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Acu-TENS lowers blood lactate levels and enhances heart rate recovery after exercise

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KEYWORDS
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Abstract *Objective:* The primary aim of this study is to investigate the effect of application of transcutaneous electrical nerve stimulation over acupuncture points (Acu-TENS) on post-exercise blood lactate level. The secondary aim is to explore the effect of Acu-TENS on heart rate recovery and its association with autonomic nervous system.
Methods: Twenty healthy subjects (mean age 26.9 $\pm$ 1.3) acting as their own controls, were randomized to receive either Acu-TENS or Placebo-TENS as the first of two intervention protocols, implemented one week apart. During Acu-TENS, subjects received 45 min TENS bilaterally over the acupoints Neiguan (PC6). Subjects receiving Placebo-TENS had identical electrode placement but with no electrical output from the TENS unit despite an active output light. Interventions were followed by a 10-min ergometer exercise at 70% age-predicted maximal heart rate. Oxygen consumption and heart rate (HR) were recorded continuously throughout exercise. Blood lactate and blood pressure were taken at 4 time points: prior to, immediately after, at 15-min after exercise, and when HR had returned to baseline values.
Results: The post-exercise blood lactate level in the Acu-TENS group was lower than that of the placebo group by 1.12 $\pm$ 0.39 mmol/L ($p = 0.01$). The Acu-TENS group also had a faster return of HR to pre-exercise level compared to placebo (9.98 $\pm$ 4.54 min, $p = 0.047$). Heart rate variability analysis inferred reduced sympathetic modulation during exercise after Acu-TENS. There was no between-group difference in post-exercise oxygen consumption.
Conclusion: Acu-TENS lowered post-exercise blood lactate level and enhanced heart rate recovery after moderate exercise. The role of Acu-TENS in exercise performance and energy metabolism warrants further investigation. (ClinicalTrails.gov Identifier: NCT01102634)

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Introduction

Energy is provided by adenosine triphosphate during performance of activities of high intensity and short duration[1]; efficient energy metabolism is essential to meet the demand of physical activity at increasing levels of intensity. It is generally believed that when strenuous exercise continues or when there is insufficient oxygen availability to facilitate glycolysis, lactate is produced. However it is now known that lactate facilitates the metabolism of carbohydrates through glycolysis and thus circulating blood lactate should be viewed as a useful form of potential energy instead of a waste product.[1–3]

According to traditional Chinese medicine concepts, the status of body homeostasis is maintained by the balance of energy flow or 'qi'. Other than pain and illness, it has been hypothesized that fatigue caused by vigorous exercise can also disrupt energy flow.[4] Acupuncture, a technique which manipulates the energy flow through insertion of a needle at specific points on the skin (acupoints), has been practiced in China for over 2000 years. Stimulation of specific acupoints has been proposed to improve physical performance,[4,5] but although acupuncture is effective, invasive and adverse effects have been reported.[6] Transcutaneous Electrical Nerve Stimulation (TENS) is a non-invasive modality commonly used for analgesia. Previous studies reported that TENS exerted analgesic effects via similar routes as acupuncture in both animal[7] and human models.[8] We have previously demonstrated that Acu-TENS, application of TENS to acupuncture point PC6 (Neiguan), resulted in a faster return to pre-exercise heart rate compared to a placebo group.[9] Recently we have also shown that application of 45 min of Acu-TENS prior to exercise was associated with less dyspnoea and prolonged exercise duration in both healthy individuals[10] and patients with asthma.[11] The positive effects of Acu-TENS were shown to be associated with an increase in blood β-endorphin level and possibly through effects on modulation of the autonomic nervous system.[10,12]

Examining the relationship between lactate kinetics and exercise performance has led to various lactate threshold concepts due in part to the wide variety of exercise protocols tested.[13] The effect of Acu-TENS on blood lactate level and exercise however has not been explored. This current study aims to investigate the effect of Acu-TENS on blood lactate levels associated with exercise. The secondary aim of this study is to explore the effect of Acu-TENS on heart rate recovery after exercise and to determine if such effect is associated with modulation of the autonomic nervous activity.

Materials and methods

Study design

This study adopted a randomized, placebo-controlled, cross-over design and followed the recommended "Standards for Reporting Interventions in Controlled Trials of Acupuncture" (STRICTA)[14] and "Consolidated Standards of Reporting Trials" (CONSORT) guideline.[15] The study protocol was approved by the Human Subjects Ethics Committee of the involved university prior to data collection. The study procedures were explained to each subject and informed consent was obtained prior to data collection. The sequence of either Acu-TENS or Placebo-TENS as the first intervention protocol was determined by the randomization computer program, "Random Allocation Software" Version 1.0.0 (University of Medical Sciences, Iran). The randomization order was concealed in an opaque envelope until commencement of the study. Data collection and entry were performed by another investigator who was blinded to the intervention. The design is outlined in Fig. 1.

Experimental procedures

Healthy subjects aged between 20 and 45 years, with no known cardiovascular, pulmonary or musculoskeletal disease, were recruited through an invitation advertisement posted on a university campus. Subjects who responded to the advertisement were invited to the cardiopulmonary laboratory. The study aim and procedures were explained and written consent was obtained from the subjects prior to data collection. Each subject was requested to visit the laboratory on 2 occasions, one week apart. Subjects were advised to refrain from caffeine or alcohol for 12 h and vigorous exercise for at least 2 days, prior to the assessment. Any prospective subject with previous acupuncture experience and those who suffered from recent illness such as upper respiratory tract infection 2 weeks prior to the study were excluded.

Upon arrival at the laboratory, each subject rested in the sitting position for 30 min and baseline measurements (see below) were taken. Each subject then received in random order, either Acu-TENS or Placebo-TENS (identical electrode placement but no electrical output from the TENS unit) for 45 min. Acupuncture points Neiguan (PC6) were identified bilaterally. These points are located 2 "cun" (one cun is the distance between the medial creases of the interphalangeal joints of an individual's middle finger) proximal to the distal crease of the wrist, between the palmaris longus and flexor carpi radialis tendons. The acupoints PC6 were selected in this study because PC6 is a point along the pericardium meridian, a meridian associated with protection and optimization of heart function; this point is often selected for management of arrhythmias and symptoms of heart disorders.[16] Furthermore, PC6 was used in previous studies on investigation of its effect on autonomic nervous system[17] and on investigation of recovery heart rate after exercise.[9]

The skin resistance over PC6 was lowered by cleaning the area with alcohol swab and ECG electrodes (3M® Monitoring Electrode 2223, 3M Co., Ltd., USA) were attached over each point. The electrodes were then attached to a TENS machine (ITO ES-120Z, ITO Co., Ltd., Japan) (Fig. 2).

Intervention stimulation protocols

Acu-TENS protocol: Burst Train Stimulation at a frequency of 2 Hz, pulse width 200 μs and at the highest tolerable intensity just short of pain, over acupuncture points Neiguan (PC6) for 45 min before exercise.

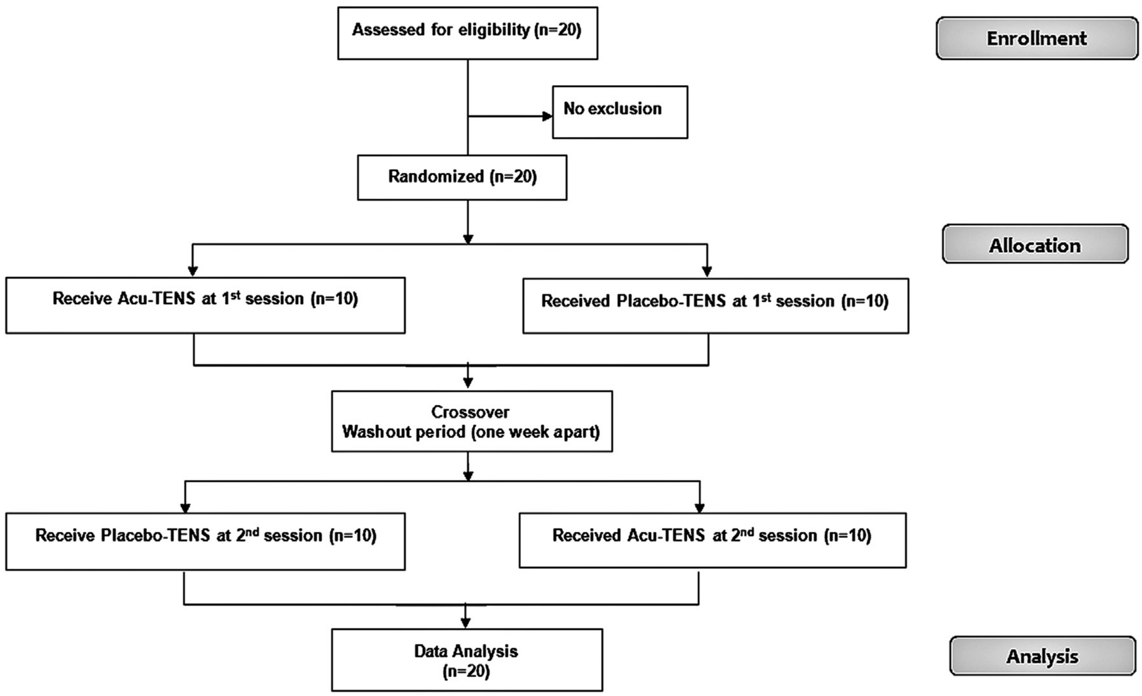

Figure 1 Design and flow diagram of the study procedures.

Placebo-TENS: similar to the Acu-TENS protocol but without electrical output from the TENS unit despite an activated output light for 45 min.

Exercise protocol

Acu-TENS or Placebo-TENS intervention was followed by an incremental exercise protocol on a cycling ergometer (Ergoselect 100 K, Ergoline, Germany). Heart rate was continuously measured during the whole exercise period and used as a reference value for adjusting the work rate. The exercise was initiated by 1 min of warm up at 40 W and 60 rpm. The work rate was then increased by 10 W per minute until the subject's exercise heart rate (HR) reached 70% of their age-predicted maximal HR. The exercise continued for a further 10 min with HR maintained at this level by adjusting the work rate as necessary. On completion of this exercise protocol, the subject remained sitting until their HR returned to its pre-exercise level.

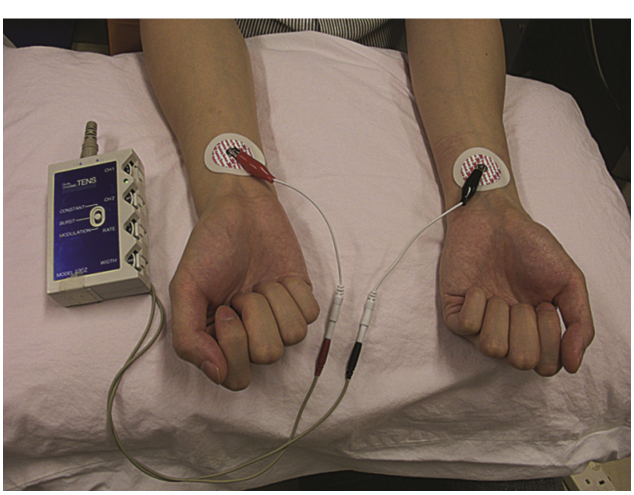

Figure 2 Application of transcutaneous electrical nerve stimulation over the acupuncture point PC 6 (Neiguan).

Outcome measures

Baseline variables included oxygen consumption VO_2 (measured by Quark PFT4 ergo, Cosmed, Italy), resting blood pressure (Portapres, FMS, The Netherlands) and resting HR (RS800CX, Polar Electro, Finland). Blood lactate level was also recorded prior to exercise using a lancet to puncture the pulp of a finger to obtain a small drop of blood (0.7 μL) (Lactate Plus, Nova Biomedical, MA). VO_2, HR and blood pressure were continuously monitored throughout exercise; blood lactate was measured at 4 time points: before exercise, immediately after exercise, 15-min post-exercise and when HR returned to pre-exercise baseline level.

To determine the effect of the interventions on sympathetic and parasympathetic modulation of HR, recorded HR data were subjected to heart rate variability (HRV) analysis by the software aHRV (Ver.11.1.0, Nevrokard, Slovenia). Data were analysed by Fast Fourier Transform frequency spectral analysis at 5-min intervals. High frequency (HF) reflected modulation by cardiac parasympathetic innervation; Low frequency (LF) reflected the changes in sympathetic and parasympathetic activities; Ratio of low to high frequency (LF/HF) derived from spectral analysis mirrored sympatho-vagal balance or reflected sympathetic modulations.[18]

Data analysis

Recorded blood lactate level and heart rate variability at different time points were processed using two-way repeated measures analysis of variance (ANOVA) to determine any between-group effect and any possible interaction between time and group. Contrast analyses were performed if a significant main effect was revealed. Paired *t*-tests were used for between-intervention comparison at a post-exercise time point. A *p*-value of <0.05 was considered statistically significant. All statistical tests were analysed using PASW Statistics for Windows, version 17.0.2 (SPSS Inc., USA).

Results

A total of 20 subjects (9 males, 11 females) participated in the study. The mean age was 26.9 ± 1.3 years. None were smokers, all were sedentary workers and none participated in regular exercise, and none had any previous experience with acupuncture or TENS. All recruited subjects completed the trial and there was no report of adverse effects associated with the data collection process. Levels of blood lactate and cardiovascular variables measured before, immediately after and at 15 min after exercise are displayed in Table 1. The peak oxygen consumption during the exercise was 60.6 ± 2.81% of predicted maximal oxygen consumption (VO_{2max}) after Acu-TENS and 59.5 ± 1.93% after Placebo-TENS ($p > 0.05$). LF, HF and LF/HF measured before and after intervention, during exercise, 15 min after exercise and heart rate recovery are shown in Table 2.

Changes in blood lactate levels

Repeated measures ANOVA showed that there was a significant Group × Time interaction effect ($p = 0.015$). At the end of the exercise protocol, the blood lactate level rose significantly compared to pre-exercise levels, but the increase was significantly less in the Acu-TENS group compared to Placebo-TENS (the difference was 1.12 ± 0.39 mmol/L, $p = 0.01$ (95% CI 0.30–1.94)) (Fig. 3).

Changes in HR and blood pressure

All subjects were required to maintain a HR that was 70% of their age-predicted HR maximum during the exercise. Following Acu-TENS, the time required for the HR to return to baseline after exercise was 36.6 ± 2.6 min, which was 9.98 ± 4.54 min shorter than HR recovery associated with the Placebo-TENS intervention, $p = 0.045$ (95% CI 0.23–19.72). Changes in blood pressure after exercise were similar for both interventions.

Changes in HR variability

Repeated measures ANOVA showed that there was a significant Group × Time interaction effect ($p = 0.031$). The spectral analysis of HR variability showed that the low to high frequency (LF/HF) ratio increased during exercise and slowly returned towards baseline after exercise.

Table 1 Blood lactate and cardiovascular variables measured before exercise, immediately after and at 15 min after exercise, and at the time when heart rate returned to baseline (Recovery). Data are mean ± SEM.

	Acu-TENS (n = 20)				Placebo-TENS (n = 20)			
	Baseline	Immediately after exercise	15 min after exercise	Recovery	Baseline	Immediately after exercise	15 min after exercise	Recovery
Blood lactate (mmol/L)	1.95 ± 0.17	5.20 ± 0.53	4.03 ± 0.49	2.05 ± 0.21	2.02 ± 0.13	6.39 ± 0.80	4.09 ± 0.39	2.84 ± 0.21
HR (bpm)	79.27 ± 2.53	134.36 ± 1.40	90.90 ± 3.37	81.50 ± 2.24	77.99 ± 2.17	134.25 ± 0.82	90.35 ± 2.08	80.47 ± 2.17
SBP (mmHg)	116.83 ± 2.77	120.81 ± 3.01	119.08 ± 2.53	121.78 ± 2.80	120.97 ± 2.07	130.09 ± 3.69	122.26 ± 3.30	123.21 ± 3.65
DBP (mmHg)	69.42 ± 1.37	73.10 ± 2.06	73.38 ± 1.56	73.53 ± 2.08	71.40 ± 1.95	77.65 ± 2.46	73.87 ± 1.93	76.11 ± 3.01
RPP	9257.95 ± 361.79	16,256.54 ± 477.73	10,916.55 ± 589.02	9908.99 ± 327.70	9424.78 ± 287.49	17,469.15 ± 514.28	11,003.00 ± 308.30	9887.61 ± 355.54

HR = Heart Rate; SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; RPP = Rate Pressure Product.

Table 2 Heart rate variability measured before exercise, immediately after intervention, during exercise, at 15 min after exercise, and at the time when heart rate returned to baseline (Recovery).

	Acu-TENS (n = 20)					Placebo-TENS (n = 20)				
	Baseline	After intervention	During exercise	15 min After exercise	Recovery	Baseline	After intervention	During exercise	15 min After exercise	Recovery
LF (unit)	0.44 ± 0.04	0.54 ± 0.04	0.70 ± 0.03	0.69 ± 0.03	0.58 ± 0.05	0.48 ± 0.05	0.59 ± 0.03	0.75 ± 0.04	0.64 ± 0.04	0.59 ± 0.05
HF (unit)	0.56 ± 0.04	0.46 ± 0.04	0.30 ± 0.03	0.31 ± 0.03	0.41 ± 0.05	0.52 ± 0.05	0.41 ± 0.03	0.25 ± 0.04	0.36 ± 0.04	0.40 ± 0.05
LF/HF (ratio)	1.02 ± 0.17	1.58 ± 0.26	3.38 ± 0.60	2.78 ± 0.38	2.65 ± 0.62	1.34 ± 0.28	1.75 ± 0.22	5.31 ± 0.91	2.98 ± 0.77	2.26 ± 0.43

LF = Low Frequency; HF= High Frequency; LF/HF= Ratio of low frequency to high frequency.

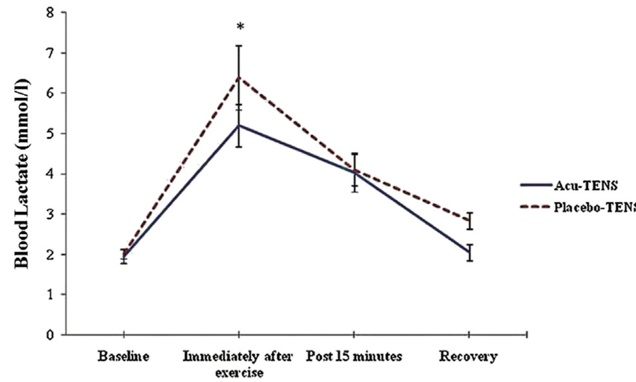

Figure 3 Blood lactate level recorded before and at different time points after exercise. * denotes significant between-group difference at $p < 0.05$; Recovery = at the time when heart rate returned to baseline.

The increase in the LF/HF ratio during exercise was significantly less after Acu-TENS compared to Placebo-TENS [by 1.61 ± 0.76 units, p = 0.047 (95% CI 0.02–3.20)] (Fig. 4).

Changes in excessive post-exercise oxygen consumption (EPOC)

There was no difference in the post-exercise oxygen consumption between the Acu-TENS or Placebo-TENS groups (Fig. 5). The mean size of EPOC recorded after Acu-TENS was 5.4 ± 1.0 L and was very similar to that recorded after Placebo-TENS (5.33 ± 1.0 L, p = 0.394).

Discussion

TENS is a common non-invasive modality used for pain relief. TENS application at acupuncture points is reported to influence respiratory and cardiovascular function.[11,19,20] This current study is the first report on the relationship between Acu-TENS and post-exercise blood lactate levels. This study showed a lower post-exercise blood lactate level when the exercise was preceded by Acu-TENS. Before 1970s, it was believed that lactic acid was a process of muscle anaerobiosis and was produced during exercise

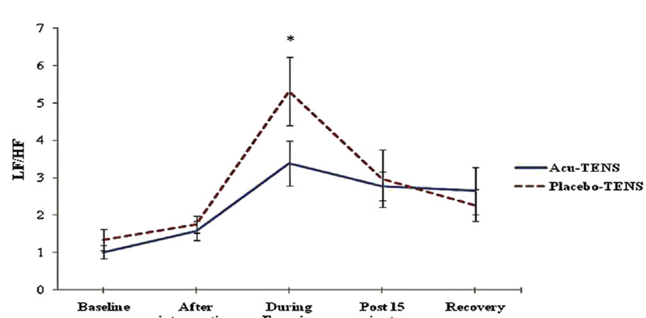

Figure 4 Low frequency to high frequency ratio (LF/HF) recorded at various time points.* denotes significant between-group difference at $p < 0.05$; Recovery = at the time when heart rate returned to baseline.

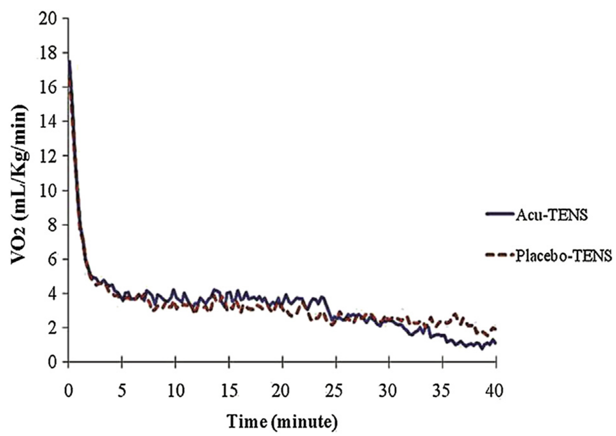

Figure 5 Post-exercise oxygen consumption after Acu-TENS and Placebo-TENS.

when there was depleted oxygen delivery to exercising muscles.[13,21] Though lactate kinetics are complex, it is now understood that lactate level in the blood is a balance of its production and clearance (oxidation).[2,3,22] During low or moderate intensity of exercise, lactate is viewed as a potential source of energy, as it can be oxidized and converted to pyruvate and then into glucose for storage or be metabolized by working muscles.[1,3] This study showed that the level of blood lactate rose significantly after exercise, this is not surprising as exercise lactate production correlates highly with metabolic rate.[23] We speculate that the lower lactate level produced after Acu-TENS in this study suggests that Acu-TENS may have facilitated the catabolic effect of blood lactate and may parallel the reduced lactate levels observed with respiratory endurance training.[24] Application of acupuncture to Neiguan (PC6) and Zusanli (ST36) has been shown to reduce maximal heart rate, maximal oxygen consumption and blood lactate level in elite basketball athletes.[5] The authors proposed that acupuncture may enhance exercise recovery in this group. The exact mechanism of how acupuncture has its effect remains speculative. However, we have demonstrated that Acu-TENS is associated with an increase in blood β-endorphin levels[20] and modulation of the autonomic nervous system.[12] An increase in β-endorphin level was previously shown to be associated with reduced muscle fatigue and increased glucose uptake[25] and the authors proposed that β-endorphin is released from the pituitary into the blood during exercise and responsible for uptake of glucose in exercising muscles.[25] The relationship between β-endorphin and glucose homeostasis was reported by many,[25–28] and it is possible that the application of Acu-TENS for 45 min prior to exercise may have altered blood β-endorphin levels, thereby influencing metabolic regulation during exercise, but further investigation in this area is necessary.

In accord with findings from our previous study, we again showed Acu-TENS prior to exercise enhanced HR recovery to pre-exercise levels.[9] Acupuncture has been shown to reduce HR in both healthy subjects and patients with coronary artery disease,[29,30] allegedly due to autonomic nervous system modulation. Reduction of HR after acupuncture stimulation over the PC6 acupoint is reportedly mediated by cardiac cholinergic neural pathways, leading to a sympathetic inhibitory effect.[31] Electroacupuncture reportedly induces a significant decrease in blood pressure after maximal exercise test,[32] however our Acu-TENS study did not support a similar effect on blood pressure. This may be because our subjects only exercised to 70% of their age-predicted heart rate and the exercise demands were much less than the cohort reported by Li and colleagues.[32] This current study recorded heart rate variability (HRV), with the intention of exploring any sympathetic and/or parasympathetic modulation by Acu-TENS. Three frequency bands can be identified by spectral analysis of HRV; these are very low frequency (<0.003–0.04 Hz); low frequency (0.04–0.15 Hz) and high frequency 0.15–4 Hz.[18,33] The low frequency to high frequency (LF/HF) ratio is most commonly used for analysis of HRV and indicative of sympatho-vagal balance.[33] When the sympatho-vagal balance is shifted towards a sympathetic predominance, the LF/HF ratio will be augmented.[34] It is anticipated that during exercise, with an increase in sympathetic output,[1] the LF/HF ratio will increase. While this study showed that the LF/HF ratio increased during exercise, such increase was dampened when the exercise was preceded by Acu-TENS, suggesting that Acu-TENS either inhibited the low frequency sympathetic spectral response and/or accentuated the high frequency parasympathetic spectral response. Our data did not support a significant increase in high frequency parasympathetic response, thus the increase in LF/HF ratio was more likely a reflection of sympathetic modulation. This study showed that "exercise-induced" increase in sympathetic output was dampened by Acu-TENS but not Placebo-TENS.

A faster recovery from exercise might suggest more efficient metabolic activity and possibly reduced EPOC. However, despite a faster recovery of HR, this study shows that the EPOC was not affected by Acu-TENS. Børsheim and Bahr have explained in detail that EPOC is affected by the exercise intensity and duration.[35] The size of EPOC recorded in our subject cohort, who exercised for 10 min at 70% of their predicted maximal heart rate, was 5–6 L, which is in accord with data reported by Sedlock et al.[36] Post-exercise oxygen consumption recorded in our subjects was comparable to that reported by subjects who exercised under 20 min.[37] It is likely that the similar EPOC recorded between the Acu-TENS group and the placebo group was due to the short duration of exercise adopted in our protocol. Further investigations of relationship between Acu-TENS and EPOC should therefore adopt exercise protocols of longer duration.

Limitation of the study

The level of blood lactate immediately after Acu-TENS intervention, prior to exercise, was not recorded in this study; therefore, any direct effect of Acu-TENS on blood lactate cannot be shown. Inclusion of an extra time point on top of the 4 blood lactate level measurements would have been considered too invasive by our subject cohort, as they acted as their own controls for both Acu-TENS and Placebo-TENS protocols.

Tissue oxygenation in exercising muscle was not monitored during this study. This information might help to explain whether the lower levels of lactic acid generated after Acu-TENS were associated with more efficient muscle oxygenation. This study however demonstrated that the faster recovery to pre-exercise HR was associated with less predominant sympathetic modulation in the Acu-TENS group. Whether the lower post-exercise blood lactate level after Acu-TENS was associated with more efficient metabolism, or possibly less energy demands on exercise, requires further evaluation.

Conclusion

This study showed that application of 45 min of Acu-TENS prior to moderate intensity exercise was associated with a lower level of blood lactate and a faster recovery to pre-exercise HR compared to Placebo-TENS. Faster HR recovery was accompanied by a lower LF/HF ratio, providing further evidence to support the hypothesis that Acu-TENS has a possible role to modulate the autonomic sympathetic system. The role of Acu-TENS in muscle metabolism warrants further investigations.

Conflicts of interest

All authors have none to declare.

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