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Original Article

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# Immediate Effects of Foam Rolling and Proprioceptive Neuromuscular Facilitation Stretching on Hamstring Flexibility

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**Purpose:** This study aimed to determine which interventions are effective in increasing hamstring flexibility due to changes in the range of motion (ROM) and pennation angle (PA) when foam rolling (FR) and proprioceptive neuromuscular facilitation (PNF) stretching were performed.

**Methods:** A total of 24 healthy participants who agreed to participate in the study were randomly chosen. The participants were divided into three groups of eight people: Control, FR, and PNF stretching groups. The hip flexion angle (ROM) and PA of the hamstrings were measured before and after the experiment. The Wilcoxon signed-rank test was used to analyze the ROM and PA for each group by comparing the before and after results. The Kruskal-Wallis test and the Mann-Whitney U test were used to analyze the increase in hamstring flexibility between the groups.

**Results:** A statistically significant difference was observed in the ROM and PA within all groups, and only the ROM was significant in the comparison between the three groups. In the comparison between the control and other two groups, a significant difference was noted in both the ROM and PA in the FR group and only the ROM in the PNF stretching group ($p < 0.05$). In the comparison between the FR and PNF stretching groups, no significant difference was observed ($p > 0.05$).

**Conclusion:** These findings FR and PNF stretching increased the ROM; however, no change in PA was observed. Therefore, FR and PNF stretching were considered effective interventions in immediately increasing hamstring flexibility.

**Keywords:** Flexibility, Pennation angle, Hamstrings, PNF stretching, Foam rolling

## INTRODUCTION

Flexibility is defined as the physiological range of motion (ROM) of each joint, which means that more than one joint can move within the ROM and is an important component for normal movement.[1] Flexibility is a significant part of motor ability, depending on the degree of the ROM, and is vital for both the prevention and rehabilitation of musculoskeletal injuries. Furthermore, the ROM is determined by the joint structure and muscles, and muscle imbalance causes a decrease in flexibility.[2,3] Decreased ability to move normally means decreased flexibility, which can lead to musculoskeletal damage. Additionally, flexibility can affect the function of muscles that generate maximum tension according to changes during their rest period.[4] Muscle structure plays a significant role in the general muscle function, and it includes muscle mass, muscle fiber length, pennation angle (PA), and sarcomere length.[5]

In addition to the ROM, several other functional (maximal isometric torque, muscle-tendon stiffness, and passive resistive torque) or structural (muscle and tendon stiffness, fascia length, and PA) parameters, which can account for functional changes, can be changed using other stretching methods.[6] The PA is a specific angle between the muscle and tendon, which depends on the fascial arrangement and muscle length.[7] Increasing muscle means increased flexibility.[8] Previous studies have established that a relationship exists between the fascial length and PA as a study reported that PA decreases as the fascial length increases.[9] The fascial length and PA can be determined using ultrasound.[10,11] The muscle group of the hamstrings is located in the posterior thigh compartment and consists of the semimembranosus, semitendinosus, and biceps femoris. The longer you sit in the chair, the more likely the length of the back thigh muscle is to be shortened. Thus, the biomechanically shortened posterior thigh muscle does not evenly use the force on the joints of the lower extremities; it is also

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less efficient in mobility.[12,13] Shortened hamstrings can negatively affect the function and biomechanics of the knee and hip joints as well as pelvic rhythm, increase posterior pelvic tilt, cause a flat back, and tend to cause lower back pain.[14] The hamstrings, which are easily shortened, are the most frequently studied muscle groups in stretching studies and are easy to evaluate. To increase muscle length, it is necessary to stretch in a line that is not disturbed by the joint capsule and ligaments.[15]

Stretching generally includes static, dynamic, and proprioceptive neuromuscular facilitation (PNF), maintaining joint flexibility and ROM, and effectively reducing the risk of injury,[16] thereby improving the body movement quality.[17] Static stretching is the safest form of stretching and can improve joint ROM and prevent damage to the muscles and tendons.[18] Static stretching moves the limb to the end of the ROM and maintains the posture for several seconds.[19] Dynamic stretching improves the joint ROM and improves flexibility by reducing passive muscle tension.[20] Dynamic stretching includes stretching to increase muscles and is performed by gradually increasing the reach and movement speed by moving parts of the body.[21] It can produce a warm-up effect relatively quickly, and it is recommended as a component of warm-up exercises before participating in recent exercise activities rather than static stretching.[22] PNF stretching improves mobility, movement control, and joint synergy.[23] Moreover, it is based on a neurophysiological mechanism that activates the Golgi tendon organ and inhibits agonist muscle activity.[24] According to a previous study, it was confirmed that muscle tone, which was high when the muscle was measured by ultrasound after PNF stretching, decreased.[25] PNF stretching is more effective in increasing the length of the hamstring muscles and ROM than static stretching.[26]

As another way to increase the ROM, foam rolling (FR) is a relatively new technique and is a general magnetic fascia training that can be performed by non-expert individuals.[27] Furthermore, owing to its portability and ease, it is widely used in athletic and rehabilitation environments,[28] and users can directly manipulate the pressure of the rollers applied to the muscles.[29] Other studies have suggested that applying FR to the hamstrings is more useful in extending the ROM than other stretching methods.[30]

The physiological mechanisms for the effect of PNF and FR interventions on flexibility have been described differently. Recently, various studies on flexibility are emerging; however, there are insufficient studies comparing the difference between each group by performing PNF stretching and FR on hamstring flexibility. Therefore, this study aimed to investigate the change in flexibility between groups by applying PNF stretching and FR, which are effective in increasing hamstring flexibility.

## METHODS

### 1. Subjects

A total of 24 healthy adult male and female students from S University were included in this study. The participants had no musculoskeletal or nervous disorders. The exclusion criteria were as follows: 1) those who did not visit or receive medical care due to pain from lumbar disease, nervous system disorders, spinal surgery, and musculoskeletal disorders; 2) those who had pain or discomfort due to waist, knee, ankle, pelvis, and shoulder movements; and 3) those who had surgery on the lumbar spine, pelvis, ankle, knee, and shoulder. The participants were fully informed of the content and purpose prior to participation and agreed to participate in the experiment (Table 1). This study was approved by the Biomedical Ethics Committee of Sunmoon (SM-202005-036-2).

### 2. Experimental methods

Before starting the experiment, the purpose, method, and procedure were fully explained to the participants. To facilitate the experiment, the participants were allowed to practice three times. Subsequently, they were divided 8 people into three groups a total 24 people: Control, FR, and PNF stretching groups. The ROM and PA (biceps femoris angles) were measured once before and after the intervention, with a 10 minutes break in between. PA was measured using ultrasound. The control group took the same amount of time off as the experimental time.

#### 1) Foam rolling for the hamstrings (FR)

The FR group placed the hamstring on one leg on top of the foam roller and moved back and forth carrying the tester's weight. The participants were asked to perform FR for 30 seconds and rest for 10 seconds for one set and then repeat 10 sets, five times per side.

**Table 1.** General characteristics of participants (N=24)

| Characteristics | Values | | |
|---|---|---|---|
| | Control (n=8) | FR (n=8) | PNF (n=8) |
| Gender (M/F) | 4/4 | 4/4 | 4/4 |
| Age (yr) | 24.4±2.8 | 24.0±2.2 | 23.0±1.0 |
| Height (cm) | 168.9±7.2 | 168.4±11.0 | 169.8±9.0 |
| Weight (kg) | 64.8±12.9 | 72.1±20.3 | 67.88±16.8 |

All values are presented as mean±standard deviation.

2) Proprioceptive neuromuscular facilitation stretching for the hamstrings (PNF)

The PNF stretching group held for 15 seconds, lifting one leg from its immediate supine position, pointing the heel to the opposite shoulder, and clasping the hands behind the thighs. Subsequently, the participants were allowed to relax for 15 seconds with their knees bent while keeping their hands behind their thighs. They were then allowed to take a 10 seconds break and repeat 10 sets, five times per set.

### 3. Measurement

1) Measured region

ROM was measured by an electronic goniometer (Digital Absolute+Axis Goniometer, 12-1027, USA, 2012) at 180°, axial with the greater trochanter of the femur, parallel to the midline on the side of the body, and midline on the side of the femur. The PA measurement of the biceps femoris was performed using B-mode ultrasound (eZono 3000, Germany, 2011) at 7-10 MHz, with a towel placed on the ankle in the prone position, creating a complete knee extension. The measurement site was the midpoint between the sciatic nodule and posterior knee joint pleats along the line of the long head of the biceps femoris.[31] PA is a specific angle of the muscle and tendon, calculating the angle between the fascia and aponeurosis.[9]

Table 2. Mean change in range of motion and pennation angle according to intervention

| | Control | FR | PNF |
|---|---|---|---|
| ROM (°) | | | |
| Pre | 64.61±11.61 | 75.78±21.49 | 80.81±10.54 |
| post | 67.28±11.35 | 88.51±19.22 | 90.55±9.28 |
| p | 0.012* | 0.012* | 0.012* |
| PA (°) | | | |
| Pre | 13.60±4.39 | 12.05± 2.16 | 13.55±2.17 |
| Post | 12.03±4.69 | 9.27±1.82 | 11.11±1.89 |
| p | 0.12 | 0.012* | 0.012* |

Mean±standard deviation, FR: foam rolling, PNF: PNF stretching, ROM: range of motion, PA: pennation angle.
*p<0.05.

### 4. Statistical analysis

All statistical analyses were conducted using SPSS 22.0 for Windows. We analyzed the ROM and PA for each group using the Wilcoxon signed-rank test to compare before and after results. The Kruskal-Wallis test was used to determine changes in ROM and PA before and after intervention in for flexibility of intergroup hamstrings. The Mann-Whitney U test was used to determine the effectiveness of FR and PNF stretching. All statistical significance levels (a) were set to $p<0.05$.

## RESULTS

After one set of FR and PNF stretching, the change in the ROM and PA of the hamstrings before and after were compared. After the intervention for the ROM, the mean values showed significant differences in the control (67.28±11.35), FR (88.51±19.22), and PNF stretching (90.55±9.28) groups. Significant differences were observed in the control (12.03±4.69), FR (9.27±1.82), and PNF stretching (11.11±1.89) groups. However, in the comparison between the three groups, only the ROM showed significant differences ($p<0.05$). Furthermore, in the comparison between the two groups, the ROM significant differences in the control and FR groups, but PA showed no statistically significant difference in the control group, and only the ROM exhibited significant differences in the control and PNF stretching groups ($p<0.05$). Both the ROM and PA showed no statistically significant difference in the FR and PNF stretching groups (Tables 2, 3).

## DISCUSSION

This study aimed to investigate the change in hamstring flexibility when FR and PNF stretching were performed. In the comparison before and after the intervention, all three groups showed a significant increase in ROM, whereas PA significantly decreased. In comparison of the amount of change in each group, there was a significant difference in ROM, and a significant increase was found in the FR and PNF groups compared to the

Table 3. Comparison of difference value according to intervention

| | Control | FR | PNF | p | $\chi^2$/Z |
|---|---|---|---|---|---|
| ROM (°) | 2.67±1.89 | 12.72±3.11 | 9.73±4.21 | 0.001* | 14.486 |
| Control vs FR | | | | 0.001* | -3.363 |
| Control vs PNF | | | | 0.003* | -2.943 |
| FR vs PNF | | | | 0.208 | -1.260 |
| PA (°) | 1.56±0.81 | 2.77±1.09 | 2.43±0.96 | 0.062 | 5.546 |

Mean±standard deviation, FR: foam rolling, PNF: PNF stretching, ROM: range of motion, PA: pennation angle.
*p<0.05.


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control group. However, there was no significant difference between the RF and PNF groups. There was a significantly decreased in PA of the RF and PNF in the before-and-after comparison, but no change in the control group. Unfortunately, the amount of change in PA for RF and PNF groups showed no significant difference compared to the control group. The PA refers to the angle between a muscle and a tendon, and the angle varies according to the length of each muscle.[32] This study applied for a short period of intervention. Significant changes in PA were considered insufficient because of a small amount of structural change. The results indicate that FR and PNF stretching can be effective in increasing the ROM of the hamstrings. In this study, the degree of change in hamstring flexibility could be confirmed by measuring and comparing PA with ROM.

FR is a magnetic fascia training performed by individuals to reduce muscle tension by stimulating the Golgi receptors. Moreover, it increases the ROM by directly manipulating the pressure of the roller.[27,29] MacDonald et al.[33] reported that the ROM of the biceps femoris was increased when FR was applied. Madoni et al.[30] reported that the hamstring length was improved when FR was performed on the hamstrings. Based on these previous studies, in this study, FR was applied to the hamstrings; the ROM significantly increased, whereas the PA decreased.

Konrad et al.[25] used acute static, ballistic, and PNF stretching as interventions. Among them, PNF stretching significantly decreased the PA, however, the fascial length did not change. This study speculates that the slight difference is caused by the more adaptive muscle tissue after stretching.[6] Conversely, FR directly and extensively exerts pressure on the soft tissue, thereby stretching the tissue and causing friction.[32] The increase in flexibility after FR can be explained by using the property that the fascia hardens when it is still and softens as it moves.[34,35] In comparison with the control group in this study, the reason for the significant difference in PA that was observed only in the FR group was that the fascia was softened and the tissue increased due to the friction generated during FR, thereby reducing PA.

Resistance to stretching includes nerve reflexes and spontaneous elements causing muscle contraction, as well as viscoelastic properties of the muscles and connective tissues.[36] PNF stretching increases the ROM by promoting spontaneous muscle contraction and relaxation to reduce nerve reflex factors that cause muscle contraction.[37] Youdas et al.[38] reported that the hamstring length was significantly improved after the antagonist contraction technique during two modified PNF stretching interventions. Yildirim et al.[26] reported that the ROM was significantly increased after the hold contraction technique with PNF stretching. Based on these previous findings, in this study, the hold contraction technique was performed with PNF stretching, and the ROM significantly increased.

From a clinical point of view, both the FR and PNF stretching groups can have a positive effect on increasing the ROM of the hamstrings. These results indicate that FR and PNF stretching are effective interventions to increase hamstring flexibility. However, whether they sufficiently increase the muscle activation required for hamstring flexibility cannot be concluded. Therefore, clinicians must find a variety of methods considering stretching that is sufficient to increase hamstring flexibility.

This study was conducted to determine which interventions are more effective in changing hamstring flexibility during FR and PNF stretching. The results indicated that FR and PNF stretching increased the range of motion; however, no change was noted in PA, which is a structural parameter. Therefore, FR and PNF stretching are considered effective interventions to immediately improve hamstring flexibility. This study has some limitations. First, the results are difficult to generalize to all ages as this study was conducted on healthy adults in their 20 seconds. Second, the results are also difficult to generalize because this study had a small sample size. Therefore, the statistical analysis of this study was performed nonparametric test. Third, the difference between the dominant and nondominant sides is difficult to determine as it was measured with the dominant leg. Fourth, the short-term study period decreases the generalizability of the results. PA refers to the angle between a muscle and a tendon, and the angle varies according to the length of each muscle. Therefore, in the future, it is necessary to study hamstring flexibility through ROM and PA by supplementing these limitations.

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