

HIP AND KNEE FLEXORS AND EXTENSORS BALANCE IN DEPENDENCE ON THE VELOCITY OF MOVEMENTS

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Abstract. Balance of the muscles in the joint is determined as the ratio of torques between the agonists and antagonists. Deficiency in one muscle group may lead to an imbalanced action in that joint and cause musculoskeletal injuries. The aim of the investigation was to determine the ratio of torque values between hip and knee joints flexors and extensors in the different positions of the range of movements at medium and high velocity of movement. The hip joint flexors and extensors, and knee flexors and extensors were tested by the dynamometer system "REV-9000" Technogym in the isokinetic movements with the medium angular velocity 100°/s and high velocity 200°/s. The 11 male students of Latvian Academy of Sports Education with the average age 24.3±4.5 years participated in the investigation. The flexors/extensors torque ratios for the hip and knee joints were calculated in different positions of the joints range of movements with the step 10° and it was found that this ratio changes in dependence on the joint angle. Our results show that the risk of the hamstring injury doubles at high velocity of movements in comparison with the medium velocity because the hip flexors/extensors torques ratio in the flexed positions of the hip (50° and 60°) at the fast velocity becomes twice higher due to growth of the hip flexors produced torques (hip flexors/extensors torques ratio is 83-93 % at the velocity 200°/s and 47-48% at 100°/s). In the knee extreme extension the hamstrings/ quadriceps torque ratio at the fast velocity of movements is slightly higher due to higher value of the hamstrings produced torques with the aim to decelerate the knee extension to prevent the knee injury.

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Key words: Hip joint - Knee joint – Dynamometry - Muscles balance - Running

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Introduction

Balance of the muscles strength in certain joint is determined as the ratio of their produced torques between the agonists and antagonists. Muscle groups on opposite sides of a joint act reciprocally to produce smooth and coordinate movements and to prevent injuries of muscles, tendons and joint elements during fast movements. Deficiency in one muscle or muscle group may lead to an imbalanced action in that joint. It may lead to occurrence of musculoskeletal injuries due to inadequate distribution of stresses and strains in muscles, tendons, joint ligaments and cartilage.

Some investigators have found that previous injury or surgery of the knee joint lead to muscle weakness and imbalance, as well as, to high rate of repeated trauma [7,11,15]. Only few authors are investigated the relationship between imbalance in muscles strength and the occurrence of injuries for healthy sportsmen. For example, Knapik *et al.* [13] revealed that the knee muscles imbalance measured at fast velocity of movements was associated with injuries.

Very high muscle strain can cause injury of the muscle and its tendon. It is indirect injury because it is caused by excessive tension loads but not from a direct trauma. Injury typically occurs during forced lengthening of the muscle contracting to decelerate high velocity movements (sprint running and other power sports).

The predisposing factors to injury are [20]: muscle imbalance, lack of flexibility, insufficient warm-up before exercises and fatigue of muscles. The hamstrings are especially susceptible to muscle strain. These muscles have biarticular function. They contracts to cause hip extension and knee flexion. Simultaneous hip flexion and knee extension lengthen hamstrings and the muscles injury may occur if the movements are very fast and forcefull (sprint running for sprinters [9,10] and athletes trained in bob sleigh, jumping and other power sports). Strain injury usually occurs late in the leg swing phase or early in the stance phase. During the late swing phase the hamstrings act to decelerate the thigh and lower leg. Early in stance the hamstrings act to extend the hip. The other factor elevating the risk of hamstrings injury in power sports is high proportion of fast – twitch muscle fibers in these muscles, which causes high intrinsic force production [19].

The peak torque and power produced by the hip joint extensors (hamstrings) are the most informative parameters for estimation of the efficiency of power sport specializations (bob sleigh etc.) athletes training process, but for endurance sport specializations they are not so important [18]. The highest hip extensors forces are detected in running (in comparison with skiing and walking) in the push-off phase using an accelerometer system mounted on the upper body of sportsmen [5]. The

movements in the hip joint are the most important for the force production in the sprint running [14]. Due to these conditions we have selected for study the muscles, which provide the movements in the hip joint. Therefore the hamstrings provide not only hip extension, but also the knee flexion, and the maximal strains in these muscles occur during hip flexion and knee extension simultaneously in the extreme leg swing phase, we have tested the knee joint too.

The aim of the present investigation is to determine the ratio of torque values between hip and knee joints flexors and extensors in the different positions of the range of movements.

Material and Methods

The hip joint flexors and extensors (hamstrings), and knee flexors (hamstrings) and extensors were tested by the dynamometer system "REV – 9000" (Technogym, Gambettola, Italy) in the isokinetic movements with the medium angular velocity 100°/s (degrees per second) and high velocity 200°/s.

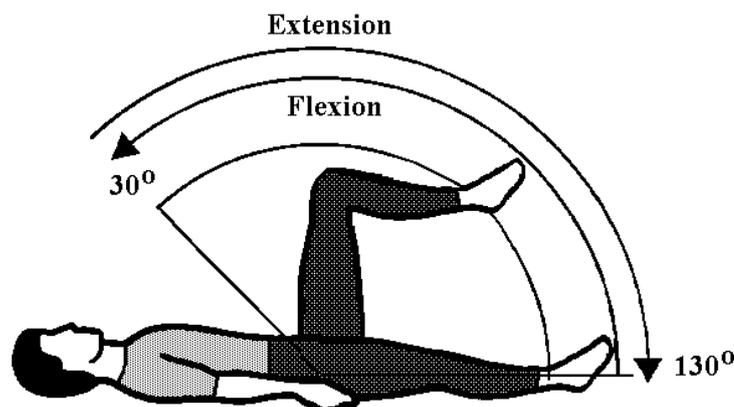


Fig. 1
Range of movements (ROM) in the hip flexion and extension, the position of athlete supine during the isokinetic dynamometry test

The range of movements (ROM) in the hip joint was from 30° in flexion to 130° in extension (Fig. 1). The person was placed in the supine position on the test table. The axis of the dynamometer system was aligned with the flexion – extension axis of the hip joint: through the greater trochanter. The support lever was fixed at the lower part of the thigh. The trunk and pelvis were stabilized using the straps. The length of the support lever was selected to allow maximal hip flexion. The test began with the hip flexion movement. The number of the flexion – extension movement repetitions was 4.

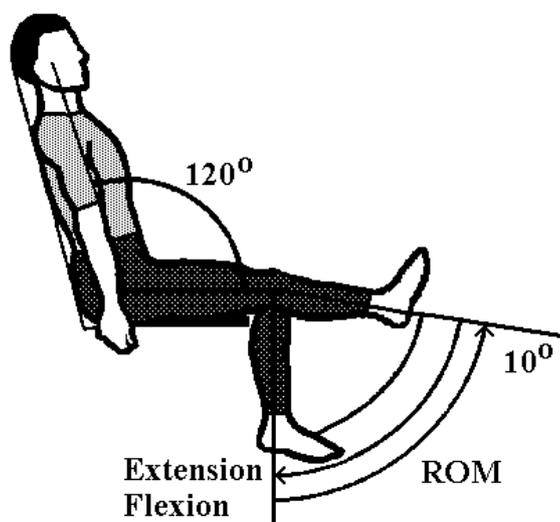


Fig. 2
Range of movements (ROM) in the knee flexion and extension, the positioning seat with the hip angle 120° of flexion during the isokinetic dynamometry test

The ROM in the knee joint was from 10° in extension to 90° in flexion (Fig. 2). The person was placed in the positioning seat with the hip at an angle of 120° of flexion. The hip and trunk were fixed by stabilizing straps. The support lever was attached at the point between the upper two thirds and the lower third of the shin. The person was fixed in position after adjustment of the depth of the seat, the height of the dynamometer and the length of support lever to be aligned with a prolonged virtual rotation axis of the knee. The rotation axis of the knee joint was determined as a line passing through the femoral condyles. The test began with the knee extension from 90° of the ROM – extreme flexion position. The movements were repeated 4 times.

The students of Latvian Academy of Sports Education trained in basketball and handball participated in the investigation. The number of athletes was 11. They all were males with the average age 24.3±4.5 years and the average weight 76.6±4.2 kg.

The torque values produced by hip and knee flexors and extensors were detected for both angular velocity values (100° and 200° per second) at the different angular positions of the range of movements (ROM) with the step of 10°. The hip at the joint ROM angles of 30°, 40°, 50°, 60°, 70°, 80°, 90°, 100°, 110°, 120° and 130°, but the knee at the ROM angles of 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80° and 90°.

Then the torque ratios of hip and knee joints flexors/extensors are calculated for every joint angle at the velocity of movement 100°/s and 200°/s from the best repetition of the flexion – extension movement. The hip and knee flexors/extensors ratios dependence on the angle of ROM is compared at the medium angular velocity (100°/s) and high velocity (200°/s).

Results

The reliability of the hip muscles produced torques measurements is low in the extreme positions of the joint flexion and extension. Due to it the torque values are taken into account only in the middle part of the ROM (from 50° to 100°) (Table 1).

Table 1

The torques produced by hip flexors and extensors at the different angular positions of the ROM at the angular velocity of 100°/s and 200°/s

Muscle group	Hip flexors torque (SD), Nm		Hip extensors torque (SD), Nm	
	100°/s	200°/s	100°/s	200°/s
Angular velocity				
Angle of ROM				
40 ⁰	81 (46)	39 (34)	139 (91)	114 (107)
50 ⁰	105 (29)	114 (32)	228 (80)	135(41)*
60 ⁰	123 (22)	122 (25)	266 (58)	173 (62)*
70 ⁰	134 (25)	121 (28)*	262 (49)	238 (55)*
80 ⁰	142 (23)	130 (35)*	255 (49)	225 (70)*
90 ⁰	153 (25)	130 (29)*	239 (43)	226 (62)
100 ⁰	152 (41)	117 (43)*	219 (47)	200 (66)*
110 ⁰	146(60)	94 (43)	182 (67)	190 (95)
120 ⁰	105(47)	76 (54)	158 (80)	98 (82)

*Difference between the torque values at the angular velocity of 100°/s and 200°/s at the same angular position of the range of movements in statistically significant (P<0.05)

If the velocity of hip joint movements is medium (100°/s), the values of hip flexors and extensors produced peak (maximal) torques are higher than at the high

velocity of hip movements (200°/s), and they are reached faster in the range of flexion and extension movements, respectively. The peak torque of hip flexors appears at the angle of ROM of 90°-100° at the velocity of 100°/s and at 80°-90° at the velocity of 200°/s. The maximal value of the hip extensors torque at the velocity 100°/s is reached at the angle of 60°, but at the velocity 200°/s - at the angle of ROM of 70°. The hip flexors/extensors ratios of the peak torques are 68%±10% at the velocity of movement 100°/s and 67%±15% at the high velocity 200°/s.

Flexion movement at high velocity (200°/s) causes significant increase ($P<0.001$) of the flexors/extensors torques ratio in flexion positions of the hip (50° and 60°), (Fig. 3). In these positions of ROM the flexors/extensors torques ratio approximately twice exceeds this ratio at the medium velocity of movement.

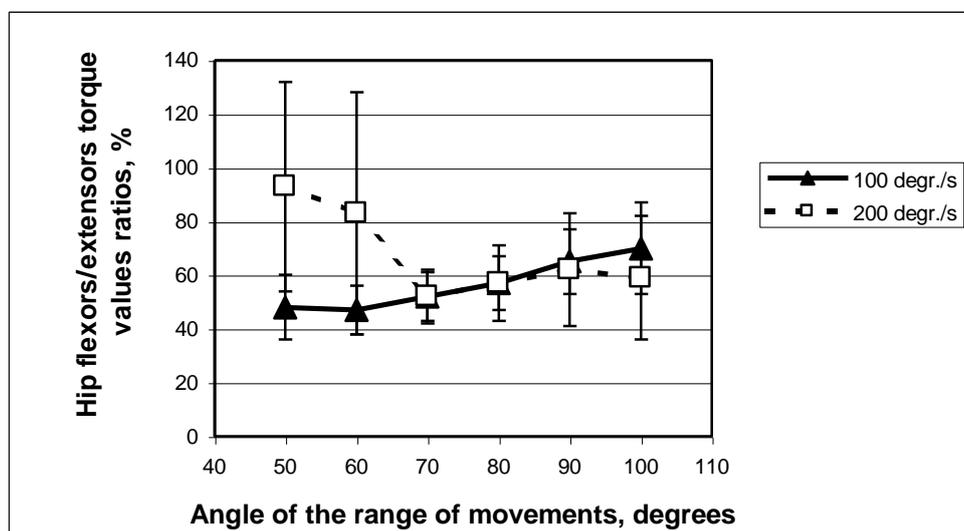


Fig. 3

Hip flexors/extensors torque ratios (%) and standard deviations at the different angular positions of the ROM at the angular velocity of movement of 100°/s and 200°/s

Table 2

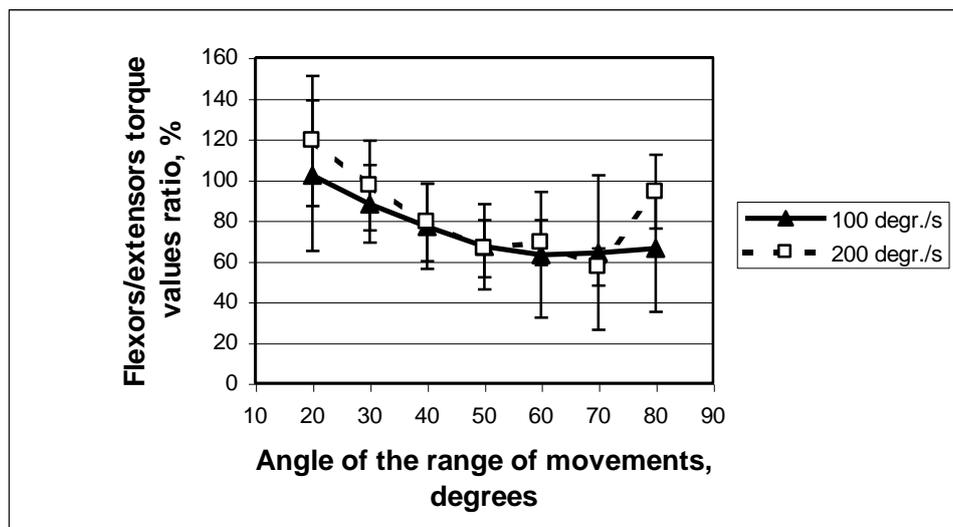
The torques produced by knee flexors and extensors at the different angular positions of the ROM at the velocity of 100°/s and 200°/s

Muscle group	Knee flexors torque (SD), Nm		Knee extensors torque (SD), Nm	
	100°/s	200°/s	100°/s	200°/s
Angular velocity				
Angle of ROM				
10 ⁰	47 (20)	41 (28)	46 (33)	42 (34)
20 ⁰	87 (22)	73 (14)*	93 (25)	74 (32)*
30 ⁰	108 (12)	98 (12)*	128 (23)	106 (19)*
40 ⁰	111 (14)	97 (18)*	155 (24)	129 (17)*
50 ⁰	110 (15)	93 (18)*	176 (23)	145 (16)*
60 ⁰	106 (13)	89 (17)*	190 (10)	155 (14)*
70 ⁰	98 (13)	81 (16)*	180 (17)	147 (18)*
80 ⁰	86 (14)	93 (16)*	148 (24)	101 (10)*
90 ⁰	33 (31)	22 (26)	16 (16)	12 (8)

*Difference between the torque values at the angular velocity of 100°/s and 200°/s at the same angular position of the range of movements in statistically significant (P<0.05)

The reliability of torque values produced by knee muscles is low at the extreme positions of the knee joint ROM: at the angles of 10° and 90° (Table 2). Therefore only the middle part of the range of movements could be estimated.

The peak torque values produced by the knee flexors and extensors are higher at the medium velocity (100°/s) than at the high velocity of movements (200°/s). The angular positions of the peak torques are the same in the knee extension at the medium and high velocity movements. In the knee flexion the maximal torque is reached faster in the ROM at higher angular velocity. The knee flexors/ extensors peak torques ratios are 61%±7% at the medium velocity of movement 100°/s and 70%±9% at the high velocity 200°/s.

**Fig. 4**

Knee joint flexors/extensors ratios in % and standard deviations at the different angular positions of the ROM at the middle (100°/s) and high (200°/s) velocity of movement

In the extreme positions of the knee extension (at the angles of ROM 10°-30°) at the fast velocity of movements (200°/s), the knee flexors/extensors torques ratio has higher value, because the knee flexors produce relatively higher torque in comparison with the knee extensors than in lower velocity (100°/s), (Fig. 4).

The knee flexors/extensors torques ratio values at the fast velocity of movements (200°/s) is higher in the flexed knee position (at the angle of the ROM of 80°). In the beginning of the knee extension movement the flexors are relatively stronger at the high velocity to decelerate the fast knee extension movement, which prevent knee joint trauma.

Discussion

To estimate the balance or imbalance in the joint it is necessary to determine flexors/extensors strength ratios for these two muscles groups. The ratios between the agonist and antagonist muscles strength values are important in treating athletic injuries. An imbalance may cause the weaker muscle group to lie more vulnerable to stress [17]. Alexander [3] was found ratios between flexion and extension peak

torques in the hip joint at slow (30°/s) and fast (180°/s) angular velocities. They were 74% at the velocity of 30°/s and 59% at 180°/s for male sprinters. It is close with the data of other investigators [6]: the hip flexors/extensors torques ratio ranged between 68% and 75%. The slight difference in the ratios can be explained by the investigation of different populations: elite sprinters and sample healthy people group. Our hip flexors/extensors ratios of the peak torques are 68%±10% at the velocity of 100°/s and 67%±15% at the 200°/s. They are close to the data obtained by other authors [3,6], but the average values of the ratios do not differ at medium and high velocities of movement.

The average value for the knee flexors/extensors (hamstrings/quadriceps femoris) torques ratio is approximately 60% at slow angular velocity of movement 30°-60°/s [6,12,16]. The value of this ratio increases with the growth of the velocity of movement, and the value is close to 80% at the fast velocity 240°-300°/s [3,8,17]. We found that the knee flexors/extensors torques ratio at the medium angular velocity 100°/s is 61%±7%, but at the high velocity 200°/s-70%±9%. These results agree with the data of Calmels *et al.* [6], they obtained the ratio 55-60 % at the slow velocity 60°/s and 63% at fast angular velocity 240°/s. The hamstrings-quadriceps femoris imbalance puts extra stress on the intra – articular ligaments of the knee, and the ability to restore the correct body alignment in response to sudden external forces is decreased [11]. Therefore the knee joint trauma may occur more probable in sport activities.

We think that it is not correct to determine the ratio of flexors/extensors for the peak torques values because they appear in the different positions (angles) of the hip or knee joint range of movements (ROM). This opinion is in good agreement with Nosse [16] skeptical view of this value of the knee joint because it is derived isometrically with the flexors peak torque at the flexion angle of 15° and the extensors maximal torque at the angle of 65°, respectively. Moreover, the angle of peak torque both – for flexors and extensors is dependent on the angular velocity of movement. This dependence of the peak torque angle on the velocity of movement is confirmed by the investigation of Blazeovich and Jenkins [4] for weight trained sprinters and weight trainers at three different angular velocities of 60°/s, 270°/s and 480°/s. From their study: peak torque values for both muscle groups (hip flexors and extensors) are reached faster in the ROM of movement (flexion or extension) with the increase of the angular velocity, which is not confirmed in our investigation. It can be explained by using of smaller angular velocities of the hip movements in our tests.

We calculated the flexors/extensors torque ratios for the hip and knee joints in different positions of the joints range of movements with the step 10° and found

that this ratio changes in dependence on the joint angle. This approach allowed us to determine the parts of the ROM, where the certain muscle groups are most vulnerable. Alteration of the strength of muscle groups especially in these parts of the ROM may cause an injury. For hamstrings the maximal strain in muscles appears in the extreme flexion of the hip joint simultaneously with the extreme knee joint extension. The weakness of extensors in the hip extreme flexion positions (late swing phase) may cause injury of the hip extensor muscles (hamstrings) [15]. Our results show that the risk of the hamstring injury doubles at high velocity of movements in comparison with the medium velocity because the hip flexors/extensors torques ratio in the flexed positions of the hip (50° and 60°) at the fast velocity becomes twice higher due to growth of the hip flexors produced torques (hip flexors/extensors torques ratio is 83-93 % at the velocity $200^\circ/\text{s}$ and 47-48 % at $100^\circ/\text{s}$). In the knee extreme extension the hamstrings/quadriceps torques ratio at the fast velocity of movements is slightly higher in comparison with the medium velocity due to higher value of the hamstrings produced torques with the aim to decelerate the knee extension to prevent the injury of knee intra-articular ligaments.

Aagaard *et al.* [1,2] investigated "functional" hamstrings/quadriceps muscles strength ratios as eccentric hamstrings and concentric quadriceps contraction in the knee extension, and concentric hamstrings and eccentric quadriceps contraction in the knee flexion. Aagaard *et al.* [1] determined this "functional" hamstrings/quadriceps ratio at the angle of ROM 50° (0° - full knee extension) it was 80%-100% for elite sailors and 80%-84% for male controls. The conventional hamstrings/quadriceps concentric peak torques ratio values were close to 50%. In other investigations Aagaard *et al.* [2] found that the "functional" hamstrings/quadriceps ratio increased during the fast knee extension in the ROM (angles 50° , 40° , 30°), which proves the role of hamstrings in dynamic knee joint stabilization at the fast movements ($240^\circ/\text{s}$). Using isokinetic machines the contractions of muscles can be concentric or eccentric in full range of movements. They are "unnatural", because during the real sport activities the eccentric muscles action occurs only through few degrees of movement of the ROM. Therefore Aagaard *et al.* [1,2] determined "functional" eccentric-concentric hamstrings/quadriceps strength ratios do not correspond to the true muscle strength ratios in sport movements. We think that the ratios obtained by Aagaard *et al.* [1,2] in the middle part of the range of movements (30° , 40° and 50°) must be higher than in real conditions, because the action of hamstrings is eccentric only in the extended knee joint position. In the greatest part of the ROM the muscles contractions are concentric. The eccentric hamstrings strength is decreased for

sprinters with a history of the hamstrings injury [10] and therefore low “functional” hamstrings/quadriceps ratios allow to predict the muscle group re-injury.

The balance of the hip and knee flexors/extensors torques ratio changes dynamically in the range of movements. Therefore we suggest that it is necessary to determine the alteration of hip and knee flexors/extensors torque ratios values in the different angles of ROM in dependence on the angular velocity of movements to detect the dangerous parts of the ROM to the certain group of muscles, which more probable may be traumatized. It will allow elaborate special training programs to strengthen the weak muscle group in the proper part of ROM.

Conclusions

1. The risk of the hamstring injury doubles at high velocity of movements in comparison with the medium velocity because the hip flexors/extensors torques ratio in the flexed positions of the hip (50° and 60°) at the fast velocity becomes twice higher due to growth of the hip flexors produced torques (hip flexors/extensors torques ratio is 83–93 % at the velocity 200°/s and 47–48 % at 100°/s).
2. In the knee extreme extension the hamstrings/quadriceps torques ratio at the fast velocity of movements is slightly higher in comparison with medium velocity due to higher value of the hamstrings produced torques with the aim to decelerate the knee extension to prevent the injury.
3. Detection of the dangerous parts in the ROM for the certain group of muscles, more probable may be traumatized, will allow to elaborate special training programs to strengthen the weak muscle group in the proper part of the range of movements.

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