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

Xian Zhang[1,2], Chun Long Liu[1,3], ZhiJie Zhang[1] and Siu Ngor Fu[1]*

[1] *Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China*

[2] *Shang Hai Yang Zhi Rehabilitation Hospital (Shang Hai Sunshine Rehabilitation Center)*

[3] *Department of Rehabilitation, College of Acupuncture and Rehabilitation, Guangzhou University of Chinese Medicine, China*

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***Corresponding author:** Siu Ngor Fu, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China

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 age 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 5minute self-pace treadmill running. During the SS session, each subject performed 2 stretching exercises to the quadriceps muscle, with 3 sets of 20seconds holding time. For the DS session, 15 sets of butt kick and walking lunge were performed. The subject sat for 10minutes 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

Abbrevations: 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 5seconds to 5minutes 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 increasedtemperature and induced post-activation potentiation were the proposed mechanism. Indeed, improvement in joint range of motion was found after dynamic stretching based on proneknee bending test[20,22]. Such approach involves the muscle-tendon-joint complex and is thereby unable to provideinformation 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 programme.

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/m^2	22.6	18.51~28.34

BMI, Body Mass Index.

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 15seconds 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.

c) Control session (CON): The subject sat for 10minutes which was the duration for either SS and DS session.

The order of the session was randomized by drawing lots and the exercises was instructed and supervised by a research assistant with basic training on physical therapy.

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 on 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 were divided by 3 [35]. Good test-retest reliability was reported with intra-session reliability of the VL and RF ranged from 0.822 to 0.829, respectively [23,36,37]. In this study, one examiner conducted the ultrasound measurement who was blinded to the type of intervention.

Prone Knee Bending Test

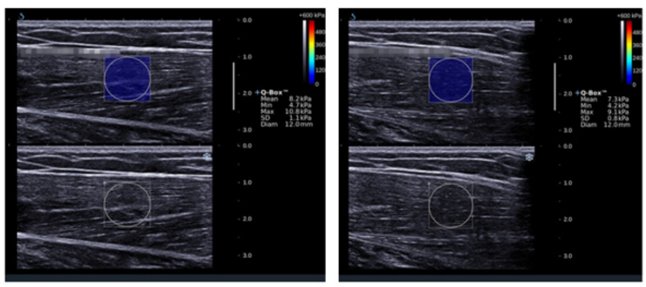
Clinical evaluation of the quadriceps flexibility was measured on the dominate leg by a standard clinical goniometer (One 12.5" (32cm) ISOM, Patterson Medical, France). Previous studies have revealed that it is a valid and reliable method to assess the muscle flexibility[38,39]. Subject was lying in prone position with his hip and knee in neutral rotation. The goniometer axis was placed on the lateral epicondyle of the femur, the proximal arm was parallel to the long axis of the femur while pointing at the greater trochanter and the distal arm was parallel to the long axis of the fibula while pointing at the lateral malleolus. Maximal flexion was determined as the point where the assessor first felt slight resistant during the knee bending[40]. Three trials were conducted both before and after the intervention. Averaged of the 3 knee flexion angle was used as the second outcome measure.

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.



(a) (b)

Upper images show color-coded elastic graph (stiffer areas were coded in red and softer areas in blue) of RF muscle of a subject before and after dynamic stretching, respectively. The circle representing the region of interest and its corresponding Young's modulus demonstrating under Q-BoxTM on the right. (a) represent the elastic graph of a subject before dynamic stretching; (b) represent the elastic graph of a subject after dynamic stretching.

Figure 1: Intra-op: Old Lower midline scar with granuloma removed.

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 from 3.23kPa to 2.65kPa (by 22 %, Table 4) and after control session from 3.04kPa to 2.80kPa (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	DS	CON		
Pretest	3.53 ± 0.93	3.23 ± 0.59	3.04 ± 0.84		
Posttest	3.69 ± 0.83	2.65 ± 0.38*	2.80 ± 0.53	p = 0.014	0.771

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

SD: Standard Deviation; SS: Static Stretching; DS: Dynamic Stretching; CON: Control

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

	Mean (kPa) SD		95% Confidence Interval		p-value
			Lower	Upper	
Pair 1-SS	-0.16	0.74	-2.052	1.104	0.514
Pair 2-DS	0.58	0.67	0.325	3.183	0.022
Pair 3-CON	0.24	0.72	-0.83	2.246	0.325

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 3.84kPa to 3.26kPa (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	DS	CON		
Pretest	3.59 ± 0.70	3.84 ± 0.81	3.31± 0.55		
Posttest	3.47 ± 0.43	3.26 ± 0.61	3.50 ± 0.52	p = 0.007	0.86

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

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

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

	Mean (kPa)	SD	95% Confidence Interval		p-value
			Lower	Upper	
Pair 1-SS	0.12	0.6	-0.936	1.634	0.554
Pair 2-DS	0.58	0.51	0.634	2.838	0.006
Pair 3-CON	-0.2	0.22	-1.057	-0.119	0.02

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	DS	CON		
Pretest	7.12 ± 1.56	7.07 ± 1.27	6.34 ± 1.20		
Posttest	7.16 ± 1.05	5.91 ± 0.81	6.30 ± 0.97	p = 0.009	.827

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

SD: Standard Deviation; SS: Static Stretching; DS: Dynamic Stretching; CON: Control.

Table 9: Paired T test results of the sum of RF and VL muscles' shear elastic modulus.

	Mean (kPa)	SD	95% Confidence Interval		p-value
			Lower	Upper	
Pair 1-SS	-0.04	1.07	-2.417	2.167	0.905
Pair 2-DS	1.16	0.95	1.448	5.532	0.004
Pair 3-CON	0.04	0.84	-1.678	1.918	0.883

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=0.108; Table 10).There were increases in the knee angle during the SS and DS sessions. However, the changes were statistically insignificant (p=0.099).

Table 10: Changes on the prone knee bending angle.

	Mean ± SD (kPa)			p-value	Observed power
	SS	DS	CON		
Pretest	119.07 ± 10.14	118.93 ± 8.62	118.23 ± 8.41		
Posttest	121.30 ± 10.11	121.40 ± 8.10	119.57 ± 8.74	p = 0.108	0.204

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

Discussion

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 flexibility 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 5minutes posttest[17]. The authorspostulated 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].Kallerud 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 make the key point on passive fascicle stiffness, it was still indicated to add risks of negative acute effect on sport performance [12,42]. An improvement on muscle power based on the performance of vertical jumps, were reported after a dynamic stretching protocol in female individuals [18,21].Sekir et al. [9]observed an increase on muscle strength in elite female athletes after having a dynamic stretching program. There were two proposed mechanisms for such effects[9,18,21]. One is related to an increased temperature associated with dynamic stretching. An increase in muscle temperature might promote the transmission rate of the impulses, improve the force-velocity relationship, as well as decrease the muscle stiffness and lactate [10,18,19,21]. The second proposed mechanism is an induction on post-activation potentiation after dynamic stretching which might lead to a positive increase in the force output [8,9,18]. Findings from the present study support the reduction on muscle stiffness after a dynamic stretching protocol. Whether this is linked to a change in temperature needs further investigation to verify.

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 2minutes of static holding. Aside from the difference in the tested tissues; muscle-tendon unit verse 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, prolong 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 30seconds[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.

It is noted that significant increase on muscle stiffness of the VL muscle was observed after resting for 10minutes with a 5minutes of self-paced running. Muscle stiffness was found to increase with activities and sports [12]. An increase in the VL muscle stiffness for 5.8% was detected in this study even after a 5minute self-paced running and its effect could extend beyond 10minutes.

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 size 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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References

1. McNair PJ, Stanley SN (1996) Effect of passive stretching and jogging on the series elastic muscle stiffness and range of motion of the ankle joint. Br J Sports Med 30(4): 313-317.
2. Murayama M, Nosaka K, Yoneda T, Minamitani K (2000) Changes in hardness of the human elbow flexor muscles after eccentric exercise. Eur J Appl Physiol 82(5-6): 361-367.
3. Behm DG, Chaouachi A (2011) A review of the acute effects of static and dynamic stretching on performance. Eur J Appl Physiol 111(11): 2633-2651.
4. Aguilar AJ, DiStefano LJ, Brown CN, Herman DC, Guskiewicz KM, et al. (2012) A dynamic warm-up model increases quadriceps strength and hamstring flexibility. The Journal of Strength & Conditioning Research 26(4): 1130-1141.
5. Carvalho FL, Carvalho MC, Simão R, Gomes TM, Costa PB, et al. (2012) Acute effects of a warm-up including active, passive, and dynamic stretching on vertical jump performance. The Journal of Strength & Conditioning Research 26(9): 2447-2452.
6. Malliaropoulos N, Papalexandris S, Papalada A, Papacostas E (2004) The role of stretching in rehabilitation of hamstring injuries: 80 athletes follow-up. Med Sci Sports Exerc 36(5): 756-759.
7. Yamauchi T, Hasegawa S, Nakamura M, Nishishita S (2016) Effects of two stretching methods on shoulder range of motion and muscle stiffness in baseball players with posterior shoulder tightness: A randomized controlled trial. J Shoulder Elbow Surg 25(9): 1395-1403.
8. Hough PA, Ross EZ, Howatson G (2009) Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. The Journal of Strength & Conditioning Research 23(2): 507-512.
9. Sekir U, Arabaci R, Akova B, Kadagan S (2010) Acute effects of static and dynamic stretching on leg flexor and extensor isokinetic strength in elite women athletes. Scand J Med Sci Sports 20(2): 268-281.
10. Werstein KM, Lund RJ (2012) The effects of two stretching protocols on the reactive strength index in female soccer and rugby players. The Journal of Strength & Conditioning Research 26(6): 1564-1567.
11. Fletcher IM, Monte-Colombo MM (2010) An investigation into the effects of different warm-up modalities on specific motor skills related to soccer performance. The Journal of Strength & Conditioning Research 24(8): 2096-2101.
12. Kallerud H, Gleeson N (2013) Effects of Stretching on Performances Involving Stretch-Shortening Cycles. Sports Medicine 43(8): 733-750.
13. Kisner C, Colby LA (2012) Therapeutic Exercise: Foundations and Techniques. Philadelphia, USA.
14. Amiri Khorasani M, Osman NAA, Yusof A (2011) Acute effect of static and dynamic stretching on hip dynamic range of motion during instep kicking in professional soccer players. The Journal of Strength & Conditioning Research 25(6): 1647-1652.
15. Yamaguchi T, Ishii K (2005) Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. The Journal of Strength & Conditioning Research 19(3): 677-683.
16. Akagi R, Takahashi H (2013) Acute Effect of Static Stretching on Hardness of the Gastrocnemius Muscle. Med Sci Sports Exerc 47(5): 1348-1354.
17. Curry BS, Chengkalath D, Crouch GJ, Romance M, Manns PJ (2009) Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women. The Journal of Strength & Conditioning Research 23(6): 1811-1819.
18. Manoel ME, Harris-Love MO, Danoff JV, Miller TA (2008) Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. The Journal of Strength & Conditioning Research 22(5): 1528-1534.
19. Van Gelder LH, Bartz SD (2011) The effect of acute stretching on agility performance. The Journal of Strength & Conditioning Research 25(11): 3014-3021.
20. Zourdos MC, Wilson JM, Sommer BA, Lee S, Park Y, et al. (2012) Effects of dynamic stretching on energy cost and running endurance performance in trained male runners. The Journal of Strength & Conditioning Research 26(2): 335-341.
21. McMillian DJ, Moore JH, Hatler BS, Taylor DC (2006) Dynamic vs. static-stretching warm up: The effect on power and agility performance. The Journal of Strength & Conditioning Research 20(3): 492-499.
22. Perrier ET, Pavol MJ, Hoffman MA (2011) The acute effects of a warm-up including static or dynamic stretching on countermovement jump height, reaction time, and flexibility. The Journal of Strength & Conditioning Research 25(7): 1925-1931.
23. Kot BCW, Zhang ZJ, Lee AWC, Leung VYF, Fu SN (2012) Elastic modulus of muscle and tendon with shear wave ultrasound elastography: variations with different technical settings. PloS one 7(8): e44348.
24. Shinohara M, Sabra K, Gennisson J, Fink M, Tanter M (2010) Real-time visualization of muscle stiffness distribution with ultrasound shear wave imaging during muscle contraction. Muscle Nerve 42(3): 438-441.
25. Bercoff J, Tanter M, Fink M (2004) Supersonic shear imaging: a new technique for soft tissue elasticity mapping. IEEE Trans Ultrason Ferroelectr Freq Control 51(4): 396-409.
26. Arda, K, Ciledag, N, Aktas E, Arıbas BK, Köse K (2011) Quantitative assessment of normal soft-tissue elasticity using shear-wave ultrasound elastography. Am J Roentgenol 197(3): 532-536.
27. Moreau B, Vergari C, Gad H, Sandoz B, Skalli W, et al. (2016) Non-invasive assessment of human multifidus muscle stiffness using ultrasound shear wave elastography: A feasibility study. Proc Inst Mech Eng H 230(8): 809-814.
28. Kary JM (2010) Diagnosis and management of quadriceps strains and contusions. Current reviews in musculoskeletal medicine 3(1-4): 26-31.
29. Hayashi D, Hamilton B, Guermazi A, de Villiers R, Crema MD, et al. (2012) Traumatic injuries of thigh and calf muscles in athletes: role and clinical relevance of MR imaging and ultrasound. Insights into imaging 3(6): 591-601.
30. Pasta G, Nanni G, Molini L, Bianchi S (2010) Sonography of the quadriceps muscle: Examination technique, normal anatomy, and traumatic lesions. Journal of Ultrasound 13(2): 76-84.
31. Nakamura M, Ikezoe T, Takeno Y, Ichihashi N (2011) Acute and prolonged effect of static stretching on the passive stiffness of the human

gastrocnemius muscle tendon unit in vivo. Journal of Orthopaedic Research 29(11): 1759-1763.

32. Siu PM, Tam BT, Chow DH, Guo J, Huang Y, et al. (2010) Immediate effects of 2 different whole-body vibration frequencies on muscle peak torque and stiffness. Arch Phys Med Rehabil 91(10): 1608-1615.
33. Cramer JT, Housh TJ, Johnson GO, Miller JM, Coburn JW, et al. (2004) Acute effects of static stretching on peak torque in women. The Journal of Strength & Conditioning Research 18(2): 236-241.
34. Hermens HJ, Freriks B, Merletti R, Stegeman D, Blok J, et al. (1999) European Recommendations for Surface Electromyography. Roessingh Research and Development the Netherlands.
35. Royer D, Gennisson J, Deffieux T, Tanter M (2011) On the elasticity of transverse isotropic soft tissues (L). J Acoust Soc Am 129(5): 2757.
36. Lacourpaille L, Hug F, Bouillard K, Hogrel J, Nordez A (2012) Supersonic shear imaging provides a reliable measurement of resting muscle shear elastic modulus. Physiol Meas 33(3): 19-28.
37. Zhang ZJ, Kot BCW, Lee WC, Fu SN (2011) Shearwave ultrasound elastography of thigh muscles: An intra- and inter-operator reliability study. J Ultrasound Med 37: 141-142.
38. Gogia PP, Braatz JH, Rose SJ, Norton BJ (1987) Reliability and Validity of Goniometric Measurements at the Knee. Physical Therapy 67(2): 192-195.
39. Smith AD, Stroud L, McQueen C (1991) Flexibility and anterior knee pain in adolescent elite figure skaters. Journal of Pediatric Orthopaedics 11(1): 77-82.
40. Gajdosik R, Lusin G (1983) Hamstring Muscle Tightness Reliability of an Active-Knee-Extension Test. Phys Ther 63(7): 1085-1088.
41. Pamboris GM, Noorkoiv M, Baltzopoulos V, Gokalp H, Marzilger R, et al. (2018) Effects of an acute about of dynamic stretching on biomechanical properties of the gastrocnemius muscle determined by shear wave elastography. PloS One 13: e0196724.
42. Hirata K, Kanehisa H, Miyamoto N (2017) Acute effect of static stretching on passive stiffness of the human gastrocnemius fascicle measured by ultrasound shear wave elastography. Eur J Appl Physiol 117(3): 493-499.
43. Funk DC, Swank AM, Mikla BM, Fagan TA, Farr BK (2003) Impact of prior exercise on hamstring flexibility: A comparison of proprioceptive neuromuscular facilitation and static stretching. The Journal of Strength & Conditioning Research 17(3): 489-492.
44. Millar L (2012) Improving your flexibility and balance.

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