EFFECTS OF TRAINING WITH HIGH AND LOW-FREQUENCY ELECTRICAL STIMULATION ON MUSCLE CONTRACTILE PROPERTIES IN RABBITS

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Abstract

Controversy exists regarding the effects of different frequencies of ES on muscle contractile properties. The purpose of this study was to investigate the role of ES frequency on muscle contractile properties. Six male rabbits were divided into 2 groups (low and high-frequency ES training groups, stimulated by using 20 and 100 Hz respectively). They were trained by using surface ES on the gastrocnemius muscle 2 h daily, 5 days per week for 4 weeks. The twitch time to peak torque decreased in the high-frequency group and increased in the low-frequency group after ES training. The peak twitch torque, maximal tetanic contraction torque, and fatigue resistance all increased in both groups. According to the results, ES training with different frequencies may result in different effects on muscle phenotype transformation, whereas, increased muscle mass, muscle fiber density, new capillaries, and circulation might be effects of ES training common to different frequencies..

Introduction/Background

Significant controversy exists regarding effects of the different frequencies of ES on muscle contractile properties.

The relative impact of ES training with different frequencies on skeletal muscles remains controversial. Understanding the relationship between different stimulation frequencies and the resultant muscle properties will be helpful for successful application of ES to improve functional muscle performance. The purpose of this study was to investigate the effect of 2 different ES frequencies on muscle contractile properties and fatigue resistance.

Methods

Subjects

Experiments were performed on 6 male rabbits. The 6 rabbits were equally divided into 2 ES training groups (low and high-frequency groups, stimulated by using 20 and 100 Hz respectively).

Electrical stimulation training

Electrical stimulation was delivered through surface electrodes. The active electrode was placed on the muscle belly of the left gastrocnemius, and the reference electrode was placed on the Achilles tendon. An intermittent balanced charge biphasic wave with an amplitude of 50 mA, a pulse width of 300 μs, and a duty cycle of 8.3% (5 s on, 55 s off) was used. The stimulation frequencies used were 20 and 100 Hz for the low- and high-frequency groups, respectively. The electrical stimulation training program was performed 2 h daily, 5 days per week for 4 weeks.

Evaluation of muscle contractile properties

To evaluate the muscle responses to ES, a balanced charged biphasic electrical current with a pulse width of 300 μs and an intensity of 100 mA constant current was used to stimulate the muscle. The electrodes were applied to the same area as that used for ES training. The ankle plantarflexion force was measured by using a miniature loadcell force sensor.

Muscle contractile properties were investigated by assessing twitch time to peak torque, peak twitch torque, maximal tetanic contraction torque, and the fatigue index in this study.

Peak twitch torque was elicited and measured by using a single electrical pulse of 100 mA. Twitch time to peak torque is defined as the time required for the twitches to reach peak torque. The maximal tetanic contraction torque and muscle fatigue index were assessed by using a consecutive 20-Hz electrical current, and the stimulation intensity was set at 100 mA. The muscle fatigue index (MFI) is defined as follows:

$$MFI\ (i) = [(X_0 - X_i)/X_0] * 100\%,$$ where

X_0 is the maximal tetanic contraction torque; i is the time in i seconds after X_0; and X_i is the muscle torque measured i seconds after X_0. The time periods (i) for the muscle tension to decay from maximal tetanic contraction torque (X_0) to 10%, 30%, and 50% of MFI were recorded.

The muscle was tested before training and at the end of the 4th week of ES training. In this study, we compared changes in muscle contractile properties by 4-week ES training between the low and high-frequency groups.

Results

All 6 rabbits completed the 4-week ES training program.

Twitch time to peak torque

In the 20-Hz ES training group, the twitch time to peak torque increased in all 3 rabbits after 4-week ES training. In contrast, the twitch time to peak torque showed an decrease in the 100-Hz ES training group (Table 1).

Peak twitch torque

Table 2 shows twitch torque in both the 20 and 100-Hz groups increased after 4-week ES training.

Maximal tetanic contraction torque

Both the 20 and 100-Hz groups showed an increase in maximal tetanic contraction torque after 4-week ES training. The values are shown in Table 3.

Fatigue resistance

All 6 animals in both groups showed increases in the time periods (i) for the muscle tension to decay from maximal tetanic contraction torque (X_0) to 10%, 30%, and 50% of MFI (Table 4). The results indicate that fatigue resistance increased in both groups after 4-week ES training.

Table 1. Twitch Time to Peak Torque before and 4 weeks after 20-Hz or 100-Hz ES training

Case	ES training frequency	Twitch time to peak torque (ms)	
		Before	After
1	100 Hz	34.20	30.66[a]
2		35.60	32.34[a]
3		35.20	30.36[a]
4	20 Hz	33.50	36.13[b]
5		28.67	34.24[b]
6		32.67	34.38[b]

[a]Decreased after ES training

[b]Increased after ES training

Table 2. Peak Twitch Torque before and 4 weeks after 20-Hz or 100-Hz ES training

Case	ES training frequency	Peak twitch torque (Nm)	
		Before	After
1	100 Hz	0.40	0.50[a]
2		0.56	0.57[a]
3		0.26	0.48[a]
4	20 Hz	0.42	0.60[a]
5		0.27	0.46[a]
6		0.45	0.52[a]

[a] Increased after ES training.

Table 3. Maximal Tetanic Contraction Torque before and 4 weeks after 20-Hz or 100 Hz ES training

Case	ES training frequency	Maximal tetanic contraction torque (Nm)	
		Before	After
1	100 Hz	0.81	1.00[a]
2		0.87	1.18[a]
3		1.07	1.42[a]
4	20 Hz	0.75	0.97[a]
5		0.72	0.97[a]
6		1.09	1.26[a]

[a]Increased after ES training.

Table 4. Changes of Fatigue Resistance of the Gastrocnemius Muscle in Each Case before and 4 Weeks after ES training

Case	ES frequency	i values (s)					
		MFI(i)=10%		MFI(i)=30%		MFI(i)=50%	
		pre ES	After ES	pre ES	After ES	Pre ES	After ES
1	100 Hz	5.81	4.92	11.28	13.79 [a]	21.14	32.53 [a]
2		4.13	7.19 [a]	9.45	13.45 [a]	20.76	23.59 [a]
3		4.36	7.85 [a]	11.44	18.96 [a]	20.08	32.60 [a]
4	20 Hz	3.76	8.79 [a]	8.08	18.50 [a]	14.11	42.45 [a]
5		6.46	8.74 [a]	14.27	17.30 [a]	23.39	50.67 [a]
6		4.92	10.60 [a]	10.34	20.01 [a]	16.06	35.11 [a]

[a]Increased i value after ES training, which indicates increased fatigue resistance. Time periods (i values) for the muscle tension to decay from maximal tetanic contraction torque (Xo) to 10%, 20%, 30%, 40%, and 50% of MFI(i) 4 weeks after ES training were individually compared with those before ES pair by pair

Discussion/Conclusions

The muscle contractile properties showed significant changes after ES training. Furthermore, the results indicate that the ES frequency plays an important role in changes of muscle contractile properties.

The impact of different frequent ES training on muscle contraction speed

In this study, the muscle trained by using 20-Hz ES showed an increase in twitch time to peak torque, while the muscle trained using 100 Hz showed a decrease. This result suggests that using 20 Hz for ES training increases the time course of muscle contraction, whereas using 100 Hz decreases it. This may imply that the phenotype of muscle composition had changed after ES training.

Muscle torque increase with ES training

Both peak twitch torque and maximal tetanic contraction torque increased after either 20 or 100-Hz ES training. Because Type 2 muscle fibers are more powerful than these of Type 1, an increase in the proportion of Type 2 fibers after high-frequency ES training may enhance twitch torque and tetanic torque.[1] However, an increase of muscle torque was also shown in the low-frequency ES training group. The results can not be explained solely by the phenotype transformation after ES training. The possible underlying mechanisms causing increases of peak twitch torque and maximal tetanic contraction torque in this study might be increased muscle mass and muscle fiber density.

In the high-frequency group, the muscle mass of the stimulated muscle may have increased and may have been transformed from Type 1 to Type 2 fibers, thereby, increasing the peak twitch torque and maximal tetanic contraction torque. In the low-frequency group, we suppose that the effects of increased muscle mass and muscle fiber density by ES may overcome the possible influence of muscle transformation from Type 2 to Type 1 resulting in an increase of muscle torque. To prove this, further studies with muscle histological changes will be helpful.

Fatigue resistance increase with ES training

In this study, both groups, stimulated by using either low or high frequencies, showed increases in muscle fatigue resistance. In the low-frequency group, increasing the proportion of Type 1 fibers may contribute to increased fatigue resistance. In the high-frequency group, although Type 1 fibers may transform into Type 2 fibers, we supposed that the increased fatigue resistance after ES may be due to increased blood flow to the stimulated muscle.[2,3]

Conclusions

According to the results of this study, we suggest that ES training using different frequencies may result in different resultant muscle phenotype transformations, whereas, increased muscle mass, muscle fiber density, new capillaries, and circulation might be effects common to ES training using different frequencies. To prove this, further studies of muscle histological changes correlated with muscle contractile property changes by ES training will be helpful.

References

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