The Effects of Static and Dynamic Stretching Exercises on Individuals of Quadriceps Components in Healthy Male Individuals

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Abstract

The purpose of this study was to evaluate the effects of static and dynamic stretching exercises on individual quadriceps components in healthy male individuals. This was a cross-over observational study. Ten healthy male individuals aged between 21 and 35 were recruited by convenience. Each subject attended three sessions with one week apart to have (1) static stretching (SS), (2) dynamic stretching (DS) and (3) control (CON) after a 5-minute self-pace treadmill running. During the SS session, each subject performed 2 stretching exercises to the quadriceps muscle, with 3 sets of 20 seconds holding time. For the DS session, 15 sets of butt kick and walking lunge were performed. The subject sat for 10 minutes during the control session. Rectus femoris (RF) and vastus lateralis (VL) muscle stiffness were quantified by Supersonic shear imaging and flexibility of the quadriceps muscle was measured using prone knee bending test before and after the intervention. Results indicated that muscle stiffness after dynamic stretching caused a significant decrease on the RF and VL muscles (p=0.022; p=0.006); insignificant change on muscle stiffness on both tested muscles was observed after static stretching. There was insignificant change on the knee flexion angle from the prone knee bending test (p=0.108). These results suggest that dynamic stretching could decrease quadriceps muscle stiffness and is recommended to include in warm-up activities for improving muscle compliance.

Keywords: Warm Up; Flexibility; Muscular Tendon Unit; Stretching; Performance

Abbreviations: SS: Static Stretching; DS: Dynamic Stretching; CON: Control; RF: Rectus Femoris; VL: Vastus Lateralis; SSI: Supersonic Shear Imaging; MTU: Muscle Tendon Unit; ASIS: Anterior Spina Iliaca Superior; ROI: Region of Interest

Introduction

Muscle stiffness is one of the main concerns on sports performance. It is defined as the ratio of the change in force of a muscle to the change in length[1,2]. A stiffer muscle could lengthen less when some force applies. This deficiency will heavily restrict joint mobility[3] and affect the sport performances and may cause injuries [3-5]. It is therefore essential to reduce muscle stiffness for performance enhancement and injury prevention during sporting activities.

Stretching is an indispensable constituent of warm-up activities, which aims to increase muscle flexibility and diminish muscle stiffness[3,5-7]. Static and dynamic stretching are two commonly recommended stretching techniques[8-10]. Static stretching involves static holding of a stretched muscle for a certain duration[11-13]. The duration could range from a minimum of 5 seconds to 5 minutes per set[11,13]. Increase in the joint range of motion[8,10,14,15] and decrease in the muscle-tendon stiffness[16,17] were observed after static stretching. However, reduction on muscle force, power output, and performance were associated with static stretching[9,11,18,19]. Dynamic stretching involves controlled movement through the active range of motion of a joint while moving[3,20]. In contrary, increase in muscle power, jump height and agility was found after dynamic stretching[9,18,21]. A decrease in muscle stiffness due to increased temperature and induced post-activation potentiation were the proposed mechanism. Indeed, improvement in joint range of motion was found after dynamic stretching based on prone knee bending test[20,22]. Such approach involves the muscle-tendon-joint complex and is thereby unable to provide information on where the changes come from. A direct measurement of muscle stiffness is needed in order to assess how much of the change is associated with changes on muscle stiffness.
More recently, supersonic shear imaging technique (SSI) is a relative new real-time diagnostic imaging technique to evaluate stiffness of different soft tissues[23,24]. It relies on measuring the propagation of shear waves generated by acoustic radiation force to estimate the shear elastic modulus of the soft tissues[23,25]. The shear wave which moving at a supersonic speed is applied to various tissues though a transducer [25]. This technique has the benefits of being noninvasive, direct, reproducible, and provides quantitative assessment for muscles and tendons tissues [26,27]. Using SSI, the gastrocnemius muscle tendon unit (MTU) stiffness was found significantly reduced after static stretching [16]. We were interested in assessing the quadriceps muscle, the major muscle responsible for shock absorption during landing and propulsion for jumping [28] required for most sporting activities. In particularly, the rectus femoris muscle is the most frequently strained during high force and speed activities, such as running and jumping [28-30]; as well as to compare the effect of static and dynamic stretching programmes.

The purpose of this investigation was to explore and compare the effects of static and dynamic stretching on muscle stiffness of the rectus femoris (RF) and vastus lateralis (VL) muscles. As part of the quadriceps muscle, the combine effect of RF and VL muscle was also considered in this study to investigate the whole effect of stretching exercises on quadriceps muscle. We hypothesize that stretching exercises to the quadriceps muscles would reduce muscle stiffness of the RF and VL muscles. The effects on muscle stiffness of the RF and VL muscles might be difference between static and dynamic stretching. Findings from this study would provide an evidenced-based recommendation on warm-up exercises aiming for reducing muscle stiffness for performance enhancement and injury prevention.

Methods
Experimental Approach to the Problem

We used a cross-over design to examine the effects of static and dynamic stretching protocols on muscle stiffness of the RF and VL muscles in healthy male individuals. The experiment was conducted in the Rehabilitation Clinic of the Hong Kong Polytechnic University. Each subject attended the clinic on 3 separate occasions separated by a week. The order in which the subjects completed the stretching protocols was randomized and blinded to the assessor. Repeated measures were used to compare the 3 stretching protocols (static stretching, dynamic stretching, and control) on the shear elastic modulus of individual quadriceps components by Supersonic imaging. The independent variable was stretching protocols. The dependent variables were the shear elastic modulus of the RF and VL muscles of subjects dominate leg; and the angles of prone knee bending test. Pre- and post-evaluations were both conducted. Subject was encouraged to continue his daily activities and prevent overloading exercise during the testing period.

Subjects

The project was approved by the ethics committee of the Hong Kong Polytechnic University. Ten healthy male students were recruited by convenience if they were aged between 18 and 35 and exercised at least once a week for their chosen activities. Subject demographic characteristics are provided in Table 1. Exclusion criteria were:

a) A history of neuromuscular disease or disorder,

b) A history of musculoskeletal injury involving lower extremities, and

c) Chronic medical conditions including cardiovascular diseases, high blood pressure, diabetes mellitus[31,32].

They were asked to avoid doing any strenuous activities for 24 hours before taking the test. Subject first completed a healthy subject questionnaire which contained basic questions to guarantee the inclusion and exclusion criteria. Explanation of the project and informed consent was completed by all subjects in accordance with Declaration of Helsinki.

| Table 1: Subject demographic characteristics. |
|---------------------------------------------|
| Mean | Range |
| Age, year | 26 | 21–35 |
| Height, cm | 171.2 | 165–183 |
| Weight, kg | 65.8 | 57–80 |
| BMI, kg/m² | 22.6 | 18.51–28.34 |

Procedures

Each subject attended 3 intervention sessions which were separated by one week interval for refraining from carry-over effect. The 3 intervention sessions was arranged on the same weekday and time period. All sessions was started with a 5-minute warm-up exercise of self-paced jogging on a treadmill, followed by one of 3 stretching protocols.

Stretching Protocol

| Table 2: Static stretching protocol. |
|-----------------------------------|
| Exercise | Description |
|---------|-------------|
| 1 | Stand upright with one hand against a wall for balance. Flex the dominate leg to a knee joint angle of 90 degrees. The ankle of the flexed leg will be grasped by the same side hand and try to help pull ankle approached buttocks. |
| 2 | Lunge with back knee on the ground and front hip and knee flexed. Flex back and hold ankle with one hand against wall for balance. Slowly pull ankle to buttocks, while leaning forward until a stretch is felt. |

a) Static Stretching (SS)[4,9,22]: The specific stretching protocol is outlined in Table 2. Each stretch had 3 sets of 20 seconds static holding when the quadriceps muscle was positioned to a point of mild discomfort[33]. A resting time of 15 seconds was giving between each set of stretch. After finishing the whole SS intervention, there was also one minute period rest for subject before the final assessments.

b) Dynamic stretching (DS): Butt kick and Walking lunge [8,9,22] were used and the details were provided in Table 3. Each exercise was first performed for 5 times at a slow pace then followed with 10 times of fast pace without bouncing. A rest of 20seconds was allowed between each stretch.
Table 3: Dynamic stretching protocol.

| Exercise     | Description                                                                 |
|--------------|-----------------------------------------------------------------------------|
| Butt kick    | Flex knee to quickly bring heel to buttocks and alternate legs without stopping. Perform the moving process forward. |
| Walking lunge| Step out with one leg from a standing position, flex both knees as pelvis drops. Bring the back leg forward when forward thigh reached horizontal, step through and repeat from standing. |

**Evaluation**

**Muscle Stiffness using Supersonic Shear Imaging Technique (SSI)**

The shear elastic modulus of the RF and VL muscles of the dominate leg was measured by Aixplorer® ultrasound unit in conjunction with a 4to15MHz, 40mm linear transducer (Supersonic Imaging, Aix-en-Provence, France) before and after the intervention. Subject was positioned in supine lying with the knee kept at 30 degree of flexion and supported on a roll in a room set at 25°C [23]. A custom-made ankle stabilizer was applied in the ankle to keep the leg in neutral alignment. The ultrasound transducer with light pressure was used to scan the muscle. The scanning sites of RF and VL muscles were decided according to the same positions recommended for surface electromyography[34].

a) RF muscle: 1/2 on the line from the anterior spina iliaca superior (ASIS) to the superior part of the patella.

b) VL muscle: 2/3 on the line from the ASIS to the lateral side of the patella.

When the muscle has detected, elastograph mode was activated and 3 images were captured for each muscle. The Aixplorer ultrasound unit generated color-coded images with a stable color distribution depending on the magnitude of muscle stiffness [16,23]. A circle delineated the region of interest (ROI) was placed in the muscle center and the diameter of the circle should cover the whole muscle. The ROI size was defined by the thickness of the muscle, which was the distance between superficial and deep muscle fasciae. The averaged elastic modulus (kPa) within the circle was automatically estimated and displaced along with the elastograph[16,23]. Averaged elastic modulus from the 3 images was used as one of the outcome measures. In order to obtain shear elastic modulus on muscle tissue, the elastic modulus obtained was used as one of the outcome measures. In order to obtain shear elastic modulus, the total shear elastic modulus of these two muscles and prone knee bending angles were analyzed using univariate repeated measure analysis of variance. Paired-sample t-tests were applied to assess the difference between different stretching protocols. The level of statistical significance (alpha value) was set at 0.05. The alpha value was adjusted to 0.025 for the shear elastic modulus of the RF and VL muscles. All the statistical analysis was done with SPSS version 18.0 software.

**Statistical Analysis**

The pre- and post-intervention on the shear elastic modulus of the RF and VL muscles, the total shear elastic modulus of these two muscles and prone knee bending angles were analyzed using univariate repeated measure analysis of variance. Paired-sample t-tests were applied to assess the difference between different stretching protocols. The level of statistical significance (alpha value) was set at 0.05. The alpha value was adjusted to 0.025 for the shear elastic modulus of the RF and VL muscles. All the statistical analysis was done with SPSS version 18.0 software.

**Results**

The baseline muscle’s shear elastic modulus of the RF and VL muscles and prone knee bending angles were indifference before the 3 intervention sessions (p >0.05). Representative of two elastic graphs of a subject before and after dynamic stretching was provided in Figure 1.

**The RF Muscle Stiffness**

Significant difference on the shear elastic modulus of the RF muscle among the 3 stretching protocols was detected (p=0.014; Table 4). The muscle’s shear elastic modulus was increased during the static stretching session from 3.53kPa to 3.69kPa (by 4.4%; Table 4); reduction in the shear elastic modulus after dynamic stretching was provided in Figure 1.
stretching from 3.23 kPa to 2.65 kPa (by 22%, Table 4) and after control session from 3.04 kPa to 2.80 kPa (by 8.3%, Table 4). In the contrast tests, significant difference was found between the SS and DS stretching (p=0.016). A strong trend of significant difference between SS and CON stretching was observed (p=0.026). Paired t-test analysis of the RF muscle’s shear elastic modulus showed a significant decrease in elastic modulus scores in DS session (p=0.022; Table 5).

**Table 4: Effects on the RF muscle’s shear elastic modulus.**

|        | Mean ± SD (kPa) | p-value | Observed Power |
|--------|-----------------|---------|----------------|
| SS     | 3.53 ± 0.93     |         |                |
| DS     | 3.23 ± 0.59     |         |                |
| CON    | 3.04 ± 0.84     |         |                |
| Pretest| 3.69 ± 0.83     | *       | 0.771          |
| Posttest| 2.65 ± 0.38*   |         |                |

*Significant difference (p < 0.025) vs. SS.

**Table 5: Paired T test results of RF muscle’s shear elastic modulus.**

|        | Mean (kPa) | SD    | 95% Confidence Interval | p-value |
|--------|------------|-------|-------------------------|---------|
| SS     | -0.16      | 0.74  | -2.052 - 1.104          | 0.514   |
| CON    | 0.24       | 0.72  | -0.83 - 2.246           | 0.022   |

SD: Standard deviation; SS: Static stretching; DS: Dynamic stretching; CON: Control.

The VL Muscle Stiffness

A significant interaction effect was found in the shear elastic modulus of the VL muscle among the 3 sessions (p=0.007; Table 6). Paired t-test indicated there was a significant decrease of the VL muscle’s shear elastic modulus when performed DS from 3.84 kPa to 3.26 kPa (by 17.8%, p=0.006<0.025), but with a significant increase during the control session (p=0.020; Table 7).

**Table 6: Effects on the VL muscle’s shear elastic modulus.**

|        | Mean ± SD (kPa) | p-value | Observed Power |
|--------|-----------------|---------|----------------|
| SS     | 3.59 ± 0.70     |         |                |
| DS     | 3.84 ± 0.81     |         |                |
| CON    | 3.31 ± 0.55     |         |                |
| Pretest| 3.47 ± 0.43     |         |                |
| Posttest| 3.26 ± 0.61   |         |                |

*Significant difference (p < 0.025) of interaction effect.

**Table 7: Paired T test results of VL muscle’s shear elastic modulus.**

|        | Mean (kPa) | SD    | 95% Confidence Interval | p-value |
|--------|------------|-------|-------------------------|---------|
| SS     | -0.40      | 1.07  | -2.417 - 2.167          | 0.905   |
| CON    | 0.04       | 0.84  | -1.678 - 1.918          | 0.883   |

SD: Standard deviation; SS: Static stretching; DS: Dynamic stretching; CON: Control.

The Summation Effects on Shear Elastic Modulus of the RF and VL Muscles

There was significant interaction effect among the 3 sessions when the summation effects on shear elastic modulus were analysis (p=0.009; Table 8). From the contrast tests, the change on the shear elastic modulus was significantly different between the DS and CON sessions (p=0.014). Paired t-test indicated a significant decrease on the total (RF+VL) shear elastic modulus of quadriceps muscle during the DS session (p=0.004; Table 9). In addition, there was an insignificant increase in the total (RF+VL) shear elastic modulus after performing SS or resting.

**Table 8: The sum of RF and VL muscles’ shear elastic modulus.**

|        | Mean ± SD (kPa) | p-value | Observed Power |
|--------|-----------------|---------|----------------|
| SS     | 7.12 ± 1.56     |         |                |
| DS     | 7.07 ± 1.27     |         |                |
| CON    | 6.34 ± 1.20     |         |                |
| Pretest| 7.16 ± 1.05     |         |                |
| Posttest| 5.91 ± 0.81    |         |                |

+Significant difference (p < 0.025) of interaction effect.

SD: Standard deviation; SS: Static stretching; DS: Dynamic stretching; CON: Control.

Prone Knee Bending Angles

There was insignificant interaction effect between the 3 stretching sessions across time (p=0.018; Table 10). There were increases in the knee angle during the SS and DS sessions. However, the changes were statistically insignificant (p=0.099).
The purpose of this study was to investigate the effects of static and dynamic stretching on muscle stiffness of individual quadriceps components in healthy male subjects using Supersonic shear imaging technique and prone knee bending test. Dynamic stretching was found to reduce muscle stiffness of the rectus femoris and vastus lateralis muscles using Supersonic shear imaging technique.

Findings from this study indicated that the dynamic stretching protocol could significantly reduce muscle stiffness of the RF and VL muscles, as well as the summation effects of the 2 muscles. Curry et al. [17] observed a significant time effects on quadriceps flexion and power output measured separately by knee flex range of motion and countermovement jump after static stretching, dynamic stretching or light aerobic activity on 24 active healthy female individuals. Meanwhile, the DS group had a better improvement (6.4%) than SS group (5.3%) in 5 minutes posttest. [17]. The authors postulated that such change was related to a decrease in muscle stiffness of the quadriceps muscle. In this study, direct measurements on muscle stiffness of the RF and VL muscles using supersonic shear imaging technique and support the hypothesis from Curry’s group. The effects of dynamic stretching on performance enhancement have been demonstrated by other research groups [9,12,18,21,41]. K ellerud and Gleeson [12] found an improvement on jump, agility performance and a potential to induce extra gains in range of motion after the subjects performed dynamic stretching. Even though static stretching may have the potential to reduce extra gains in range of motion, the subjects performed dynamic stretching. As an indirect way to assess quadriceps muscle stiffness, the increase in the knee flexion angle was slightly greater after stretching (both static and dynamic) when compared with no stretching. Such observation was in accordance with the result reported by Perrier et al. [22]. Note that prone knee bending test measures the flexibility of the quadriceps muscle as well as the whole knee system, such as knee joint, muscle, ligaments. As a useful clinical test for muscle flexibility, it also has the limitation on distinguishing the specific part which induces the changes among the whole muscular system. Any change on the muscle stiffness may not be large enough to be reflected by this measurement. That is also the reason that direct measurement for muscle stiffness was performed in this study.

This study could not detect any effect of static stretching on muscle stiffness on the RF and VL muscles, as well as the summation effects of the 2 muscles. These observations were differed from that investigated from Akagi and Takahashi [16]. The authors observed a reduction of the muscle stiffness of the gastrocnemius muscle-tendon unit after a static stretching protocol that consisted of 3 sets of 2 minutes of static holding. Aside from the difference in the tested tissues; muscle-tendon unit versus muscle tissues, the other difference is on the duration of holding between our study and the study from Akagi and Takahashi. Note that the effects of static stretching is relate to the time of holding. It is believed that long duration stretching would decrease the muscle-tendon stiffness by changing the viscoelastic properties of the muscle and thereby increase its compliance [11, 18, 21]. However, prolonged static holding was found to hinder muscle performance [8, 11, 19, 21]. The recommended holding time from the American College of Sports Medicine is 15 to 30 seconds [43, 44]. The present study adopted such recommendation and our protocol included 3 sets of 20 seconds of static holding to the quadriceps muscle. The 2 stretching exercises chosen are commonly used for stretching the quadriceps muscle [4, 9, 22, 36]. The inability in detecting a significant change on muscle stiffness might relate to the small sample that we used. Further study with larger sample size is suggested.

We also used prone knee bending test, a clinical test commonly used in assessing quadriceps flexibility to examine the effects of static and dynamic stretching protocols. Insignificant change on the angle of knee flexion was observed after static and dynamic stretching. As an indirect way to assess quadriceps muscle stiffness, the increase in the knee flexion angle was slight greater after stretching (both static and dynamic) when compared with no stretching. Such observation was in accordance with the result reported by Perrier et al. [22]. Note that prone knee bending test measures the flexibility of the quadriceps muscle as well as the whole knee system, such as knee joint, muscle, ligaments. As a useful clinical test for muscle flexibility, it also has the limitation on distinguishing the specific part which induces the changes among the whole muscular system. Any change on the muscle stiffness may not be large enough to be reflected by this measurement. That is also the reason that direct measurement for muscle stiffness was performed in this study.

Finally, some limitations exist in this study. Muscle stiffness was assessed on two but not all of the four quadriceps muscle. The effects of both stretching protocols on the vastus intermediate and vastus medialis muscles could not be generalized from the present study. However, the rectus femoris and vastus lateralis muscles are the most commonly tested muscles. In addition, our results were based on a sample of 10 subjects. Further studies with larger sample sizes are highly recommended because effectively programme in reducing muscle stiffness is an important issue for athletes both on performance enhancement and injury prevention. In addition,
we used male healthy subjects whom participated in sports at least once per week. Information could not be generalized to female and more active individuals.

Practical Applications

Our findings suggest that dynamic could reduce muscle stiffness of the rectus femoris and vastus lateralis muscles. Dynamic stretching is recommended as part of the warm up exercises for preparing athletes for sporting activities in order to decrease muscle stiffness and diminish sports injuries. Based on the present study, the effect of static stretching has not been established.

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