Original papers

The influence of menstrual cycle on the efficiency of stretching

Piotr Michalik[1,A–D,F], Tomasz Michalski[1,A–C], Jarosław Witkowski[2,E,F], Wojciech Widuchowski[3,4,A,E,F]

[1] Department of Kinesitherapy and Special Methods, School of Health Sciences in Katowice, Medical University of Silesia, Katowice, Poland
[2] Department of Traumatology and Hand Surgery, Wroclaw Medical University, Poland
[3] District Hospital of Orthopedics and Trauma Surgery, Piekary Śląskie, Poland
[4] Physiotherapy School of Higher Education in Wrocław, Poland

A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation;
D – writing the article; E – critical revision of the article; F – final approval of the article

Advances in Clinical and Experimental Medicine, ISSN 1899–5276 (print), ISSN 2451–2680 (online) *Adv Clin Exp Med*. 2022;31(4):381–387

Address for correspondence
Piotr Michalik
E-mail: pmichalik@sum.edu.pl

Funding sources
None declared

Conflict of interest
None declared

Received on February 10, 2021
Reviewed on June 25, 2021
Accepted on July 12, 2021

Published online on January 13, 2022

Abstract

Background. Muscle stretching has been practiced by people for thousands of years. Its effectiveness is well-proven, but the diversity of the obtained results should prompt a search for causative factors. One of the possible explanations can be hormonal fluctuations, which occur during the menstrual cycle.

Objectives. To assess the influence of menstrual cycle on the efficiency of static stretching of hamstrings with special reference to changes in their length.

Materials and methods. A total of 534 young women were recruited for the study, but after applying the inclusion criteria, only 48 of them have been accepted. The inclusion criteria for the study comprised a reduced length of the hamstring muscles and a regular menstrual cycle. The whole study included a twofold examination of hamstring length before and after the stretching (3 × 45 s), performed by a physiotherapist. All the measurements were carried out 3 times in individual phases of the menstrual cycle.

Results. Statistically significant influence of static stretching upon the length of hamstring muscle was revealed. A change in the passive knee extension (PKE) test was 13.34% (standard deviation (SD) = 10.97), and in active knee extension (AKE) test it was 8.46% (SD = 9.26). Hamstrings length demonstrated no differences in various phases of the menstrual cycle.

Conclusions. Static stretching is an effective tool for the improvement of the length of the hamstring muscle in young women. However, the effectiveness of stretching in healthy women is not influenced by the menstrual cycle phases.

Key words: elasticity, menstrual cycle, muscle stretching exercises, hamstring muscle

Cite as
Michalik P, Michalski T, Witkowski J, Widuchowski W. The influence of menstrual cycle on the efficiency of stretching. *Adv Clin Exp Med*. 2022;31(4):381–387. doi:10.17219/acem/140163

DOI
10.17219/acem/140163

Background

Stretching in its various manifestations has been a part of human motor behavior for centuries. It was first mentioned in India about 5000 years ago, and after that in China around 2600 BCE.[1]

In modern times, initially used ballistic exercises were replaced in the 1960s by static stretching (SS), introduced as part of the warm-up.[2,3]

Static stretching is an effective form of increasing the length of the muscle, and the hamstrings (HAMS) area is most often used one for the therapeutic intervention. The length of the muscle is a measure resulting from the distance between its attachments. The most common indicator for the evaluation of the elongating capacity of a given muscle is the point of discomfort (POD) felt during stretching.[1,4]

The HAMS flexibility is traditionally measured using the straight leg raise (SLR) test. Other popular HAMS flexibility tests are the active knee extension (AKE) test and the passive knee extension (PKE) test, which measure the knee joint extension excluding the movement of the pelvis, which helps to isolate the tested motion.[1,4–6] The effect of static stretching based on PKE was an increase in the range of motion (ROM) by 7.53° to 9.62°.[7–9] According to the systematic review from 2016, the obtained results confirmed the effectiveness of the SS, increasing the length of HAMS by 8.58° in the PKE test and by 8.35° in AKE test, respectively.[1,5]

The differences between the tests indicate higher values in tests performed passively compared to those performed actively.[1,4,5] Significant differences in HAMS flexibility were observed among athletes engaging in various sport disciplines; however, no differences were noted between the dominant and nondominant leg.[10,11]

The reasons for increasing the length of muscles after stretching are not fully understood.[12] A long-term exposure of muscles to elongation stimuli may lead to the structural changes consisting of the increased number of sarcomeres in the sequence and changes in muscle stiffness.[13,14] However, some researchers claim that the observed improvement in mobility after stretching is not caused by muscle remodeling, but by an increased tolerance to stretching, i.e., sensory adaptation.[12,15,16]

The improvements in flexibility occur regardless of the gender, although the results are significantly better in women than in men. In the SLR test, women showed 10% bigger elasticity than men.[11] On the other hand, the phenomenon of sensory adaptation to stretching occurred only in men who also showed higher passive stiffness and greater sensitivity to pain than women.[10] The discrepancies in the results obtained in the conducted researches lead to the question whether the changes in elasticity are the result of plastic changes within the muscle subjected to stretching or whether they are related to the adaptive changes within the nervous system.[17] It is worth noting that the level of pain perception may be also influenced by, among others, gender and the phase of the menstrual cycle.

Female reproductive hormones fluctuating during the menstrual cycle affect numerous parameters of the cardiovascular, respiratory, thermoregulatory and metabolic systems, which in turn can affect the physiology of the locomotor system. The presence of estrogen and progesterone receptors in bones, skeletal muscles, ligaments and the nervous system has been proven, and the fluctuations in their levels during the menstrual cycle may affect the physical properties of these structures.[18]

The studies showed that the differences in estrogen levels during the menstrual cycle were associated with a different amount of collagen-I and -III. In periovulatory phase, the amount of collagen-III rose whereas the amount of collagen-I decreased leading to higher tolerance to mechanical stretching.[19] The risk of anterior cruciate ligament (ACL) damage increases fourfold with a decrease in passive stability by 1.3 mm. There is a suspicion that one of the potential causes of this phenomenon may be hormonal changes occurring in menstruating women.[20–22] At ACL Research Retreat VIII, the study of hormonal changes during the menstrual cycle was considered a priority area for future research on reducing the risk of ACL injuries.[23,24]

The research on the influence of the menstrual cycle on muscle flexibility is scarce and the results are inconclusive. No significant effect was observed by Teixeira et al. when testing young women using the Sit And Reach global mobility test.[25] Sung and Kim showed complex changes in flexibility in the flexor and extensor muscles of the knee joint during the menstrual cycle. The vastus medialis (VM) and the semitendinosus (ST) increased their stiffness during ovulation, while the vastus lateralis (VL) and the biceps femoris (BF) remained unchanged.[26] In a study by Eiling et al., muscle stiffness showed significant variability depending on the phase of the menstrual cycle, with the lowest levels being reached during the ovulatory phase.[27] An inverse relationship has been found between estrogen levels and muscle stiffness.[28,29] The force necessary to perform passive knee flexion movement decreased during ovulation, indicating increased flexibility of these muscles in this phase.[30] The potential impact of the cycle phase on the effectiveness of stretching was assumed by Hoge et al., who therefore conducted the experiments during the first days of the menstrual cycle, when the levels of these hormones are low.[31]

Despite the widespread use of stretching and the awareness of the need for proper muscle flexibility, there is little research on the effects of hormonal changes occurring during the menstrual cycle on the stretching efficiency. Table 1 presents a summary of the publications in this area together with the assessment of their methodological quality, in accordance with the Physiotherapy Evidence Database (PEDro) scale guidelines. As most of the studies were observational, the obtained scores indicate rather low quality. On the other hand, the discrepancies in the obtained results indicate the need for further research in this area.

Table 1. Summary of the publications with an assessment of their methodological quality in accordance with the Physiotherapy Evidence Database (PEDro) scale guidelines

Criteria	Teixeira et al.[25]	Sung and Kim[26]	Eiling et al.[27]	O'Hora et al.[7]	Bell et al.[28]	Lee et al.[30]	Hoge et al.[31]	Miyamoto et al.[33]
1. Eligibility criteria were specified	yes	yes	yes	yes	yes	yes	yes	yes
2. Subjects were randomly allocated to groups	0	0	0	1	0	0	0	0
3. Allocation was concealed	1	0	0	0	0	0	0	0
4. The groups were similar at baseline regarding the most important prognostic indicators	1	0	0	1	0	0	0	0
5. There was blinding of all subjects	0	0	0	1	0	0	0	0
6. There was blinding of all therapists who administered the therapy	0	0	0	1	0	0	0	0
7. There was blinding of all assessors who measured at least one key outcome	0	0	0	0	0	0	0	0
8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	1	1	1	1	1	1	1	1
9. All subjects for whom outcome measures were available received the treatment or control condition as allocated	0	0	0	0	0	0	0	0
10. The results of between-group statistical comparisons are reported for at least one key outcome	1	0	0	1	0	0	0	0
11. The study provides both point measures and measures of variability for at least one key outcome	1	1	1	1	1	1	1	1
Total score	5	2	2	7	2	2	2	2

Objectives

The assessment of the influence of static stretching on the length of HAMS in various phases of the menstrual cycle.

Materials and methods

Forty-eight women aged 21–24 were selected out of 534 women randomly chosen for the study. The study group was homogenous in terms of parameters such as age, body weight, height, body mass index (BMI), and the length of the menstrual cycle. The average age was 21.4 years (standard deviation (SD) = 0.4). The average value of body weight was 60.34 kg (SD = 7.51), and the average BMI value in this group was 21.49 (SD = 1.93). The height of the studied women oscillated between 158 cm and 177 cm (mean 167.34 cm, SD = 6.14 cm). The duration of the menstrual cycle ranged from 26 to 32 days (mean 29.25 days, SD = 1.74).

The inclusion criteria were: the lack of any orthopedic disorders within the spine and lower limbs, shortening of HAMS above 20° measured using PKE test, BMI between 18.5 and 24.99, regular menstrual cycle for the last 6 months lasting 28 days (±5 days), and not using hormonal contraception.

The initial stage of qualification for the research was the assessment of flexibility of HAMS in the dominant leg. Only 180 out of 534 (33.7%) women met the assumed criterion of muscle shortening. In the next stage of the study, the respondents completed an original personal questionnaire. The obtained data excluded participants whose answers eliminated the possibility of precisely determining the phase of the menstrual cycle. Only 48 (26.6%) women were qualified for further measurements. The length of the menstrual cycle for each participant was determined by averaging the length of her last 6 menstrual cycles, which allowed to define the phases of the menstrual cycle:

1. follicular phase (FOL) – from 2nd to 5th day of the menstrual cycle;
2. ovulatory phase (OV) – from 12th to 15th day of the menstrual cycle;
3. luteal phase (LUT) – from 16th to the 28th day of the menstrual cycle.

The study involved a therapeutic intervention of 3 × 45 s static stretching and 2 measurements of flexibility of HAMS of the dominant leg performed before and immediately after this intervention during each phase of the menstrual cycle. All the measurements were conducted by the same 2 researchers (A and B) who had many years of experience in physiotherapy, each of whom had specific tasks to perform, in accordance with the prepared test protocol. Researcher B was responsible for operating the inclinometers and entering data to the test report. Researcher A performed the tests but was not informed about the result obtained by researcher B.[32]

To evaluate the flexibility of HAMS muscles, the following tests were used:

Test No. 1. Passive extension of the knee joint to the POD (PKE test). Before the measurements, a line connecting 2 bone points: the greater trochanter and the lateral epicondyle of the femur was marked. The lower limb of the examined subject was bent to the position of 90° at the knee and hip joints. The subject was informed that her knee will be passively extended until POD in the back of the limb. The test was performed 3 times.

Test No. 2. Active knee extension (AKE test). The subject's position and inclinometers placement were as in the previously described test. The participant was instructed to actively extend the knee joint avoiding hip rotation and pelvic lifting. The test was repeated 3 times, and the participant's task was to perform them with a similar force and speed during all repetitions of the active movement.

The study of mobility ranges in the knee joint in the tests was carried out by means of 2 Saunders electronic inclinometers (The Saunders Group, Inc., Chaska, USA) attached to the front of tibia and lateral side of femur in all measurements performed in this project. The BMI was assessed on Tanita Corporation scales.

Therapeutic intervention consisted of static stretching. The position was identical to the one used in the measurement phase for the PKE test. The researcher performed passive extension of the lower limb in the knee joint, while maintaining the unchanged position in the hip joint until the patient feels POD. This position is held for 45 s for 3 consecutive repetitions with a 15 s interval between the repetitions.[15]

Statistical analysis was performed using IBM SPSS v. 23 software (IBM Corp., Armonk, USA) with a significance level of $\alpha = 0.05$.

Basic descriptive statistics were analyzed together with two-factor analyses of variance (ANOVAs) in the within-group schema, one-factor ANOVAs in the within-group schema, Student's t-tests, and correlation analyses with Pearson correlation coefficient (r).

The project of the study was approved by Bioethical Committee of Medical University of Silesia, Katowice, Poland (approval No. KNW/0022/KB1/26/17). All subjects gave their informed consent to participate in the study. The study was carried out in accordance with the Declaration of Helsinki.

Results

PKE level depending on the phase of the cycle and intervention

Static stretching was performed in particular phases of the menstrual cycle, and the observed difference in flexibility after SS were 8.5° in FOL, 8.5° in OV and 6.6° in LUT (Fig. 1).

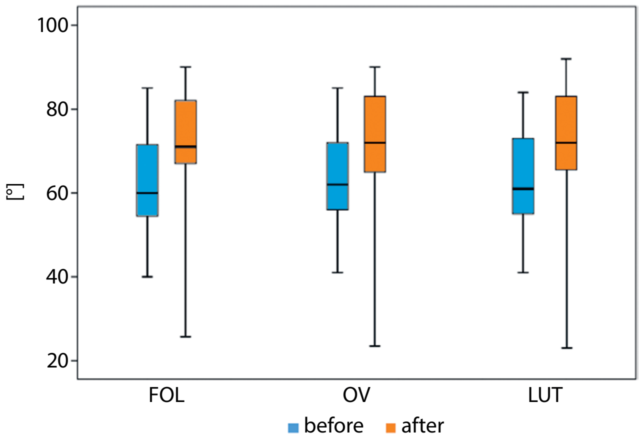

Fig. 1. Passive knee extension (PKE) level in all 6 measurements

FOL – follicular phase; OV – ovulatory phase; LUT – luteal phase.

There was no statistically significant or even nearly statistically significant effect of the main phase of the cycle on PKE ($F(2;92) = 0.26$; $p = 0.772$; $\eta^2 = 0.01$).

However, the main effect of the procedure was statistically significant ($F(1;46) = 230.63$; $p < 0.001$; $\eta^2 = 0.83$).

AKE level by cycle phase and intervention

Static stretching was performed in various phases of the menstrual cycle, and the results of the observed changes

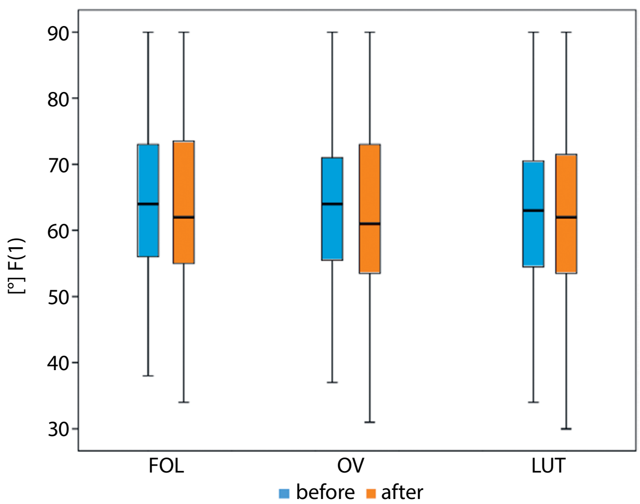

Fig. 2. Active knee extension (AKE) level in all 6 measurements

FOL – follicular phase; OV – ovulatory phase; LUT – luteal phase.

in flexibility after SS were 5.1° in the FOL, 5.7° in the OV and 4.1° in the LUT (Fig. 2).

The next step of the research aimed to verify whether the AKE level is different depending on the phase of the cycle and whether the measurement was carried out before or after the intervention.

There was no statistically significant or even nearly statistically significant effect of the main phase of the cycle on AKE ($F(2;92) = 0.03$; $p = 0.967$; $\eta^2 = 0$). However, the main effect of the intervention was statistically significant ($F(1;46) = 76.84$; $p < 0.001$; $\eta^2 = 0.63$). The strength of the observed effect was very high. As shown in Fig. 2, higher scores were recorded after the treatment. Additionally, there was no statistically significant interaction effect of the examined factors ($F(2;92) = 1.64$; $p = 0.200$; $\eta^2 = 0.03$).

For a better visualization of the changes taking place after the application of SS, the obtained results were expressed as a percentage, and the base value for all tested parameters was the state of the muscle before the intervention (100%). Then, the percentage values after stretching were compared to the values before stretching in 3 different phases of the cycle. One-factor ANOVAs were performed in the within-group schema. There were no statistically significant differences, as shown in Table 2.

Next, it was examined whether the percentage ratio of the results after stretching to the results before stretching is different in the case of AKE and PKE. Three paired samples t-tests were performed, separately in the FOL, OV and LUT. As shown in Table 3, all the observed differences turned out to be statistically significant. Higher values were recorded for the PKE. The strength of the observed effect in the case of the OV was moderately high, and in the case of the other 2 phases – low.

The correlations between the PKE and AKE indices were also examined. The correlation analyses with Pearson correlation coefficient (r) were performed. There were statistically significant positive relationships between these indices for the FOL ($r = 0.453$; $p = 0.001$), OV ($r = 0.606$; $p < 0.001$) and LUT ($r = 0.432$; $p = 0.002$). The strength of the relationship in the case of the OV was high, and moderately high in the other 2 phases.

Discussion

The effectiveness of stretching as well as flexibility depends on the gender and is definitely greater for women.[10] According to some researchers, including Hoge et al., it results from the occurrence of the so-called sensory adaptation through changes in sensory reactivity.[31,33] The strength of this phenomenon was significantly higher in men, but the reasons for these differences are still the subject of scientific research.[31]

This study is an attempt to assess whether the differences are due to variability associated with the phases of the menstrual cycle and whether this affects the effectiveness of SS. In the study, 2 tests were used to assess the length of the hamstring muscle: AKE and PKE. Both tests are based on the subjectively perceived end of movement associated with the feeling of discomfort. The results of both tests confirmed the effectiveness of the SS in improving HAMS flexibility. The observed change in the AKE test was 8.46% and it was lower than those obtained in the PKE test (13.34%), which is consistent with the results of other studies in this field.[1,4,5] The improvement of ROM assessed with the AKE test, examined immediately after the intervention, was comparable to the previous studies with similar methodology resulting in changes in ROM of 9.62° and 9.1°.[9] In the study by O'Hora et al., the SS effect based on the passive extension of the knee joint was an increase in ROM by 7.53° (PKE).[7]

When examining the correlations between the AKE and PKE tests, statistically significant positive relationships were noted in all phases: strong correlation in the OV and medium in the FOL and LUT. However, the results of both tests showed no significant influence of the phase of the menstrual cycle on HAMS length. There was also no

Table 2. The level of results after stretching as compared to the results before stretching depending on the phase

Test	Follicular phase		Ovulation phase		Luteal phase		F	df	p-value	η^2
	M	SD	M	SD	M	SD				
PKE	114.11	13.2	114.32	9.79	111.6	9.53	0.97	2.92	0.384	0.02
AKE	108.42	8.6	109.93	9.67	107.05	9.47	1.60	2.92	0.208	0.03

PKE – passive knee extension; AKE – active knee extension; M – mean; SD – standard deviation; df – degrees of freedom; η^2 – eta-squared.

Table 3. The percentage ratio of the post-procedure results to pre-procedure results for passive knee extension (PKE) and active knee extension (AKE) tests

Phase	PKE		AKE		t	df	p-value	d
	M	SD	M	SD				
Follicular	114.11	13.20	108.42	8.60	3.24	46	0.002	0.48
Ovulation	114.32	9.79	109.93	9.67	3.49	46	0.001	0.52
Luteal	111.60	9.53	107.05	9.47	3.08	46	0.003	0.46

M – mean; SD – standard deviation; df – degrees of freedom; t – Student's t-test result; d – Cohen's d.

significant influence of individual phases on the effectiveness of using SS within it.

The comparison of these results with the results of other studies is difficult due to the fact that the assessment of the efficiency of SS is an innovative project that has not yet been explored by other researchers. The flexibility changes occurring during the menstrual cycle are a possible reference. In a study by Teixeira et al., the whole myofascial superficial back line was assessed with a global test performed actively in 20 young women. In present study, no significant influence of the phase of the menstrual cycle on flexibility was shown. No differences were also observed in comparison to the results in the control group, to which 24 women using hormonal contraception were recruited.[25] Research on muscle elasticity assessed in various phases of the menstrual cycle conducted by Miyamoto et al. using shear wave elastography showed no significant reaction of this variable on muscle stiffness.[33] The study failed to prove any effect of the phases and the corresponding changes in muscles performed close to POD, similarly to the conditions applied in this study.

The research of Bell et al. brought contrary results. The HAMS length improved significantly in the OV (89.7–104.7°), as compared to the FOL (81.7–96.9°).[28] However, the study by Bell et al. remarkably differs from the present study. In the study by Bell et al., the assessments were performed only twice in the OV and FOL, thus omitting the LUT, which is studied in this project. It was assumed that the differences in the estrogen level are the highest when FOL and OV are compared, which would allow to determine their effect on HAMS. Furthermore, SLR test was applied instead of AKE and PKE tests used in our study. Also, the value of the SLR test obtained in the study by Bell et al. is 104.7°; therefore, it is much higher than normal values for this test, which confirms that patients without HAMS deficits were admitted for the tests. The effectiveness of SS in the group of subjects selected in that way can differ from the strict criteria of selection assumed in our study. However, the biggest difference results from the small size of the tested group (n = 8), which constitutes a high risk of random results.[28]

An important element for the interpretation of the obtained results, based on the moment of occurrence of POD, is the possible effect of the menstrual cycle phases on pain perception. As both tests assessing the length of HAMS were based on the subjective flexibility threshold related to POD, the changes in pain perception can influence the results. It is assumed that the fluctuations of sex hormone levels contribute to a higher, clinically and experimentally observed sensitivity to pain in women as compared to the men. These differences refer to both the higher sensitivity to nociceptive stimuli and pain sensation distribution, but the results of the research on the influence of hormonal changes occurring during the cycle on pain perception are ambiguous. Some researchers have indicated regular fluctuations of pain sensitivity depending on the cycle phases.[34] The research on potential estradiol regulation upon the functioning of neurotransmission of the endogenous opioids is a confirmation of such thinking. During the OV, a high activity level of this system, comparable to men's, was observed. However, during the FOL, when the estradiol level reaches its minimum, a reduction of the activity modulating the influence of opioids on pain perception occurred.

A result of the changes occurring during the menstrual cycle can be the reduction of tissue sensitivity to nociceptive stimuli during the OV, and the opposite reaction during the FOL. The influence of the menstrual cycle phase can also be observed in the differences in sensitivity to compression stimuli applied to muscles. Higher sensitivity occurred during the FOL than during the OV and LUT.[35] Veldhuijzen et al. studied the effect of the cycle upon the changes in the brain areas connected with pain, and presented similar conclusions.[36] In the systematic review of 2014, the majority of the studies indicated a possible effect of estrogen on pain sensitivity, with a clear tendency for the opposite relationship between these 2 parameters.[37] As the self-reporting of pain during the measurement can be influenced by hormonal changes during menstrual cycle, the objective methods of muscle extensibility assessment would be beneficial to exclude the possible changes of stretch tolerance on the efficiency of stretching.

Limitations

There are some limitations in this study. First, the assessment of menstrual cycle phase was based on expected hormonal peak levels, according to data obtained from a personal questionnaire. The ideal study would evaluate serum hormonal levels on a regular basis over a period longer than a single cycle in order to account for cycle differences, which occur even in women with regular cycle length. Second, the classical method used in this study to measure hamstrings flexibility (AKE and PKE tests) focuses on the maximum range of motion based on subjective pain response. More advanced methods, such as isokinetic dynamometry or muscle elastography, allow for the measurement of objective muscle length and passive stiffness. The tests used in this project cannot provide the arguments in the debate over the possible causes of changes in elasticity after SS related to either stretch tolerance or tissue remodeling.

Conclusions

The length of the hamstring muscles after SS increased significantly by 13.34% in the PKE test and by 8.46% in the AKE test. However, the effectiveness of stretching in healthy women is not influenced by the menstrual cycle phases.

ORCID iDs

Piotr Michalik https://orcid.org/0000-0002-6328-4106
Tomasz Michalski https://orcid.org/0000-0001-5505-256X
Jarosław Witkowski https://orcid.org/0000-0002-2754-1339
Wojciech Widuchowski https://orcid.org/0000-0002-3684-7823

References

1. Behm DG. *The Science and Physiology of Flexibility and Stretching*. London, UK: Routledge; 2018.
2. Dridi A, Chamari K, Wong DP, et al. Static stretching can impair explosive performance for at least 24 hours. *J Strength Cond Res*. 2014;28(1):140–146. doi:10.1519/jsc.0b013e3182964836
3. Judge LW, Petersen JC, Bellar DM, et al. An examination of preactivity and postactivity stretching practices of crosscountry and track and field distance coaches. *J Strength Cond Res*. 2013;27(9):2456–2464. doi:10.1519/JSC.0b013e318257703c
4. Gajdosik RL, Rieck MA, Sullivan DK, Wightman SE. Comparison of four clinical tests for assessing hamstring muscle length. *J Orthop Sports Phys Ther*. 1993;18(5):614–618. doi:10.2519/jospt.1993.18.5.614
5. Medeiros DM, Cini A, Sbruzzi G, Lima CS. Influence of static stretching on hamstring flexibility in healthy young adults: Systematic review and meta-analysis. *Physiother Theory Pract*. 2016;32(6):438–445. doi:10.1080/09593985.2016.1204401
6. Gnat R, Kuszewski M, Koczar R, Dziewońska A. Reliability of the passive knee flexion and extension tests in healthy subjects. *J Manipulative Physiol Ther*. 2010;33(9):659–665. doi:10.1016/j.jmpt.2010.09.001
7. O'Hora J, Cartwright A, Wade CD, Hough AD, Shum GL. Efficacy of static stretching and proprioceptive neuromuscular facilitation stretch on hamstrings length after a single session. *J Strength Cond Res*. 2011;25(6):1586–1591. doi:10.1519/JSC.0b013e3181df7f98
8. Lim KI, Nam HC, Jung KS. Effects on hamstring muscle extensibility, muscle activity, and balance of different stretching techniques. *J Phys Ther Sci*. 2014;26(2):209–213. doi:10.1589/jpts.26.209
9. Puentedura EJ, Huijbregts PA, Celeste S, et al. Immediate effects of quantified hamstring stretching: Hold-relax proprioceptive neuromuscular facilitation versus static stretching. *Phys Ther Sport*. 2011;12(3):122–126. doi:10.1016/j.ptsp.2011.02.006
10. Marshall PW, Siegler JC. Lower hamstring extensibility in men compared to women is explained by differences in stretch tolerance. *BMC Musculoskelet Disord*. 2014;15(1):223. doi:10.1186/1471-2474-15-223
11. Sierra-Silvestre E, Torres Lacomba M, de la Villa Polo P. Effect of leg dominance, gender and age on sensory responses to structural differentiation of straight leg raise test in asymptomatic subjects: A cross-sectional study. *J Man Manip Ther*. 2017;25(2):91–97. doi:10.1080/10669817.2016.1200216
12. Magnusson SP. Passive properties of human skeletal muscle during stretch maneuvers: A review. *Scand J Med Sci Sports*. 1998;8(2):65–77. doi:10.1111/j.1600-0838.1998.tb00171.x
13. Coutinho EL, Gomes ARS, França CN, Oishi J, Salvini TF. Effect of passive stretching on the immobilized soleus muscle fiber morphology. *Brazilian J Med Biol* Res. 2004;37(12):1853–1861. doi:10.1590/s0100-879x2004001200011
14. Kay AD, Blazevich AJ. Moderate-duration static stretch reduces active and passive plantar flexor moment but not Achilles tendon stiffness or active muscle length. *J Appl Physiol (1985)*. 2009;106(4):1249–1256. doi:10.1152/japplphysiol.91476.2008
15. Ben M, Harvey LA. Regular stretch does not increase muscle extensibility: A randomized controlled trial. *Scand J Med Sci Sports*. 2010;20(1):136–144. doi:10.1111/j.1600-0838.2009.00926.x
16. Ylinen J, Kankainen T, Kautiainen H, Rezasoltani A, Kuukkanen T, Häkkinen A. Effect of stretching on hamstring muscle compliance. *J Rehabil Med*. 2009;41(1):80–84. doi:10.2340/16501977-0283
17. Wiech K, Ploner M, Tracey I. Neurocognitive aspects of pain perception. *Trends Cogn Sci*. 2008;12(8):306–313. doi:10.1016/j.tics.2008.05.005
18. Barros RPA, Gustafsson JÅ. Estrogen receptors and the metabolic network. *Cell Metab*. 2011;14(3):289–299. doi:10.1016/j.cmet.2011.08.005
19. Fede C, Pirri C, Fan C, et al. Sensitivity of the fasciae to sex hormone levels: Modulation of collagen-I, collagen-III and fibrillin production. *PLoS One*. 2019;14(9):e0223195. doi:10.1371/journal.pone.0223195
20. Królikowska A, Sikorski Ł, Czamara A, Reichert P. Effects of postoperative physiotherapy supervision duration on clinical outcome, speed, and agility in males 8 months after anterior cruciate ligament reconstruction. *Med Sci Monit*. 2018;24:6823–6831. doi:10.12659/MSM.912162
21. Królikowska A, Sikorski Ł, Czamara A, Reichert P. Are the knee extensor and flexor muscles isokinetic parameters affected by the duration of postoperative physiotherapy supervision in patients eight months after ACL reconstruction with the use of semitendinosus and gracilis tendons autograft? *Acta Bioeng Biomech*. 2018;20(4):89–100. PMID:30520446.
22. Myer GD, Ford KR, Paterno MV, Nick TG, Hewett TE. The effects of generalized joint laxity on risk of anterior cruciate ligament injury in young female athletes. *Am J Sports Med*. 2008;36(6):1073–1080. doi:10.1177/0363546507313572
23. Shultz SJ, Schmitz RJ, Cameron KL, et al. Anterior cruciate ligament research retreat VIII summary statement: An update on injury risk identification and prevention across the anterior cruciate ligament injury continuum, March 14–16, 2019, Greensboro, NC. *J Athl Train*. 2019;54(9):970–984. doi:10.4085/1062-6050-54.084
24. Cieślik-Bielecka A, Bold T, Ziółkowski G, Pierchała M, Królikowska A, Reichert P. Antibacterial activity of leukocyte- and platelet-rich plasma: An in vitro study. *Biomed Res Int*. 2018;2018:9471723. doi:10.1155/2018/9471723
25. Teixeira AL da S, Fernandes W, Marques FAD, de Lacio ML, Dias MRC. Influence of different phases of menstrual cycle on flexibility of young women. *Rev Bras Med Esporte*. 2012;18(6):361–364. doi:10.1590/S1517-86922012000600002
26. Sung ES, Kim JH. The difference effect of estrogen on muscle tone of medial and lateral thigh muscle during ovulation. *J Exerc Rehabil*. 2018;14(3):419–423. doi:10.12965/jer.1836110.055
27. Eiling E, Bryant AL, Petersen W, Murphy A, Hohmann E. Effects of menstrual-cycle hormone fluctuations on musculotendinous stiffness and knee joint laxity. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(2):126–132. doi:10.1007/s00167-006-0143-5
28. Bell DR, Blackburn JT, Norcorss MF, et al. Estrogen and muscle stiffness have a negative relationship in females. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(2):361–367. doi:10.1007/s00167-011-1577-y
29. Schleip R, Jäger H, Klingler W. What is "fascia"? A review of different nomenclatures. *J Bodyw Mov Ther*. 2012;16(4):496–502. doi:10.1016/j.jbmt.2012.08.001
30. Lee H, Petrofsky JS, Daher N, Berk L, Laymon M, Khowailed IA. Anterior cruciate ligament elasticity and force for flexion during the menstrual cycle. *Med Sci Monit*. 2013;19:1080–1088. doi:10.12659/MSM.889393
31. Hoge KM, Ryan ED, Costa PB, et al. Gender differences in musculotendinous stiffness and range of motion after an acute bout of stretching. *J Strength Cond Res*. 2010;24(10):2618–2626. doi:10.1519/JSC.0b013e3181e73974
32. Gnat R, Kuszewski M, Koczar R, Dziewońska A. Reliability of the passive knee flexion and extension tests in healthy subjects. *J Manipulative Physiol Ther*. 2010;33:659–665. doi:10.1016/j.jmpt.2010.09.001
33. Miyamoto N, Hirata K, Miyamoto-Mikami E, Yasuda O, Kanehisa H. Associations of passive muscle stiffness, muscle stretch tolerance, and muscle slack angle with range of motion: Individual and sex differences. *Sci Rep*. 2018;8(1):8274. doi:10.1038/s41598-018-26574-3
34. Bartley EJ, Fillingim RB. Sex differences in pain: A brief review of clinical and experimental findings. *Br J Anaesth*. 2013;111(1):52–58. doi:10.1093/bja/aet127
35. Rezaii T, Hirschberg AL, Carlström K, Ernberg M. The influence of menstrual phases on pain modulation in healthy women. *J Pain*. 2012;13(7):646–655. doi:10.1016/j.jpain.2012.04.002
36. Veldhuijzen DS, Keaser ML, Traub DS, Zhuo J, Gullapalli RP, Greenspan JD. The role of circulating sex hormones in menstrual cycle-dependent modulation of pain-related brain activation. *Pain*. 2013;154(4):548–559. doi:10.1016/j.pain.2012.12.019
37. Hassan S, Muere A, Einstein G. Ovarian hormones and chronic pain: A comprehensive review. *Pain*. 2014;155(12):2448–2460. doi:10.1016/j.pain.2014.08.027