps strength, but also its functional quality. These two parameters were both obtained from the measurement of the PT on an isokinetic evaluation.

Regarding LSI, the results detailed in the previous section show a significant difference between the two groups (p = 0.023); the group has benefited from OKC and CKC based rehabilitation having the highest values. In addition, the average of this first group is 77.2% (as a reminder, an LSI of 100% allows us to consider that there is no difference in strength between the quadriceps of the healthy and injured leg). In comparison, it is 60.2% for the CKC group, i.e., a difference of 22% between the two groups. These results suggest a significant benefit from the early introduction of a protocol including OKC exercises to correct inter-limb strength deficits. By putting into perspective with other studies testing the introduction of a rehabilitation protocol including OKC exercises, the results obtained are in agreement with the study by Mikkelsen et al. in 2000 [5], which had measured a significant difference in LSI by

comparing a mixed OKC and CKC protocol to a protocol exclusively in CKC, introduced six weeks after ACL reconstruction. The difference between the means of the two groups was 26.6% for 22% in our study; nevertheless, the evaluation was carried out six months after surgery against three months in our case, and the introduction of the protocols is later. As the study was conducted over a more extended period, they compared the LSI values to the rate of RTS of their subjects, which our study did not allow us. Another study [12] measured a difference in LSI of 15% between a mixed OKC and CKC group and a CKC group after four months of rehabilitation. However, this rehabilitation did not systematically follow an ACL injury but various injuries and impairments involving the same ligament.

Conversely, our results go against those obtained by the study by Heijne et al. in 2007 [13], which did not find a significant difference in the LSI obtained after a 3-month post-operation assessment between their two groups. However, their rehabilitation protocol, which included OKC exercises, did not include strengthening sessions on an isokinetic machine or electrostimulation, but only leg extensions on a quadriceps machine. Therefore, the two protocols are not comparable, which may help justify such differences in LSI between the two studies. Because of the importance of limiting strength deficits between the two legs, which has been shown several times in the literature [14-16], it was essential to evaluate this parameter to test the benefits of a protocol including exercises in OKC.

Our study also considered the PT/WB values obtained from the maximum torque measured during isokinetic balances. The difference between our two groups is very significant here ($p < 0.001$), with a difference of the order of 43% between the groups, which agrees with the symmetry indices obtained to suggest a benefit from the association of OKC and CKC exercises at an early stage of the RTS process, on the one hand on the correction of strength deficits but also the improvement of the functional quality of the quadriceps. Most studies with protocols approaching ours have considered the LSI and the PT [5,12,13,17], although the PT/WB is equally relevant [3,18]. As our study did not standardize the level of practice of the subjects and the preoperative strength values, a comparison based on the PT alone was not possible because it was carried out on a single assessment. We chose to use the PT/WB to attest to the functional quality of the subject's quadriceps because although it does not allow direct measurement, it is a powerful predictor of the subjects' functional recovery in the longer term [8]. It also seemed necessary to us to attest to the effects of the protocol on such an indicator because of the critical importance of the functional quality of the knee extensors in the success of the rehabilitation process [19]. Although the difference in PT/WB between the two groups matches the LSI, the difference between our two groups is much more than significant, and even though it is not the same variable, it is much higher. Beyond the PT differences found in the literature. For example, Kang et al. in 2012 [17] report a difference of 15% between the PT of the mixed rehabilitation group OKC and CKC and the CKC group, but the study does not provide any details. On the chronology of the rehabilitation protocol and the evaluation. The study by Mikkelsen et al. in 2000 [5] also shows a significant difference between his two groups and a difference of about 23% between the mean PT of the two groups. Therefore, such a gap between our groups seems to be put into perspective, and although it supports our hypotheses, it is necessary to consider certain limits that could explain it. Indeed, our study does not present a standardization of levels between the players, including having a sufficient sample induces a bias. There may be a prior imbalance between the two groups and, therefore, players with a higher relative strength preoperative and pre-injury. To minimize this bias, it would be ideal to have preoperative strength data for each of the subjects, which is difficult to achieve outside professional sport because this would imply systematic monitoring of a cohort of players over several years an ACL tear is not predictable. Although the rehabilitation protocols are similar within the groups, we couldn't control the attendance of certain participants, and the context of early rehabilitation could lead practitioners to regulate the exercises proposed according to the participants (for example, if a subject reported pain on particular exercises or specific movements, etc.)

The Pearson test that we performed indicates a strong positive correlation between the LSI and the PT/WB ($r = 0.817$). This relation met before the link between the LSI, a quantitative witness because it is an index of the balance of the force between the observed leg and the healthy leg, and the PT/WB, which qualitatively testifies not only to the relative force. The quadriceps of the injured leg but also its functional quality. Indeed, we know that although the LSI is a criterion considered in the decision making during the continuum of RTS, as an indication, for the quadriceps, the LSI must be greater than 70% at 60 $°.s^{-1}$ to authorize the RTR [4], this decision-making is multifactorial and must not obscure other parameters. Here the PT/WB is significantly higher for the group with a mixed OKC and CKC rehabilitation with an average of 2.16 Nm/kg. Still, for a subject who presented an LSI allowing absolute terms a RTR, the PT/WB is also to be considered because a relative force that is too low despite a high LSI does not allow the RTR. Rehabilitation and, therefore, the choice of protocols must meet an objective of partly correcting imbalances and a functional objective, which requires a relatively high PT/WB. The study by Pietrosimone et al. in 2016 [8] recommends a threshold of 3.10 Nm/kg to maximize the functional quality of the quadriceps and succeed in its rehabilitation. Such a threshold seems even higher and even more at an early stage of rehabilitation because it implies that a 70kg person develops a PT of 217Nm, which for a subject is achievable but more difficult to envisage for a sedentary population.

This underlines the importance of maximizing the balance of force between the two legs and the functional quality

of the quadriceps, which must be the objective and the result of the rehabilitation protocols proposed within the framework of the RTS.

CONCLUSION

In soccer, the success rates of RTS following an ACL injury are still low in an amateur context, and the length of rehabilitation time has an impact on both the player and the team. The objective of our study was to highlight the benefits of using OKC at an early stage of rehabilitation due to the proven importance of optimizing the muscle strength of the quadriceps and its functional quality on the success of the return-to-performance process. This demonstrated a dual benefit of the early combination of exercises in OKC and CKC as part of rehabilitation following an ACL tear, both in the correction of quadriceps strength deficits and improved functional quality. The results obtained show a better LSI and a higher PT/WB for the group that has followed a mixed OKC and CKC protocol than the group having only undergone rehabilitation in CKC. However, our study has limitations, and to get a better idea of the results of the early combination of OKC and CKC exercises in the rehabilitation protocol, it would be relevant to conduct a study by standardizing the level of practice of the players included. Furthermore, to test the effects of protocols on the same variables and have a higher level of evidence. It would also be relevant to have the rates of return to successful sport of subjects to be able to compare between groups.

REFERENCES

[1] Lai, Courtney C. H., Clare L. Ardern, Julian A. Feller, et Kate E. Webster. « Eighty-Three per Cent of Elite Athletes Return to Preinjury Sport after Anterior Cruciate Ligament Reconstruction: A Systematic Review with Meta-Analysis of Return to Sport Rates, Graft Rupture Rates and Performance Outcomes ». *British Journal of Sports Medicine* 52, nº 2 (1 janvier 2018): 128-38. https://doi.org/10.1136/bjsports-2016-096836

[2] Ardern, Clare L., Philip Glasgow, Anthony Schneiders, Erik Witvrouw, Benjamin Clarsen, Ann Cools, Boris Gojanovic, et al. « 2016 Consensus Statement on Return to Sport from the First World Congress in Sports Physical Therapy, Bern ». *British Journal of Sports Medicine* 50, nº 14 (1 juillet 2016): 853-64. https://doi.org/10.1136/bjsports-2016-096278.

[3] Dingenen, Bart, et Alli Gokeler. « Optimization of the Return-to-Sport Paradigm After Anterior Cruciate Ligament Reconstruction: A Critical Step Back to Move Forward ». *Sports Medicine (Auckland, N.Z.)* 47, nº 8 (août 2017): 1487-1500. https://doi.org/10.1007/s40279-017-0674-6.

[4] Rambaud, Alexandre J. M., Clare L. Ardern, Patricia Thoreux, Jean-Philippe Regnaux, et Pascal Edouard. « Criteria for Return to Running after Anterior Cruciate Ligament Reconstruction: A Scoping Review ». *British Journal of Sports Medicine* 52, nº 22 (1 novembre 2018): 1437-44. https://doi.org/10.1136/bjsports-2017-098602.

[5] Mikkelsen, C., S. Werner, et E. Eriksson. « Closed Kinetic Chain Alone Compared to Combined Open and Closed Kinetic Chain Exercises for Quadriceps Strengthening after Anterior Cruciate Ligament Reconstruction with Respect to Return to Sports: A Prospective Matched Follow-up Study ». *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA* 8, nº 6 (2000): 337-42. https://doi.org/10.1007/s001670000143

[6] Rambaud, Alexandre J. M., Bertrand Semay, Pierre Samozino, Jean-Benoît Morin, Rodolphe Testa, Rémi Philippot, Jérémy Rossi, et Pascal Edouard. « Criteria for Return to Sport after Anterior Cruciate Ligament Reconstruction with Lower Reinjury Risk (CR'STAL Study): Protocol for a Prospective Observational Study in France ». *BMJ Open* 7, nº 6 (30 juin 2017): e015087. https://doi.org/10.1136/bmjopen-2016-015087.

[7] Perriman, Alyssa, Edmund Leahy, et Adam Ivan Semciw. « The Effect of Open- Versus Closed-Kinetic-Chain Exercises on Anterior Tibial Laxity, Strength, and Function Following Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-Analysis ». *The Journal of Orthopaedic and Sports Physical Therapy* 48, nº 7 (juillet 2018): 552-66. https://doi.org/10.2519/jospt.2018.7656.

[8] Pietrosimone, Brian, Adam S. Lepley, Matthew S. Harkey, Brittney A. Luc-Harkey, J. Troy Blackburn, Phillip A. Gribble, Jeffrey T. Spang, et David H. Sohn. « Quadriceps Strength Predicts Self-Reported Function Post-ACL Reconstruction ». *Medicine and Science in Sports and Exercise* 48, nº 9 (septembre 2016): 1671-77. https://doi.org/10.1249/MSS.0000000000000946.

[9] Lynch, Andrew D., David S. Logerstedt, Hege Grindem, Ingrid Eitzen, Gregory E. Hicks, Michael J. Axe, Lars Engebretsen, May Arna Risberg, et Lynn Snyder-Mackler. « Consensus Criteria for Defining "successful Outcome" after ACL Injury and Reconstruction: A Delaware-Oslo ACL Cohort Investigation ». *British Journal of Sports Medicine* 49, nº 5 (mars 2015): 335-42. https://doi.org/10.1136/bjsports-2013-092299.

[10] Undheim, Marit Baste, Ciaran Cosgrave, Enda King, Siobhán Strike, Brendan Marshall, Éanna Falvey, et Andrew Franklyn-Miller. « Isokinetic Muscle Strength and Readiness to Return to Sport Following Anterior Cruciate Ligament Reconstruction: Is There an Association? A Systematic Review and a Protocol Recommendation ». *British Journal of Sports Medicine* 49, nº 20 (octobre 2015): 1305-10. https://doi.org/10.1136/bjsports-2014-093962.

[11] Impellizzeri, Franco M., Mario Bizzini, Ermanno Rampinini, Ferdinando Cereda, et Nicola A. Maffiuletti. « Reliability of Isokinetic Strength Imbalance Ratios Measured Using the Cybex NORM Dynamometer ». *Clinical Physiology and Functional Imaging* 28, nº 2 (mars 2008): 113-19. https://doi.org/10.1111/j.1475-097X.2007.00786.x.

[12] Tagesson, Sofi, Birgitta Oberg, Lars Good, et Joanna Kvist. « A Comprehensive Rehabilitation Program with Quadriceps Strengthening in Closed versus Open Kinetic Chain Exercise in Patients with Anterior

Cruciate Ligament Deficiency: A Randomized Clinical Trial Evaluating Dynamic Tibial Translation and Muscle Function ». *The American Journal of Sports Medicine* 36, nº 2 (février 2008): 298-307. https://doi.org/10.1177/0363546507307867.

[13] Heijne, Annette, et Suzanne Werner. « Early versus Late Start of Open Kinetic Chain Quadriceps Exercises after ACL Reconstruction with Patellar Tendon or Hamstring Grafts: A Prospective Randomized Outcome Study ». *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA* 15, nº 4 (avril 2007): 402-14. https://doi.org/10.1007/s00167-006-0246-z.

[14] Grindem, Hege, Lynn Snyder-Mackler, Håvard Moksnes, Lars Engebretsen, et May Arna Risberg. « Simple Decision Rules Can Reduce Reinjury Risk by 84% after ACL Reconstruction: The Delaware-Oslo ACL Cohort Study ». *British Journal of Sports Medicine* 50, nº 13 (juillet 2016): 804-8. https://doi.org/10.1136/bjsports-2016-096031.

[15] Kyritsis, Polyvios, Roald Bahr, Philippe Landreau, Riadh Miladi, et Erik Witvrouw. « Likelihood of ACL Graft Rupture: Not Meeting Six Clinical Discharge Criteria before Return to Sport Is Associated with a Four Times Greater Risk of Rupture ». *British Journal of Sports Medicine* 50, nº 15 (août 2016): 946-51. https://doi.org/10.1136/bjsports-2015-095908.

[16] Palmieri-Smith, Riann M., Abbey C. Thomas, et Edward M. Wojtys. « Maximizing Quadriceps Strength after ACL Reconstruction ». *Clinics in Sports Medicine* 27, nº 3 (juillet 2008): 405-24, vii-ix. https://doi.org/10.1016/j.csm.2008.02.001.

[17] Kang, Hyungkyu, Jinhwa Jung, et Jaeho Yu. « Comparison of Strength and Endurance between Open and Closed Kinematic Chain Exercises after Anterior Cruciate Ligament Reconstruction: Randomized Control Trial ». *Journal of Physical Therapy Science* 24, nº 10 (2012): 1055-57. https://doi.org/10.1589/jpts.24.1055

[18] Welling, Wouter, Anne Benjaminse, Koen Lemmink, Bart Dingenen, et Alli Gokeler. « Progressive Strength Training Restores Quadriceps and Hamstring Muscle Strength within 7 Months after ACL Reconstruction in Amateur Male Soccer Players ». *Physical Therapy in Sport: Official Journal of the Association of Chartered Physiotherapists in Sports Medicine* 40 (novembre 2019): 10-18. https://doi.org/10.1016/j.ptsp.2019.08.004.

[19] Williams, Glenn N., Lynn Snyder-Mackler, Peter J. Barrance, et Thomas S. Buchanan. « Quadriceps Femoris Muscle Morphology and Function after ACL Injury: A Differential Response in Copers versus Non-Copers ». *Journal of Biomechanics* 38, nº 4 (avril 2005): 685-93. https://doi.org/10.1016/j.jbiomech.2004.04.004.