

The Impact of Strength Electromyostimulation Training on Muscle Stiffness and Blood Flow: An Exploration Using Shear Wave Elastography and Superb Microvascular Imaging

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Abstract To assess the acute effect of strength exercises combined with EMS on blood flow and muscle stiffness using SMI and SWE. This prospective study included 20 participants. Subjects were divided into groups base on calisthenics strength training with EMS and without EMS. Rectus femoris (RF) blood flow was measured at rest and post-exercise with the vascularity index (%) and stiffness was measured in kPa mode to compare the groups. When values are compared at rest and post-exercise, all cases had significantly increased blood flow and stiffness increase in RF post-exercise (resting mean VI [%]: 1.42±0.58 and post-exercise mean VI [%]: 5.36±3.03; resting mean stiffness [kPa]: 8.85±1.38) and post-exercise mean stiffness [kPa]: 10.57±1.79). The blood flow and stiffness values in the group with EMS and exercise had greater increases than the group with exercise without EMS (p=0.007, p=0.05, respectively). Calisthenics strength training increases RF blood flow and stiffness in the acute period. SMI and SWE are beneficial and practical radiological methods that may be used to show these variations. Strength exercises using EMS may be associated with better athletic performance.

Keywords Calisthenics Training, Electromyostimulation, Muscle Blood Flow, Muscle Stiffness, Shear Wave Elastography, Superb Microvascular Imaging

diseases related with muscle condition, sports injuries and/or physical rehabilitation [3-5]. In recent years, EMS has begun to be popularly used in the fields of exercise and sports. There are many studies investigating the effect of EMS training on speed, vertical jump, strength, resistance, flexibility, aerobic and anaerobic capacities, neural adaptation, muscle activation and muscle functions [6-9].

It is stated the vascular structures and functions of physically active individuals are better compared to those of sedentary individuals [10,11]. Resistance-type exercise causes increases in the vascular lumen diameter and arterial cross-sectional area [12]. Physical inactivity is stated to cause narrowing of the arterial cross-section area [13,14]. Larger vascular diameter increases the amount of oxygen reaching muscles and provides better perfusion of muscles allowing the possibility of better nutrition [15]. As a result, better intramuscular blood flow provides the opportunity to produce higher levels of physical performance.

Superb microvascular imaging (SMI) is an application added to the ultrasound device and is a novel Doppler method. Compared to conventional Doppler techniques like power Doppler and color Doppler, it uses a higher frame rate and the most significant advantage of SMI is successful imaging of very fine vascular structures [16]. There is still not much information in the literature about the use of this technique for muscles.

Shear wave elastography (SWE) is a non-invasive radiological method used to measure the stiffness of tissue, that obtains a quantitative estimation of the elasticity of different tissues in the body Tissue stiffness measurements may be beneficial for the identification and treatment of a variety of disorders. However, there are limited studies investigating the effect of muscle stiffness determined with this method on athletic performance. Calisthenics training is a type of exercise using only the person's body weight.

1. Introduction

Electromyostimulation (EMS) is defined as electrical currents applied to muscle tissue and motor points [1,2]. EMS training has been used for treatment of some chronic

To the best of our knowledge, there is no study in the literature about how EMS training combined with calisthenic strength exercises affects tissue stiffness and blood flow.

The aim of this study is to assess the acute effect of calisthenic strength exercises combined with EMS on blood flow and muscle stiffness using SMI and SWE. Additionally, acute biomechanical properties induced in muscles by exercises with and without EMS were compared.

2. Material and Methods

2.1. Participants

Twenty healthy individuals (10 females and 10 males) voluntarily participated in the study. All participants were individuals involved in sports on at least 3 days per week. The study abided by the Helsinki Declaration. Subjects were given necessary information about the scope and content of the study and signed a voluntary consent form. The study received permission from the ethics committee.

2.2. Study Design

Before beginning the study, all participants had height and body weight measured. The stiffness and blood flow in

the rectus femoris (RF), one of the quadriceps muscle group members, were measured at rest. Subjects performed calisthenic strength exercises, and immediately after exercise RF stiffness and blood flow were measured again, with the difference between the two measurements assessed. The participants were divided into 2 subgroups in the study. The first group of participants performed 3 different leg movements (squat, split squat and lunge) in 3 sets of 15 repetitions without using EMS (Fig-1). There were 30-seconds rest between sets and 1-minute rest between repetitions. The second group of participants used EMS and performed the same number of the same movements and had the same rest periods. The variations in stiffness and blood flow in the muscle were compared between the groups.

2.3. EMS Protocol

EMS application used a Miha Bodyex GmbH device. An 85 cm long, 8 cm wide leg pad was placed on the center point of the thigh. Before applying electrical current, the internal surface of the leg pad was wetted with a small amount of water. The pad had current flow set to 65 Hz (high flow). This level of current created minimal tingling in the subject's leg. The electric current was applied to the subject during exercise, with current stopped during rest periods between sets and repetitions.



Figure 1. Leg movements and body position in calisthenic strength training. Squat (a), split squat (b) and lunge (c) are illustrated.

2.4. SWE and SMI Techniques

Measurements were completed using an Aplio 500 Platinum ultrasound device (Toshiba Medical Systems, Japan) and high-frequency linear probe (frequency range 5-14 MHz). The measurements were completed by an experienced pediatric radiologist with more than 5 years of SWE and 2 years of SMI experience. The measurement location for RF was determined based on previous studies [17-18]. The same location was used for both SWE and SMI examinations. RF was examined at the midpoint between the lateral epicondyle of the femur, and the anterior superior iliac in supine position with the legs extended, and relaxed. This reference point was clearly marked on the skin with a pen. The transducer was placed in a longitudinal orientation along the muscle until a clear image of the fibers inside the muscle could be identified.

For SWE, the 2D-SWE map (left side) and quality mode (right side) were examined in split-screen mode. The quality mode, which is identified as the propagation mode (arrival time contour), is a mode in which reliable data is obtained when the lines are parallel and smooth, and the

increase in the distance between the lines is parallel to the increase in elasticity. Subsequently, a 10x10 mm dimension “square region of interest (ROI)” was used to take measurements at three different points with three repeated acquisitions (Fig-2). The mean of the measured data points was calculated. For measurements, the elasticity modulus in kiloPascals (kPa: range 0-50) and shear wave velocity modulus in meters/second (m/s: range 0-8) were used.

SMI investigation used >50 Hz frame rates. Pulse repetition frequency set was 220–234 Hz for SMI. The color gain was set to 30-40 decibels to suppress background artifacts. SMI imaging used color mode. The vascularity index (VI [%]) measurement method was used to identify blood flow. In color mode, a rectangular ROI was manually drawn on a fixed window with 15 x 10 mm dimensions. Within the ROI, the proportion of color pixels in the whole area was automatically calculated by the device in percentages to obtain vascularity index (%) (VI) values including arterial and venous total vascularity supply (Fig-3).

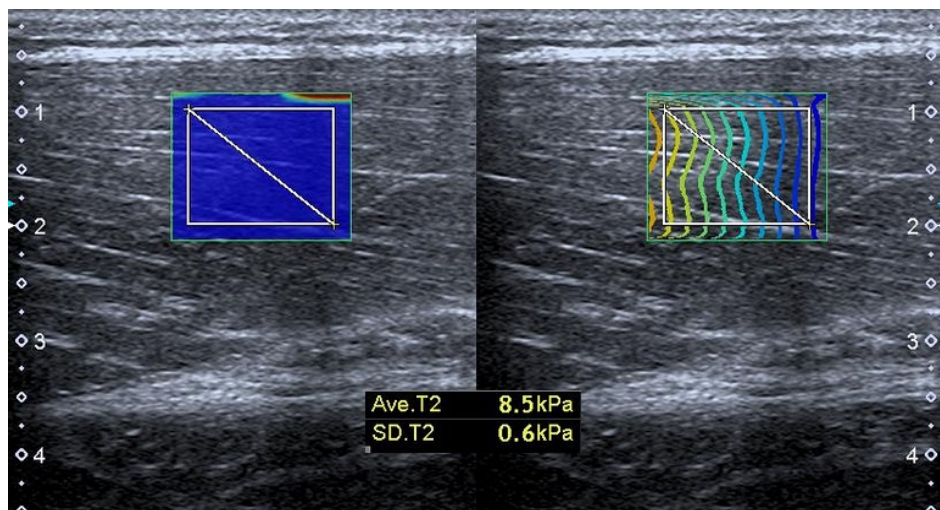


Figure 2. SWE measurement of RF was completed using a square ROI that was placed on homogeneous muscle parenchyma in longitudinal plane. 2D-SWE map (left side) and quality mode (right side) are seen. The measurement was recorded in kPa mode.

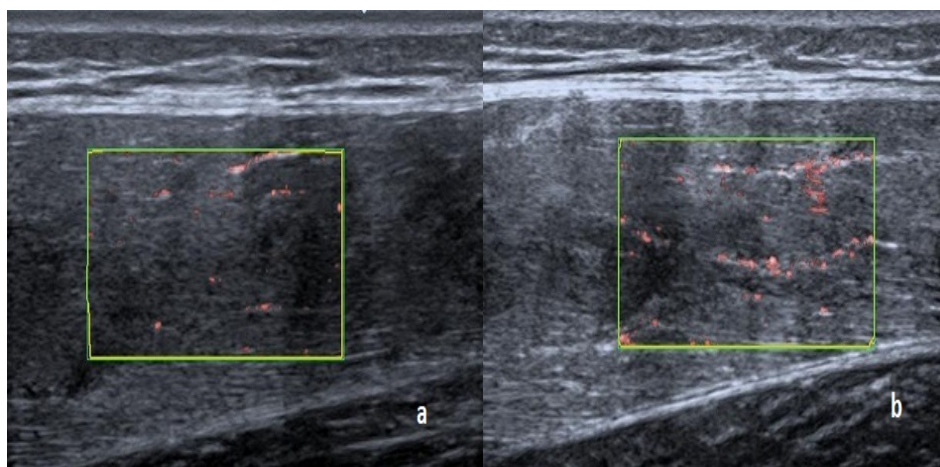


Figure 3. On SMI, an example demonstrating how strength exercises increase muscle blood flow. Clear variation is observed in RF VI (%) in a subject using EMS for training before exercise (a) and after exercise (b).

2.5. Statistics

Statistical analysis was performed with the SPSS (Statistical Package for the Social Sciences) program. Descriptive characteristics of the groups are given as minimum, maximum, mean and standard deviation. The difference in muscle stiffness and blood flow before and after training in the groups was assessed with the Wilcoxon test, a nonparametric test due to values not showing normal distribution. The differences within the groups were identified with the Mann Whitney U test. P values of less than 0.05 were considered statistically significant.

3. Results

The median age of all cases (n=20) was 21.4 (17.4-29.2) years. The mean weight and height of all cases (n=20) were 69.86 (44.10-116.50) kilograms and 1.70 (1.52-1.86) meters, respectively.

When the values at rest and post-exercise are compared, in all cases there were significant increases in blood flow

and stiffness in RF post-exercises (p<0.001) (resting mean VI [%]: 1.42 ± 0.58 and post-exercise mean VI [%]: 5.36 ± 3.03; resting mean stiffness [kPa]: 8.85 ± 1.38) and post-exercise mean stiffness [kPa]: 10.57 ± 1.79) (Table-1).

In the group with EMS exercises, when resting (mean VI [%]: 1.07 ± 0.29) and post-exercise (mean VI [%]: 7.17 ± 2.88) RF blood flow measurements and resting (mean kPa: 9.19 ± 1.18) and post-exercise (mean kPa: 11.35 ± 1.73) RF stiffness measurements are compared, there were significant increases in blood flow and stiffness post-exercise (z: -2.803b p: 0.005; z: -2.805b p: 0.005, respectively) (Table-2).

In the group with exercise but no EMS, when resting (mean VI [%]: 1.77 ± 0.59) and post-exercise (mean VI [%]: 3.55 ± 1.97) RF blood flow measurements and resting (mean kPa: 8.51 ± 1.55) and post-exercise (mean kPa: 9.79 ± 1.55) RF stiffness measurements are compared, there were significant increases in blood flow and stiffness post-exercise (z: -2.807b, p: 0.005; z: -2.807b, p: 0.005, respectively) (Table-2).

Table 1. Differences in resting and post-exercise measurements of blood flow and stiffness in the all subjects

n=20	mean	standard deviation	minimum	maximum	z	p
Resting VI (%)	1.42	0.58	0.70	2.50	-3.922 ^b	<0.001
Post-exercise VI (%)	5.36	3.03	1.5	12.00		
Resting stiffness kpa	8.85	1.38	6.90	12.10	-3.922 ^b	<0.001
Post-exercise stiffness kpa	10.57	1.79	7.60	14.00		

n: number of subjects, VI: vascularity index, kPa: kiloPascal

Bold values depict significant difference.

Table 2. Difference between resting and post-exercise measurements in the groups with and without EMS in terms of blood flow and stiffness

	n=20	mean	standard deviation	min	max.	z	p
With EMS n=10	Resting VI (%)	1.07	0.29	0.70	1.60	-2.803 ^b	0.005
	Post-exercise VI (%)	7.17	2.88	2.00	12.00		
	Resting stiffness	9.19	1.18	7.60	10.90	-2.805 ^b	0.005
	Post-exercise stiffness	11.35	1.73	8.50	14.00		
Without EMS n=10	Resting VI (%)	1.77	0.59	0.80	2.50	-2.807 ^b	0.005
	Post-exercise VI (%)	3.55	1.97	1.50	8.60		
	Resting stiffness	8.51	1.55	6.90	12.10	-2.807 ^b	0.005
	Post-exercise stiffness	9.79	1.55	7.60	13.00		

EMS: electromyostimulation, max: maximum, min: minimum, n: number of subjects, VI: vascularity index, kPa: kiloPascal

Bold values depict significant difference.

Comparing the post-exercise RF VI (%) and RF stiffness values in the groups with EMS and without EMS exercises, there was a significant difference between the groups (Fig-4).

The blood flow and stiffness values in the group with EMS exercises had greater increases compared to the group without EMS ($p=0.007$, $p=0.05$, respectively) (Table-3).

4. Discussion

This study was completed with the aim of investigating the acute effect of calisthenic strength exercises combined with EMS and calisthenic strength exercises without EMS on RF blood flow and stiffness. According to the results of the study, in both groups with EMS and without, blood

flow and stiffness increased after exercise. However, the group with EMS exercises had greater increases in blood flow and stiffness compared to the group without EMS.

Previous studies related to EMS focused on muscle strength, muscle volume, nervous system and rehabilitation after sports injury with EMS. Among these, the majority of studies about EMS are related to muscle strength. Based on studies showing EMS training increases voluntary muscle strength and muscle volume, this training method began to be intensely included in strength training plans. In relation to resistance training, EMS training increases the muscle cross-section and increases maximum voluntary muscle strength [19]. However, there are studies stating that the increase in strength with EMS strength exercises is not greater than the increase in strength with classic strength exercises [19,20].

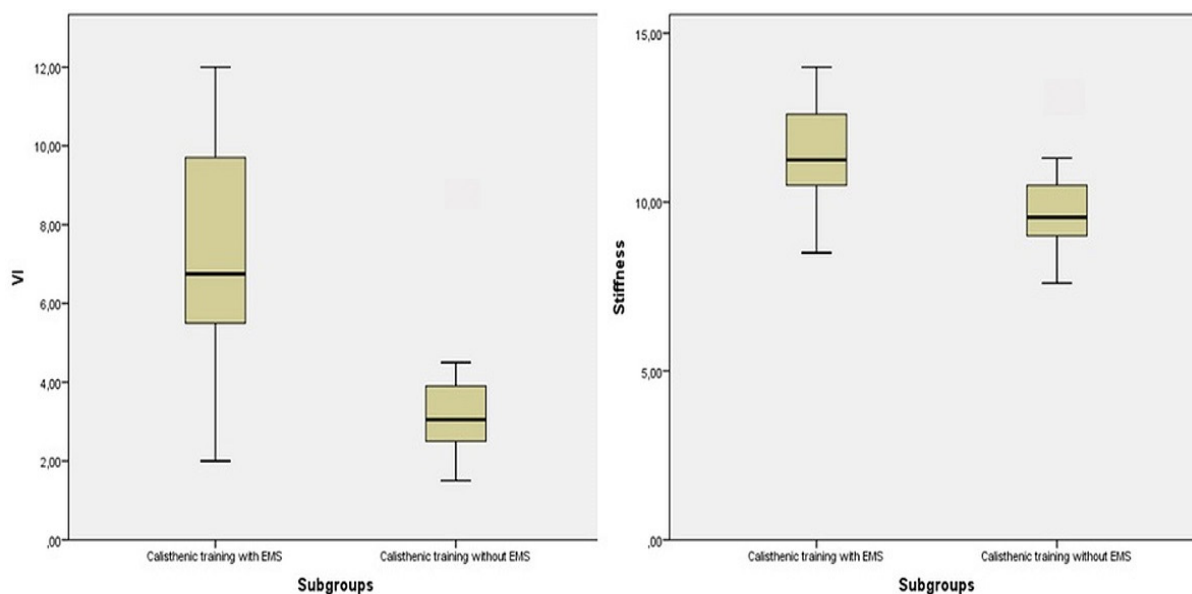


Figure 4. The mean blood flow and stiffness obtained with calisthenic strength training with EMS was significantly higher than the mean blood flow and stiffness obtained with calisthenic strength training without EMS.

Table 3. Comparing the post-exercise RF blood flow and RF stiffness differences in the groups with EMS and without EMS exercises.

	<i>n</i> =20	mean	standard deviation	min.	max.	<i>z</i>	<i>p</i>
Stiffness	With EMS <i>n</i> =10	11.35	1.73	8.50	14.00	-1.854	0.05
	Without EMS <i>n</i> =10	9.79	1.55	7.60	13.00		
VI (%)	With EMS <i>n</i> =10	7.17	2.88	2.00	12.00	-2.686	0.007
	Without EMS <i>n</i> =10	3.55	1.97	1.50	8.60		

EMS: electromyostimulation, max: maximum, min: minimum, *n*: number of subjects, VI: vascularity index

Bold values depict significant difference.

Intramuscular perfusion is accepted as an important parameter in sporting performance and physical fitness. It has been proven in previous studies that physically active individuals have better blood flow and vascular diameters compared to sedentary individuals [10,11]. When studies related to blood flow are investigated, after 4 weeks of applied strength exercises, there were increases in superficial femoral and carotid artery diameter and blood flow. After stopping training, the blood flow and arterial diameters return to normal values [21]. After acute EMS training in spinal cord injury patients, leg perfusion was found to increase [5]. It was found that vibration training increased blood flow and that EMS applied to leg muscles with combined vibration training increased calf perfusion [22-24]. Labrunée et al reported that EMS is able to directly reduce sympathetic activity in patients with chronic heart failure. They also showed that this putative beneficial effect linked to a sensory stimulation was preserved while chronic heart failure patients were exposed to EMS, the latter combining sensory and muscular stimulation [25]. Kemmler et al concluded that EMS appears to be an effective training tool for reducing low back pain [26]. Bruce et al mentioned that home-based EMS was an acceptable alternative to exercise therapy in the management of knee osteoarthritis, producing similar improvements in functional capacity [27]. Similar to these studies, our study found that strength training with and without EMS increased acute RF blood flow. Different to these studies, the variation in muscle blood flow was investigated in detail with the novel radiological method of SMI. From this aspect, our study is unique. Additionally, according to our results, the muscle blood flow increase values in the group with EMS and exercise were found to be higher than in the group with exercise but no EMS. These results show that EMS exercise increases muscle blood flow more and may be beneficial for athletic performance.

The number of studies about muscle stiffness using the SWE method is very few compared to other organs in the body. Additionally, the studies investigating the association between muscle stiffness and athletic performance are insufficient. In this study, the relationship between passive muscle stiffness on athletic performance in adolescent female basketball players was investigated and there was no correlation found between vertical jumping and oxygen use capacity with muscle stiffness. It is not known how acute and chronic training affect muscle stiffness in sedentary individuals and sportspeople. At the end of our study, there was an increase found in muscle stiffness in the hyperacute period after strength exercises both with and without EMS. However, the increase in muscle stiffness among those with EMS exercises was greater compared to those exercising without EMS. This result shows that acute strength training increases muscle stiffness. When these strength exercises are combined with EMS training, it is more effective on muscle stiffness.

There is a need for more comprehensive studies to investigate the chronic effects of exercises using EMS on athletic performance.

There are some limitations to our study. The first is the low number of subjects. Another limitation is that the study only investigated variations in blood flow and stiffness in a single muscle (rectus femoris). Additionally, the study only investigated the acute effects on the muscle, with long-term effects of training not investigated.

5. Conclusions

In conclusion, strength exercises increased blood flow and stiffness of the RF muscle in the acute period. Strength exercises combined with EMS increased muscle blood flow and stiffness more compared to classic exercise methods. As a result, strength exercises completed using EMS may be more beneficial for good athletic performance. Future studies will investigate the chronic effects of EMS combined with calisthenics strength exercises.

Conflict of Interest

The authors declare that none of them has any conflict of interest.

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