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Original research

Quadriceps force production during straight leg raising at different hip positions with and without concomitant ankle dorsiflexion

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ABSTRACT

Objective: Due to the significant prevalence of knee disorders and patellofemoral pain syndrome, as well as the importance of quadriceps strengthening in knee rehabilitation programs, it is necessary to specify the best method to activate and strengthen the quadriceps muscles. The current study aimed at comparing the maximum generated isometric force during an active straight-leg-raising (SLR) maneuver in a sitting position by changing the hip rotational position with and without the simultaneous contraction of the ankle dorsiflexor muscles.
Methodology: The current study was performed on 30 healthy males recruited with a non-random and available sampling method. The maximum generated force was measured during the SLR maneuver in six compound internal and external rotations and in a neutral position with and without ankle dorsiflexor contraction. The obtained generated force was analyzed using repeated measures ANOVA.
Results: The generated forces in the SLR with and without contracting the ankle dorsiflexors were significantly different ($p = 0.001$), and taking different positions of hip rotation led to significant changes in the generated force ($p = 0.005$).
Conclusion: The adoption of external hip rotation with the contraction of ankle dorsiflexors during the SLR maneuver generated the most force. Based on the interaction of these conditions, the general recommendation is to perform the SLR exercise in an external hip rotation with the simultaneous contraction of the ankle dorsiflexors in subjects with quadriceps muscle weakness.

1. Introduction

Strengthening the quadriceps muscle is one of the main prerequisites for proper knee performance (Anwer and Alghadir, 2014). Therefore, exercises to strengthen these muscles are among the main objectives for knee rehabilitation (Choi et al., 2011). Exercise therapy can improve patellar alignment and reduce the recurrence of symptoms by focusing on improving quadriceps strength and the biomechanical disorders of the lower limbs (Wilk and Reinold, 2001). Based on the high prevalence of patellofemoral pain syndrome, quadriceps-strengthening exercises with a straight-leg-raising (SLR) maneuver to address the vastus medialis oblique (VMO) muscle seem necessary to activate and strengthen the patellofemoral-stabilizing muscles (O'sullivan and Popelas, 2005). Exercise therapy is a critical and complementary intervention in physiotherapy and can be included in the treatment plan without the need for any equipment, based on the proper training of patients. Hence, numerous studies have investigated various exercises at different hip, knee, and ankle joint positions to achieve the ideal setup for quadriceps strengthening (Papadopoulos et al., 2015; Uthman et al., 2013). SLR is one of the exercises frequently recommended in knee exercise therapy programs (Anwer and Alghadir, 2014). Furthermore, SLR is an essential part of many exercise therapy programs for patients with patellofemoral pain syndrome and osteoarthritis due to the low contact force and discomfort in the knee joint (Mirzabeigi et al., 1999; O'sullivan and Popelas, 2005). Researchers have evaluated hip rotational positions

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(Kushion et al., 2012; Sykes and Wong, 2003) and contractions of the ankle dorsiflexors (Choi et al., 2014) as the two variables that can affect the quadriceps' involvement in the SLR maneuver. Thus far, there is no consensus among researchers regarding the effect of hip rotation on the level of force in the SLR maneuver. However, considering the importance of ankle dorsiflexors and the results of the conducted studies, contracting the ankle dorsiflexors can affect quadriceps activation in the SLR maneuver. Different studies have supported a reflective connection between the pretibial and quadriceps muscles; according to their results, sensory inputs from group I and II pretibial muscle receptors have an excitatory effect on the quadriceps motoneurons (Rafsanjani et al., 2017).

The current study aimed at evaluating the effect of hip rotational positions and ankle dorsiflexors contraction on the level of force produced in the muscles involved in the SLR maneuver.

2. Materials and methods

2.1. Participants

The current study was conducted on 30 healthy males from the personnel and students of the School of Rehabilitation of Shahid Beheshti University of Medical Sciences, Tehran, Iran, and they were chosen with a convenient, non-random sampling method. The inclusion criteria were: healthy young people aged 18–36 years without any history of knee joint pain in the three months prior to the study, a body mass index (BMI) from 20 to 30 kg/m^2, and a lack of pain in performing more than two of the following activities: running, jumping, kneeling, long-term sitting, and climbing up and down stairs.

2.2. Study design

Different sitting positions based on hip rotational positions with and without contraction of the ankle dorsiflexors were performed during the SLR maneuver. Accordingly, six positions were randomly selected as the independent variables:

1) SLR with hip neutral position and without contraction of the dorsiflexor muscles.
2) SLR with hip neutral position and with contraction of the dorsiflexor muscles.
3) SLR with hip internal rotation and without contraction of the dorsiflexor muscles.
4) SLR with hip external rotation and without contraction of the dorsiflexor muscles.
5) SLR with hip internal rotation and with contraction of the dorsiflexor muscles.
6) SLR with hip external rotation and with contraction of the dorsiflexor muscles.

The subjects' height, weight, and BMI were measured using a tape measure and a digital scale, and the data were recorded in a demographic datasheet after obtaining a signed informed consent form. The subjects were free to withdraw from the study at any stage, and all the tests were performed at a certain place and time.

A pilot study was performed based on a methodological survey to evaluate the relative and absolute reliability of the collected data from the 10 subjects. All the selected positions were tested twice at 4-min fixed intervals, with two days between tests, and all positions were repeated three times consecutively, with 1-min fixed intervals.

Before the main study, the intervention's details and stages were explained to the subjects in a briefing session. In addition, the subjects performed a warm-up program of running at a normal speed for 5 min on a treadmill and then stretching the quadriceps, hamstrings, calf muscles, and hip adductors. The muscles were stretched three times each for 30 s under the supervision of a physiotherapist (Kushion et al., 2012). The subjects were then asked to sit on a chair purposefully designed for this study and to adopt different positions during the SLR with maximum isometric strength. A belt affixed the subjects' trunks to the chair, their hands were in a resting position on the top of their legs, and they were trained to push the dynamometer with their leg without any contraction in the trunk muscles. The position order was selected for each subject based on a table of random numbers. To measure the maximum isometric SLR force, the subjects were asked to sit in the designated chair and to push the load-cell placed over their lower leg with their maximum strength. To take different hip rotation positions, the subjects were asked to turn their hips in such a way that their big toe was parallel with the axis embedded on the load-cell. To induce contraction in the dorsiflexors, the subjects were also asked to maximally dorsiflex their ankle. After being assured that the limb was fixed at its position during the SLR maneuver, the amount of force production was recorded (Fig. 1).

All measurements were recorded three times and at 1-min intervals. After the measurement of each position, the subjects were given 4 min to rest, and the procedure was repeated similarly for the other positions of the SLR maneuver.

2.3. Data handling and statistical analysis

For a more objective evaluation, the calculated maximum forces were normalized and considered as the ratio of the reference contraction (neutral hip position without contraction of ankle dorsiflexors). All statistical analyses were conducted based on the calculated ratios using SPSS version 17. A Kolmogorov–Smirnov (K–S) test was used to evaluate the normal distribution of the data, and based on the obtained results, the data were normally distributed ($p > 0.05$). Repeated measures analysis of variance (ANOVA) with two within-group factors of hip rotational positions and ankle dorsiflexion contraction was used for statistical analysis. Post hoc comparisons using Bonferroni's method were employed for a pairwise comparison, and a p-value of <0.05 was considered statistically significant.

3. Results

Table 1 shows the subjects' demographic data, including age, weight, height, and BMI.

To evaluate the reliability of the maximum force at different positions during the SLR maneuver, the intra-class correlation

Fig. 1. The designed chair to measure the maximum SLR force.

Table 1
Demographic data of study subjects.

n = 30	Minimum	Maximum	Mean	Standard Deviation
Age (year)	19	33	22.1	2.77
Weight (kg)	55.16	86	68.66	8.2
Height (cm)	166	185	176.27	5.01
BMI(kg/m^2)	20.22	26.06	22.1	2.5

coefficient (ICC) was calculated. The results of the current study indicated that the reliability of force was greater than 0.75 for all applied positions.

Table 2 shows the raw data of the average maximum force at all applied SLR positions. To evaluate the results of the study more objectively, Table 2 data are expressed as the percentage of the raw data to the reference contraction (SLR in hip neutral position without contraction of the dorsiflexor muscles), and the statistical analysis was performed based on these calculated ratios.

According to the results of the repeated measures ANOVA, hip rotation had a significant effect on the maximum force ($p = 0.005$), and external rotation produced the highest force.

The pairwise comparison across the three studied rotational positions of the hip revealed no difference between the internal hip rotation and the neutral hip position in terms of maximum force ($p = 0.232$). There was also no significant difference between the external hip rotation and the neutral hip position ($p = 0.295$). A significant difference was found between the maximum force produced at the external and internal hip rotations, and there was more force produced in the external hip rotation ($p = 0.008$; Fig. 2).

Contractions of the ankle dorsiflexors had a significant effect on the maximum force ($p = 0.001$), with a significantly increased level of SLR force following the contraction of the ankle dorsiflexors (Fig. 3).

Regarding maximum SLR force, there was no statistically significant difference between the interactions of the three hip rotational positions with the contraction of the ankle dorsiflexors ($p = 0.06$). The results of the Bonferroni's analysis showed there was a significant difference between the neutral hip position with contraction of the ankle dorsiflexors and the neutral hip position without contracting the ankle dorsiflexors during the SLR maneuver ($p = 0.006$). The difference between the internal hip rotation with contraction of the ankle dorsiflexors and the internal hip rotation without contracting the ankle dorsiflexors during the SLR maneuver was not statistically significant ($p = 0.061$). There was a significant difference between the external hip rotation with contraction of the ankle dorsiflexors and the external hip rotation without contracting the ankle dorsiflexors during the SLR maneuver ($p = 0.001$), and the mean maximum force in the external hip rotation with contraction of the ankle dorsiflexors was higher than those of the other positions.

Fig. 4 shows the changes in the maximum force at different hip rotational positions with and without contraction of the ankle dorsiflexors.

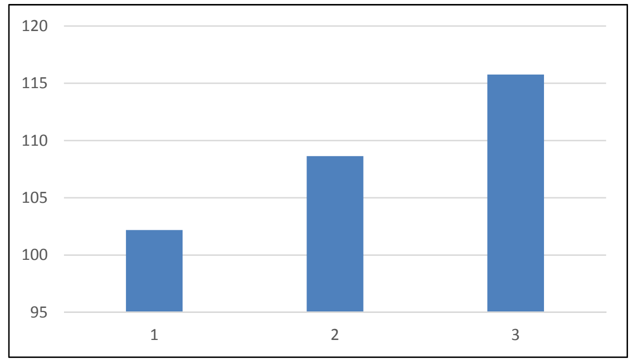

Fig. 2. The effects of hip rotation on the maximum force variation (%): 1) hip internal rotation, 2) hip neutral position, and 3) hip external rotation.

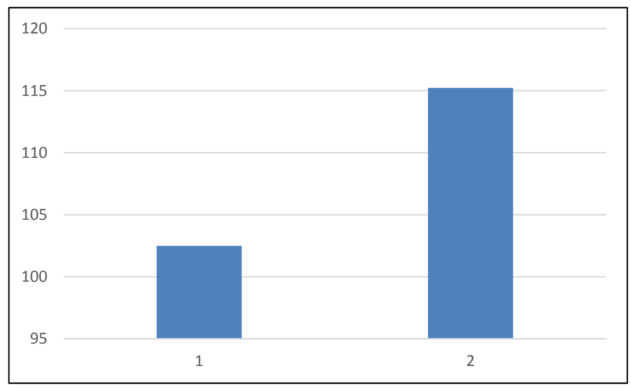

Fig. 3. The effect of the contraction of the ankle dorsiflexors on the maximum force variation (%): 1) without dorsiflexors contraction and 2) with dorsiflexors contraction.

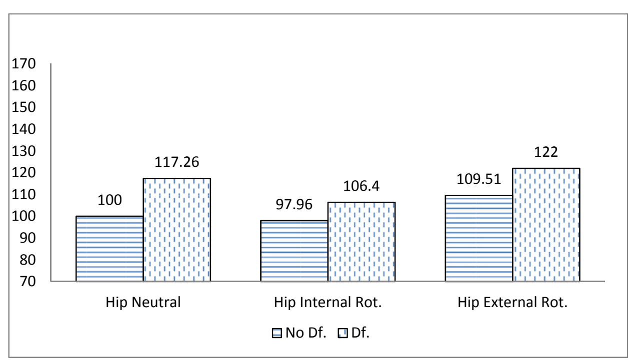

Fig. 4. The interaction between hip rotation with and without a contraction of the ankle dorsiflexors and the level of maximum force.

Table 2
The raw data of the average maximum force of different SLR positions.

	Mean ± SD (Kg)	Standard Error (Kg)	Mean ± SD (%)	Standard Error (%)
SLR in hip neutral position without dorsiflexor muscles contraction	6.26 ± 2.25	0.51	100 ± 0.00	0
SLR in hip neutral position with dorsiflexor muscles contraction	6.97 ± 1.99	0.47	117.26 ± 23.80	4.34
SLR in hip internal rotation without dorsiflexor muscles contraction	5.95 ± 2.42	0.44	97.96 ± 18.83	3.43
SLR in hip external rotation without dorsiflexor muscles contraction	6.34 ± 1.98	0.36	109.51 ± 27.32	4.98
SLR in hip internal rotation with dorsiflexor muscles contraction	6.32 ± 2.80	0.41	106.40 ± 27.08	4.94
SLR in hip external rotation with dorsiflexor muscles contraction	7.03 ± 2.60	0.36	122 ± 33.94	6.19

4. Discussion

Straight-leg raising is a common exercise prescribed for patients with knee disorders to strengthen the quadriceps muscle. Straight-leg raising involves different muscles, including the rectus abdominis, iliopsoas, and quadriceps muscles. Although the SLR force production comes from contracting these muscles, the status employed in this study has dismissed some of these muscles from being influenced by changes in the hip rotational positions. Trunk flexors, such as the rectus abdominis, are not influenced by changes in the hip rotational position because of their origin and insertion. Although the action line and the contribution of the iliopsoas muscle as a hip flexor can be changed by hip rotation, the flexed position of the hip employed during SLR in this study placed this muscle in its shortened position, which could cause an actively insufficient situation. The rectus femoris muscle is a bi-articular muscle involved in hip flexion as well as knee extension. Flexion in the hip and extension in the knee joint could also place this muscle into an actively insufficient situation, even more than the iliopsoas muscle. Based on the anatomy and the biomechanics of the rectus femoris in lying down or sitting positions during the SLR maneuver, the vastus muscles are expected to dominate the rectus femoris in the sitting position (Kushion et al., 2012). Because the rectus femoris is not sufficiently active while sitting, it can be expected that the mono-articular parts of the quadriceps muscle dominate the rectus femoris, which could be an optimum situation for exercise therapy in patients with patellofemoral pain syndrome (Herzog et al., 1990).

The position in which the SLR produces maximum force is of great importance when planning exercise programs for those with knee pain. According to the current study's results, hip rotational positions can affect the level of this variable; specifically, hip external rotation leads to greater force during the SLR maneuver and is consistent with the findings of a study by Sykes and Wong (2003). There is evidence that during the SLR maneuver, along with the external hip rotation, the adductor magnus and adductor longus fibers move to the surface and collaborate with the SLR maneuver based on the connection between the VMO and the adductor magnus, as well as the adductor longus; accordingly, the level of force increases. However, with external hip rotation, the VMO should inevitably overcome greater gravitational force, resulting in greater force production in the quadriceps (Livecchi et al., 2002).

In the present study, the involvement of ankle dorsiflexion in the SLR maneuver increased the SLR force, and this is consistent with the results of Choi et al. (2014). Based on neurophysiological studies and the exercise overflow in proprioceptive neuromuscular facilitation (PNF), the muscle's contraction level may affect distant muscles, and the energy transfer can be proven with irradiation (Shimura and Kasai, 2002). According to electromyographic studies on abdominal muscles, the involvement of ankle dorsiflexion increases the activity of the abdominal muscles via energy transfer (Chon et al., 2010).

In addition, different studies have supported an excitatory reflective connection between the pretibial and quadriceps muscles. Muscle receptors in the pretibial muscles involved in the ankle dorsiflexors have a strong excitatory effect on quadriceps motoneurons. These excitatory pathways have a regulatory effect on quadriceps activation during walking (Kalantari and Baxendale, 2009; Kalantari et al., 2011). Furthermore, the knee and hip joint position influences this reflective pathway's activity. The excitatory effect is maximized as the knee and hip joint approaches the greater extension and flexion position, respectively (Kalantari and Baxendale, 2007). This is the position that was employed in the present study, and the authors believe the increased SLR force induced by adding ankle dorsiflexor contraction is at least partially related to the reinforcement effect of this excitatory pathway.

Although strengthening the quadriceps muscles, particularly the VMO, remains a general approach in the rehabilitation of PFPS patients, some researchers have reported that proximal exercises, such as strengthening the lumbo-pelvic and hip girdle muscles, can also improve functional outcomes in PFPS patients (Peters and Tyson, 2013). This may suggest the complexity of the mechanical factors involved in PFPS. From the biomechanical aspect, one could expect that in close kinematic chain activities, which are the usual form of activities in the lower limbs, any muscle in the activity chain could affect the performance of all the chain's segments. Therefore, it would be rational to accept that to have a proper rehabilitation approach for knee problems, it would be necessary to address all the malfunctions in any part of the chain from top to bottom.

According to the current study's results, simultaneous involvement of ankle dorsiflexion and external hip rotation can produce the highest SLR force, which can be partially justified by the increase in the activity of the mono-articular quadriceps muscles, including the VMO (Choi et al., 2014).

5. Conclusions

The current study showed that changing hip rotational positions during the SLR maneuver could change the maximum force produced by the muscles involved in the SLR, and the mean force production at the external hip rotation is greater than that of the other situations. Considering the interaction between the hip positions and ankle dorsiflexor contraction, it seems that hip external rotation along with contraction of the ankle dorsiflexors during the SLR maneuver in patients with quadriceps weakness can be helpful for strengthening the quadriceps.

5.1. *Suggestions*

Further studies on healthy subjects from both genders and on individuals with patellofemoral pain syndrome, osteoarthritis, and other knee injuries are recommended.

5.2. *Study limitations*

As the current study's subjects were healthy males, the results cannot be generalized to the total community, which is one of the study's limitations. The current study was a cross-sectional survey, which can also be considered a limitation; conducting a longitudinal study of exercise therapy programs could be beneficial.

Conflicts of interest

None.

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