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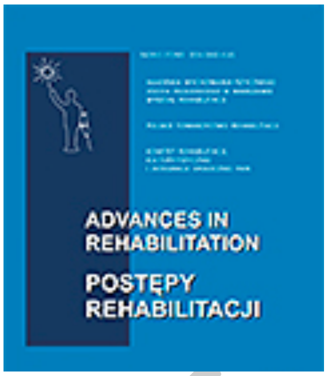

Title: Investigation of knee flexor and extensor muscle strength in athletes with and without trunk muscle strength asymmetry

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Investigation of knee flexor and extensor muscle strength in athletes with and without trunk muscle strength asymmetry

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Abstract
Introduction: Lower extremity injuries may be associated with proximal muscle weakness and decreased motor control. Our study aims to examine knee flexor and extensor muscle strength in athletes with and without trunk muscle strength asymmetry.
Methods: This matching control study involved a total of 80 athletes; 40 athletes with asymmetrical trunk muscle strength(asymmetric group) and 40 athletes with symmetrical trunk muscle strength(symmetrical group). Strength measurements of trunk and knee muscles were made with the IsoMed 2000 isokinetic device. Independent Samples T-Test or Mann Whitney-U test was used to compare variables according to their distribution status. The statistical error level was determined as $p<0.05$.
Results: In the symmetric group, the isokinetic muscle strength of the trunk flexor muscles was stronger than the asymmetric group($p<0.05$) and the trunk extensor muscles were weaker than the asymmetric group(p 0.05). The Limb Symmetry Index(LSI) value of the two groups at 60°/sec was significantly different($p=0.032$), and the dominant side in the symmetric group and the non-dominant side in the asymmetric group were stronger than the other side.
Conclusions: This result may be associated with knee joint injuries which are common in athletes with weak muscle strength, and can be attributed to the literature knowledge that core muscle weakness may increase the frequency of knee injury. Therefore, symmetrical core strengthening training can prevent possible injuries of athletes with asymmetrical trunk muscle strength. However, we think that more studies are needed to reveal this relationship.

Keywords: knee, injury, sport, strength ratio

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Introduction

Core stabilization is the ability to maintain intra-abdominal pressure and stabilize the spine by contracting the muscles around the trunk and hips [1]. Core stabilization provides stability and mobility of the passive system (static tissues), active system (muscles), and neural system [2]. These three systems work together to achieve neuromuscular control of core stability [2, 3]. Core stability controls the trunk in response to internal and external disturbances generated from distant body segments, as well as the forces generated by both expected or unexpected perturbations [4]. The abdominal (front), paraspinal and gluteal (back), diaphragm (top), pelvic floor (bottom), and transversus abdominis muscles (sides) play a role in core stabilization. These muscles contract synchronously and increase intra-abdominal pressure, thus; the stabilization of the spine and core region is provided [5, 6]. By providing stabilization of the spine, the center of gravity of the body is kept within normal limits during upper and lower extremity movements, and the reaction forces from the distal extremities are absorbed [7].

In some previous studies, it has been stated that core region muscles are activated first, regardless of the direction of movement in upper and lower extremity movements [7-10].In particular, the transversus abdominis and multifidus muscles first contract in preparation for motion and provide spinal stabilization by increasing intraabdominal pressure [8]. Any defects in core neuromuscular control cause uncontrolled trunk movements during athletic movements, and in the case of closed kinetic chains, these uncontrolled movements can cause injuries, especially in the lower extremities [9, 10].

Lower extremity injuries are a common problem in many sports branches [11-13]. There are many studies in literature investigating the parameters that cause lower extremity and knee injuries [1, 7-9, 14, 15]. One previous study suggested that knee muscle strength and muscle strength asymmetry may be a factor in knee injuries [15]. It is also stated that lower extremity injuries (foot-ankle injuries, patellofemoral pain syndrome, iliotibial band friction syndrome, anterior cruciate ligament injuries, hamstring injuries) may be associated with proximal muscle weakness and decreased motor control [9, 16-20]. Zazulak et al. revealed that athletes with weak trunk neuromuscular control impairment are at risk for knee injuries (especially the anterior cruciate ligament) during long-term follow-up [21]. In Devlin's study of sports injuries of rugby athletes, abdominal fatigue is stated to be a contributing factor to hamstring injuries [19]. It is explained that in case of weakening of trunk flexors, the hamstring muscles are responsible for pelvic stability by working actively against strong trunk extensors and knee extensors [19, 22, 23].

Previous studies have reported that the hamstring muscle is unable to resist pelvic instability under a core strength imbalance and is at risk of injury during eccentric contraction [22, 23]. Similarly, trunk flexor muscles are expected to work actively due to weak hamstring muscles to prevent an excessive anterior tilt of the pelvis [24]. This phenomenon will trigger the overactivity of one of the muscles working synergistically on the pelvis and increase the difference in muscle strength between the muscles working synergistically. Both a weak and overactive hamstring muscle impairs lumbopelvic control. This disorder increases the risk of a hamstring muscle injury [22, 23].

There are studies in literature showing that there is a relationship between the strength of the core muscles and lower extremity injuries [16-21]. However, no studies have been found investigating the relationship between the strength balance of core muscles and lower extremity muscle strength imbalance, which is a risk factor in lower extremity injuries [15].

So, our hypothesis is that athletes with trunk muscle strength asymmetry may also have strength asymmetry in their lower extremities. Therefore, our study aims to examine knee flexor and extensor muscle strength in athletes with and without trunk muscle strength asymmetry.

Methods

The study was conducted according to the Helsinki declaration criteria and declared to all subjects who met the criteria. All athletes were informed about the procedure and they were asked to read and sign the informed consent agreement approved by the XXX Training and Research Hospital’s Ethics Committee (Ethics Committee Approval IRB study protocol:2012-KAEK-15/1610).

This matching control study was conducted in the athlete's educational health and research center. A total of 638 athletes (skating, judo, boxing, athletics, gymnastics, taekwondo, tennis, wrestling, canoeing, karate) were evaluated in the 2017-2018 and 2018-2019 time periods. The age, height, body weight, body mass index, gender and sport experience of the athletes were recorded. Among these athletes, athletes with symmetrical trunk muscle strength (trunk flexor/extensor muscle strength ratio is 79% or more and trunk right rotator / left rotator muscle strength ratio is between 90% -100%) indicated by McGill, were included in the symmetric group for the control group [25]. For the asymmetric group; athletes with the same demographic characteristics, gender, sports year, and sports branch as the control group athletes, but with trunk muscle strength asymmetry were selected. Later, the athletes evaluated by the sports physician and who met the inclusion criteria and did not have exclusion criteria were included in the study. Inclusion criteria for the study was being a professional athlete for at least three years, no history of lower extremity, upper extremity and trunk injuries, no known systemic problems, and volunteering to participate. Exclusion criteria from the study was acute or chronic low back pain or disc herniation, body posture asymmetry or scoliosis and left-sided dominance. As a result of this selection process, 80 athletes (34 females, 46 males) (mean year: 17.16±1.87 years; mean body weight: 63.18±12.71 kg; mean body height: 1.7±0.09m; mean body mass index: 21.78±2.78kg/m^2) from different branches [skating (n = 4), judo (n = 16), boxing (n = 4), athletics (n = 8), gymnastics (n = 4), taekwondo (n = 12), tennis (n = 8), wrestling (n = 16), canoeing (n = 4), karate (n = 4)] were included the study. Trunk and knee muscle strength were evaluated with an isokinetic dynamometer on different days.

Evaluation of Muscle Strength: Isokinetic Strength Test

The muscular strength of the athletes was evaluated with an isokinetic dynamometer (IsoMed 2000, D. & R. Ferstl GmbH, Hemau, Germany). The demographic characteristics of all the athletes were recorded on the device. Before the tests, the athletes were warmed up with a reciprocal bicycle ergometer for 10 minutes at 60-70 rpm. Verbal encouragement was given to the athletes during the tests. Trunk flexor / extensor, right-left rotator and knee flexor / extensor muscle strength measurements were made on different days.

Evaluation of Isokinetic Trunk Muscle Strength

The strength of the flexor and extensor muscles of the trunk were examined with the trunk flexion and extension module of the IsoMed 2000 device while the athlete was sitting, as described in the user manual of the device. The fixing apparatus of the device was tightened to the shoulders and thighs of the athletes. The athletes were fixed in the lumbar region and the sole until adequate stabilization was achieved by the isokinetic device sensor. To start, five trunk flexion / extension exercises were performed at angular speeds of 120º / s and 90º / s to warm up and practice. Next, five trunk flexion / extension exercises were performed at 60°/ s to determine isokinetic muscle strength for the study [26]. As a result of the evaluation; Peak Torque (PT) and Peak Torque / Body Weight (PT / BW) values of trunk flexor and extensor muscles were recorded and used in the statistical analysis.
The strength of the right / left rotator muscles of the trunk was examined with the trunk rotator module using the IsoMed 2000 device while the athlete was sitting as described in the

user manual of the device. The athletes were fixed with a shoulder and leg apparatus and in a sitting position. Their hips were fixed until adequate stabilization was achieved from the sides. Firstly, five body right / left rotation exercises were performed at angular speeds of 120º / s and 90 º/ s for warm-up and application. Then, five trunks right/left rotation exercises were performed at 60º / s to determine isokinetic muscle strength for the study [26]. As a result of the evaluation; PT and PT/BW values of the trunk right/left rotator muscles were recorded, and used in the statistical analysis.

Evaluation of Isokinetic Knee Muscle Strength

While sitting; the athletes were stabilized with the shoulder apparatus over the shoulders, and stabilization bands on the waist and distal femur. The athletes were evaluated in a sitting position, and the pivot point was adjusted to be the lateral condyle of the femur. The strength of the dominant and non-dominant side knee flexor/extensor muscles was evaluated with five flexion/extension exercises at 60º/s angular velocity and with fifteen flexion/extension exercises at 180º/s of angular velocity.Three flexion / extension exercises were performed before each angular velocity for the warm up and practice in the assessment. The dominant right side was evaluated first, and after 3 minutes the non-dominant left side was evaluated [15]. As a result of the evaluation; PT and PT/BW values were recorded for knee flexor and extensor muscles and used in statistical analysis. Limb Symmetry Index (LSI) (Dominant extremity muscle strength/non-dominant extremity muscle strength x 100) was used to compare the strengths of the same muscle groups in the dominant and non-dominant extremities. According to this index, athletes were defined as symmetric between two extremities with a maximum difference of 10% in paired comparisons. The difference of more than 10% was described as asymmetry [27].
In addition, the Conventional Ratio (CR), which can be defined as the flexor / extensor muscle strength ratio of the same extremity, was calculated and recorded. According to this ratio, it was reported that the normal CR at 60º/s angular velocity was between 50-60%, and the normal CR at 180º/s angular velocity was between 60-65% [28]. The LSI and CR were calculated automatically by the device.

Statistical Analysis

Statistical analysis was performed using SPSS ver. 20.0 (SPSS Inc., Chicago, IL, USA). Visual (histogram, probability plots) and analytical methods (Kolmogorov-Smirnov test) were used to determine whether the variables were normally distributed. The Mann Whitney-U test was used to compare variables that were found to be not normally distributed (Trunk flexion PT, trunk flexion PT/BW, left trunk rotation PT, right trunk rotation PT/BW at of 60°/s angular velocity; Non-dominant (NDM) side knee flexion PT, dominant (DM) side flexion PT/BW, NDM side knee flexion PT/BW, LSI of flexor muscles, NDM side knee extension PT and NDM side knee extension PT/BW at 60°/s angular velocity; LSI of knee flexor muscles, DM side knee flexion PT/BW, NDM side knee flexion PT/BW, DM side Conventional Ratio (CR), NDM side CR at 180 ° / s angular velocity). The Independent Samples T-Test was used to compare variables that were determined to be normally distributed. The statistical error level was determined as $p<0.05$.

Results

The demographic characteristics of the athletes included in the study are given in Table 1.

Tab. 1. Comparison of demographic characteristics of the groups

	Symmetric Group Med ± IQR (25-75) N=40	AsymmetricGroup Med ± IQR (25-75) N=40	Z¥	P¥
Age (year)	17 (16-18)	17 (16-18)	-0.152	0.879
Height (m)	1.69 (1.63-1.75)	1.68 (1.64-1.77)	-0.164	0.870
Body Weight (kg)	60.85 (53.5-69)	61.9 (54.3-68.55)	-0.019	0.985
BMI (kg/m^2)	21.46 (19.95-23.1)	21.3 (19.89-23.21)	-0.034	0.973
Professional Experience (year)	6 (5-7.5)	6.5 (5-8)	-0.561	0.575

¥Mann Whitney-U Test, m: meter, kg: kilogram, BMI: Body Mass Index, Med: median, IQR: inter quartile range

There was no difference between the demographic characteristics of the symmetrical and asymmetric groups (p> 0.05). Trunk flexion muscle PT and PT / BW of the symmetric group were found to be higher than the asymmetric group at an angular velocity of 60 ° / s (p = 0.010, <0.001). However, trunk extension muscle PT and PT / BW of the symmetric group were found to be lower than the asymmetric group at 60 ° / s (p = 0.011, 0.001). The trunk flexor / extensor muscle strength ratio was 85.45% in the symmetric group and 56.6% in the asymmetric group, and the difference between the two groups was statistically significant (p <0.05).

Right and left rotator PT and PT/BW values and left/right rotation PT ratios of both groups at 60°/s angular velocity were similar and among the expected values determined by McGill [25] (p>0.05) (Table 2).

Tab. 2. Comparison of trunk muscle strength of symmetric and asymmetric groups

<table>
<tr><td colspan="3"></td><td>Symmetric Group
Med ± IQR
Mean ± SD</td><td>Asymmetric Group
Med ± IQR
Mean ± SD</td><td>z¥, t*</td><td>p*, ¥</td></tr>
<tr><td rowspan="11">TrunkMuscleStrength</td><td rowspan="2">60°/sec Flexion</td><td>PT</td><td>191.6 ± 60.25</td><td>157.99 ± 53.74</td><td>2.633*</td><td>0.010*</td></tr>
<tr><td>PT/BW</td><td>3.02 ± 0.63</td><td>2.49 ± 0.65</td><td>3.378*</td><td><0.001*</td></tr>
<tr><td rowspan="2">60°/sec Extension</td><td>PT</td><td>203.35(150.5-260.2)</td><td>227.2 (194.6-315)</td><td>-2.550¥</td><td>0.011¥</td></tr>
<tr><td>PT/BW</td><td>3.39(2.78-3.95)</td><td>3.93 (3.44-4.71)</td><td>-3.315¥</td><td>0.001¥</td></tr>
<tr><td colspan="2">60°/sec F/E PT Ratio</td><td>85.45 (81.35-100)</td><td>56.6 (48.05-75.35)</td><td>-6.048¥</td><td><0.001¥</td></tr>
<tr><td rowspan="2">60°/sec LeftRotatio n</td><td>PT</td><td>150.9 ±39.93</td><td>152.58 ± 41.27</td><td>-0.185*</td><td>0.854*</td></tr>
<tr><td>PT/BW</td><td>2.41 (2.17-2.69)</td><td>2.44 (2.11-2.84)</td><td>-0.308¥</td><td>0.758¥</td></tr>
<tr><td rowspan="2">60°/sec Right Rotation</td><td>PT</td><td>152.2 (113.95-174.55)</td><td>159.45 (114.5-191.35)</td><td>-0.929¥</td><td>0.353¥</td></tr>
<tr><td>PT/BW</td><td>2.38 ± 0.49</td><td>2.53 ±0.53</td><td>-1.311*</td><td>0.194*</td></tr>
<tr><td colspan="2">60°/secLeft/Right Rotation PT Ratio</td><td>101.6 ±10</td><td>96.51 ± 9.24</td><td>-0.875*</td><td>0.384*</td></tr>
</table>

¥Mann Whitney-U Test, *Independent Samples t-Test, SD: Standard Deviation PT: Peak Torque, PT/BW: Peak Torque/Body Weight, F: Flexion, E: Extension, sec: second

There was no significant difference between the knee flexor and extensor muscle strength of the symmetric and asymmetric groups (p <0.05). There was a significant difference of LSI in knee flexor muscles at an angular velocity of 60 ° / s between the groups (p =0.032). However, as LSI values were less than 10% in both groups, they were within the clinically normal limits [27]. The dominant lower extremity knee flexors were stronger in the symmetric group than the non-dominant side, and the knee flexors of the non-dominant lateral extremity were stronger in the asymmetric group than the dominant side (Table 3).

Tab. 3. Comparison of knee muscle strength of symmetric and asymmetric groups at the 60°/sec and 180°/sec angular velocities

<table>
<tr><td colspan="3"></td><td>Symmetric Group
Med ± IQR
Mean ± SD</td><td>Asymmetric Group
Med ± IQR
Mean ± SD</td><td>z¥, t*</td><td>p*, ¥</td></tr>
<tr><td rowspan="4">KneeMuscle</td><td rowspan="4">60°/sec Flexion</td><td>DM PT</td><td>89.45(71.05-116.35)</td><td>88.85(77.45-114.6)</td><td>-0.279¥</td><td>0.780¥</td></tr>
<tr><td>NDM PT</td><td>94.25±31.38</td><td>98.33±25.14</td><td>-0.641*</td><td>0.523*</td></tr>
<tr><td>DM PT/BW</td><td>1.52±0.30</td><td>1.51±0.24</td><td>0.123*</td><td>0.902*</td></tr>
<tr><td>NDM PT/BW</td><td>1.49±0.30</td><td>1.56±0.23</td><td>-1.15*</td><td>0.254*</td></tr>
</table>

	60°/sec Flexion LSI		102.73±10.45	97.54±10.83	**2.180***	**0.032***
	60°/sec Extension	**DM PT**	167.8(145.7-210.5)	191.75(149.05-235.1)	-0.741¥	0.459¥
		NDM PT	180.87±54.86	187.74±45.12	-0.612*	0.543*
		DM PT/BW	2.94(2.67-3.27)	2.98(2.79-3.37)	-0.982¥	0.326¥
		NDM PT/BW	2.86±0.51	2.98±0.45	-1.14*	0.258*
	60°/sec Extension LSI		102.65(97.45-110.05)	103.8(94.7-106.8)	-0.433¥	0.665¥
	60°/sec DM F/E		51.85(46.9-56.95)	49.2(46.95-53.8)	-1.054¥	0.292¥
	60°/sec NDM F/E		51.15(48.5-55.8)	52.25(48.45-54.85)	-0.217¥	0.829¥
	180°/sec Flexion	**DM PT**	71.9(59.6-94.45)	75.65(61.4-94.5)	-0.269¥	0.788¥
		NDM PT	68.95(58.7-90.4)	74.3(60.5-97.25)	-0.645¥	0.519¥
		DM PT/BW	1.15(1.06-1.38)	1.24(1.08-1.33)	-0.260¥	0.795¥
		NDM PT/BW	1.22(1.01-1.40)	1.23(1.08-1.37)	-0.505¥	0.613¥
	180°/sec Flexion LSI		101.79±13.85	98.88±8.83	1.118*	0.267*
	180°/sec Extension	**DM PT**	123.35(104.2-160.1)	131.4(105.3-161.95)	-0.265¥	0.791¥
		NDM PT	127.1(101.75-166.85)	136.35(105-168.5)	-0.563¥	0.573¥
		DM PT/BW	2.14±0.39	2.14±0.36	0.083*	0.934*
		NDM PT/BW	2.10±0.41	2.17±0.35	-0.883*	0.380*
	180°/sec Extension LSI		100.45(95.75-108.15)	98.5(92.3-106.45)	-1.102¥	0.271¥
	180°/sec DM F/E		58.79±8.02	58.02±7	0.459*	0.647*
	180°/sec NDM F/E		59.78±9.57	57.70±6.10	1.159*	0.250*

¥Mann Whitney-U Test, *Independent Samples t-Test, DM: dominant, NDM: non-dominant, PT: Peak Torque, PT/BW: Peak Torque/Body Weight, LSI: Limb Symmetry Index, F: Flexion, E: Extension, sec: second

Discussion

As a result of this study, examining the effect of the trunk muscle strength asymmetry on lower extremity strength symmetry, the LSI of knee flexor muscles of athletes was different between symmetric and asymmetric groups. In addition, dominant lower extremity knee flexors were stronger in the symmetric group than the non-dominant side, and the non-dominant lateral extremity knee flexors were stronger than the dominant side in the asymmetric group.

Several studies indicate that proximal structures affect the biomechanical function of the lower extremities, and cause lower extremity injuries [8, 12]. It is theoretically suggested that the strong core region transfers forces from the lower extremity to the upper extremity with minimal energy loss in the trunk [29]. In addition, the core muscles contract synergistically and stabilize the trunk, and thus these muscles form a stable base and prepare the lower extremity muscles for movement [30]. Thus, core neuromuscular control disorders cause injuries not only to the lumbar region but also to the lower extremities [7, 8, 13, 14]. One study indicated that core stabilization exercises targeting symmetrical muscle strength can reduce ligament injuries in the knee joint by 72% [9]. In this regard, core muscle strength deficiencies play an important role in determining the risk of lower extremity injury in athletes [13, 31]. It is also emphasized that athletes with symmetrical flexor extensor and rotator trunk muscle strength have lower injury rates [13]. As a result of our study, we found that the trunk flexion / extension muscle strength ratio of the group with symmetrical trunk muscle strength was 85.45%, and clinically within the limits of McGill's values [25]. However, the trunk flexion / extension muscle strength ratio of the asymmetrical trunk muscle strength was 56.6%, and clinically below McGill's values [25], and trunk muscle strength imbalance did not make a difference in the lower extremity muscle strength. However, the LSI of the knee flexor muscles was different between the groups, and the knee flexor muscle strength was different between the groups according to the dominance of the extremities.

It is stated in the literature that the LSI should be 10% or less and the dominant limb is typically stronger than the non-dominant side [32, 33]. In our study, it was observed that the dominant lower extremity flexors of the athletes in the asymmetric trunk muscle strength group were weaker than the non-dominant side. This data suggested that the weakness of the dominant extremity may be a risk factor for injury in athletes. Also, in the literature, muscle strength is accepted as one of the Return to Game Criteria after lower extremity injuries [34].

In order to meet the return to sports criteria, the muscle strength of the injured side must reach 90% of the non-injured side. However, these results obtained in our study suggest that it is not appropriate to compare muscle strength with the non-dominant extremity after returning to sports after dominant lower extremity injury in athletes with symmetrical trunk muscle strength. The reasoning is it may not be enough to reach 90% of the non-dominant muscle strength in these athletes. It is stated that neuromuscular deficit in the abdominal muscles is important for early assessment of a hamstring injury risk [19]. According to our study, considering that the asymmetric trunk muscle strength group has weaker trunk flexor strength, it can be mentioned that this may be the cause of possible hamstring muscle injuries. Because the trunk flexors work synergistically with the hamstring muscles by taking the pelvis to posterior tilt, and provide optimal hamstring muscle contraction [22,30,]. The results of our study showed that the LSI of the knee flexor muscles was lower in the dominant extremity of the asymmetric trunk muscle group, and the conventional rate in the asymmetric trunk muscle group was below the normal limit 50% -60%. These results are consistent with the literature [28].

In the study of Raschner et al. when examining the risk factors for anterior cruciate ligament injuries in adolescent athletes, a low trunk flexor/extensor muscle strength ratio (79% or less) was reported to be a risk factor for anterior cruciate ligament injuries. In the same study, they showed that core muscle strength is one of the primary factors in predicting injury risk [13]. In our study, the trunk flexor / extensor muscle strength ratio was found to be 56.6% in the asymmetric trunk muscle strength group. In the study of Rascher et al., trunk flexor / extensor muscle strength ratio was found to be 65% in 17-year-old individuals with anterior cruciate ligament injury and 95% in uninjured individuals [13]. In our study, although the athletes had no lower extremity injury history, the flexor / extensor ratio was considerably below the values given in the literature for the same age group. According to the literature, this data may indicate that the athletes in the study group are at risk of a lower extremity injury.Symmetrical core strengthening training may prevent possible injuries of the athletes with asymmetrical trunk muscle strength.

Isokinetic evaluation of the trunk muscle is the strength of the study. However, the limitations of our study are not the evaluation of functional ratio, lack of long-term follow-up and acute muscle strength measurement. Therefore, we think that futher studies are needed to examine the lower extremity functional ratios in athletes with and without symmetrical trunk muscle strength, and to follow the injury status and to relate this to both trunk and lower extremity muscle strength and strength balance.

Conclusion

In conclusion, trunk muscle strength asymmetry may not affect lower extremity strength and strength balance. However, the LSI of knee flexor muscles can be affected. This result can be attributed to the literature knowledge that core muscle weakness may increase the frequency of knee injury. Therefore, we think that symmetrical core strengthening training can prevent possible injuries of athletes with asymmetrical trunk muscle strength, but further studies are needed to investigate this deeper.

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