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RESEARCH

Comparative analysis of quadriceps and hamstring strength and limb circumference between operated and non-injured legs after anterior cruciate ligament reconstruction in recreational athletes

Rekreasyonel sporcularda ön çapraz bağ rekonstrüksiyonu sonrası opere ve sağlam bacaklar arasında kuadriseps - hamstring kuvveti ile uyluk çevrelerinin karşılaştırılması

Özgür Günaştı[1], Çiğdem Özdemir Postallı[1], Kerem Tuncay Özgünen[1], Ertuğrul Gezgin[1] Abdullah Kılcı[1], Ömer Cumhur Boyraz[1], Erkan Tiyekli[1], Selcen Korkmaz Eryılmaz[1], Sanlı Sadi Kurdak[1]

[1]Çukurova University, Adana, Türkiye

Abstract

Purpose: The aim of our study was to compare the thigh muscle strengths between the operated and non-injured legs and to evaluate the hamstring/quadriceps (H/Q) ratios by the isokinetic dynamometer at different angular velocities, in individuals with unilateral interior cruciate ligament (ACL) surgery.
Material and Methods: Five female and fifteen male recreational athletes with a single-limb ACL operation within the last 1 year enrolled in the study. After physical examination, thigh circumferences were measured. Isokinetic testing of the hamstring and quadriceps were performed at different angular velocities. Peak torque and H/Q ratio values were evaluated from the isokinetic data, and the relation between leg circumference differences were analyzed.
Results: The isokinetic extension and flexion muscle strengths at 60, 180, and 240°/sec (19.4 ± 11.5%, 16.6 ± 13.2%, 17.4 ± 13.2% higher in extension, 17.9 ± 14.5%, 19.7 ± 15.9%, 21.9 ± 17.4% higher in flexion, respectively) and the 10cm and 15cm above the patella circumferences were significantly higher in non-injured leg than operated leg. The extension fatigue index was significantly higher in the non-injured leg(30.6±9.5%) than operated leg (24.7±10.9%). In the operated leg, significant correlation was found between flexion peak torque at 60°/sec and flexion fatigue index.
Conclusion: The decreases in peak strengths indicate atrophy of the thigh muscles in the operated leg. The muscle atrophy will lead to imbalance and may cause complications. In the post-operative period, it is important

Öz

Amaç: Çalışmamızın amacı, tek taraflı ön çapraz bağ (ÖÇB) ameliyatı geçirmiş bireylerde, farklı açısal hızlarda izokinetik dinamometre ile opere ve sağlam bacaklar arasındaki uyluk kas kuvvetlerini karşılaştırmak, bacak çevre uzunlukları ve hamstring/quadriceps (H/Q) oranlarını değerlendirmektir.
Gereç ve Yöntem: Çalışmaya son bir yıl içinde tek bacak ÖÇB operasyonu geçirmiş beş kadın ve on beş erkek rekreasyonel sporcu katılmıştır. Fizik muayeneden sonra uyluk çevreleri ölçülmüştür. Hamstring ve kuadriseps kas kuvvetlerinin belirlenmesi amacıyla farklı açısal hızlarda izokinetik test uygulanmıştır. İzokinetik verilerden pik tork değerleri ve H/Q oranı değerleri değerlendirilip bacak çevresi farklılıkları arasındaki ilişki analiz edilmiştir.
Bulgular: İzokinetik dinamometrede 60, 180 ve 240°/sn'deki ekstensiyon ve fleksiyon kas kuvvetleri (%19.4±11.5, %16.6±13.2, %17.4±13.2 oranında ekstensiyonda, %17.9±14.5, %19.7±15.9, %21.9±17.4 oranında fleksiyonda) ile patellanın 10cm ve 15cm üzeri çevreleri sağlam bacakta anlamlı olarak daha yüksek bulunmuştur. Ekstensiyon yorgunluk indeksi sağlam bacakta (%30.6±9.5) opere bacaktan (%24.7±10.9) anlamlı olarak yüksek bulunmuştur. Opere bacakta, 60°/sn'de fleksiyon pik tork değeri ile fleksiyon yorgunluk indeksi arasında anlamlı korelasyon bulunmuştur.
Sonuç: Opere bacakta ekstensiyon ve fleksiyon pik tork değerlerindeki düşüşler uyluk kaslarının atrofisine işaret etmektedir. Kas atrofisi, kuvvet açısından dengesizliğe yol açarak komplikasyonlara neden olabilecektir. Ameliyat sonrası dönemde, izokinetik dinamometre ile kuvvet

Address for Correspondence: Özgür Günaştı: Çukurova University, Faculty of Medicine, Department of Physiology, Division of Sports Physiology, Adana, Turkiye E-mail: ogunasti@gmail.com
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to detect the deficit with an isokinetic dynamometer and organize appropriate treatment protocols at early stages to enable the patient to regain their preoperative health.

Keywords:. Anterior cruciate ligament reconstruction, muscle atrophy, muscle strength dynamometer, return to sport.

farkının tespiti, hastaların ameliyat öncesi sağlığına kavuşması için erken aşamalarda uygun tedavi protokollerinin düzenlenmesi açısından önem taşımaktadır.

Anahtar kelimeler: Kas atrofisi, kas gücü dinamometresi, ön çapraz bağ onarımı, spora dönüş

INTRODUCTION

The anterior cruciate ligament (ACL) is the primary ligament that stabilize the knee joint, and maintains the joint integrity during movements[1,2]. The ACL injuries are common musculoskeletal disorders observed in athletes and physically active individuals[3]. Particularly, tears or ruptures in this ligament may cause progressive quadriceps and hamstring muscle atrophy, in addition, post-operative disuse also contributes to atrophy[4]. Muscle atrophy can alter the strength ratio of the quadriceps and hamstring muscles in the same limb, and may create strength difference between the extensor and flexor muscle groups in the operated and non-injured legs[5]. The asymmetric muscle strength among two extremities and/or hamstring and quadriceps imbalance may lead re-injury following ACL reconstruction[6]. Therefore, determining the strength loss after ACL reconstruction is important to manage the rehabilitation process and ensure that the individual could return to their pre-surgery health[7].

An objective and reliable tool is necessary to assess the muscle strength after ACL reconstruction, for monitoring recovery and return to sport decisions. Isokinetic dynamometers are the "gold standard" tool to determine the force exerted by a muscle group on a fixed anatomical axis[8]. The isokinetic dynamometers can also evaluate the strength differences between agonist and antagonist muscles and between right and left extremities[9]. The hamstring–quadriceps (H/Q) ratio, indicates the agonist-antagonist ratio for the upper thigh, the value of 60% at an angular velocity of 60°/s is considered as the normal range[10]. Thus, it will be possible to prevent possible injuries by detecting deficits. On the other hand, when considering the isokinetic strength of the right and left legs, the literature recommends that the ideal strength deficit for return to sport should be 10% or less[11,12]. Moreover, isokinetic dynamometers are also used in the treatment of these muscle strength and recover imbalances among muscle groups. Detecting strength asymmetry and performing the correct strengthening exercises to counter atrophy is important to prevent re-injury[6].

Following ACL reconstruction, muscle atrophy may develop due to the immobilization, and this atrophy may manifest as a reduction in thigh circumference[13]. The difference in leg circumference measured between the operated and the non-injured side is considered an objective indicator of asymmetry in muscle mass. This asymmetry can negatively affect performance and prolong the duration of return-to-sports[12]. In addition to that, changes in muscle volume during the rehabilitation process. In this context, upper leg circumference measurements have been adopted in clinical use as an easily applicable, low-cost, and practical assessment tool.

The aim of our study was to compare the hamstring and quadriceps muscle strengths between the operated and non-injured legs and to evaluate the H/Q ratios for each leg using the isokinetic dynamometer test at different angular velocities, in comparison with thigh circumference measurements, in individuals with unilateral ACL surgery. We hypothesized that operated leg's thigh circumference and isokinetic muscle strength values are significantly lower than the non-injured leg following the ACL reconstruction. This study will contribute to the literature by determining the strength losses after ACL repair and the disproportions that occur in agonist/antagonist muscle groups.

MATERIALS AND METHODS

Sample

Five female and fifteen male recreational athletes (age: 24.1 ± 8.5 years; min: 14.3, max: 40.9) enrolled in this retrospective study. The athletes were admitted to Çukurova University Healthy Life and Sports Sciences Research and Application Center for an isokinetic dynamometer test after a single-limb ACL operation within the last 1 year. The files of 51 patients were reviewed. It was determined that 38 patients underwent isokinetic dynamometer test for knee extension and flexion.

The study was conducted with 20 patients who met the inclusion and exclusion criteria. The inclusion criteria were a single-leg ACL operation, the operation did not involve other ligaments or muscle groups associated with the knee, a first ACL operation, no previous operation history that may have caused muscle atrophy in the other leg, and not involved a performance enhancing specific training program after the operation. Also, individuals with a disease or disability other than the specified operation and additional pathologies that may affect the results were accepted as exclusion criteria.

A power analysis was performed for the planned study. The minimum sample size required to detect a significance difference using this test should be at least 8 in each group, (16 in total), considering type I error (alfa) of 0.05, power (1-beta) of 0.8, effect size of 1.52 and two-sided alternative hypothesis[14]. Our study was conducted with 20 patients.

Procedure

Ethical approval was obtained from the Clinical Research Ethics Committee of the Faculty of Medicine, Çukurova University (approval number: 155/37, decision date: 16.05.2025). All procedures were conducted in compliance with the Declaration of Helsinki. Participants were provided with detailed information regarding the study procedures, and written informed consent was obtained prior to enrollment.

Physical examination

The tests were performed during morning hours at a consistent ambient temperature (23 ± 1°C). Physical examinations were performed by a physician, and found that there had been no health issues with the lower extremity. All participants did not have any knee or foot deformities related to the musculoskeletal system during or prior to the evaluation. During physical examinations, upper leg circumference measurements above the patella, 10 cm above the patella, and 15 cm above the patella were taken for both legs, which were taken by the same researcher using an inelastic tape. Measurements were taken three times, and the highest value was accepted. Participants' body weights were recorded using a digital scale (Kurdaklar Baskül, Turkey) with 0.02 kg sensitivity, and their heights were measured in a standing position using a stadiometer (Sport Expert, Turkey) accurate to 0.01 cm.

Isokinetic test procedure

Isokinetic testing of the knee extensor and flexor muscle forces were measured by using a Cybex Norm dynamometer (Computerized Sports Medicine Inc., USA). All isokinetic tests were performed by investigators of this study. The athletes were seated on the dynamometer with the backrest positioned at a 90° angle. The pelvis and chest straps were applied for stabilization, and an ankle strap was secured approximately 3 cm above the dorsum of the foot. The range of motion was set between full knee extension (0°) and 90° of flexion. A standardized warm-up consisting of approximately 10 minutes of treadmill walking was performed before the measurements. To familiarize the participants with the testing protocol, an initial set of seven repetitions at an angular velocity of 240°/s was completed; however, data from this set were excluded from the analysis.

The athletes performed the same maximal contraction protocol from slow (60°/s) to high (240°/s) angular velocities (5 repetitions for 60°/s, seven repetitions for 180°/s, 20 repetitions for 240°/s)[15]. The fatigue index was calculated from the 20 repetitions data at 240°/s[10]. The hamstring–quadriceps (H/Q) ratio was calculated by dividing the peak torque force of the hamstrings by the peak torque force of the quadriceps and multiplying by 100, and the value of 60% at an angular velocity of 60°/s is considered as the normal range[10,12,16]. Athletes were instructed to perform each contraction with maximal effort throughout the full range of motion, with a 1-minute rest period provided between sets. Verbal encouragement was delivered during testing to ensure the exertion of maximal effort. All data are stored on 2 separate hard disks, and written copies are filed separately at the research center.

Statistical analysis

The statistical analysis were performed by SPSS version 21. Shapiro–Wilk test was used to determine the data distribution. Paired samples t-test was used for leg circumference values, isokinetic muscle strength, and fatigue indexes which had normal distribution. Correlation analyses were performed by the Spearman rank-order test. A 95% confidence interval was adopted, and results were reported as mean ± standard deviation. Statistical significance was considered at $p < 0.05$.

RESULTS

The mean age, height, and body weight of the participants were 24.1 ± 8.5 years, 178.2 ± 6.7 cm, and 75.1 ± 9.9 kg, respectively. The age at rupture was 23.4 ± 8.5 years. The athletes were operated on 2.6 ± 2.5 months (median: 1.0 month) after the injury. The isokinetic testing was performed 7.7 ± 3.1 months (median: 6.5 months) after the operation. The rupture in the dominant leg was in 11 patients (9 right legs dominant, 2 left legs dominant), and in the non-dominant leg was in 9 patients (all had a non-dominant left leg). In terms of right and left legs, 9 of the ruptures occurred in the right leg and 11 in the left leg. In assessing the degree of atrophy, the differences between limb circumference measurements were compared. In the leg circumference measurements before the isokinetic test, operated and non-injured legs were 38.8 ±2.1 and 38.8 ±1.8 cm above the patella, 46.8 ±2.5 and 48.3 ±2.2 cm 10 cm above the patella ($p<0.05$), 51.4 ±2.7 and 53.1 ±2.3 cm 15 cm above the patella ($p<0.05$), respectively. The circumference measurement taken just above the patella was correlated with all isokinetic peak torque forces in the non-injured leg ($p<0.05$), while no correlation was found between other circumference measurements and peak torque values.

Isokinetic muscle strengths of the patients were presented as the ratio of peak torque to body weight. At angular velocities of 60, 180, and 240°/sec, the peak torque/body weight values in extension and flexion were significantly lower in operated leg than non-injured leg (Table 1). The peak torque difference ratios for each angular velocity between the operated and non-injured legs of the patients are presented in Table 2.

Table 1. The comparison of extension and flexion peak torque values at different angular velocities. *: Significantly lower than the non-injured leg for the same angular velocity, p<0.05.

	Operated Leg Extension	Non-injured Leg Extension	Operated Leg Flexion	Non-injured Leg Flexion
60°/ sec (Nm/kg)	2.3 ± 0.6*	2.8 ± 0.6	1.3 ± 0.4*	1.5 ± 0.4
180°/ sec (Nm/kg)	1.7 ± 0.4*	2.1 ± 0.4	1.0 ± 0.3*	1.2 ± 0.2
240°/ sec (Nm/kg)	1.5 ± 0.4*	1.8 ± 0.3	0.9 ± 0.3*	1.0 ± 0.2

Table 2. The peak torque difference ratios between the extensor and flexor muscles of the operated and non-injured legs at different angular velocities.

	Peak torque difference percentage for extension	Peak torque difference percentage for flexion
60°/ sec	19.4 ± 11.5	17.9 ± 14.5
180°/ sec	16.6 ± 13.2	19.7 ± 15.9
240°/ sec	17.4 ± 13.2	21.9 ± 17.4

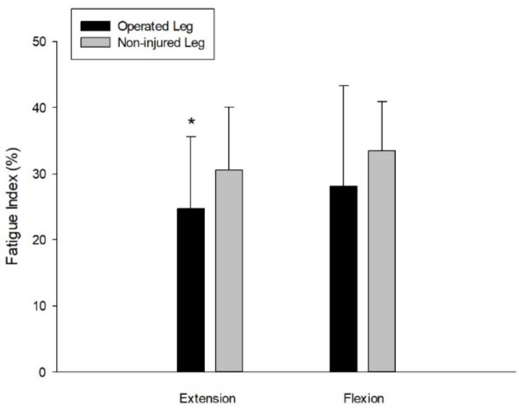

Figure 1. The comparison of fatigue indexes of operated and non-injured legs. *: Significantly lower than the non-injured leg for extension, p<0.05.

The fatigue index during extension was significantly higher in the non-injured leg (30.6 ± 9.5%) than in the operated leg (24.7 ± 10.9%; $p < 0.05$). Conversely, flexion values (33.5 ± 7.4% vs. 28.1 ± 15.2%) did not differ significantly between legs (Figure 1). However, in the operated leg, significant correlation was found between the flexion peak torque value at 60°/sec and the flexion fatigue index ($p<0.05$, Figure 2). Hamstring to quadriceps ratios for the operated and non-injured limbs were 59.1 ± 13.0% and 55.2 ± 7.2% at 60°/s, 59.3 ± 15.2% and 56.2 ± 6.0% at 180°/s, and 60.6 ± 16.1% and 57.4 ± 6.2% at 240°/s, respectively; and no statistically significant differences were observed across these values Figure 3).

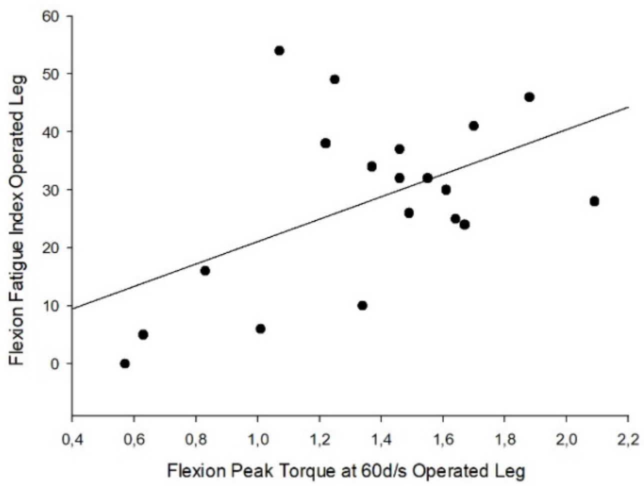

Figure 2. The correlation between the flexion fatigue index and the flexion peak torque value at 60°/sec in the operated leg (p<0.05, r=0.511).

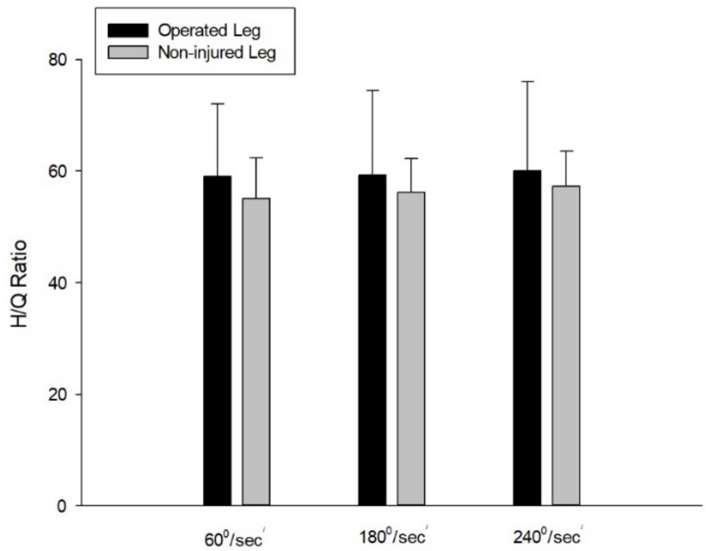

Figure 3. The comparison of hamstring quadriceps ratios (H/Q) at different angular velocities.

DISCUSSION

The results of the present study indicate two primary findings. The first finding was that the non-injured legs' extension and flexion peak torque values were significantly higher than the operated leg at all angular velocities. Stabilization of knee requires proportional strength development of both flexor and extensor muscle groups, which is basicly discussed as H/Q ratio. Second interesting finding in our study was that this H/Q ratio was not changed during the injury period.

Rapid muscle atrophy in the operated leg is expected during the post-operative period[3]. The decrease in peak extension strength in our patients indicates atrophy of the quadriceps muscle in the operated leg. From the perspective of both sedentary and active individuals, muscle atrophy will lead to imbalance in terms of knee stabilization and may cause complications[17,18]. In the post-operative period, it is important to detect the deficit with an isokinetic dynamometer and to organize appropriate treatment protocols to enable the patient to regain their preoperative health[19].

In a previous study evaluating lower-limb strength in athletes who had undergone ACL reconstruction, the authors demonstrated a significant difference was found between the operated and non-injured legs of patients after ACL surgery at an angular velocity of 60 degrees/second in extension, however, no statistically significant findings were found at other angular velocities or in flexion movements[1].

On the other hand, there are studies in the literature on strength loss in the hamstring muscle group[20-22]. In our study, peak torque deficits were found both in extension and flexion at all angular velocities. The strength deficits at angular velocities of 60°/s, 180°/s, and 240°/s in both extension and flexion is consistent with the existing literature. In addition to the prolonged period of immobilization following ACL surgery, the lack of effective muscle-strengthening exercises prior to initiating isokinetic dynamometer–based rehabilitation may exacerbate muscle atrophy, thereby widening the strength gap between the operated and the non-injured limb.

The strength difference between the operated and non-injured legs in our patients was higher than the beyond the commonly accepted 10% difference reported in the literature [11]. The primary goal of both isokinetic and field-based training is to reduce the interlimb strength asymmetry to below the commonly accepted 10% difference, thereby minimizing the risk of re-injury. In some cases the strength deficit between the two limbs may persist for up to 12 months[11,23]. The correction of strength asymmetry through appropriate rehabilitation programs and exercise routines is crucial for athletes to return to their professional life. In our study, the athletes underwent surgery approximately 2.5 months after the rupture and isokinetic tests were performed 7 months after surgery. Therefore, the strength measurements presented in our dataset reflect assessments conducted roughly 9–10 months after the ACL rupture. Indeed, in appropriate cases, preoperative strengthening may reduce the rate of strength loss and facilitate return to sports. In this context, monitoring patients individually through isokinetic measurements may be particularly important.

Although there was a statistically significant difference in leg circumference between operated and non-injured legs, the lack of correlation between pre-test knee circumference measurements and strength parameters suggests that solely morphometric parameters such as circumference measurements are not sufficient to represent functional strength performance. Several factors, including muscle adipose tissue, oxidative capacity, neuromuscular activation, and motor unit characteristics, may influence muscle strength[24]. The lack of correlation between thigh circumference measurements and isokinetic strength values may be attributed to these intramuscular variables. In the literature, studies on pre- and post-operative strength performance indicate that strength shows a strong correlation with pre-op values, emphasizing that circumference measurements alone are insufficient to predict the performance[25]. To understand the underlying mechanisms of strength loss after injury, future studies that focus on evaluating intramuscular determinants of force production may be valuable.

The literature emphasizes that in the evaluation of these patients, relying solely on the muscle strength would be insufficient, because the abnormality of H/Q ratio indicates the immobility of knee joint which may increase the risk of re-injury[6,16]. There was no significant difference between the operated and non-injured legs' H/Q ratios at all angular velocities, which suggests that the ratio is maintained due to the loss of strength in both quadriceps and hamstring muscle groups. However, the positive correlation between flexion peak torque, fatigue index and H/Q ratio indicates that flexor muscle groups' strength was preserved compared to extensor muscle groups. In such injuries, the quadriceps muscle is directly associated with the ACL and is therefore the primary muscle group targeted in rehabilitation. However, weakness of the hamstring muscle group is also important, as it may predispose to subsequent injuries[20]. The lower fatigue index observed in the flexor muscles and significantly in the extensors of the operated limb suggests that these muscles, which have lower peak torque capacities, fatigue less over time. Therefore, a low fatigue index indicates that the muscle fibers, which are already unable to generate substantial force, exhibit only a limited decline in force production.

The relatively small sample size and the lack of grouping of participants according to surgical techniques are limitations of our study. Studies involving more patients will help to analyze the results in detail. Furthermore, grouping patients according to the surgical techniques may help to gain more detailed information about the muscle strength loss that may occur. Addressing these limitations in future studies will also contribute to the literature. On the other hand, it is thought that conducting isokinetic strength tests in future studies, separated into early and late postoperative periods, may guide to return sports. On the other hand, our study will contribute to the literature by determining the strength losses after ACL repair and the disproportions that occur in agonist/antagonist muscle groups.

In conclusion, the determination of post-operative strength asymmetries may help athletes to optimize their training strategies and support a successful return to pre-injury performance by reducing re-injury risk.

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