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Human Kinetics
ORIGINAL RESEARCH REPORT

No Relationship Between Preoperative and Early Postoperative Strength After ACL Reconstruction

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Context: All rehabilitative programs before anterior cruciate ligament (ACL) reconstructive surgery, which are focused on recovery of proprioception and muscular strength, are defined as prehabilitation. While it has shown that prehabilitation positively affects the overall outcome after ACL reconstruction, it is still controversial whether preoperatively enhancing quadriceps strength has some beneficial effect on postoperative strength, mainly during the first period. ***Objective:*** To determine whether there is any relationship between preoperative and early postoperative quadriceps strength. ***Design:*** Case control. ***Setting:*** University research laboratory. ***Participants:*** Fifty-nine males (18–33 y; age: 23.69 [0.71] y) who underwent ACL reconstruction with patellar-tendon autograft were examined the day before surgery, and at 60 and 90 days after surgery. ***Main Outcome Measures:*** The limb symmetry index (LSI) was quantified for maximal voluntary isometric contraction of the knee extensor muscles and of the knee flexor muscles at 90° joint angle. A k-means analysis was performed on either quadriceps or hamstrings LSI before surgery to classify the patients in high and low preoperative LSI clusters. Differences in postoperative LSI were then evaluated between the high and low preoperative LSI clusters. ***Results:*** Following surgery, there were no differences in the quadriceps LSI between patients with high and low preoperative quadriceps LSI. Sixty days after surgery, the hamstrings LSI was higher in patients with high than low preoperative hamstrings LSI (84.0 [13.0]% vs 75.4 [15.9]%; $P < .05$). ***Conclusions:*** Findings suggest that quadriceps strength deficit is related to the ACL injury and increases further after the reconstruction without any correlation between the preoperative and postoperative values. Therefore, it appears that there is no need to delay surgery in order to increase the preoperative quadriceps strength before surgery.

Keywords: quadriceps strength, prehabilitation, maximal voluntary isometric contraction

Anterior cruciate ligament (ACL) rupture is one of the most common traumatic injuries among physically active individuals. Surgical reconstruction remains the standard approach for athletes who aim to return to high-level sporting activities and aims to re-establish the ligamentous stability of the knee joint. Even if ACL reconstruction (ACLr) has shown good results in terms of knee stability, residual and persistent quadriceps strength deficit is reported as one of the limiting factors in return to preinjury level of function and activity,[1–4] and this deficit can persist for more than 2 years after surgery. It has been reported that quadriceps weakness is predictive of poor knee function after injury or surgery.[5,6] Therefore, quadriceps weakness and its potential long-term negative influence on knee function is a major concern after ACL injury and surgery.

It has been reported that preoperatively enhancing quadriceps strength may improve the outcomes of subjects undergoing ACLr,[7–9] and preoperative rehabilitative programs are commonly believed to be useful to restore strength prior to surgery.[10–12] All these rehabilitative programs, which are mainly focused on recovery of proprioception and muscular strength, are defined as prehabilitation. The preoperative phase may be useful to reduce the risk of postoperative complications and to improve a successful return to high-level activity. Many studies have confirmed these effects in the long term after surgery with better quadriceps strength and better evaluation scores.[10,13,14] Therefore, for these reasons, a period of preoperative rehabilitation in order to increase the muscular strength is advised by many surgeons before the surgery. But, in our practice, this period is quite difficult to arrange for athletes who have specific time requirements as to when surgery can be performed. Nevertheless, the relationship between preoperative and postoperative quadriceps strength is more uncertain[10] when the quadriceps strength is evaluated 3 months after surgery. In addition, most of the previous studies were carried out in cohorts of ACL patients who were not homogeneous, in terms of time elapsed from injury, different graft source, gender, age, and type of muscular assessment.

Therefore, persistent quadriceps weakness following surgery presents a difficult clinical dilemma for the treating clinician. An important underlying factor contributing to this problem is the arthrogenic muscle inhibition, which remains understudied. Different studies[15–17] have demonstrated that muscular wasting occurs mainly during the first postoperative month, suggesting that there is a surgically induced effect that occurs immediately after ACLr. The purpose of the present study was to determine if there is any relationship between preoperative and early postoperative quadriceps strength after ACLr, mainly during the first 3 months when the greatest wasting of muscular strength occurs. We hypothesized that the early postoperative quadriceps strength was not influenced by its preoperative value but that other factors related to surgery may induce muscular wasting during the first months.

Methods

We limited our study to the first 3 months for several reasons. The main was that it is that at this time frame, it occurs the most

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significant decline in maximal voluntary isometric contraction (MVIC) and voluntary activation.[15,16] The mean MVIC decreases of 50% in comparison with nonaffected limb during the first postoperative month and increases approximately linearly during the following rehabilitation phases. Likewise, Drechsler et al[16] reported a side-to-side difference of 59% at 1 month postoperatively and a decrease to a difference of 34% 3 months after ACLr. Zech et al[15] have demonstrated a significant deficit not only for the MVIC but also for voluntary activation during the first postoperative month in the affected limb, suggesting that there is a surgically induced unilateral voluntary activation deficit immediately after ACLr. Another reason to limit our investigation to the early postoperative period was because it is difficult to have a homogenous cohort of patients who follow the same protocol of muscular strengthening with the same intensity and volume of exercises during the late phases of rehabilitation. Differences in age, gender, type of activity, and sports may influence the time committed to rehabilitation with different types and volume of exercises.

Participants

From January to December 2013, the data of 250 patients who underwent arthroscopic ACLr were serially enrolled as part of a larger series of studies aimed at investigating the effect of ACLr on lower limb health. For this study, 59 patients (18–33 y; age: 23.69 [0.71] y), operated by a single surgeon (P.P.M.) were selected based on the following inclusion criteria: (1) male gender, (2) preinjury Tegner level 9 or 8, (3) occurrence of ACL injury from 30 to 60 days before surgery, (4) isolated ACL injury without meniscal or cartilage lesions as verified at magnetic resonance imaging and at arthroscopy, (5) reconstruction with ipsilateral autologous bone-patellar tendon-bone graft, and (6) physical therapy carried out at same center with the same protocol for 3 months. Another reason to limit our investigation to the early postoperative period was because it is difficult to have a homogenous cohort of patients who follow the same protocol of muscular strengthening with the same intensity and volume of exercises during the late phases of rehabilitation. Differences in age, gender, type of activity, and sports may influence the time committed to rehabilitation with different types and volume of exercises.

Exclusion criteria were as follows: (1) history of previous injury or surgery on either knee and (2) presence of swelling or pain during the postoperative phase. None of the patients followed any strengthening rehabilitative protocol prior to surgery. A standardized postoperative rehabilitation protocol was administered at the same center under supervision of physical therapists 5 days per week. Prior to testing, all subjects were informed of all study procedures and provided their informed consent during initial enrolment and prior to data collection. The study also was approved by the University of Rome Foro Italico Review Board.

Data Collection

Strength testing was carried out in all patients the day before surgery (time 0), and at 60 (time 1) and 90 (time 2) days after surgery. Each patient warmed up on an exercise bicycle for 5 minutes at a low resistance before performing the strength test. All participants were tested for MVIC of the knee extensor muscles at 90° and of the knee flexor muscles at a 90° joint angle in both limbs. During the test, participants were seated comfortably on a leg-extension machine (Technogym, Forli-Cesena, Italy) for the knee extension MVIC and on a leg-curl machine (Technogym I) for the knee flexion. Patients were positioned with their trunk erect and fastened by 3 crossing belts on both machines. Muscle force was recorded using a load cell connected to a computerized system unit (MuscleLab 4020e; Bosco-System Technologies, Rieti, Italy). The MVIC task consisted of an increase to a maximum in the force exerted by the leg muscles. Participants were able to follow their performance on the computer screen and were verbally encouraged to achieve a maximum and to maintain it for at least 2 seconds before relaxing. A target line was always set on the computer screen at a value 20% higher than the best performance. MVIC was calculated as the largest 1-second average reached within any single force recording. For each test (90° extension MVIC and 90° flexion MVIC), a minimum of 3 attempts were performed separated by 3 minutes and that with the highest force value was chosen as MVIC. Participants were asked to make a further attempt if the MVIC of their last trial exceeded that of previous trials.

Statistical Analysis

Side-to-side symmetry was quantified for each isometric MVIC test using the limb symmetry index (LSI), which was calculated as the ratio between the involved and uninvolved limb expressed as a percentage. A 1-way repeated-measures analysis of variance (ANOVA) was used to compare LSI between time 0, time 1, and time 2. A k-means cluster analysis was performed on the preoperative LSI to identify any natural grouping that may exist in the involved sample of individuals. The obtained clusters represented individuals characterized by different preoperative LSI, for example, low and high LSI. A 2-factor analysis of variance was then used to evaluate between-clusters differences in LSI at time 1 and time 2. Pearson product–moment correlation coefficients (r) were calculated to evaluate the relationship between LSI at time 0 and at time 1 and time 2 in all patients. The correlation of determination (R^2) between LSI at time 0 and LSI at time 1 and time 2 was also calculated to assess the proportion of the variance of LSI at time 1 and time 2 that is predictable from the LSI at time 0. k-means, ANOVA, and correlation analyses were performed using SPSS software (version 20.0; SPSS, Inc, Chicago, IL). A significance level of $P < .05$ was adopted.

Results

Descriptive statistics of quadriceps and hamstrings LSI in all patients are reported in Table 1.

Relationship Between Preoperative and Postoperative LSI of Knee Extension MVIC

Cluster analysis on the LSI of quadriceps MVIC at 90° knee angle during time 0 led to definition of 2 distinct clusters: One cluster (n: 39) was characterized by high preoperative LSI (98.8 ± 10.0%), whereas the other cluster (n: 20) was characterized by low preoperative LSI (63.0 ± 9.4%). As shown in Figure 1, there were no differences in the LSI between these 2 clusters during both time 1 and time 2. Accordingly, correlation analysis revealed no significant relationship between preoperative and postoperative LSI of quadriceps.

Relationship Between Preoperative and Postoperative LSI of Knee Flexion MVC

Cluster analysis on the LSI of hamstrings MVC at 90° knee angle during time 0 led to definition of 2 distinct clusters: One cluster

Table 1 Descriptive Statistics for LSI of Quadriceps and Hamstrings Muscles MVC at a 90° Knee Angle in All Patients Before and After ACLr With Patellar Tendon

	Time 0	Time 1	Time 2
Quadriceps LSI, %	83.4 ± 17.6	50.9 ± 20.3*	59.6 ± 18.0*·**
Hamstrings LSI, %	86.3 ± 18.2	80.9 ± 14.6	91.5 ± 14.6**

Abbreviations: ACLr, anterior cruciate ligament reconstruction; LSI, limb symmetry index; MVC, maximal voluntary contraction; time 0, preoperative evaluation; time 1, postoperative evaluation 60 days following surgery; time 2, postoperative evaluation 90 days following surgery.
*Significant difference from time 0. **Significant difference from time 1.

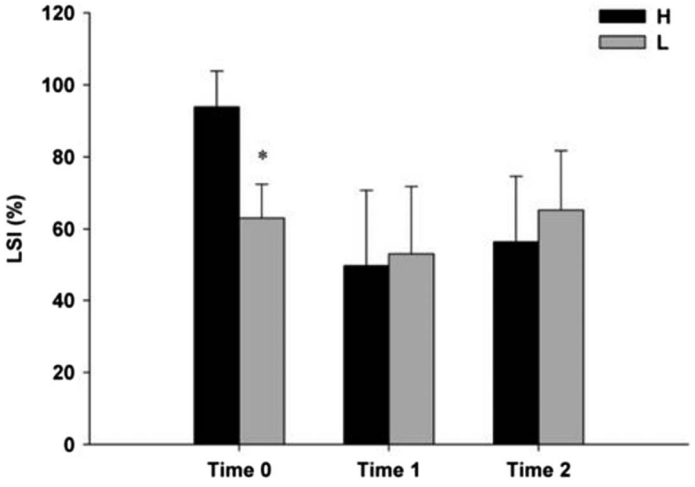

Figure 1 — Limb symmetry indexes during MVC of the quadriceps at a 90° knee angle in the high (H; n: 39) and low (L; n: 20) LSI clusters of patients at Time 0 (before surgery), Time 1 (60 d after surgery) and Time 2 (90 d after surgery). *Significantly different from H. LSI indicates limb symmetry index; MVC, maximal voluntary contraction.

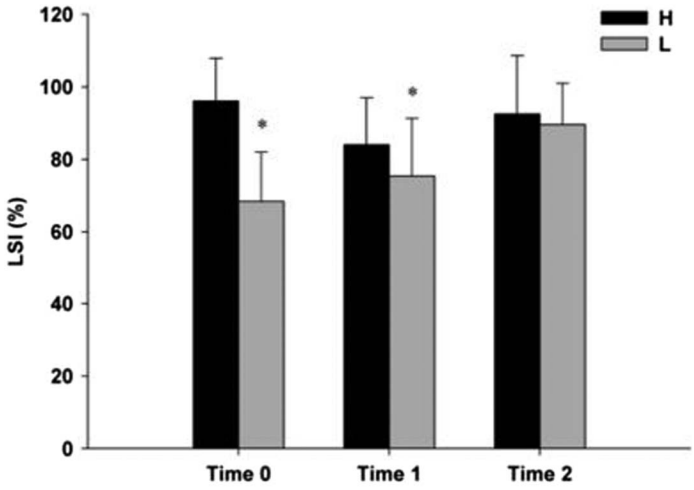

Figure 2 — Limb symmetry indexes during MVC of the hamstrings at a 90° knee angle in the high (H; n: 38) and low (L; n: 21) LSI clusters of patients at Time 0 (before surgery), Time 1 (60 days after surgery) and Time 2 (90 days after surgery). *Significantly different from H. LSI indicates limb symmetry index; MVC, maximal voluntary contraction.

(n: 38) was characterized by high preoperative LSI (96.1 ± 11.8%), whereas the other cluster (n: 21) was characterized by low preoperative LSI (68.4 ± 13.6%). The statistical analysis of the differences in the LSI of hamstrings between these 2 clusters showed a main effect for the group factor during time 1 ($F = 5.0$; $P < .05$). As shown in Figure 2, the LSI of hamstrings MVC during time 1 was significantly higher in the high preoperative LSI cluster (84.0 ± 13.0%) than in the low preoperative LSI cluster (75.4 ± 15.9%). Consistently, correlation analysis in all patients revealed a significant relationship for the LSI of hamstrings between time 0 and time 1 ($r = .33$; $R^2 = .10$; $P < .05$).

Discussion

Our hypothesis was supported as the relationships between preoperative and early postoperative have not been confirmed by our findings. The fast shut down of quadriceps functions, which occurs mainly during the early postoperative period, arises from arthrogenic muscle inhibition, driven by pain, inflammation, and swelling, as well as joint proprioceptors damage. It is regarded as the main mechanism by which quadriceps weakness may persists for a long time after ACL injury or surgery.[17–19] Clinically, it is important for treating clinicians to devise strategies to overcome this impairment. Many surgeons advise as necessary a period of muscular strengthening before surgery in order to improve outcome after ACLr. For these reasons, during the last years, the concept of "prehabilitation" has emerged to optimize postoperative outcomes of ACLr and to reduce the muscular deficits. With the term of prehabilitation, it is defined the period of rehabilitation before surgery, mainly focused on quadriceps strengthening and neuromuscular training.[12] This preoperative strategy seems suitable for improving the final outcomes assessed by self-report score as IKDC2000[13] or Modified Cincinnati Knee Rating[10] and to avoid a persistent or prolonged quadriceps strength deficit after surgery. Grindem et al[14] have described a 5-week progressive prehabilitation program including heavy-resistance strength training and plyometric drills. The patients who followed this program have shown superior knee function both preoperatively and 2 years after surgery. Shaarani et al[10] provided evidence that the preoperative quadriceps strength predicts a better function of the knee after ACLr regarding the Cincinnati score and the single-legged hop test. Indeed, the prehabilitation increases the patient's compliance during all postoperative phases of rehabilitation and may prepare mentally and physically the patient to follow the long period of rehabilitation. Moreover, when the inflammatory process is particularly acute after injury, the prehabilitation is mandatory to reduce the risk of complications, such as arthrofibrosis.

But the effects of the prehabilitation on the quadriceps strength after surgery are more uncertain. McHugh et al[20] have found that preoperative strength of the knee extensors was not a significant predictor of strength following 6 months from surgery. By contrast, Shelbourne and Johnson[9] have shown that patients with "good" preoperative strength (LSI > 90%) had higher postoperative strength than patients with "poor" preoperative strength (LSI < 75%).

Similarly, Eitzen et al[7] have shown a positive relationship between preoperative and postoperative strength of the quadriceps at 2 years after ACLr. Lepley et al[21] have reported that the quadriceps isometric strength prior to ACLr was positively related to postoperative strength in both the affected and unaffected limbs. Ueda et al[22] have shown a positive relation between preoperative and postoperative strength when evaluated at 6 months and 1 year. In all these studies, the assessment of quadriceps strength was performed after 6 months or later from surgery. At shorter time of evaluation, the results are more conflicting. Shaarani et al[10] have showed that despite an improvement in terms of outcome, there was a significant decrease in quadriceps peak torque of the injured limb at 12 weeks postoperatively without differences between who were followed a prehabilitation program and the control group. Their results are in accord with our findings.

Therefore, from these studies, it is difficult to draw definitive conclusions and how to improve the quadriceps strength after ACL injury or reconstruction still remains uncertain. Most of the previous studies were carried out in cohorts of ACL patients who were not homogeneous. Moreover, the mean interval from injury to surgery ranged from 3 months to 15 years in the different studies with also differences of gender and of age that may be predictors for delayed muscle recovery. Finally, the method to assess strength also varied greatly. Although isokinetic evaluation is one of the most common methods for strength testing, it should be underlined that the isokinetic test should not be usually performed in the first 2 to 3 months of recovery after ACLr. Recent findings suggest that isometric assessment following ACLr shows construct validity and sensitivity for monitoring recovery of muscle function comparable with those of isokinetic evaluations.[23,24]

Major strengths of the study are therefore: (1) the early assessment of strength, 2 to 3 months after ACL surgery, which rules out other factors underlying strength recovery, such as any change in daily living activities and adherence to the rehabilitation protocol and personal motivations; (2) the homogeneity of patients, as we have included individuals of the same gender, narrow age range, similar activity level with same amount of training who underwent the same surgical technique by a single surgeon at the same center and the same postoperative rehabilitation protocol; and (3) the fact that the patients of the present study were divided into 2 groups (low and high strength) based on the preoperative LSI of either quadriceps or hamstrings MVIC by means of a clustering approach. The adopted k-means cluster analysis is an unsupervised technique, which identifies an optimal data-driven grouping, that is, low and high preoperative LSI clusters, rather than establishing an arbitrary a priori cutoff point of preoperative muscle strength as carried out in previous study. With this approach, we found no differences in postoperative strength of the quadriceps between the low and high preoperative strength clusters, which together with the lack of significant results from the correlation analysis, confirms that there is no relationship between preoperative and postoperative isometric strength of the quadriceps.

There are several weaknesses in our study. First, we have run a prospective observational study in which it has been demonstrated that there is no correlation between preoperative and postoperative strength of the quadriceps in patients who underwent ACLr. Cause–effect relationship is therefore partly speculative. Second, we have limited our observation only to the first 3 months after surgery, and we did not perform any evaluation of our patients until the end of all rehabilitative protocols. Finally, we did not measure arthrogenic muscle inhibition, which is a fundamental factor contributing to the quadriceps muscle weakness in both ACL injured and reconstructed patients.

Conclusions

The results from the present study indicated that there was no relationship between preoperative and early postoperative isometric strength of the quadriceps following ACLr with patellar tendon. From the clinician's perspective, these results should be considered in the design of preoperative rehabilitation protocols incorporating strengthening exercises. Delaying surgery in order to have a good quadricipes strenght does not seem to be necessary. Our data suggest that quadriceps strength deficit is related to the ACL injury and increases further after the reconstruction without any correlation between the preoperative and postoperative values. After ACLr, early quadriceps exercises are necessary in order to lead to more accelerated muscular recovery.

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