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Original Article

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The Effects of Tibial Rotation on Muscle Activity and Force of Hamstring Muscle During Isometric Knee Flexion in Healthy Women

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| Abstract |

Purpose: The purpose of this study was to determine how the position of tibial rotation affects peak force and hamstring muscle activation during isometric knee flexion in healthy women.

Methods: Seventeen healthy women performed maximum isometric knee flexion at 30° with three tibial rotation positions (tibial internal rotation, neutral position, and tibial external rotation). Surface electromyographic (EMG) activity was recorded from the medial hamstring (MH) and lateral hamstring (LH) muscles. The strength of the knee flexor was measured with a load-cell-type strength-measurement sensor. Data were analyzed using one-way repeated analysis of variance.

Results: The results showed that MH and LH activities and peak force were significantly different among the three tibial rotation conditions ($p < 0.01$). The post-hoc comparison revealed that the MH EMG activity in tibial neutral and internal rotation positions were significantly greater than tibial external rotation ($p < 0.01$). The LH activity in tibial external rotation was significantly greater than the tibial neutral position and internal rotation ($p < 0.01$). The peak force of the knee flexor was also greater in the external tibial rotation position compared with the tibial neutral and internal rotation positions ($p < 0.01$).

Conclusion: Our findings suggest that hamstring muscle activation could be changed by tibial rotation.

Key Words: Hamstring, Female, Tibial rotation, Electromyography

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Ⅰ. Introduction

The functions of the hamstring muscles are to generate knee flexion and hip extension torques and to contribute to the control of tibiofemoral motion (Norkin & Levangie, 1992). The hamstring muscles have also been proposed to serve as dynamic knee stabilizers by controlling anterior tibial translation during functional and athletic activities (Houck, 2003). The hamstring muscles are often classified as the medial hamstrings (MH), including the semitendinosus (ST) and semimembranosus (SM) muscles, and the lateral hamstrings (LH), including the biceps femoris (BF) long and BF short, according to their rotational function on the tibia (Onishi et al., 2002). However, the capacity of the MH and LH to generate torque may not be equal.

The imbalance in torque between the MH and LH is one of the factor that explain why osteoarthritis (OA) of the medial compartment of the knee is more common in Western populations than lateral compartment disease (Felson, 1998). In addition, individuals with medial OA have reportedly increased the activities of the LH and decreased the activities of the MH during their gait compared with healthy controls. Therefore, to counteract this mechanical imbalance, a form of exercise must be designed that selectively activates the MH and LH (Lynn & Costigan, 2009).

Electromyographic (EMG) recordings acquired during isometric contraction of the knee flexor in a prone position showed that the MH and LH can be selectively recruited using tibial rotation. Fiebert et al. (1997) found that the MH created 40% more activity with medial tibial rotation, and while the LH had a 59% increase with lateral tibial rotation when subjects performed resisted knee flexion at 45°. Mohamed et al. (2003) demonstrated that the semitendinosus and semimembranosus muscles have significantly greater mean activity during medial rotation (compared with lateral rotation) when the knee is flexed to 70° in the prone position. Conversely, both the long and short heads of the BF muscle yielded significantly higher activities during lateral compared with medial rotations. Fiebert et al. (1992) also suggested that the LH produces less EMG activity than the MH following internal tibial rotation, while the activity of the LH is higher with external tibial rotation during isometric knee flexion at 90° in a prone position.

Beyer et al. (2019) investigated the effects of the angle of knee flexion and tibial rotation on hamstring activation in healthy individuals. According to the findings of this previous study, peak MH muscle activation was found at knee flexions of 60° with the tibia in the neutral position, while the peak LH muscle activation was found at 30° of knee flexion with the tibia in the neutral or external rotation position. However, this previous study by Beyer et al. (2019) included both men and women subjects. According to the study by Almquist et al. (2013), gender-specific differences were reported regarding the amount of the tibial rotation range: the females yielded a larger range of rotation by 10-20% compared with males during tibial rotation.

Based on the previous findings, gender-specific differences in the biomechanical property of knee joint may affect selective hamstring activation during knee flexion with tibial rotation. Thus, the effects of tibial rotation on hamstring activity should be identified by studying the females and males separately. In addition, considering that the magnitude of tibial rotation reached a maximum knee flexion rotation of 30° (Matsumoto et al., 2000), knee flexion of 30° should be considered to demonstrate the effects of maximal tibial rotation on hamstring muscle activity during isometric knee flexion. Thus, the present study was performed to demonstrate the effects of tibial rotation on MH and LH activity, as well as knee flexor strength, during isometric knee flexion at 30° in healthy female. The findings of this study would help design selective hamstring training program for women with muscle imbalance of MH and LH.

Ⅱ. Methods

1. Subjects

A total of 17 healthy women were selected for the study (age = 34.82 ± 7.38 years; height = 161.88 ± 4.15cm; body weight = 51.53 ± 4.16kg). Exclusion criteria were (1) the presence of pain in the lower extremity; (2) any neuromuscular or musculoskeletal disorder, and/or (3) a previous history of hamstring injury or knee ligament deficiency. Prior to enrollment, an examiner explained all procedures. All subjects were informed about this study and agreed to participate in this study.

G*Power software (version 3.1.2; Franz Faul, University of Kiel, Kiel, Germany) was used to estimate the required sample size based on previous findings (Mohamed et al., 2002). The results of the power analysis indicated that at least six subjects would be required to achieve a power of 0.8 at a significance level of 0.05.

2. Instruments

1) Surface electromyography and data processing

Raw EMG signals were collected with a EMG system (Trigno wireless system, Delsys Inc., USA) and sampled at 2,000Hz. The EMG signals were full wave rectified and filtered with a bandpass filter (20 - 450Hz). The root-mean-squared (RMS) value was calculated over a 50-ms window. The electrode sites were shaved and cleaned by rubbing the shaved skin with alcohol pads. Two surface electrode pairs were placed on the SM/ST for the MH and BF long and short for LH in the dominant leg. The dominant leg was selected based on various tasks, such as mobility and stability. Several studies have reported that the dominant leg typically requires mobilization for activity, whereas the non-dominant leg requires postural stability for activity (Velotta et al., 2011). Electrodes were placed over each muscle group at a distance halfway between the ischial tuberosity and the medial femoral epicondyle in the case of the MH muscles and between the ischial tuberosity and the lateral femoral epicondyle in the case of the LH muscles. The MH and LH muscles were palpated manually at these regions during a submaximal contraction to identify the muscle bellies for electrode placement (Boguszewski et al., 2016). In the present study, the mean value of the EMG amplitude of the middle 3 s of each isometric knee flexion was estimated over a time period of 5s. The mean EMG value of the three test trials at each tested condition (e.g., tibial neutral, tibial internal rotation, or tibial external rotation condition) were calculated for data analysis. In addition, calculated EMG data were normalized to maximum RMS value among all isometric knee flexion test trials, and then expressed as %maximum voluntary isometric contraction (%MVIC).

2) Force measurement

The load cell sensor (Smart KEMA strength sensor, KOREATECH Co., Ltd, Korea) was used to measure the peak force during knee flexion. The two ends of the sensor were attached to the distal end of the lower leg by a strap and to a fixed bar with an adjustable non-elastic belt. The belt length and fixation point of the belt at the bar were adjusted according to the physical characteristics of the subjects. The gauge tension was 3kg at the starting position to control the tension of the belt at each test position.

3. Procedure

Before data collection, the subjects stretched their hamstring muscles by standing and raising one leg on a chair, followed by the execution of anterior pelvic tilt while they maintained their back in an upright position (Sullivan et al., 1992). Every stretch lasted 20-30s, and was performed three times with a 45 seconds rest period between stretches (Fiebert et al., 1992). The hamstring stretching was performed to improve flexibility and prevent muscle strain (Witvrouw et al., 2003). Each subject was then placed in a prone position on a table with a pillow under the pelvis at the anterior superior iliac spine. The hips were stabilized with a Velcro strap at the level of the iliac crest, and the knees were stabilized with an abductor pillow with a securing strap. Subsequently, subjects performed maximal isometric knee flexion of the dominant leg at 30°. Three repeats that lasted 5s each with a 15s rest period between contractions were performed for each of the three tibial rotation conditions: 1) neutral position, 2) external rotation and 3) internal rotation. Subjects were asked to rotate their knees internally and externally as far as they felt comfortably possible. A period of 3 min was provided between the tibial rotation positions. The order of the tibial rotation positions was randomized.

4. Statistical analyses

SPSS for Windows (version 18.0, SPSS Inc., USA) was used to analyze the degree of muscle activation of the MH and LH, as well as the force of the knee flexor. All data were expressed as means ± standard deviations. A one sample Kolmogorov-Smirnov test was used to assess the normality of the distribution of the EMG and the force of the knee flexor. Differences in the EMG activity and peak force among the three conditions (tibial neutral position, tibial internal rotation, external tibial rotation) were assessed with one-way repeated analysis of variance (ANOVA). Follow-up analyses included a pairwise comparison test using Bonferroni correction that applied the significance level with adjustment (0.05/3=0.0167).

Ⅲ. Results

The MH and LH EMG muscle activity and peak knee flexor force were significantly different among the three tibial rotation positions ($p < 0.01$; Tables 1 and 2). The post hoc comparison revealed that the MH muscle activity in the tibial neutral ($p < 0.01$) and internal rotation ($p < 0.01$) positions were significantly greater than that in the tibial external rotation position (Fig. 1A). In addition, there were no significant differences in the MH muscle activity between the tibial neutral position and internal tibial rotation position ($p = 1.00$). Conversely, the LH muscle activity was greater in the external tibial rotation position compared with the tibial neutral ($p < 0.01$) and internal rotation positions ($p < 0.01$), while greater LH

Table 1. Descriptive data of %MVIC during isometric knee flexion

Muscle	Tibial internal rotation position	Tibial neutral position	Tibial external rotation position	ANOVA
	Mean ± SD	Mean ± SD	Mean ± SD	P value
MH	84.33 ± 12.94	87.92 ± 7.13	68.27 ± 17.17	<0.01
LH	63.21 ± 17.25	80.24 ± 11.48	91.85 ± 4.78	<0.01

SD: standard deviation, MVIC: maximum voluntary isomeric contraction, ANOVA: analysis of variance, MH: medial hamstring, LH: lateral hamstring.

muscle activity was found in the tibial neutral position compared with the tibial internal rotation position ($p < 0.01$) (Fig. 1B). The peak force of the knee flexor was greater in the external tibial rotation position compared with the tibial neutral ($p < 0.01$) and internal rotation ($p < 0.01$) positions, while no significant differences were found between the tibial neutral and internal tibial rotation positions regarding the peak force of knee flexor ($p > 0.01$) (Fig. 1C).

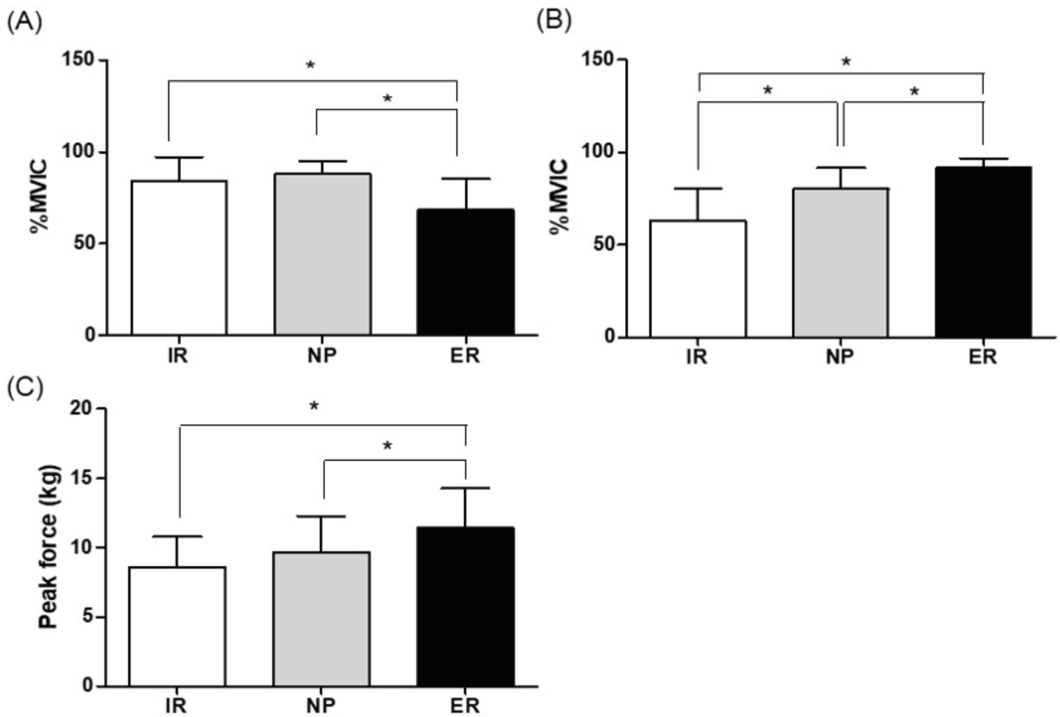
Ⅳ. Discussion

The purpose of this study was to investigate how the three tibial rotation positions (internal rotation, neutral position, and external rotation) affected MH and LH muscle activities and peak force during isometric knee flexion at knee angle of 30° in women. As a result, the MH muscle activity was greater in the neutral tibial position and internal tibial rotation than the external tibial

Table 2. Descriptive data of force (kg) of knee flexor during isometric knee flexion

Variable	Tibial internal rotation position	Tibial neutral position	Tibial external rotation position	ANOVA P value
	Mean ± SD	Mean ± SD	Mean ± SD	
Peak force	8.60 ± 2.17	9.67 ± 2.59	11.42 ± 2.87	<0.01

ANOVA: analysis of variance



Abbreviations. ER: external rotation. IR: internal rotation, MVIC: maximum voluntary isomeric contraction, NP neutral position.

Fig. 1. Electromyographic (EMG) activity (A: medial hamstring, B: lateral hamstring) and peak force (C) of knee flexor at three tibial rotation conditions during isometric knee flexion.

rotation. The LH muscle activity and peak force were the greatest during external tibial rotations.

The hamstring group consist of four muscles (i.e., ST, SM, and the long and short heads of the BF), and are active during knee flexions. These muscles are often classified as MH (ST and SM) and LH (BF long and BF short) depending on the tibial rotation function (Herzog & Read, 1993; Wickiewicz et al., 1983). Lynn and Costigan (2009) reported that active external rotation of the tibia selectively activates the LH and active internal rotation of the tibia selectively activates the MH during standard lower limb exercises. This is consistent with results of present study that the MH muscle activity increased from external to internal tibial rotation, whereas the LH muscle activity increased from internal to external rotation. Based on previous and present findings, it is clear that the direction of tibial rotation influences increase in muscle activity of MH and LH. However, in our study, EMG activity of MH was not significantly different between internal tibial rotation and neutral tibial position while MH muscle activity was greater during the internal tibial rotation condition compared with the external rotation tibial conditions. These results are consistent with previous reports that investigated the angle of knee flexion and tibial rotation that induced the greatest hamstrings activation in healthy adults (Beyer et al., 2019). The authors of a previous study suggested that no significant change in MH muscle activity between the internal tibial rotation and neutral tibial positions may result from relatively small amounts of internal tibial rotation angle (Beyer et al., 2019). This is because anatomically, the range of the internal tibial rotation is smaller than the range of external tibial rotation (Brandenburg & Matelic, 2018; Boguszewski et al., 2016). Therefore, based on previous findings and anatomical characteristics for a range of tibial rotation, the MH muscle activity in the internal tibial rotation and neutral tibial position were greater than those obtained during the external tibial rotation. By contrast, the MH muscle activity was not changed between the neutral and internal tibial rotation positions during isometric knee flexion in our study.

In the present study, LH activity during external tibial rotation was significantly greater than that recorded during internal tibial rotation and the neutral position. In comparison with a previous study that confirmed hamstring muscle activity during various knee positions and tibial rotations (Beyer et al., 2019), the results of MH muscle activity patterns in our study were similar with those in previous studies. However, the results of LH muscle activity patterns of our study and the previously conducted study were different. The previous findings by Beyer et al. (2019) showed no significant changes in LH muscle activity during isometric knee flexion at 30° among three different tibial rotation conditions, while our study shows significant greater LH muscle activity during isometric knee flexion at 30° with external tibial rotation. A previous study has demonstrated differences in the biomechanical properties of the knees among men and women during knee flexion with tibial internal and external rotations (Park et al., 2008). They found higher laxity and lower knee joint stiffnesses during tibial external rotation conditions in women compared with men (Park et al., 2008). For this reason, the range of the external tibial rotation may have been greater in the subjects in our study than subjects in the previous study by Beyer et al. (2019). This is because our study included only women, while the previous study by Beyer et al. (2019) included both men and women. Thus, it is believed that LH muscle activity may be facilitated more owing to the greater external tibial rotation that influences an enhanced LH muscle activity when it was subjected to the external tibial rotation condition in the present study.

The peak strength with external tibial rotation was also significantly greater than that recorded with tibial internal rotation and neutral position during isometric knee flexion. It has been reported that LH has a greater contribution for total hamstring muscle activation than MH during knee flexion whe subjected to maximal and submaximal isometric conditions (Fiebert et al., 2001). Moreover, the contribution of LH to isometric knee flexion was greater during maximal compared with submaximal contraction conditions (Fiebert et al., 2001). These previous findings suggest that LH has a more important role in producing maximal knee flexion force than MH. Based on previous findings, it is inferred that an external tibial rotation condition leads to greater LH muscle activation, and consequently results in a greater peak knee flexor force during maximal isometric knee flexion in the present study.

This study has several limitations. First, we did not provide external stabilization to the tibia when we maintained the maximal tibial rotation positions. Second, although the surface electrodes were located precisely to minimize the crosstalk in our study, it was difficult to completely eliminate the crosstalk between the MH and LH.

Ⅴ. Conclusion

The study applied internal tibial rotation, neutral tibial position and external tibial rotation to isometric knee flexion at 30° in women. As a result, the MH muscle activity was the greatest in the neutral tibial position and internal tibial rotations, while the LH muscle activity and peak force were the greatest in external tibial rotations. These findings suggest that hamstring muscle activation pattern can be changed by tibial rotations. Based on our findings, clinicians can use tibial rotation strategy to facilitate selective hamstring muscle activation when treating individuals with muscle imbalance of MH and LH.

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