Özgün Çalışma / Original Article

Ankara Eğt. Arş. Hast. Derg., 2023 ; 56(2) : 94-98
DOI:10.20492/aeahtd.1249355

Statik Germe Süresinin Gastroknemius Kas Vaskülarizasyonu Üzerine Akut Etkilerinin Superb Mikrovasküler Görüntüleme Yöntemi ile İncelenmesi

An Examination of the Acute Effects of Static Stretching Duration on Gastrocnemius Muscle Blood Flow by Superb Microvascular Imaging Method

Kamile UZUN AKKAYA[1], Habip Eser AKKAYA[2]

ABSTRACT

AIM: Static stretching (SS) exercises are frequently used to increase muscle flexibility, improve physical performance, and reduce musculoskeletal injuries. The purpose of this study was to examine the acute effects of different SS duration applied to the gastrocnemius muscle on muscle blood flow by superb microvascular imaging (SMI) method and compare the impact of stretching at different duration immediately after stretching and 10 minutes later.

MATERIAL AND METHOD: 30 healthy volunteers aged between 18-35 years were included in this study. The individuals were divided into two groups randomly. 2-minute SS was applied to the gastrocnemius muscle of the first group, and 5-minute SS was performed to the gastrocnemius muscle of the second group. Blood flow in the muscle after stretching was evaluated by the SMI method.

RESULTS: It was obtained that muscle blood flow raised as a result of stretching applications for 2 minutes and 5 minutes, stretching application for 5 minutes increased blood flow more than stretching application for 2 minutes ($p<0.05$), and blood flow values returned to baseline values after 10 minutes ($p>0.05$).

CONCLUSION: It was thought that 2 or 5 minutes of stretching applications to increase circulation in healthy individuals might be sufficient.

Keywords: blood flow; static stretching; ultrasonography

ÖZET

AMAÇ: Statik germe (SG) egzersizleri, kas esnekliğini artırmak, fiziksel performansı iyileştirmek ve kas-iskelet yaralanmalarını azaltmak amacıyla sıklıkla kullanılır. Bu çalışmanın amacı gastroknemius kasına uygulanan farklı SG sürelerinin kas kan akımı üzerine akut etkilerini superb mikrovasküler imaging (SMI) yöntemi ile incelemek ve farklı sürelerde germenin germeden hemen sonra ve 10 dakika sonra etkilerini karşılaştırmaktır.

GEREÇ VE YÖNTEM: Çalışmaya 18-35 yaşları arasında sağlıklı, 30 gönüllü birey dahil edildi. Bireyler randomize olarak iki gruba ayrıldıktan sonra birinci grubun gastroknemius kasına 2 dakikalık SG, ikinci grubun gastroknemius kasına ise 5 dakikalık SG uygulaması yaptırıldı. Germe sonrası kastaki kan akımı SMI yöntemi ile değerlendirildi.

BULGULAR: 2 dakika ve 5 dakika germe uygulamaları sonucunda kas kan akımının arttığı, 5 dakika germe uygulamasının 2 dakika germe uygulamasına göre kan akımını daha fazla artırdığı ($p<0.05$) ve 10 dakika sonra kan akımı değerlerinin başlangıç değerlerine döndüğü sonucuna varıldı ($p>0.05$).

SONUÇ: Sağlıklı bireylerde dolaşımı artırmak için 2 veya 5 dakikalık esneme uygulamalarının yeterli olabileceği düşünüldü.

Anahtar kelimeler: statik germe, kan akımı, ultrasonografi

[1]Gazi Üniversitesi, Sağlık Bilimleri Fakültesi, Fizyoterapi ve Rehabilitasyon Bölümü, Ankara, Türkiye
[2]Ankara Eğitim ve Araştırma Hastanesi, Radyoloji Kliniği, Ankara, Türkiye;

Makale geliş tarihi / submitted: Şubat 2023 / February 2023

Makale Kabul tarihi / accepted: Ağustos 2023 / August 2023

Sorumlu Yazar / Corresponding Author:
Kamile UZUN AKKAYA
Adres: Emek mah. Bişkek Cad. 6. Cad. (eski 81. sokak) No:2 06490 Çankaya/ANKARA
Telefon: +90 312 216 2683
E posta: kamileuzunakkaya@gazi.edu.tr
ORCID: 0000-0003-3608-5192

Yazar Bilgileri /Author Information:
Habip Eser AKKAYA: heserakkaya@gmail.com; ORCID: 0000-0002-8447-3627

INTRODUCTION

Static stretching (SS) exercises are easy and reliable exercises used to increase muscle flexibility, improve physical performance, and reduce musculoskeletal injuries.[1,2] It is frequently used in warming-cooling periods before and after exercise.[3] Leg cramps are seen in adults, especially in calf muscles, and the mechanism is not fully known.[4] One of the easiest conservative treatment methods applied to muscle cramps in healthy and sick individuals is stretching applications.[5]

With increased blood flow in the muscle, more oxygen comes to the muscle, and thus better nutrition of the muscle is provided. Increased intramuscular blood flow also contributes to the development of physical performance.[6] There are not many studies in the literature examining the effects of stretching on blood flow in muscle tissue. In healthy young individuals, the passive movement has been found to increase muscle blood flow and interstitial vascular endothelial-induced growth factor (VEGF) and endothelial nitric oxide synthase (eNOS) mRNA independently of metabolic or central hemodynamic changes.[7,8] In a study conducted on rats, mechanical stretching/overload has been shown to increase VEGF levels and capillarization of skeletal muscles.[9] In another study conducted with rats, they concluded that blood flow increased in plantar flexors after daily stretching for 4 weeks.[10] The effects of SS exercise applied to the rectus femoris muscle in healthy adolescents on muscle blood flow were evaluated by superb microvascular imaging (SMI) method, and it was reported that blood flow in the muscle increased after stretching. In the study, the acute effects of stretches applied for different SS duration were examined; however, they were not compared.[11]

SMI is a novel Doppler imaging method developed in recent years to determine blood flow in microvascular structures. SMI eliminates the complexity of signals received from normal tissue and vascular structures and protects signals obtained only from vascular structures so that even very low rapid blood flows can be detected. This new technique supplies detailed information about very slow and fine vascular structures and allows the imaging of microvascular structures.[12,13]

The acute effects of SS exercises on flexibility and performance have been investigated in many studies in the literature.[1,2] Stretching exercises are known to increase muscle blood flow; however, the number of studies investigating the effects of stretching time is small.[10,11] The purpose of this study was to examine the acute effects of different SS duration applied to the gastrocnemius muscle on muscle blood flow with SMI, a new method, and to compare the effects of stretching at different duration immediately after stretching and 10 minutes later.

MATERIAL AND METHOD

Participants

30 healthy volunteers aged between 18-35 years were included in the study. Sedentary individuals without ankle, knee, hip pathology, and who did not undergo any surgery in the lower extremity were included in the study. Participants with rheumatic, vestibular, neurological, and musculoskeletal diseases, bone pathologies, metabolic syndrome, diabetes, diffuse joint laxity, inflammatory or arthritic problems were excluded from the study. Individuals were asked not to exercise heavily in the last 24 hours before the study. The ethics committee approval was obtained by the Clinical Research Ethics Committee of Ankara Training and Research Hospital on 25.06.2020 with the decision number 235/2020. A signed, written consent form was gotten from the participants indicating that they agreed to join in the study.

According to the reference study [11] results, they had a large effect size (dz=0.9) for both groups from the VI difference results. Assuming we can achieve an effect size at that level, a power analysis was performed before the study. Accordingly, when at least 15 participants for each group (total at least 30 participants) were included in the study, that would result in 80% power with %95 confidence level (%5 types 1 error rate).

Procedures

Participants were divided into two groups randomly. A free web-based instrument (Research Randomizer, Social Psychology Network, Middletown, CT) was used for randomization. SS was applied to the gastrocnemius muscle of the first group for 2 minutes, and the second group for 5 minutes. SS was applied to the dominant lower extremity of individuals. In order to determine the dominant extremity of the individuals, they were asked which foot they kick the ball with. Evaluations were performed before, immediately after, and 10 minutes after the SS application. The effects of different stretching duration were compared.

SS exercise was performed actively by the individual under the supervision of a physiotherapist. Individuals were allowed to place the non-stretching side limb slightly bent forward from the knee, and the stretching side foot sole was placed back so that it would not lift off the ground, and they were placed on a wall edge facing the wall with their arms in a position to receive support. Individuals were asked to stay in this position for 30 seconds by springing forward until they felt discomfort in the gastrocnemius muscle.[14] Individuals were warned that while the head, neck, spine, pelvis, and back limb were aligned in this position, the back limb was not in external rotation

Figure 1: Gastrocnemius muscle static stretching methods

Individuals were divided into 2 groups. The first group underwent 2-minute stretching consisting of 2 sets with 30 seconds stretching and 30 seconds rest, while the second group underwent 5-minute stretching composed of 5 sets with 30 seconds stretching and 30 seconds rest.

Measures

After stretching, blood flow in the muscle was performed with SMI by a radiologist who had 8 years of experience in ultrasound and 2 years of experience in a new method, SMI. Aplio 500 Platinum ultrasound device (Toshiba-Can Medical Systems Corporation, Japan) with a high-frequency linear transducer (frequency range, 5-14 MHz) was used for evaluations. Ultrasound evaluations were performed while the individuals were comfortable with their knees in extension and ankles in plantar flexion in the prone position. The probe was placed at 30% of the lower leg length (from the popliteal crease to the lateral malleolus) distal to the popliteal crease[15]

Figure 2: Ultrasound measurement

During SMI examination, pulse repetition frequency was set to 200-230 Hz, frame rate>50 Hz, and color gain was set to 37-42 decibels.

The vascularity index (VI) measurement method was used to evaluate gastrocnemius muscle blood flow. In SMI mode, a 15 × 10 mm rectangular ROI was drawn manually. VI values were automatically calculated by the device

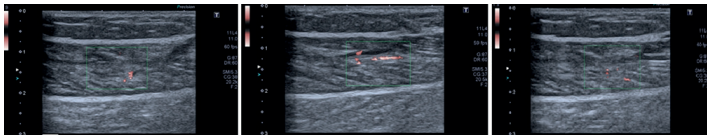

Figure 3: SMI images before stretching (A), immediately after stretching (B), and 10 minutes later (C).

This calculation was made by dividing the colored pixels showing blood flow by the total number of pixels in the ROI.

Statistical Analysis

All statistical analyses were performed using SPSS 25.0 software (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY:IBM Corp.). The normal distribution of variables was examined analytical and visually with method. Categorical variables were defined by number and percent, and continuous variables were described by the mean ± standard deviation or medians and interquartile range. For independent group comparisons, the Independent samples t-test was used when parametric test assumptions were provided, the Mann-Whitney U test was used when parametric test assumptions were not provided. Friedman test (post hoc: Wilcoxon signed-rank test with Bonferroni Correction) was used for pre- and post-treatment comparisons. The Fisher Exact test was used to analyse differences between categorical variables. Statistical significance was determined as p<0,05.

RESULTS

30 healthy individuals, 12 of whom were female and 18 of whom were male, were included in the study. Demographic data of individuals such as age, height, body mass, gender were similar before treatment (p>0.05)

Treatment type	2 minute of SS (n=15)	5 minute of SS (n=15)	Total	p
Age (year) Mean ± SD	29.67 ± 4.42	28.67 ± 4.97	29.17 ± 4.65	0.565[β]
Height (m) Mean ± SD	1.71 ± 0.1	1.76 ± 0.1	1.74 ± 0.1	0.158[β]
Weight (kg) Mean ± SD	67.4 ± 12.36	74.67 ± 12.16	71.03 ± 12.6	0.116[β]
BMI (kg/m²) Mean ± SD	23 ± 3.12	23.9 ± 2.19	23.45 ± 2.69	0.37[β]
Gender F/M (%)	7/8 (46.7/53.3%)	5/10 (33.3/66.7%)	15/15 (50/50%)	0.456[ψ]

SS: Static stretching; SD: Standard deviation; m: meter; kg: kilogram;

BMI: Body mass index; F: Female, M: Male, [β]Independent samples t-test, [ψ]Fisher's exact test

Table 1: Demographic data of individuals

The VI values of the individuals were similar in the groups before treatment (p>0.05). There was a significant difference in the VI value in the 2-minute stretching group (p=0.0001) and the 5-minute stretching group (p=0.0001) immediately after the treatment. VI values were similar to pre-treatment values in both groups 10 minutes after treatment (p>0.05)

	Pre-treatment Median (25-75 IQR)	Immediately after SS Median (25-75 IQR)	10 minute after SS Median (25-75 IQR)	p
Vascularity Index (%)				
2 minute of SS	1.2 (0.9 – 1.7)	2.3 (2.2 - 3)	1.2 (0.9 – 1.7)	**0.0001***[&] (1-2, 2-3)
5 minute of SS	1.2 (0.8 – 1.8)	3.6 (2.9 - 5)	1.7 (1.2 – 2.1)	**0.0001***[&] (1-2, 2-3)

*p<0.05 statistically significant, SS: Static stretching; IQR: Interquartile range

1: Pre-treatment, 2: Immediately after SS, 3: 10 minutes after SS, [&] Friedman Test

Table 2: Comparison of pre- and post-treatment groups

When the differences after the treatment were examined, it was found that the increase in VI values was significantly higher in 5 minutes immediately after and 10 minutes after the treatment compared to the SS application for 2 minutes

	2 minute of SS	5 minute of SS	Intergroup p
Vascularity index (%) (Rest-Immediately after) Mean ± SD	-1.29 ± 0.51	-2.93 ± 2.11	**0.01***[β]
Vascularity index (%) (Rest-10 minute after) Median (25-75 IQR)	0 (-0.3 – 0)	0.2 (0 – 1.2)	**0.01***[§]
Vascularity index (%) (Immediately after-10 minute after) Median (25-75 IQR)	1.3 (1 – 1.8)	1,5 (1.2 – 3.3)	0.074[§]

*p<0.05 statistically significant; S.D: Standard Deviation, SS: Static stretching;

IQR: Interquartile range, [β]Independent samples t-test, [§]Mann-Whitney *U* test

Table 3: Change values between groups

DISCUSSION

In this study, in which we purposed to investigate the acute effects of different SS durations applied to the gastrocnemius muscle on muscle blood flow by SMI method, it was determined that 5-minutestretching application increased blood flow more than 2-minute stretching application and blood flow values returned to their initial values after 10 minutes.

SS exercises are frequently used in rehabilitation to increase muscle flexibility, normal joint movement, reduce pain, and provide muscle relaxation.16-18 It is thought that the evaluation of muscle hemodynamics during and after stretching is important because an increase in muscle microcirculation due to stretching may be associated with an increase in muscle flexibility and elongability.19 The effects of SS exercises on muscle flexibility have been extensively investigated in the literature. 16,20,21; however, the impact of stretching exercises on muscle blood flow on humans has been examined in a small number of studies. Studies have shown that muscle blood volume decreases during stretching, and muscle blood flow increases after stretching.22 This is thought to be the hyperaemic response after stretching.22,23 Hotta et al.10 reported that daily stretching exercises in elderly rats for 4 weeks increased endothelial-induced vasodilatation and induced angiogenesis and thus increased blood flow in skeletal muscles. Matsuo et al.23 investigated the effects of SS exercise applied to the gastrocnemius muscle at different times (20 second, 1 minute, 2 minute, 5 minute, 10 minute) on muscle oxygenation and blood volume in healthy individuals with near-infrared spectroscopy. They reported that muscle oxygenation and blood volume increased after stretching, and stretchings performed for 2 minutes and longer were more effective for 5 minutes after stretching to increase blood flow than stretching applied for 20 seconds. As a result of the study, they stated that the minimum stretching time was 2 minutes to maintain the increase in muscle blood volume after stretching.23 Çalışkan et al.11 evaluated muscle blood flow by two

different radiologists with SMI after SS applications to the athletes' rectus femoris muscle. They concluded that the SMI method is a reliable method to obtain quantitative data to evaluate muscle blood flow. Their study reported that blood flow increased after stretching for 2 minutes and after stretching for 5 minutes; however, they did not compare the effects of different application times. Kruse et al.24 evaluated blood flow during and after passive stretching and stated that microvascular blood volume increased 10 minutes after stretching. In their study, mean blood flow values and baseline values were similar at the end of 10 minutes. In this study, the effects of SS exercise on gastrocnemius muscle were evaluated for the first time in healthy individuals with SMI method, the acute effects of different stretching duration were examined and compared immediately after stretching and 10 minutes later. The result of our study was in parallel with other studies conducted in the literature. In stretches performed for 2 minutes and 5 minutes, muscle blood flow values increased significantly immediately after stretching, and muscle blood flow increased more after stretching for 5 minutes; however, the values returned to their initial values after 10 minutes in both stretches. As reported in other studies, the accumulation of vasodilator metabolites due to hyperaemia after stretching may have caused an increased blood flow. Simultaneously, mechanical microvascular compression may have caused an increase in blood flow due to the effect of stretching in the muscle.[22,25]

SS exercises are frequently used in a warm-up and cool-down exercises. According to Swanson, warm-up exercises prepare the athlete for training or competition.[26] Well-designed warm-up causes physiological changes in the body prevents musculotendinous injuries27 and improves performance by increasing the athlete's mental focus on the next task.[28] On the contrary, there are some studies in the literature on the acute negative effects of SS exercises on some performance parameters.[29,30] For this reason, it may be more effective to apply short SS exercises such as 2 minutes before the activity. Cooling exercises are performed after the exercise to increase healing and reduce muscle damage. Cooling exercises are essential in terms of metabolic changes such as increased circulation and nutrients, reaching tissues, and reducing lactic acid in tissues.6 According to our study results, it may be sufficient to use 2 or 5-minute SS exercises to increase circulation in these exercises applied after the exercise.

The study has some limitations. We think that conducting studies involving more individuals, examining the effects of stretching applications for a long time, and applying stretching exercises in different muscles will contribute to the literature. Also, only the effects of muscle stretching time on blood flow were investigated in our study. In future studies, there is a need for studies examining the relationship between increased flexibility and increased blood flow due to stretching exercises.

In our study, it was concluded that SS exercises applied to the gastrocnemius muscle at different times increased muscle blood flow in healthy individuals, and the increase in muscle flow after 5 minutes of the application was higher than the increase in blood flow after 2 minutes of application. Also, in our study, it was observed that muscle bleeding returned to baseline values in both groups 10 minutes after stretching. It was concluded that stretching applications for 2 or 5 minutes would be sufficient for increasing circulation in a warm-up and cool-down exercises.

Acknowledgments:
The authors declare that there is no conflict of interest. There is no financial support from any institution or person for the study

REFERENCES

1.Lewis J. A systematic literature review of the relationship between stretching and athletic injury prevention. Orthop Nurs. 2014; 33(6):312-320. doi: 10.1097/NOR.0000000000000097.
2.Zakaria AA, Kiningham RB, Sen A. Effects of static and dynamic stretching on injury prevention in high school soccer athletes: A Randomized Trial. J Sport Rehab. 2015;24(3):229-235. doi: 10.1123/jsr.2013-0114.
3.Apostolopoulos NC, Metsios GS, Flouris A, Koutedakis Y, Wyon MA. The relevance of stretch intensity and position—a systematic review. Front Psychol. 2015;6:1128. doi: 10.3389/fpsyg.2015.01128.
4.Bordoni B, Sugumar K, Varacallo M. Muscle Cramps In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing. 2020.
5.Blyton F, Chuter V, Walter KE, Burns J. Non-drug therapies for lower limb muscle cramps. Cochrane Database Syst Rev. 2012; 18;1(1):CD008496. doi: 10.1002/14651858.CD008496.pub2.
6.Bassett DR, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc. 2000;32(1):70-84. doi:10.1097/00005768-200001000-00012.
7.Hellsten Y, Rufener N, Nielsen JJ, Høier B, Krustrup P, Bangsbo J. Passive leg movement enhances interstitial VEGF protein, endothelial cell proliferation, and eNOS mRNA content in human skeletal muscle. Am J Physiol Regul Integr Comp Physiol. 2008;294(3):R975-82. doi: 10.1152/ajpregu.00677.2007.
8.McDaniel J, Ives SJ, Richardson RS. Human muscle length-dependent changes in blood flow. J Appl Physiol. 2012;112(4):560-565. doi: 10.1152/japplphysiol.01223.2011.
9.Rivilis I, Milkiewicz M, Boyd P, Golstein J, Brown MD, Egginton S, et al. Differential involvement of MMP-2 and VEGF during muscle stretch- versus shear stress-induced angiogenesis. American J Physiol Heart Circ Physiol. 2002;283(4):H1430-8. doi: 10.1152/ajpheart.00082.2002.
10.Hotta K, Behnke BJ, Arjmandi B, Ghosh P, Chen B, Brooks R, et al. Daily muscle stretching enhances blood flow, endothelial function, capillarity, vascular volume, and connectivity in aged skeletal muscle. J Physiol. 2018;596(10):1903-1917. doi: 10.1113/JP275459.
11.Caliskan E, Akkoc O, Bayramoglu Z, Gözübüyük ÖB. Effects of static stretching duration on muscle stiffness and blood flow in the rectus femoris in adolescents. Med Ultrason. 2019;21(2):136-143. doi: 10.11152/mu-1859.
12.Xiao XY, Chen X, Guan XF, Wu H, Qin W,Luo BM. Superb microvascular imaging in the diagnosis of breast lesions: a comparative study with contrast-enhanced ultrasonographic microvascular imaging. Br J Radiol. 2016;89(1066):20160546. doi: 10.1259/bjr.20160546.
13.Mao Y, Mu J, Zhao J, Xin X. The value of superb microvascular imaging in differentiating benign renal mass from malignant renal tumor: a retrospective study. Br J Radiol. 2018;91(1082):20170601. doi: 10.1259/bjr.20170601.
14.Capobianco RA, Mazzo MM, Enoka RM. Self-massage prior to stretching improves flexibility in young and middle-aged adults. J Sports Sci. 2019;37(13):1543-1450. doi: 10.1080/02640414.2019.
15.Chino K, Kawakami Y, Takahashi H. Tissue elasticity of in vivo skeletal muscles measured in the transverse and longitudinal planes using shear wave elastography. Clin Physiol Funct Imaging. 2017;37(4):394-399. doi: 10.1111/cpf.12315.
16.Umegaki H, Ikezoe T, Nakamura M, Nishishita S, Kobayashi T, Fujita K, et al. Acute effects of static stretching on the hamstrings using shear elastic modulus determined by ultrasound shear wave elastography: Differences in flexibility between hamstring muscle components. Man Ther. 2015;20(4):610-613. doi: 10.1016/j.math.2015.02.006.
17.Law RY, Harvey LA, Nicholas MK, Tonkin L, Sousa MD, Finniss DG. Stretch exercises increase tolerance to stretch in patients with chronic musculoskeletal pain: A randomized controlled trial. Phys Ther. 2009;89(10):1016-1026. doi: 10.2522/ptj.20090056.
18.Funase K, Higashi T, Sakakibara A, Tanaka K, Takemochi K, Ogahara K, et al. Neural mechanism underlying the H-reflex inhibition during static muscle stretching. Adv Exerc Sports Physiol. 2003;9(4):119-127.
19.Matsuo S, Suzuki S, Iwata M, Banno Y, Asai Y, Tsuchida W, et al. Acute effects of different stretching durations on passive torque, mobility, and isometric muscle force. J Strength Cond Res. 2013;27(12):3367-3376. doi: 10.1519/JSC.0b013e318290c26f.
20.Nakamura M, Ikezoe T, Nishishita S, Umehara J, Kimura M, Ichihashi N. Acute effects of static stretching on the shear elastic moduli of the medial and lateral gastrocnemius muscles in young and older women. Musculoskelet Sci Pract. 2017;32:98-103. doi: 10.1016/j.msksp.2017.09.006.
21.Zhou J, Liu C, Zhang Z. Non-uniform Stiffness within Gastrocnemius-Achilles tendon Complex Observed after Static Stretching. J Sports Sci Med. 2019;18(3):454-461.
22.Otsuki A, Fujita E, Ikegawa S, Mizumura MK. M. Muscle oxygenation and fascicle length during passive muscle stretching in ballet-trained subjects. Int J Sports Med. 2011;32(07) 496–502. doi: 10.1055/s-0031-1275297.
23.Matsuo H, Kubota M, Shimada S, Kitade I, Matsumura M, Nonoyama T, et al. The Effect of Static Stretching Duration on Muscle Blood Volume and Oxygenation. J Strength Cond Res. 2022;36(2):379-385. doi: 10.1519/JSC.0000000000003457.
24.Kruse NT, Silette CR, Scheuermann BW. Influence of passive stretch on muscle blood flow, oxygenation, and central cardiovascu-

lar responses in healthy young males. Am J Physiol Heart Circ Physiol. 2016;310(9):H1210-21. doi: 10.1152/ajpheart.00732.2015.
25.Yamato Y, Higaki Y, Fujie S, Natsuki H, Horii N, Aoyama H, et al. Acute effect of passive one-legged intermittent static stretching on regional blood flow in young men. Eur J Appl Physiol. 2021;121(1):331-337. doi: 10.1007/s00421-020-04524-0.
26.Swanson J. A functional approach to warm-up and flexibility. Strength Cond J. 2006;28(5):30-36.
27.Small K, Mc Naughton L, Matthew, M. A systematic review into the efficacy of static stretching as part of a warm-up for the prevention exercise-related injury. Res Sports Med. 2008;16(3):213-231. doi: 10.1080/15438620802310784.
28.McGowan CJ, Pyne DB, Thompson KG, Rattray B. Warm-up strategies for sport and exercise: mechanisms and applications. Sports Med. 2015;45(11):1523-1546. doi: 10.1007/s40279-015-0376-x.
29.Behm DG, Kibele A. Effects of differing intensities of static stretching on jump performance. Eur J Appl Physiol. 2007;101(5):587-594. doi: 10.1007/s00421-007-0533-5.
30.Cramer JT, Beck TW, Housh TJ, Massey LL, Marek SM, Danglemeier S, et al. Acute effects of static stretching on characteristics of the isokinetic angle – torque relationship, surface electromyography, and mechanomyography. J Sports Sci. 2007;25(6):687–698. doi: 10.1080/02640410600818416.