

KNEE MUSCLE TORQUE AND H:Q RATIO CHANGES BEFORE ACL SURGERY AND AFTER REHABILITATION

Dovilė Parulytė¹, Nerijus Masiulis¹, Vaida Aleknavičiūtė^{1,2}, Rima Solianik¹, Gintarė Dargevičiūtė¹, Albertas Skurvydas¹, Vytautas Streckis¹

Lithuanian Academy of Physical Education¹, Kaunas, Lithuania
Šiauliai State College², Šiauliai, Lithuania

ABSTRACT

Research background and hypothesis. Anterior cruciate ligament (ACL) of the knee joint is often quite a fragile structure of the knee. After the rupture of ACL neuromuscular control worsens and sensorimotor system breaks down (Risberg et al., 2007), muscle activation is poor and muscle strength decreases (Croce, Miller, 2006). Some authors have reported greater strength loss in *quadriceps femoris* than in *hamstring femoris* muscle (Busch-Joseph et al., 2001; Neeter et al., 2006), therefore we hypothesized that strength loss in knee extensors may affect *hamstring/quadriceps* torque (H:Q) ratio.

Research aim of this study was to investigate knee extensors and flexors isometric and dynamic torque and H:Q ratio alterations before ACL surgery and after rehabilitation.

Research methods. Ten volunteers with ACL ruptured knee were tested before surgery and after rehabilitation. Isokinetic dynamometer was used for this testing. Maximal isometric torque was performed during flexion and extension at 90°, 60° knee angles. Dynamic torque was performed at 30, 180, 300°/s angular velocities.

Research results. Results of this study show that after rehabilitation isometric and dynamic torque of the involved leg decreased. Isometric flexion and extension torque of the uninjured leg was greater than that of the injured leg, but after rehabilitation the extension torque of the injured leg was lower than that before surgery.

Discussion and conclusions. Before ACL surgery and after rehabilitation *quadriceps femoris* muscle torque of the uninjured leg was more affected than *hamstring femoris* muscle torque. After rehabilitation H:Q ratio of the injured leg was not dependent on angular velocity and knee joint angle.

Keywords: maximal voluntary torque, muscle balance, muscle contraction.

INTRODUCTION

Anterior cruciate ligament (ACL) of the knee joint is often quite a fragile structure of the knee. After the rupture of ACL neuromuscular control worsens and sensorimotor system breaks down (Risberg et al., 2007), muscle activation is poor and muscle strength decreases (Croce, Miller, 2006). The ratio of maximal isokinetic hamstring muscle strength relative to

maximal isokinetic quadriceps muscle strength (H:Q ratio) is a parameter commonly used to describe the muscle strength properties about the knee joint (Aagaard et al., 1998). Normal H:Q ratio for healthy people is 0.5–0.8 (Holcomb et al., 2007). The H:Q ratio is greater at the highest velocity (0.8 ± 0.1 at $360^\circ/\text{s}$) compared to the lowest angular velocity (0.47 ± 0.2 at $30^\circ/\text{s}$)

(Hewett et al., 2008). If H:Q ratio is closer to 1, the hamstring muscles are stronger and knee joint is more stable (Aagaard et al., 1998). Isokinetic and isometric different muscle group testing is applied to assess muscle strength recovery, and this enables us to know the H:Q ratio between healthy and unhealthy leg muscles (Rosene et al., 2001) and then decide whether the patient is able to return to sport (Keays et al., 2000).

To our knowledge, there is no detailed study which compare knee extensors and flexors isometric and dynamic torque and the H:Q ratio in one study after ACL rupture and how these parameters change after 3 months of rehabilitation. Some authors have reported greater strength loss in *quadriceps femoris* than in *hamstring femoris* muscle (Busch-Joseph et al., 2001; Neeter et al., 2006), therefore we hypothesized that strength loss in knee extensors may affect H:Q ratio. Therefore, the aim of this study was to investigate knee extensors and flexors isometric and dynamic torque and H:Q ratio alterations before ACL surgery and after rehabilitation.

RESEARCH METHODS

The study was accomplished in accordance with the principles of the Declaration of Helsinki, concerning the ethics of experimenting with humans. Ten untrained males with left leg ACL rupture took part in this study (their mean age was 28.4 ± 7.1 years, height – 179.8 ± 8.5 cm, weight – 76.0 ± 14.0 kg.). The inclusion into the research criteria were as follows: 1) during the surgery not more severe than grade I cartilage violation was observed; 2) the other knee joint was not damaged; 3) the subjects were not older than 35 years; 4) three or fewer months had passed from ACL injury to surgery. The exclusion criteria were as follows: 1) previously they had had knee injury or had undergone surgery; 2) they had osteoarthritis or posterior cruciate ligament rupture; 3) had II–IV grade knee cartilage damage.

Isokinetic dynamometer (*Biodex Medical System 3, Shirley, New York, USA*) was used for the measurements applied.

Isometric maximal voluntary contraction (MVC) torque measurement. MVC torque was measured isometrically when the leg was fixed at the knee joint at 90° and 60° degrees and the subjects were asked to increase maximal flexion and extension torque and to hold it for 5 s. The procedure was repeated 3 times, there was 1 min

rest between repetitions and the highest torque was used for calculation. The participants were encouraged to reach maximal torque and they were able to see their achieved torque on the screen.

Dynamic muscle torque measurement. Concentric isokinetic torque for extension and flexion (injured and uninjured legs) was measured using a isokinetic dynamometer at randomly ordered 3 angular velocities: 30, 180, and $300^\circ/\text{s}$. We asked the subjects to flex and extend their knees as fast as they could. There was 1 min rest between the tests at different velocities.

H:Q ratio. Concentric and isometric H:Q strength ratio is calculated by dividing maximal concentric knee flexor (hamstring) moment by the maximal concentric knee extensor (quadriceps) moment obtained at a given joint angular velocity (Aagaard et al., 1998).

Rehabilitation programme. Rehabilitation started 2 weeks after surgery: physiotherapy, massage, electrical stimulation (16 times, 3 times per week). After 16 procedures the treatment was continued in the gym. During the physiotherapy procedure (45 min) the range of motion, strength, balance and coordination exercises were applied. During the electrotherapy procedure (30 min) we applied electrostimulation (*Neuro Trac, Sports XL, Hampshire, UK*), at the intensity of 20 Hz, exercises in the gym and swimming pool (30 min), and a range of motion and strength exercises. To reduce pain, the patients were recommended to apply freezing compresses at the knee joint.

Organization of the research. The subjects performed warm-up exercises which consisted of 5 minutes of veloergometric exercise at the intensity that corresponded to the heart rate (HR) of 130–150 beats / min (about 70% of maximum HR). HR was measured using a Polar HR recorder (*Polar Electro*). After 5 min interval we measured maximal voluntary leg flexion and extension (at 90° , 60° of the knee joint) torque and dynamic muscle torque at 30, 180, and $300^\circ/\text{s}$ velocities. The testing was carried out 2 times: 1) before ACL surgery; 2) 3 months after rehabilitation.

Statistical analysis. The research data were processed using *Microsoft Excel 2007* program mathematical statistical analysis. The data are reported as group mean values \pm standard deviations. The mean peak torque and the H:Q ratio were compared between groups using a Student's *t* test. The level for statistical significance was set to an alpha level of $p < 0.05$.

RESEARCH RESULTS

After rehabilitation we found statistically significant differences ($p < 0.05$) between injured and uninjured legs, when the leg at the knee joint was flexed 60 and 90 degrees (Table 1). After rehabilitation MVC torque of the injured and uninjured legs flexion decreased at 60° and 90° knee angles, but we did not find any significant difference.

Extension MVC torque significantly ($p < 0.05$) differed between the ruptured and the unruptured leg before surgery and after rehabilitation when the leg at the knee joint was flexed at 60° and 90° (Table 2). After rehabilitation the MVC torque

at 60° and 90° of the ruptured leg significantly ($p < 0.05$) decreased.

The injured leg flexion torque (Table 3) was statistically significantly lower than that of the uninjured leg at all speeds before surgery and after rehabilitation. After rehabilitation the injured leg flexion torque at 180°/s was significantly lower than that before surgery.

The injured leg flexion torque (Table 4) was significantly less than that of the uninjured leg at all speeds before surgery and after rehabilitation, except for the 300°/s speed after rehabilitation, where we did not find statistically significant difference ($p > 0.05$) between the injured and the uninjured legs.

Table 1. MVC torque of flexion of injured and uninjured legs before surgery and after rehabilitation

Place	Time		Before surgery		After rehabilitation	
	Knee joint angle		60°	90°	60°	90°
Injured leg, N·m	124.72 ± 23.58	73.58 ± 14.72	98.56 ± 39.17*	68.32 ± 32.1*		
Uninjured leg, N·m	136.42 ± 46.45	91.98 ± 40.22	125.64 ± 37.98	99.66 ± 33.84		

Note. * – $p < 0.05$ between injured and uninjured legs.

Table 2. MVC torque of extension of injured and uninjured legs before surgery and after rehabilitation

Place	Time		Before surgery		After rehabilitation	
	Knee joint angle		60°	90°	60°	90°
Injured leg, N·m	273.24 ± 58.87*#	235.94 ± 41.09*#	223.26 ± 28.01*	166.42 ± 44.27*		
Uninjured leg, N·m	347.52 ± 69.7	347.82 ± 130.15	328.34 ± 69.19	328.08 ± 117.39		

Note. * – $p < 0.05$ between injured and uninjured legs; # – $p < 0.05$ difference before surgery and after rehabilitation.

Table 3. Isokinetic flexion torque of injured and uninjured legs before surgery and after rehabilitation

Legs	30°/s		180°/s		300°/s	
	Before surgery	After rehabilitation	Before surgery	After rehabilitation	Before surgery	After rehabilitation
Injured leg, N·m	105.8 ± 21.79*	92.02 ± 21.4*	92.98 ± 19.75*#	72.7 ± 17.08*	94.62 ± 14.71*	84.94 ± 14.26*
Uninjured leg, N·m	150.04 ± 25.76	131.8 ± 23.28	123.86 ± 32.71	96.86 ± 16.99	104.2 ± 14.61	98.06 ± 9.72

Note. * – $p < 0.05$ between injured and uninjured legs; # – $p < 0.05$ difference before surgery and after rehabilitation.

Table 4. Isokinetic extension torque of injured and uninjured legs before surgery and after rehabilitation

Legs	30°/s		180°/s		300°/s	
	Before surgery	After rehabilitation	Before surgery	After rehabilitation	Before surgery	After rehabilitation
Injured leg, N·m	219.44 ± 69.44*#	156.8 ± 53.03*	141.7 ± 44.47*	134.48 ± 41.98*	147.8 ± 33.72*	148.6 ± 32.35
Uninjured leg, N·m	298.64 ± 39.7	273.52 ± 59.21	197.36 ± 42.12	182.2 ± 41.32	190.04 ± 38.75	166.66 ± 31.21

Note. * – $p < 0.05$ between injured and uninjured legs; # – $p < 0.05$ difference before surgery and after rehabilitation.

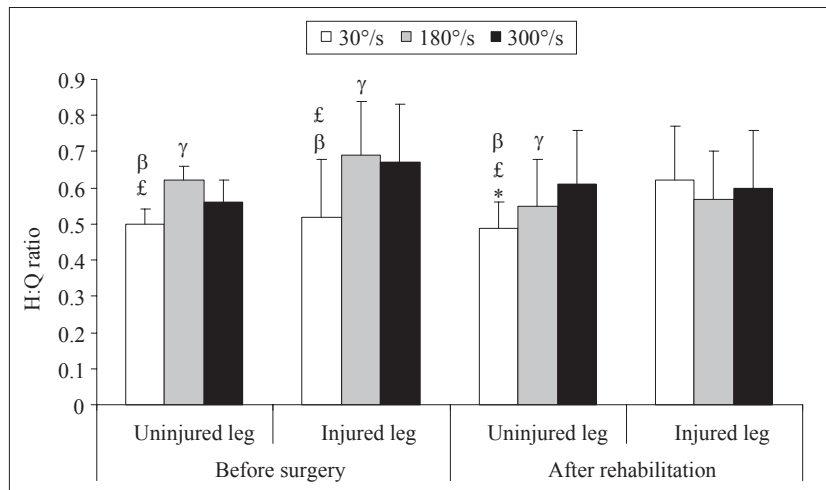


Figure 1. Isokinetic torque H:Q ratio at different angular velocities

Note. * – $p < 0.05$ between injured and uninjured legs; ϵ – $p < 0.05$ between 30 and 180°/s; β – $p < 0.05$ between 30 and 300°/s; γ – $p < 0.05$ between 180 and 300°/s.

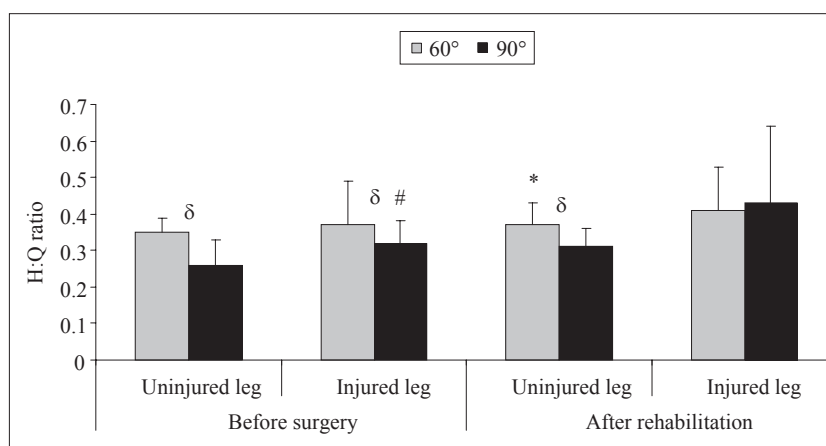


Figure 2. Isometric torque H:Q ratio at different angles

Note. * – $p < 0.05$ between injured and uninjured legs; # – $p < 0.05$ before surgery and after rehabilitation; δ – $p < 0.05$ between 60° and 90°.

After rehabilitation, the uninjured leg H:Q ratio at 30°/s angle speed was significantly lower than that of the injured leg (Figure 1). However, at a different speed we did not find significant differences between the injured and the uninjured legs before surgery and after rehabilitation. Before surgery we found significant differences between the task performance at different speeds (30 / 180, 30 / 300 and 180 / 300°/s) when it was performed with the injured and the uninjured legs. After rehabilitation significant differences were found between all speeds when the task was performed with the uninjured leg, but when the task was performed with the injured leg significant differences were not established.

After rehabilitation, the uninjured leg H:Q ratio at 60° knee angle was significantly lower than that of the injured leg (Figure 2). After rehabilitation the injured leg H:Q ratio at 90° knee angle was significantly higher than that before surgery. But at other knee angles we did not find significant differences between the injured and the uninjured legs before surgery and after rehabilitation. H:Q ratio of the injured and the uninjured legs before surgery and of the

uninjured leg after rehabilitation were dependent on the knee angle, but after rehabilitation the injured leg H:Q ratio was independent on the knee angle.

DISCUSSION

Results of this study show that after rehabilitation isometric and dynamic torque of the involved leg decreased. Isometric flexion and extension torque of the uninjured leg was greater than that of the injured leg, but after rehabilitation the extension torque of the injured leg was lower than that before surgery. After rehabilitation H:Q ratio of the injured leg was not dependent on the angle velocity and the knee joint angle.

Isometric MVC torque. We found that after rehabilitation isometric extension torque of the involved leg decreased. Before surgery and after rehabilitation the extension torque of the involved leg was lower than that of the uninjured leg. After rehabilitation flexion torque was lower in the involved leg than that in the uninjured leg. Therefore we suggest that ACL rupture affects isometric extension torque reduction, but it does

not affect flexion torque. Reflex inhibition of the lower motor neurons, pain, inadequate training, muscle disuse have been shown to cause significant atrophy of type I and type II muscle fibers of the quadriceps and that can lead to quadriceps deficit (Pua et al., 2008).

We found that after rehabilitation the quadriceps and hamstrings muscle torque of the involved leg decreased, but the one of the uninvolved leg did not change. However, we found different results than those of other researchers. T. L. Chmielewski et al. (2004) found, that ACL rupture affected *quadriceps femoris* muscle torque reduction not only in the involved leg but also in the uninvolved leg. The differing reports found in current literature may be partly explained by differences in the rehabilitation programs and the fact that the measurements were done at various points in time. We think that our results differ, because the patients had all three months of rehabilitation, and the uninvolved leg strength restored, and the involved leg strength did not manage to fully recover.

Dynamic torque. Maximal dynamic extension and flexion torque was registered when the angle velocity was the lowest. These findings coincide with the results of many researchers who indicate that the size of the torque is dependent on the joint angle (Aagaard et al., 1998; Croce, Miller, 2006) and angle velocity (Hiemstra et al., 2004). For healthy people the maximum torque of the hamstring muscle is reached at 30 and 180°/s angular velocity, and quadriceps muscle is the strongest at 60°/s angular velocity (Itoh et al., 1992). These data confirm the results of our study claiming that at lower speed flexion and extension torque is the highest. We found that after rehabilitation dynamic torque of the involved leg decreased. A. Clair Gibson et al. (2000) also found that quadriceps and hamstrings peak torque values were significantly decreased in ACL deficient compared to the uninvolved limb. A. Czamara et al. (2011) observed 9% deficit in extensor muscle strength measured under isokinetic conditions of the involved knees compared to the uninvolved knees. Our results led us to conclude that the physiotherapy was of too low intensity and that the period of physiotherapy should be extended for patients.

Dynamic and isometric torque H:Q ratio. We found that after rehabilitation H:Q ratio of

the involved leg was higher than that of the uninvolved leg at 30°/s angular velocity and 60° knee angle. We believe that this is due to the fact that after the rehabilitation the quadriceps muscle torque of the involved leg decreases more than the hamstring muscle torque, thus reducing the torque difference between these muscle groups (i. e. H:Q ratio approaching 1). After rehabilitation H:Q ratio of the involved leg is not dependent on the angle velocity and knee joint angle. Our data do not coincide with the data in M. J. Rosene et al. (2001) study where H:Q ratio is dependent on the angular velocity and joint angle. It is argued that in order to avoid the hamstrings muscle and knee joint injuries, the optimal H:Q ratio should be not less than 0.6. This may change with the velocity in which strength is tested. P. Kannus (1988) found that the rate of this ratio must be calculated individually for all patients, because each patient is different and H:Q ratio is also different.

H. Lund-Hanssen et al. (1996) measured H:Q ratio after ACL surgery and found that H:Q ratio of the injured leg is higher at higher angle velocity (240°/s) compared to the one of the uninjured leg, but at lower angle velocity (60°/s) they did not find significant differences. P. Kannus (1988) also found that H:Q ratio of the injured leg was higher at higher angle velocity (180°/s) compared to the one of the uninjured leg. We found, that at 180°/s angular velocity H:Q ratio reduced more than at 30°/s, and we think that this is due to quadriceps muscle torque reduction and fast muscle fiber atrophy.

We found that concentric torque at different velocities showed that bigger differences between injured and uninjured legs were visible at higher velocity. Lower H:Q ratio between injured and uninjured legs shows that muscle torque is not yet full reached and needs further rehabilitation (Aagaard et al., 1998). We can make a conclusion that H:Q ratio is higher at higher velocity; H:Q ratio after ACL surgery depend on quadriceps muscle torque reduction; the goal of rehabilitation should be the achievement of H:Q ratio of the injured leg equal to the one of the uninjured leg. It is very important to calculate H:Q ratio because it was found that the risk of ACL rupture depended on the H:Q ratio (Devan et al., 2004) and strength imbalances were associated with the risk of injury in sports (Pua et al., 2008).

CONCLUSIONS AND PERSPECTIVES

Before ACL surgery and after rehabilitation *quadriceps femoris* muscle torque of the uninjured leg was more affected than *hamstring femoris*

muscle torque. After rehabilitation H:Q ratio of the injured leg was not dependent on angular velocity and knee joint angle.

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ŠLAUNIES RAUMENŲ JĖGOS MOMENTŲ IR JŲ SANTYKIO POKYTIS PRIEŠ PKR OPERACIJĄ IR PO REABILITACIJOS

Dovilė Parulytė¹, Nerijus Masiulis¹, Vaida Aleknavičiūtė^{1,2}, Rima Solianik¹, Gintarė Dargevičiūtė¹, Albertas Skurvydas¹, Vytautas Streckis¹

Lietuvos kūno kultūros akademija¹, Kaunas, Lietuva

Šiaulių kolegija², Šiauliai, Lietuva

SANTRAUKA

Tyrimo pagrindimas ir hipotezė. Kelio sąnario priekiniai kryžminiai raiščiai (PKR) – dažnai pažeidžiama kelio sąnario struktūra. Po PKR plyšimo suprastėja neuroraumeninė kontrolė, sutrinka sensomotorinė sistema (Risberg et al., 2007), raumenų aktyvacija ir sumažėja raumenų jėga (Croce, Miller, 2006). Keleto mokslininkų atliktų tyrimų rezultatai parodė: po PKR plyšimo labiau sumažėja keturgalvio šlaunies raumens nei užpakalinių šlaunies raumenų jėga (Busch-Joseph et al., 2001; Neeter et al., 2006). Taigi manytume, kad kelio tiesiamųjų raumenų jėgos sumažėjimas turi įtakos keturgalvio ir užpakalinių šlaunies raumenų santykiui (H:Q).

Tikslas: ištirti kelio tiesiamųjų ir lenkiamųjų raumenų izometrinės bei dinaminės jėgos momento ir H:Q santykio pokyčius prieš PKR operaciją ir po reabilitacijos.

Metodai. Tirta 10 fiziškai aktyvių vyrų, kurių PKR pažeisti. Testavimai atlikti prieš PKR rekonstruojamąją operaciją ir po 3 mėnesių reabilitacijos. Tiriamieji buvo testuojami izokinetiniu dinamometru. Išmatuotas maksimaliosios lenkimo ir tiesimo (esant 90°, 60° kampams) izometrinės kojų raumenų jėgos momentas. Dinaminės jėgos momentas tirtas esant 30, 180, 300°/s kampiniams greičiams.

Rezultatai. Remiantis tyrimo rezultatais galima teigti, kad po reabilitacijos sumažėjo pažeistos kojos izometrinės ir dinaminės jėgos momento dydis. Sveikos kojos izometrinės lenkimo ir tiesimo jėgos momentas buvo didesnis nei pažeistos, tačiau po reabilitacijos pažeistos kojos tiesimo momentas mažesnis nei prieš operaciją.

Aptarimas ir išvados. PKR plyšimas daugiau turėjo įtakos pažeistos nei sveikos kojos keturgalvio raumens jėgos momento sumažėjimui prieš operaciją ir po reabilitacijos nei užpakalinių šlaunies raumenų. Po reabilitacijos pažeistos kojos H:Q santykis nepriklausė nuo greičio ir kelio sąnario kampo.

Raktažodžiai: maksimaliosios jėgos momentas, raumenų pusiausvyra, raumenų susitraukimas.

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Corresponding author **Dovilė Parulytė**
Lithuanian Academy of Physical Education
Sporto str. 6, LT-44221 Kaunas
Lithuania
Tel +370 606 95214
E-mail d.parulyte@lkka.lt