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Abstract

Introduction. The purpose of this study was to assess the isometric muscle strength (IMS) of the knee extensors and flexors, bilateral asymmetry (BA) and the hamstring: quadriceps ratio (H:Q ratio) between the dominant leg (DL) vs. the non-dominant leg (NDL) of males trained with free-weights vs. machines. Material and Methods: Thirty males were recruited and separated into two groups: Free-weights (n = 15) and Machines (n = 15) groups. All study participants performed the IMS testing for knee extensors and flexors in the DL and NDL using a commercially available load cell. The highest value obtained from the three trials was used for statistical analysis. Results: The IMS of the quadriceps and hamstring muscles for DL and NDL showed a significant increase in the Free-weight group when compared to the Machine group. In addition, a significant difference (p <.03) in the IMS of hamstring muscles between DL vs. NDL was observed in the Machine group. The H:Q ratio on DL (p < .002) and NDL (p < .01) was significantly higher in the Free-weight group. Conclusion: This study showed better isometric muscle strength of the thigh (hamstring and quadriceps) and the H:Q ratio in males trained with free weights. In addition, males trained with machines showed a bilateral asymmetry of the hamstring muscles and a lower H:Q ratio – consequently, a higher risk of knee injuries.

Keywords

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An assessment of isometric muscle strength and the hamstring: Quadriceps ratio among males trained with free weights vs. machines

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1. Introduction

Resistance exercise (RE) is a systematic physical activity modality with the objective of increasing muscle strength to overcome resistance [1, 2]. Thus, RE has been suggested in sports guidelines aiming at improving physical conditioning, health and injury prevention [3, 4]. This physical activity modality is a combination of dynamic actions and static effort with the principle of increasing muscle strength and power from multiple variables, such as: exercise order, rest interval between sets, exercise mode, training frequency, movement velocity, training volume, repetitions per set, number of sets, type of muscle action, and the load intensity that can all be manipulated to meet the training goals and individual differences in training needs [1–4]. On the other hand, there are differences of opinion whether the use of a RE program that consists of free weights or machines is better for building muscle mass, strength and injury prevention. Free weights utilize isotonic resistance that provides the same amount of resistance throughout the range of motion. Thus, free weights allow for movement in multiple planes requiring balance [3, 5]. However, the machines are a fixed-form exercise that is limited to moving through fewer planes with a stable environment [3, 5].

Muscle strength is defined as the maximum force generated by a muscle or a muscle group during maximal voluntary contraction against resistance [1–3]. The methods of assessing the maximal muscle strength can be recorded in different contraction regimens, such as isokinetic dynamometers or the most often applied isometric, concentric and eccentric contraction regimens [6–8]. Particularly, the isometric muscle strength testing involves a maximal voluntary contraction performed at a specific joint angle against immovable resistance. Therefore, some studies have shown that the maximum isometric contraction of the quadriceps occurs at 70° of knee extension [9]. On the other hand, values of the maximal isometric contractions occur at a fixed knee flexion position at 30° [7]. Hence, measurement of isometric muscle strength is crucial for providing information regarding the muscular condition, functional capacity, muscle imbalance and the ratio between the peak torque of the hamstring (H) and the quadriceps (Q) measured during a concentric contraction (H:Q ratio) [6–8].

The difference of strength between the dominant leg (DL) vs. the non-dominant leg (NDL) has been the topic of several studies that identified the bilateral asymmetry (BA) is detrimental to performance increasing the risk of injury [10, 11]. Some studies report that BA higher than 10% results in a loss of muscle power, slower change of direction speed times, and an increased risk of lower limb injuries [12, 13]. However, strength asymmetries > 15% are four-to-five times more likely to cause a hamstring strain and knee injuries [14]. In addition, the H:Q ratio provides important information about the optimal quadriceps and hamstring muscles functioning or muscle imbalances [9, 15]. Thus, the H:Q ratio has been used to assess the risks of knee and hamstring injuries, and its values of <0.6 enhance these risks of injury [15–17]. But, interestingly, in regard to isometric muscle strength of the thigh and BA between lower limbs and the H:Q ratio, the scientific literature has shown a limited number of studies that have assessed resistance training models (Free-weight vs. Machine). Therefore, the purpose of this study was to assess the muscular strength of the knee extensors and flexors, BA and the H:Q ratio between DL vs. NDL of males trained with free weights vs. machines. It was hypothesized that RE with free weights would contribute to greater isometric muscle strength, H:Q ratio and no BA.

2. Materials and Methods

2.1. Study Design

This is a randomized comparative study. The sample size was determined by including all participants that complied with the eligibility criteria. All participants were practitioners of RE with free weights or machines and underwent three tests to assess the isometric muscle strength of hamstring and quadriceps muscles. All tests were performed in a single assessment session. All assessments were taken in a temperature-controlled environment (temperature 21°C, 65% relative humidity) by a Hygro-Thermometer with Humidity Alert (Extech Instruments, Massachusetts, EUA). All assessments occurred between 2:00 and 4:00 P.M.

2.2. Participants

Thirty males were recruited and separated into two groups: Free-weights (n = 15) and Machines (n = 15) groups. All study participants performed the IMS testing for knee extensors and flexors in the DL and NDL using a commercially available load cell. Considering the fact that there is not a large number of studies directly regarding the relationship between neur working with people who have high levels of stress caused by the same centers in the brain which are highly active during the feeling of loneliness and alexithymia was included [14].

2.3. Anthropometric Measurements

Body composition was measured following an 8-h overnight fast by bioelectrical impedance analysis using a device with built-in hand and foot electrodes (BIO 720, Avanutri, Rio de Janeiro, Brazil). The participants wore their normal indoor clothing and were instructed to stand barefoot in an upright position with both feet on separate electrodes on the device's surface and with their arms abducted and both hands gripping two separate electrodes on each handle of the device. All biometric measurements were carried out in an air-conditioned room (21°C). No clinical problems occurred during the study.

2.4. Isometric Muscle Strength Testing

The isometric muscle strength (IMS) was measured using commercially available load cells (E-lastic, E-sporte Soluções Esportivas, Brasília, Brazil). The knee extensors and flexors in the dominant (DL) and the nondominant leg (NDL) were tested concentrically. During the knee extension and flexion tests, the left and right ankles were individually secured by bands and fixed in the load cells (Figure 1). The tests were carried out by random sampling. Before the isometric muscle strength test, all participants performed a warm-up exercise for 10 min on a stationary cycloergometer (no resistance) with moderate velocity (70–80 revolutions per minute).

The assessment of the knee extension was carried out in a sitting position. The participants sat on a chair with their knee initially positioned at 90°. Force values of the maximal isometric contractions were measured at a fixed knee extension position at 70° [9] (Figure 1A; 1B). On the other hand, the knee flexion assessment was initially performed with the subjects lying prone with an extended knee on a standard treatment table. Force values of the maximal isometric contractions were measured at a fixed knee flexion position at 30° [7] (Figure 1C; 1D). All participants were stabilized with belts around the torso and pelvis to avoid compensatory movements in both tests (knee extension and flexion). Thus, only the knee to be tested was moving with a single degree of freedom. Participants performed three times of knees extension and three times of knee flexion for both knees, and the highest value obtained from the three trials was used for statistical analysis.

Force values were registered during 5 seconds of maximal isometric contraction and rest interval of 60 secs between the trials. All tests (i.e., concentric contractions of the knee extensors and flexors) used a five-minute recovery between them. The isometric force data of the load cell were simultaneously transferred via Bluetooth to a mobile cellphone (sample rate = 10 Hz). All participants were strongly encouraged to make maximal effort for each action, and no subjects were excluded through injury during the experimental procedure. This testing method has shown intra-rater reliability measures greater than 0.96.

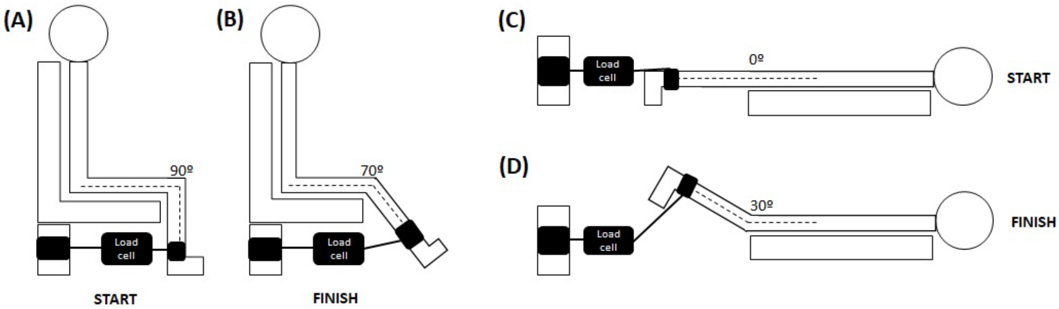

Fig. 1. Schematic image of isometric muscle strength testing.

2.4. Statistical Analysis

All data are presented as mean ± standard deviation. Statistical analysis was initially performed using the Shapiro–Wilk normality tests and the homoscedasticity test (Bartlett criterion). To test the reproducibility between the tests, the intraclass correlation coefficient (ICC) was used. The mean values for the DL and NDL tests were evaluated with student's T-test. The hamstring to quadriceps ratio (H:Q ratio) was calculated from the division of the strength of the hamstring muscles by the strength of the quadriceps in a concentric motion. The calculation of the bilateral asymmetry (BA) occurred from of the difference of IMS between DL and NDL divided by the IMS of DL and multiplied by 100. The level of statistical significance was set at an alpha level of $P < 0.05$ using GraphPad Prism® software (Prism 6.0, San Diego, CA, USA).

3. Results

All analyzed data presented normal distribution. Table 1 compares the isometric muscle strength of the quadriceps and hamstring muscles among males trained with Free-weight vs. Machine. Assessment of the IMS of the quadriceps and hamstring muscles for DL and NDL showed significant differences between Free-weight group and Machine group (Table 1). In addition, a significant difference ($p < .03$) of the IMS of the hamstring muscles was observed between DL vs. NDL to the machine group (Table 1).

Table 1. Performance of isometric muscle strength among males trained with free weights vs. machines (n = 30).

		Free-weight	Machine	Mean of differences (95% CI)	*p* <
IMS quadriceps (kg)	DL	57.1 ± 12.3	47.7 ± 8.3	9.4 (0.2 to 18.5)	< .04
	NDL	57.1 ± 9.3	48.9 ± 8.2	8.1 (0.1 to 16.1)	< .04
BA (%)		6.1 ± 4.8	8.2 ± 4.2	-	-
IMS hamstring (kg)	DL	35.1 ± 6.5	25.1 ± 5.3	10.1 (4.8 to 15.3)	< .001
	NDL	34.6 ± 6.1	26.7 ± 6.1*	7.8 (2.6 to 13.1)	< .006
BA (%)		6.9 ± 4.3	11.1 ± 3.6	-	-

*$p < .03$ significant difference between machine group (DL vs. NDL)
BA = Bilateral asymmetry
IMS = Isometric muscle strength

The H:Q ratio on DL ($p < .002$) and NDL ($p < .01$) was significantly higher in the Free-weight group (DL = 0.62 ± 0.09 and NDL = 0.61 ± 0.09) when compared to the Machine group (DL = 0.52 ± 0.05 and NDL= 0.54 ± 0.07) (Figure 2).

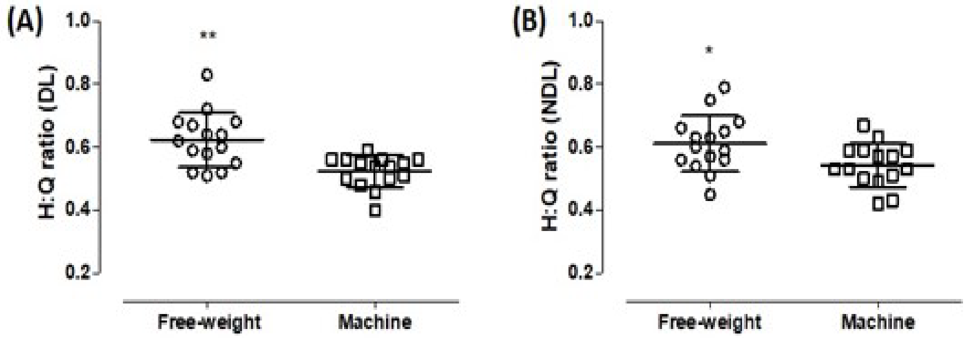

Fig. 2. Mean ± SD values of the H:Q ratio between the Free-weight group vs. the Machine group.

4. Discussion

This study aimed to assess the isometric muscle strength of the hamstring and quadriceps muscles as well as the H:Q ratio among male practitioners of RE with free-weights or machines. The main results obtained in this study were that (a) the Free-weight group showed greater IMS of the hamstring and quadriceps muscles for DL and NDL when compared to the Machine group during the evaluation of the isometric muscle strength; (b) the Free-weight group revealed a significant increase in the H:Q ratio for DL and NDL.

The ability to generate force is related to the transverse section size, motor unit recruitment and action of synergist muscles [6, 15]. Thus, the quantification of muscle strength becomes an essential component of the neuromuscular assessment being an important component of fitness and physical performance [6, 10]. However, the decreased strength of the quadriceps and hamstring muscle contributed to decreasing an ability to stabilize the knee, resulting in a faulty alignment of the lower extremity and high incidence of injury [18]. Specifically, on the isometric muscle strength during contraction of the quadriceps and hamstring, our results showed that the free-weight group had greater production of isometric strength than the machine group for both DL and NDL. But there is a lack of studies comparing the isometric muscle strength of the quadriceps and hamstring among free weights and machines. A possible explanation might be that exercises on machines contribute to movements made only in a single plane of motion and that ballistic movements are impossible to perform [5, 19]. Thus, machine exercises stabilize the environment, tend to facilitate exercise performance, reduce the participation of some synergist muscles, and favor the dominance of quadriceps or hamstring, which negatively affects the knee by increasing strain on the anterior cruciate ligament (ACL) [19–21]. Conversely, free-weight exercises constitute compound variable resistance that provides a load which changes to match the ability of the musculoskeletal lever system to produce force throughout the range of motion [22, 23]. In addition, free-weight exercises show a more balanced quadriceps-to-hamstrings coactivation ratio by producing a compressive joint load that forces the articular surfaces together, consequently resulting in less anteroposterior displacement of the tibia relative to the femur and minimizing ACL loading [20, 24, 25].

The assessment of the isometric muscle strength between DL vs. NDL may suffer imbalance between DL and NDL in subjects trained on machines because the increase in muscle activity contributes to the decrease in stability, asymmetry of muscle strength and may cause functional or even structural disproportionateness [26]. Our findings showed an asymmetry of muscle strength of 11% for the hamstring muscles between DL vs. NDL during the IMS test in the machine group. Scientific research has reported that an increased risk of knee injury occurs when the strength asymmetries are equal to or greater than 10% between DL vs. NDL, which can be higher in the NDL than in the DL during unilateral dynamic movements [27, 28].

Muscular performance and a reduced risk of knee injury depends on the balance of the strength ratios of agonist and antagonist muscle groups [9, 15]. Thus, the H:Q ratio describing the knee joint stability of the absolute knee extension muscle force should exceed the knee flexion force by a magnitude of 3:2, i.e., a normative value equal to or greater than 0.60 [9, 15, 17]. In the present study it was observed that the free-weight group showed a value >0.60. On the other hand, the machine group showed values below 0.55. The scientific literature shows that a concentric H:Q ratio less than 0.55 (95% CI: 0.47–0.67) is associated with an increased risk (4 times more likely) of developing hamstring injuries and ACL rupture [11, 17, 28]. On the other hand, the value > 0.60 of the H:Q ratio (95% CI: 0.60 to 0.80) has been an adequate value for minimizing the risks of muscle and joint injuries [9]. In addition, some studies showed that the concentric H:Q ratio > 0.60 minimizes the risks of hamstring injuries and reduces the risk of anterolateral subluxation of the tibia [16, 17, 29]. In general, the muscle imbalance between isometric muscle strength of the hamstring and quadriceps muscles observed in the machine group may affect the joint reaction force passing through the knee; consequently, impairing the distribution of the joint reaction force across the medial and lateral condyle, epicondyles, menisci and cruciate ligaments [7, 30]. Thus, these findings have applications regarding the prescription of training for optimizing physical development and minimizing the risk of injury.

The limitation of the study is the absence of measures of physiological parameters and analysis of EMG signals, which would be interesting. Yet this does not affect the answer to the study question. However, our sample was homogeneous although longitudinal studies are needed to define a cause-and-effect relationship among resistance training model, H:Q ratio, bilateral asymmetry, and knee functional performance.

5. Conclusions

This study showed better isometric muscle strength of the thigh (hamstring and quadriceps) and H:Q ratio in males trained with free weights. On the other hand, males trained with machines showed bilateral asymmetry of the hamstrings muscles and lower H:Q ratio, consequently, higher risk of knee injuries. These data contribute to the qualitative and quantitative understanding between resistance training models (Free-weight vs. Machine) in the normal knee function. Thus, these assessments may be helpful for coaches, physicians and physical therapists regarding neuromuscular performance and injury prevention.

References

1. Marocolo M, Marocolo IC, Cunha FSB, Mota GR, Maior AS. Influence of percentage of 1RM strength test on repetition performance during resistance exercise of upper and lower limbs. Arch Med Deporte. 2016;33(6):387–392.
2. Baz-Valle E, Schoenfeld BJ, Torres-Unda J, Santos-Concejero J, Balsalobre-Fernández C. The effects of exercise variation in muscle thickness, maximal strength and motivation in resistance trained men. PLoS One. 2019;14(12):e0226989. DOI: 10.1371/journal.pone.0226989
3. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009;41(3): 687–708. DOI: 10.1249/MSS.0b013e3181915670
4. Faigenbaum AD, Myer GD. Resistance training among young athletes: safety, efficacy and injury prevention effects. Br J Sports Med. 2010;44(1):56-63. DOI: 10.1136/bjsm.2009.068098
5. Stone M, Plisk S, Collins D. Training principles: evaluation of modes and methods of resistance training—a coaching perspective. Sports Biomech. 2002;1(1):79–103. DOI: 10.1080/14763140208522788
6. Park HW, Baek S, Kim HY, Park JG, Kang EK. Reliability and validity of a new method for isometric back extensor strength evaluation using a hand-held dynamometer. Ann Rehabil Med. 2017;41(5):793-800. DOI: 10.5535/arm.2017.41.5.793

7. Mendes B, Firmino T, Oliveira R, Neto T, Infante J, Vaz JR, et al. Hamstring stiffness pattern during contraction in healthy individuals: analysis by ultrasound-based shear wave elastography. Eur J Appl Physiol. 2018;118(11):2403–2415. DOI: 10.1007/s00421-018-3967-z
8. Augustsson J, Bruno M, Swärd J. Development of a new isometric strength test using an isoinertial-based weight machine. Adv Physio. 2010; 12(2): 81–86. DOI: 10.3109/14038191003706537
9. Coombs R, Garbutt G. Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance. J Sports Sci Med. 2002;1(3):56–62.
10. Bonetti LV, Floriano LL, dos Santos TA. Isokinetic performance of knee extensors and flexors in adolescent male soccer athletes. Sport Sci Health. 2017; 13: 315–321. DOI: 10.1007/s11332-017-0360-y
11. Gkrilias P, Zavvos A, Fousekis K, Billis E, Matzaroglou C, Tsepis E. Dynamic balance asymmetries in pre-season injury-prevention screening in healthy young soccer players using the Modified Star Excursion Balance Test – A pilot study. J Phys Ther Sci. 2018;30(9):1141–1144. DOI: 10.1589/jpts.30.1141
12. Hoffman JR, Ratamess NA, Klatt M. Do bilateral power deficits influence direction-specific movement patterns? Res Sports Med. 2007;15:1–8. DOI: 10.1080/15438620701405313
13. Bell DR, Sanfilippo JL, Binkley N. Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. J Strength Cond Res. 2014; 28: 884–891. DOI: 10.1519/JSC.0000000000000367
14. Croisier JL, Ganteaume S, Binet J. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. Am J Sports Med. 2008; 36:1469–1475. DOI: 10.1177/0363546508316764
15. Sousa LA, Soares ALA, Lima AB, Paes RR, Nakamura LR, Carvalho HM. Modeling the Angle-Specific Isokinetic Hamstring to Quadriceps Ratio Using Multilevel Generalized Additive Models. Medicina (Kaunas). 2019;55(8):411. DOI: 10.3390/medicina55080411
16. Li RC, Maffulli N, Hsu YC, Chan KM. Isokinetic strength of the quadriceps and hamstrings and functional ability of anterior cruciate deficient knees in recreational athletes. Br J Sports Med. 1996;30:161–164. DOI: 10.1136/bjsm.30.2.161
17. Torres G, Chorro D, Navandar A, Rueda J, Fernández L, Navarro E. Assessment of Hamstring: Quadriceps Coactivation without the Use of Maximum Voluntary Isometric Contraction. Appl Sci. 2020;10(5):1615. DOI: 10.3390/app10051615
18. Faxon JL, Sanni AA, McCully KK. Hamstrings and Quadriceps Muscles Function in Subjects with Prior ACL Reconstruction Surgery. J Funct Morphol Kinesiol. 2018;3(4):56. DOI: 10.3390/jfmk3040056
19. Morrissey MC, Hudson ZL, Drechsler WI, Coutts FJ, Knight PR, King JB. Effects of open versus closed kinetic chain training on knee laxity in the early period after anterior cruciate ligament reconstruction. Knee Surg Sport Traumatol Arthrosc. 2000;8(6):343–8. DOI: 10.1007/s001670000161
20. Uçar M, Koca I, Eroglu M, Eroglu S, Sarp U, Arik HO, et al. Evaluation of open and closed kinetic chain exercises in rehabilitation following anterior cruciate ligament reconstruction. J Phys Ther Sci. 2014; 26(12):1875-8. DOI: 10.1589/jpts.26.1875
21. Da Silva EM, Brentano MA, Cadore EL, De Almeida APV, Kruel LFM. Analysis of muscle activation during different leg press exercises at submaximum effort levels. J Strength Cond Res. 2008, 22; 1059–1065. DOI: 10.1519/JSC.0b013e3181739445
22. Welch N, Moran K, Antony J, Richter C, Marshall B, Coyle J, et al. The effects of a free-weight-based resistance training intervention on pain, squat biomechanics and MRI-defined lumbar fat infiltration and functional cross-sectional area in those with chronic low back. BMJ Open Sport Exerc Med. 2015;1(1):e000050. DOI: 10.1136/bmjsem-2015-000050
23. Baroni BM, Pompermayer MG, Cini A, Peruzzolo AS, Radaelli R, Brusco CM, et al. Full range of motion induces greater muscle damage than partial range of motion in elbow flexion exercise with free weights. J Strength Cond Res. 2017;31(8):2223–2230. DOI: 10.1519/JSC.0000000000001562
24. Beynnon BD, Johnson RJ, Fleming BC, Stankewich CJ, Renstrom PA, Nichols CE. The strain behavior of the anterior cruciate ligament during squatting and active flexion-extension: A comparison of an open and a closed kinetic chain exercise. Am J Sports Med. 1997;25(6):823–829. DOI: 10.1177/036354659702500616
25. Begalle RL, Distefano LJ, Blackburn T, Padua DA. Quadriceps and hamstrings coactivation during common therapeutic exercises. J Athl Train. 2012;47(4):396-405. DOI: 10.4085/1062-6050-47.4.01

26. Martín-Fuentes I, Oliva-Lozano JM, Muyor JM. Evaluation of the lower limb muscles' electromyographic activity during the leg press exercise and its variants: A systematic review. Int J Environ Res Public Health. 2020;17(13):4626. DOI: 10.3390/ijerph17134626
27. Daneshjoo A, Rahnama N, Mokhtar AH, Yusof A. Bilateral and unilateral asymmetries of isokinetic strength and flexibility in male young professional soccer players. J Hum Kinet. 2013;36:45-53. DOI: 10.2478/hukin-2013-0005
28. Wang J, Fu W. Asymmetry between the dominant and non-dominant legs in the lower limb biomechanics during single-leg landings in females. Adv Mechan Eng. 2019;11(5):1–8. DOI: 10.1177/1687814019849794
29. Raunest J, Sager M, Burgener E. Proprioceptive mechanisms in the cruciate ligaments: an electromyographic study on reflex activity in the thigh muscles. J Trauma. 1996;41:488-493. DOI: 10.1097/00005373-199609000-00017
30. Goldblatt JP, Richmond JC. Anatomy and biomechanics of the knee. Operat Tech Sports Med. 2003; 11(3): 172–186. DOI: 10.1053/otsm.2003.35911

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