



Isokinetic profile of subjects with the ruptured anterior cruciated ligament

Izokinetički profil osoba sa rupturom prednjeg ukrštenog ligamenta

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Abstract

Background/Aim. All changes in the knee that appear after anterior cruciate ligament (ACL) lesion lead to difficulties in walking, running, jumping especially during sudden changes of the line of movement. This significantly impairs quality of life of these subjects and leads to decrease in physical activity. Knee injuries make 5% of all most severe acute sport injuries. The aim of the study was to determine strength of the thigh muscles in persons with unilateral rupture of the ACL and to evaluate potential bilateral differences between healthy and injured leg. **Methods.** This study involved 114 male athletes of different sport specialties with the clinical diagnosis of ACL rupture. Each subject had unilateral ACL rupture and the other leg was actually the control for this research. An isokinetic device was used to evaluate the muscle strength of thigh muscles. Testing was performed for two testing speeds, 60°/s and 180°/s. **Results.** Data analysis showed a statistically significant difference ($p < 0.01$) between the ACL and the healthy leg in the following parameters: peak torque for thigh extensors (Ptrq_E), angle to peak torque during extension (Ang_E), power of extension (Pow_E) and work during extension (Work_E). Analysing hamstrings to quadriceps (H/Q) ratio we found the unilateral disbalance of thigh muscle strength in ACL leg. **Conclusion.** A high level of validity makes isokinetic dynamometry the method for evaluation of thigh muscles strength and leaves this field of research open for new studies in order to improve both diagnostic and rehabilitation of patients with the insufficient ACL.

Key words:

knee injuries; anterior cruciate ligament; muscle, skeletal; muscle strength.

Apstrakt

Uvod/Cilj. Promene u zglobu kolena koje nastupaju nakon lezije prednjeg ukrštenog ligamenta (*ligamentum cruciatum anterius* – LCA) dovode do poteškoća u hodanju, trčanju i skakanju, pogotovo prilikom nagle promene pravca kretanja. Ovakva pojava u značajnoj meri umanjuje kvalitet života kod takve osobe i dovodi do smanjenja nivoa fizičke aktivnosti. Povrede kolenog zgloba čine 5% ukupnog broja najtežih akutnih sportskih povreda. Cilj ovog istraživanja bio je da se utvrdi snaga mišića natkolenice kod osoba sa jednostranom rupturom LCA, kao i razlika snage mišića između zdrave i povređene noge. **Metode.** U istraživanje je bilo uključeno 114 muškaraca, aktivnih sportista, različitih sportskih disciplina, sa kliničkom dijagnozom rupture LCA. Kod svakog ispitanika postojala je ruptura LCA na jednom kolenu, tako da je zdrava noga predstavljala kontrolnu grupu u ovom istraživanju. Pomoću izokinetičkog aparata merili smo snagu mišića natkolenice i to za dve test brzine, 60°/s and 180°/s. **Rezultati.** Utvrđena je statistički značajna razlika ($p < 0,01$) između zdrave i povređene noge i to za merene parametre: maksimalni obrtni moment za bedrene ekstenzore (Ptrq_E), maksimalni iznos ugla ekstenzije (Ang_E), snaga ekstenzije (Pow_E) i rad tokom ekstenzije (Work_E). Za odnos mišići zadnje lože/kvadriceps (H/Q) utvrdili smo da postoji izražen disbalans u mišićnoj snazi kod povređene noge. **Zaključak.** Postoji visok stepen vrednosti izokinetičke dinamometrije kao metode za određivanje snage mišića natkolenice. Ovu oblast potrebno je dodatno istraživati u cilju unapređenja kako dijagnostike, tako i rehabilitacionih programa kod osoba sa insuficijencijom LCA.

Ključne reči:

koleno, povrede; ligament, prednji ukršteni; mišići, skeletni; mišići, snaga.

Introduction

The knee is one of the biggest joints in the human body. It is a complex structure both anatomically and biomechanically.

All changes in the knee that appear after the lesion of the anterior cruciate ligament (ACL) lead to difficulties in walking, running, jumping, especially during sudden changes in line of movement. This significantly impairs quality of life of these sub-

jects and leads to decrease in physical activity. Knee injuries make 5% of all most severe acute sport injuries¹. Anatomy and physiology of the knee dictate the type, character and degree of the consequences to the physical activity after injury. Ones of the most often and the most difficult are the injuries of the ligaments which usually are not isolated but combined with trauma of the menisci and joint capsule. Incidence of meniscus tears together with rupture of ligaments is reported to be from 37% to 86%^{2,3}. The presence of combined lesion of menisci and cruciated ligaments will soon lead to degenerative changes of joint cartilage of knee.

Clinical examination has the leading role in putting of the proper diagnosis of the soft tissue structures of the knee together with functional tests⁴.

During inspection of the injured knee we can observe swollen structures due to rupture of blood vessels which nourish the ACL, though the absence of one does not mean that it is not ruptured. In old ruptures of the ACL we can see atrophy of the medial head of quadriceps muscle (*musculus vastus medialis*) because of immobilisation and/or decrease in activity due to pain. Palpation is used to assess state of collateral ligaments. Stability evaluation of the knee joint is performed using clinical examination tests (Lachman test, Pivot shift test, tests of front and rear "drawer") which can be used in both old and acute cases. According to data from the literature, the most accurate results are obtained via "Lachman" test and "Pivot shift" test⁵.

According to the principles of good practise it is necessary to perform radiographic imaging [anterior-posterior (AP) and profile scan] in order to exclude possible avulsion of bony part of ligament insertion or associated trauma⁶. Introduction of magnetic resonance imaging (MRI) changed the approach to evaluation of ligament lesions of the knee^{7,8}. Noninvasiveness and the absence of harmful radiation are the main contributors to the usage of this imaging method with the reliability more than 95%.

Measuring muscle strength has significance in everyday practice both in persons with physical disorders and healthy active population^{9,10}. Dynamic recording of muscle actions can be performed with specially designed machines. Isokinetic devices measure maximal strength and other aspects of physical performances (speed, power, explosiveness)¹¹⁻¹³.

The aim of the study was to measure the parameters of strength of the thigh muscles in persons with unilateral rupture of the ACL, as well as to evaluate the potential bilateral differences between the healthy and the injured leg.

Methods

Our study involved 114 male athletes of different sport specialities (in average high 184.14 cm with body mass, 86.5 kg, aged 24.32 year) with the clinical diagnosis of ACL rupture. This diagnose was later confirmed during surgical reconstruction of the teared ACL. Each subject had unilateral ACL rupture and the other leg was actually the control for this research. All measurements were conducted at the Department of Physiology, Faculty of Medicine, University of Novi Sad, Novi Sad, Serbia, and at the Provincial Department for Sports, Novi Sad, Serbia. All the subjects were informed in detail on the design of the study and gave their written consent.

The isokinetic device was used to evaluate muscle strength of the thigh muscles (EASY – TECH prima doc). Prior to each testing the machine was calibrated and the range of movement (ROM) set to 90°. The dynamometer seat was set for each subject in order to bring the axis of the rotation of the knee in the center of the axis of rotation of the machine. We used tapes to stabilize subjects to the seat in order to isolate the single movement of the thigh extensors and thigh flexors. Testing was performed for two testing speeds, 60°/s and 180°/s. Complete testing was performed according to standard protocol, first the injured leg (ACL leg) and then the healthy one. Five maximal contractions were performed in the concentric-concentric mode including visual feedback.

Results

Analysis of the isokinetic parameters for the test speed of 60°/s found a statistically significant difference ($p < 0.01$) between the ACL leg and the healthy leg for following parameters: peak torque for thigh extensors (Ptrq-E), angle to peak torque during extension (Ang-E), power of extension (Pow-E) and work during extension (Work-E) (Table 1). The

Table 1
Analysis of the isokinetic parameters for the test speed of 60°/s

Parameter	Healthy leg	ACL leg	<i>t</i>	<i>p</i>
	$\bar{x} \pm SD$	$\bar{x} \pm SD$		
Ptrq_E (nm)	264.2 ± 30.8	213.9 ± 43.6	-5.565	0.000*
Ptrq_F (nm)	125.9 ± 19.4	119.1 ± 27.4	-1.240	0.218
Ang_E (°)	23.1 ± 8.5	27.9 ± 9.1	2.392	0.019*
Ang_F (°)	23.6 ± 5.2	25.4 ± 12.4	1.475	0.143
Pow_E (W)	377.0 ± 59.5	316.9 ± 74.0	-3.562	0.001*
Pow_F (W)	146.5 ± 21.6	137.5 ± 37.8	-0.934	0.353
Work_E (J)	1135.4 ± 104.9	984.9 ± 156.4	-4.520	0.000*
Work_F (J)	295.7 ± 32.6	290.7 ± 48.3	-0.249	0.804

*Statistically significant difference, $p < 0.01$ (except for the parameter Ang_E for which the significance was set at $p < 0.05$).

ACL – anterior cruciate ligament.

Ptrq_E – peak torque for thigh extensors; Ptrq_F – peak torque for thigh flexors; Ang_E – angle to peak torque during extension, Ang_F – angle to peak torque during flexion; Pow_E – power of extension; Pow_F – power of flexion; Work_E – work during extension; Work_F work during flexion; nm – newton metre; W – watt; J – joule.

parameters peak torque for thigh flexors angle to peak torque during flexion, power of flexion and work during flexion did not show any significant difference.

For the test speed of 180°/s analysis of the isokinetic parameters revealed the same result (Table 2). Hamstrings to quadriceps (H/Q) ratio for both testing speeds presenting unilateral disbalance in ACL leg is shown in Figure 1.

tive carrier of an athlete is over. However, nowadays orthopaedic surgery is able to perform reconstruction of the defect which enables further active training and competition in athletes and in recreational individual avoidance of progressive degenerative changes in the knee.

A revolutionary study of Johnson¹⁴ in the field of isokinetic rehabilitation after surgical reconstruction of ACL

Table 2

Parameter	Analysis of the isokinetic parameters for the test speed of 180°/s		<i>t</i>	<i>p</i>
	Healthy leg $\bar{x} \pm SD$	ACL leg $\bar{x} \pm SD$		
Ptrq_E (nm)	213.3 ± 40.7	178.8 ± 43.4	4.298	0.000*
Ptrq_F (nm)	130.3 ± 39.5	114.4 ± 40.4	-1.001	0.320
Ang_E (°)	17.4 ± 11.4	23.5 ± 12.7	-4.147	0.000*
Ang_F (°)	26.8 ± 25.9	27.6 ± 24.9	0.981	0.330
Pow_E (W)	716.0 ± 134.9	597.1 ± 156.7	-4.885	0.000*
Pow_F (W)	259.7 ± 86.6	237.8 ± 90.2	-1.228	0.223
Work_E (J)	1029.7 ± 213.8	844.4 ± 236.5	5.265	0.000*
Work_F (J)	258.4 ± 82.4	230.7 ± 79.1	0.141	0.888

*Statistically significant difference ($p < 0.01$);
For abbreviations, see under Table 1.

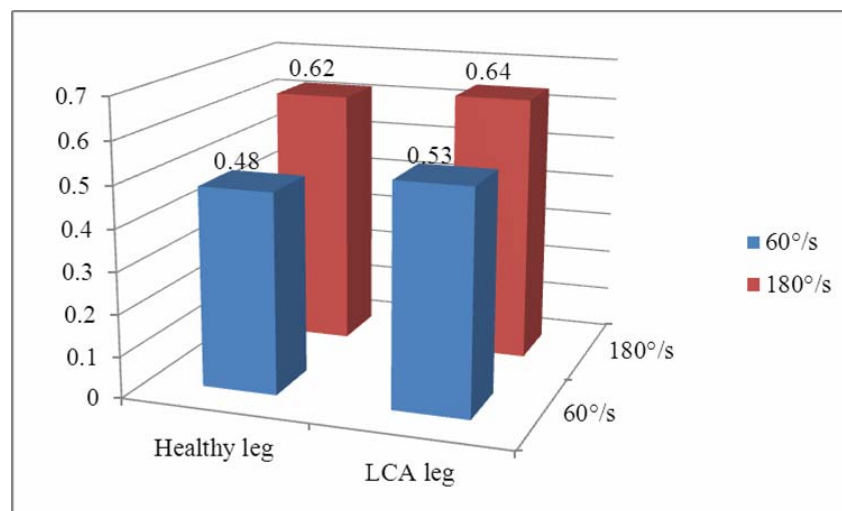


Fig. 1 – Hamstrings to quadriceps (H/Q) ratio for both testing speeds.
LCA – *ligamentum cruciatum anterius*.

Discussion

Assessment of voluntary muscle action is the key element in research of physical performance in human subjects. Gathered information are used by both researchers and clinicians to create rehabilitation or training protocols to cope with disabilities and impairments. In the late 80s of the 20th century isokinetic devices appeared on the scene of muscle testing. This device adapts to the strength of the test subject by maintaining the constant speed of movement through the whole ROM. The reduction of pain and discomfort during testing is extended greatly, so this method was possible to introduce in early stages of medical rehabilitation in patients, as well as in the population of healthy competitive sportsman.

Special attention is paid to anatomical and functional integrity of the knee, that is active and passive stabilizers. In case of rupture of ACL it is probable that active compe-

was presented in 1982. He explained the use of the anti-shear mechanism on the isokinetic device which provided early rehabilitation protocol to be introduced. This device protected the knee against front movement of the distal part of the lower leg and acted as a protective factor to newly reconstructed graft. In this way Johnson provided so much required early rehabilitation protocol after ACL reconstruction.

In the first 20 years of exploitation of isokinetic dynamometry the knee joint was in the center of interest. Analysing the literature we spotted that over 75% of all studies referring to isokinetics was dealing with the knee physiology, pathology and training. Nevertheless, the knee joint is still in the focus though not in such an extent. The reason could be successful surgery and rehabilitation protocols after injury¹⁵⁻¹⁷.

Testing speed that the isokinetic device can provide varies from 0°/s to 550°/s. For testing muscle strength and en-

duration it is proposed to use speeds ranging from 60°/s to 180°/s¹⁸. In our research we used these testing speeds as proven to be most appropriate.

Analyzing the gathered data it appears that the muscle strength for the left and the right leg in the same subject does not differ more than 10%. This became the standard value of bilateral difference of muscle strength for quadriceps and hamstring muscles. Calmels et al.¹⁹ reported that in the group of healthy high school children tested at 60°/s, 120°/s and 180°/s no significant bilateral difference was found.

Capranica et al.²⁰ and Brady et al.²¹ found no significant difference in strength parameters recorded *via* the isokinetic dynamometer between the dominant (kicking) leg and nondominant one in the group of competitive soccer players.

Epidemiological studies following the incidence of sport injuries reported 20% of all injuries to be related with the knee²²⁻²⁴. This data is referring to all the participants in the sport both recreational and competitive. These studies also showed the incidence of injuries in relation to specific sport. Sports with the incidence close to 20% were football, basketball, soccer and show dance. A somewhat lower incidence, around 10%, was reported in boxing, fencing, ice hockey. The lowest incidence was found in cycling and swimming, less than 5%. Among the most severe injuries during sporting activities (5%) are accounted to injuries of ligaments and menisci of the knee¹.

Bilateral muscle testing is one of the most used methods for evaluation the results in isokinetics²⁵. Subjects with knee pathology are at the same time both the control and the experimental group since one leg is healthy and the other one is with specific pathology. Bilateral muscle strength asymmetry more than 10% suggests the presence of changes in muscles, tendons and ligaments. Grace et al.²⁶ presented that the difference in extensors of the knee was 16.6% and in flexors 11%. Similar results were presented in a recent study by de Jong et al.²⁷ where they found the deficit of 13.6%.

In our study in the group of athletes with insufficient ACL we found deficit for extensors (16%) and flexors (9.7%) for the testing speed of 60°/s, while for the testing speed of 180°/s we found the deficit of 16% and 12%, respectively.

Dvir et al.²⁸ reported findings in the group of subjects with chronic lesion of ACL. Rupture was 1.5 years old on the average. Testing thigh muscles was conducted according to the standard testing protocol for the testing speed of 30°/s in the concentric-concentric mode. The results showed the average deficit of 21% and 14% for extensors and flexors, respectively. Bonamo et al.²⁹ followed a group of recreational athletes with the diagnosed ACL tear. They tested them for the testing speed of 60°/s and found the deficit for extensors 11% and for flexors only 3%. The subjects were

treated conservatively but never were able to return to full level of performance prior to injury.

It is noticed that for the lower testing speeds the observed deficit between the injured leg and the healthy one is higher. As the speed increases the deficit is getting less obvious. A group of papers proposed explanation to this statement³⁰⁻³². At the lower testing speed there is higher force acting to the joint capsule during movement. Since the knee is compromised due to the trauma pain appears during quadriceps contraction which provokes a significant muscle spasm of extensors and reflex contraction of thigh flexors. Such mechanism further attenuates force output of the quadriceps. Tsuda et al.³³ presented firm evidence for a connection between the reflex activity of the ligaments of the knee and thigh muscles.

The ratio between flexor and extensor muscles of the thigh is considered as good indicator of normal – physiological functionality of these muscles though it is highly dependent on testing speed³⁴. For lower testing speeds (0°/s – 60°/s) it is 50–60% depending on test subjects and the isokinetic device. The H/Q ratio is especially significant in the acyclic sports and in the dominant side of the body^{35,36}.

Our results for testing speeds of 60°/s and 180°/s for the ACL leg were 53 and 64 and for healthy leg 48 and 62, respectively. A possible explanation of this finding could be that there is no significant difference in the measured isokinetic strength of thigh flexors. Namely, thigh flexors act as knee stabilizers in subjects with insufficient ACL. They prevent forward movement of tibia during forceful extensor actions. Aside to this strictly numerical analysis researchers noticed that the curve obtained during the recording of the movement on isokinetic device can be very informative³⁷. Beside curve analysis, electromyography recording is a useful tool, as well. In this way voluntary muscle action can be monitored for the level of effort and even become a legal medical tool for assessment of impairment³⁸.

Conclusion

Isokinetic testing of thigh muscles provides solid parameters which define functional abilities of the tested muscles. Our results present a statistically significant difference between the ACL and the healthy legs for the following parameters: Ptrq_E, Ang_E, Pow_E and Work_E. Analysing the H/Q ratio showed a unilateral disbalance in the ACL leg.

The gathered results indicate a high level of validity of isokinetic dynamometry as the method for evaluation of thigh muscles strength and leave this field of research open for new studies in order to improve both diagnostic and rehabilitation of patients with the insufficient ACL.

R E F E R E N C E S

- Bahr R, Møhlum S. Clinical Guide to Sport Injuries. Champaign, IL: Human Kinetics; 2004.
- Bellabarba C, Bush-Joseph CA, Bach BR. Patterns of meniscal injury in the anterior cruciate-deficient knee: a review of the literature. *Am J Orthop (Belle Mead NJ)* 1997; 26(1): 18–23.
- Serpas F, Yanagawa T, Pandy M. Forward-dynamics simulation of anterior cruciate ligament forces developed during isokinetic dynamometry. *Comput Methods Biomech Biomed Engin* 2002; 5(1): 33–43.
- Dvir Z. Isokinetics. Muscle testing, Interpretations and Clinical applications, 2nd ed. Edinburgh: Churchill Livingstone; 2004.
- Hendrich V. Diagnosis of fresh combined injuries of the knee ligaments (clinical and technical diagnosis). *Langenbecks Arch Chir Suppl II Verh Dtsch Ges Chir* 1989: 415–9. (German)
- Noesberger B. Diagnosis of acute tears of the anterior cruciate ligament, and the clinical features of chronic anterior instability. In: *Jacob RP, Staubli H, editors. The knee and the cruciate ligaments.* Berlin, Heidelberg, New York, London, Paris: Springer – Verlag; 1992. p. 143–56.
- Falchbook FS, Tigges S, Carpenter WA, Branch TP, Stiles RG. Accuracy of direct signs of tears of the anterior cruciate ligament. *Can Assoc Radiol J* 1996; 47(2): 114–20.
- Sanchis-Alfonso V, Martínez-Sanjuán V, Gastaldi-Orquín E. The value of MRI in the evaluation of the ACL deficient knee and in the post-operative evaluation after ACL reconstruction. *Eur J Radiol* 1993; 16(2): 126–30.
- Andrade MS, Cohen M, Piçarro IC, Silva AC. Knee performance after anterior cruciate ligament reconstruction. *Isokinet Exerc Sci* 2002; 10(2): 81–6.
- Cardone C, Menegassi Z, Emygdio R. Isokinetic assessment of muscle strength following anterior cruciate ligament reconstruction. *Isokinet Exerc Sci* 2004; 12(3): 173–7.
- Porter GK, Kaminski TW. Knee angle does not affect ankle eversion to inversion peak torque ratios derived from an isokinetic dynamometer. *Isokinet Exerc Sci* 2004; 12(2): 99–104.
- Sykaras E, Mylonas A, Malliaropoulos N, Zakas A, Papacostas E. Manual massage effect in knee extensors peak torque during short-term intense continuous concentric - eccentric isokinetic exercise in female elite athletes. *Isokinet Exerc Sci* 2003; 11(3): 153–7.
- Lund H, Søndergaard K, Zachariassen T, Christensen R, Biilow P, Henriksen M, et al. Learning effect of isokinetic measurements in healthy subjects, and reliability and comparability of Biodex and Lido dynamometers. *Clin Physiol Funct Imag* 2005; 25(2): 75–82.
- Johnson D. Controlling anterior shear during isokinetic knee extension exercise. *J Orthop Sports Phys Ther* 1982; 4(1): 23–31.
- Strauss GR, Božiković AJ, Jones GL, Neale GC, Spüttes MR, Boyle JJ. Knee extensor strength 12 and 18 weeks post anterior cruciate ligament reconstruction. *Isokinet Exerc Sci* 1998; 7(1): 19–26.
- Beynon BD, Johnson RJ, Abate JA, Fleming BC, Nichols CE. Treatment of anterior cruciate ligament injuries. Part I. *Am J Sports Med* 2005; 33(10): 1579–602.
- Andersen LL, Magnusson S, Nielsen M, Haleem J, Poulsen K, Aagaard P. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: implications for rehabilitation. *Phys Ther* 2006; 86(5): 683–97.
- Burkett LN, Ahar B, Irvin J. Determining the optimal knee angle for testing maximal isometric hamstring peak torque on an isokinetic dynamometer. *Int Sports J* 2001; 6: 171–5.
- Calmels P, van den Borne I, Nellen M, Domenach M, Minaire P, Drust M. A pilot study of knee isokinetic strength in young, highly trained, female gymnasts. *Isokinet Exerc Sci* 1995; 5(1): 69–74.
- Capranica L, Cama G, Fanton F, Tessitore A, Figura F. Force and power of preferred and nonpreferred leg in young soccer players. *J Sports Med Phys Fitness* 1992; 32(4): 358–63.
- Brady EC, O'Regan M, McCormack B. Isokinetic assessment of uninjured soccer players. In: *Reilly T, Clarys J, Stibbe A, editors. StibbeScience and football.* London: Spon; 1993.
- Caine DJ, Caine CG, Lindner KJ. Epidemiology of sport injuries. Champaign, IL: Human Kinetics; 1996.
- Heitkamp HC, Fleck M, Mayer F, Horstmann T, Dickhutb HH. Balance training in male and female judokas: Gain in strength. *Isokinet Exerc Sci* 2002; 10(1): 64–73.
- Imamura RT, Hreljac A, Escamilla RF, Edwards WB. A three-dimensional analysis of the center of mass for three different judo throwing techniques. *J Sports Sci Med* 2006; 5(CSSD): 122–31.
- Almosnino S, Brandon SC, Day AG, Stevenson JM, Dvir Z, Bardana DD. Principal component modeling of isokinetic moment curves for discriminating between the injured and healthy knees of unilateral ACL deficient patients. *J Electromyogr Kinesiol* 2014; 24(1): 134–43.
- Graue TG, Sweetser ER, Nelson MA, Ydens LR, Skipper BJ. Isokinetic muscle imbalance and knee joint injuries. A perspective blind study. *J Bone Joint Surg Am* 1984; 66(5): 734–40.
- de Jong SN, van Caspel DR, van Haeff MJ, Saris DB. Functional assessment and muscle strength before and after reconstruction of chronic anterior cruciate ligament lesions. *Arthroscopy* 2007; 23(1): 21–8.
- Dvir Z, Eger G, Halperin N, Shklar A. Thigh muscle activity and anterior cruciate ligament insufficiency. *Clin Biomech* 1989; 4(2): 87–91.
- Bonamo JJ, Fay C, Firestone T. The conservative treatment of the anterior cruciate deficient knee. *Am J Sports Med* 1990; 16(6): 618–23.
- Akima H, Takahashi H, Kuno S, Katsuta S. Coactivation pattern in human quadriceps during isokinetic knee-extension by muscle functional MRI. *Eur J Appl Physiol* 2004; 91(1): 7–14.
- Sbriccoli P, Solomonow M, Zhou B, Lu Y, Sellards R. Neuromuscular response to cyclic loading of the anterior cruciate ligament. *Am J Sports Med* 2005; 33(4): 543–51.
- Zemach L, Almozniño S, Barak Y, Dvir Z. Quadriceps insufficiency in patients with knee compromise: How many velocities should an isokinetic test protocol consist of? *Isokinet Exerc Sci* 2009; 17(2): 129–33.
- Tsuda E, Okamura Y, Otsuka H, Komatsu T, Tokuya S. Direct evidence of the anterior cruciate ligament-hamstring reflex arc in humans. *Am J Sports Med* 2001; 29(1): 83–7.
- Olmo J, Castilla N. Explosive strength - related isokinetic parameters in high - level sprinters and long - distance runners: The relative power index. *Isokinet Exerc Sci* 2005; 13(4): 243-9.
- Scoville CR, Arciero RA, Taylor DC, Stoneman PD. End Range Eccentric Antagonist/Concentric Agonist Strength Ratios: A New Perspective in Shoulder Strength Assessment. *J Orthop Sports Phys Ther* 1997; 25(3): 203–7.
- Aagaard P, Simonsen EB, Magnusson SP, Larsson B, Dyhre-Poulsen P. A new concept for isokinetic hamstring: quadriceps muscle strength ratio. *Am J Sports Med* 1998; 26(2): 231–7.
- Ikeda H, Kurosawa H, Kim S. Quadriceps torque curve pattern in patients with anterior cruciate ligament injury. *Int Orthop* 2002; 26(6): 374–6.
- Almosnino S, Stevenson JM, Day AG, Bardana DD, Diaconescu ED, Dvir Z. Differentiating between types and levels of isokinetic knee musculature efforts. *J Electromyogr Kinesiol* 2011; 21(6): 974–81.

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